



Northern Hydrology and Engineering

P.O. Box 2515, McKinleyville, CA 95519

Telephone: (707) 839-2195; email: Jeff@northernhydrology.com

Engineering – Hydrology – Stream Restoration – Water Resources

TECHNICAL MEMORANDUM

Date: 22 February 2021

To: Jeremy Svehla, PE
Project Manager
GHD Inc.
718 3rd Street
Eureka, CA 95501

From: Jeffrey K. Anderson, P.E., C50713
Brian Draeger



Expires: 30 Sep. 2021

Re: Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA

INTRODUCTION AND BACKGROUND

This technical memorandum describes the hydraulic modeling effort conducted by Northern Hydrology & Engineering (NHE) to support the Sea Level Rise Adaptation Plan for Humboldt County Transportation Infrastructure (Phase 1) Project (Project) for the County of Humboldt (County). The Project Area consists of the Eureka Slough hydrologic sub-unit of Humboldt Bay (Figure 1). NHE is part of a collaborative Project Team consisting of GHD Inc. (GHD), Environmental Science Associates (ESA), GMA Hydrology, Aldaron Laird and Philip King.

The purpose of the hydraulic modeling effort was to develop an analytical/quantitative tool to better understand the complicated flooding and inundation regimes within the Project Area from riverine flooding and coastal extreme high-water events. Most of the Project Area buildings, infrastructure, assets, and agricultural and state lands are protected by an extensive system of levees and the railroad grade along Humboldt Bay, and remnant tidal wetlands. Flooding within the Project Area can occur from both riverine and/or coastal events that either overtop the levees and/or inundate the tidal wetlands. Most of the existing levees and railroad grade were constructed over 100-years ago and are vulnerable to overtopping from extreme events today. As sea-levels rise, not only will the frequency of overtopping increase, but the inundation depth and duration of the protected Project Area lands will also increase. The hydraulic model was used to provide flooding/inundation regimes for existing conditions, and how these regimes will change into the future with sea-level rise.

Work products described in this memo include:

1. Description of data sets used to support the modeling effort.
2. Development of the hydraulic model and the flood/high-water extreme event conditions analyzed.
3. Specific modeling results requested by the Project Team are presented in this memo. Other results are directly provided in the main report.

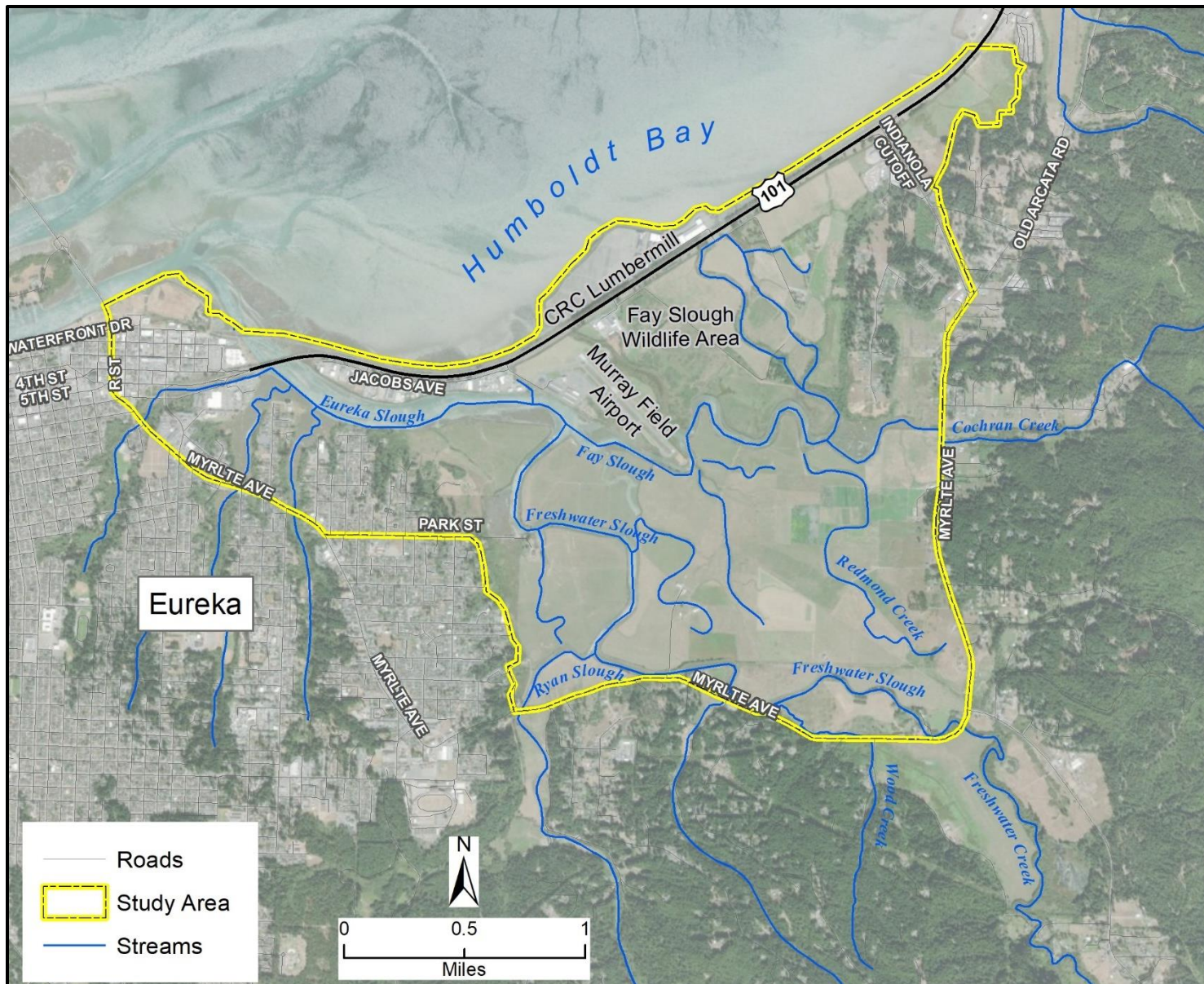


Figure 1. Map showing extent of Sea Level Rise Adaptation Plan for Humboldt County Transportation Infrastructure (Phase 1) Project Area.

PROJECT AREA MODELING DOMAIN AND EXTENTS

The modeling domain generally encompasses most of the Project Area (Figure 1 and Figure 2) and includes Eureka Slough, Freshwater Slough, the lower reach of Ryan Slough, Fay Slough, and a portion of Humboldt Bay. Also included in the domain are the former tidal wetland areas which include private, commercial, industrial, agricultural, state and county lands, and remnant tidal wetlands. The modeling domain is bounded by Myrtle Avenue along most of the southerly and easterly edges, the upper extent of remnant tidal wetlands along the westerly edge, and Humboldt Bay along the northerly edge.

Eureka Slough is a relatively short slough channel beginning at the confluence of Freshwater and Fay Sloughs and ending at its confluence with Humboldt Bay. Freshwater Slough is the lowest section of Freshwater Creek and extends upstream from the confluence of Eureka and Fay Sloughs to the upper end of the Project Area. Ryan Slough extends from its confluence with Freshwater Slough to the upper end of the Project Area. Fay Slough is a terminal slough channel extending upstream from its confluence with Eureka and Freshwater Sloughs.

The Freshwater Slough/Freshwater Creek and Fay Slough drainage basins are shown on Figure 2. Riverine flood events were developed for these basins, along with Wood Creek and Ryan Slough which are in the Freshwater Slough/Freshwater Creek basin, and Cochran and Redmond Creeks which are in the Fay Slough basin.

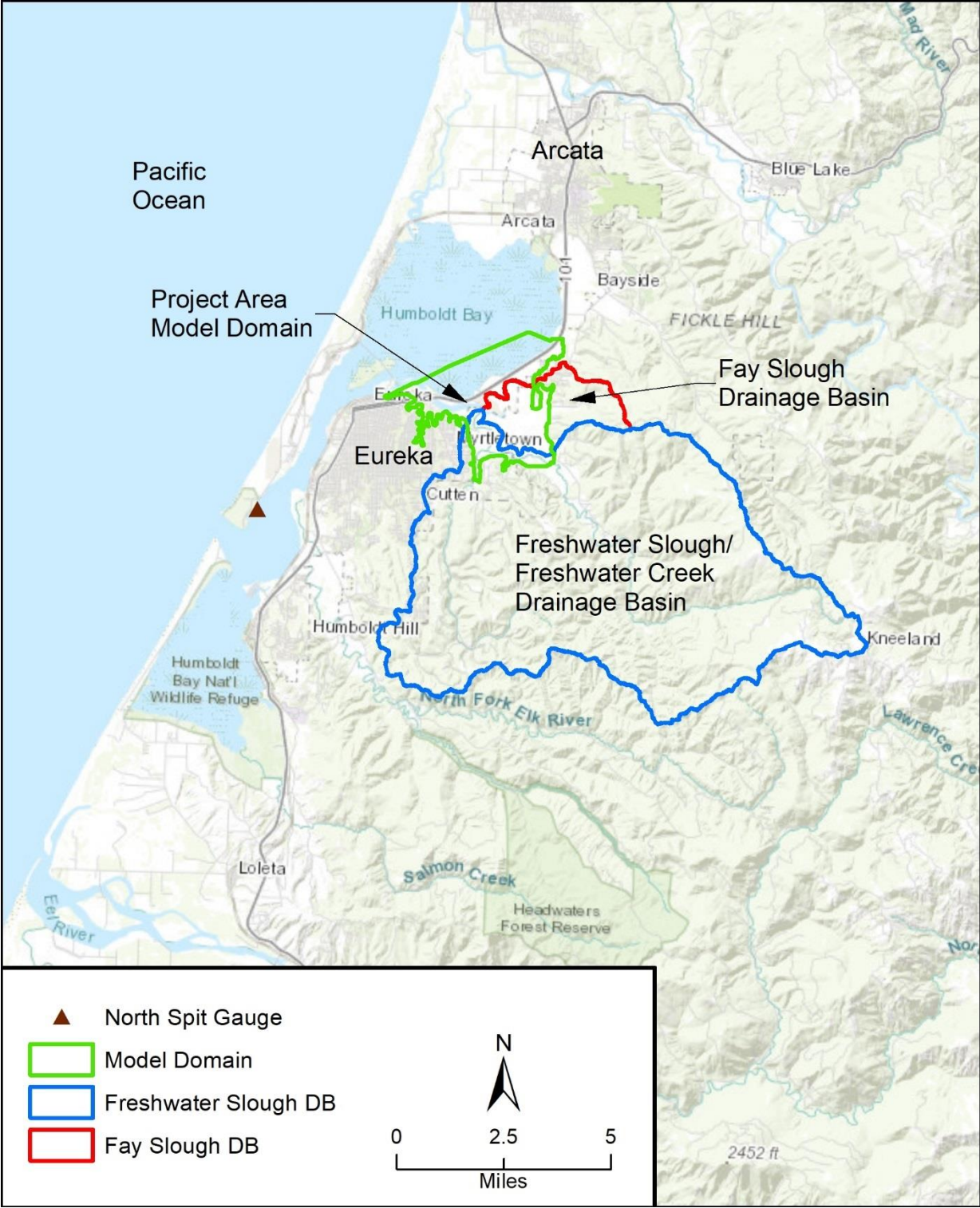


Figure 2. Map of Sea Level Rise Adaptation Plan for Humboldt County Transportation Infrastructure (Phase 1) Project Area modeling domain, Freshwater Slough/Freshwater Creek drainage basin (includes Wood Creek and Ryan Slough), and Fay Slough drainage basin (includes Cochran Creek and Redmond Creek).

DATA SOURCES

This section summarizes the existing data sources in the Project Area used to support this modeling effort (Figure 3).

Topographic and Bathymetric data

Project Area topography consisted of multiple sources of topography and bathymetry data (Figure 3). The entire Project Area is covered by the 2009-2011 California Coastal Conservancy Coastal LiDAR project: Hydro-flattened Bare Earth Digital Elevation Model (Coastal LiDAR). The Coastal LiDAR can be downloaded from the NOAA Coastal Services Center Digital Coast website (<http://csc.noaa.gov/digitalcoast/>).

In 2011, the County retained Sousa Land Surveys, Inc. (Sousa, 2011) to conduct a LiDAR based topographic survey of the general Jacobs Avenue Levee area (Jacobs Avenue LiDAR). A TIN surface of the Jacobs Avenue LiDAR topography was provided by the County.

In 2015, GMA Hydrology, Inc. conducted bathymetric surveys of 30 cross-sections in Eureka, Freshwater and Fay Sloughs to support the County's Jacob Avenue Levee Study (GMA, 2015). The bathymetric survey was conducted using a single beam sonar and utilized the same geodetic control as the Jacobs Avenue LiDAR survey.

In 2016, the County conducted a topographic survey along the top of the Jacobs Avenue Levee and a portion of the Murray Field Levee (County, 2016). The purpose of the survey was to better define the crown elevation of the levees for the Jacobs Avenue Levee study, and the survey used the same geodetic control as the Jacobs Avenue LiDAR survey.

In 2017, Gutierrez Land Surveying (GLS, 2017) conducted a topographic survey along the top of the railroad grade that parallels Highway 101 between North Humboldt Bay and the Project Area (Railroad Grade Topography) to support the Humboldt Bay Trail project. An AutoCAD drawing containing the Railroad Grade Topography survey points was provided by GHD.

Previous Hydraulic Modeling Efforts in Project Area

NHE developed a one-dimensional hydraulic model using HEC-RAS to support the Wood Creek Restoration Project (NHE, 2008). The model cross-sections in Freshwater Slough were based on a topographic map developed for the Wood Creek project area, and included topographic data collected in Freshwater Slough.

As part of the County Jacobs Avenue Levee Study, NHE developed a HEC-RAS one-dimensional hydraulic model for Eureka Slough and the lower portions of Freshwater and Fay Sloughs (NHE, 2016). The developed model was based on the GMA (2015) cross-section surveys, the Jacobs Avenue LiDAR (Sousa, 2011), and the County (2016) levee crest surveys.

NHE is currently working on a restoration project of Cochran Creek (NHE, 2018). As part of that work, NHE has developed both a one-dimensional and two-dimensional hydraulic model of the Cochran Creek project area using HEC-RAS. Both models extend into upper Fay Slough, and model cross-sections and topography in Fay Slough are based on in-channel cross-section surveys.

Humboldt Bay Coastal Still Water Flood Elevations

The coastal still water boundary conditions for this modeling work were taken from the Humboldt Bay sea-level rise modeling and inundation vulnerability mapping project (NHE, 2015). As part of the NHE (2015) work, a two-dimensional hydrodynamic model (2D model) was developed and used to predict water levels within the existing shoreline of Humboldt Bay for five SLR scenarios: year 2012 existing sea levels and half-meter SLR increments of 0.5, 1.0, 1.5 and 2.0 m. The 2D model was forced by a 100-yr long stationary hourly sea level height series developed for the Crescent City tide gauge. The 100-yr hourly series accounts for astronomical tides, and varying effects including wind, sea level pressure and El Niño variability, and represents ocean still water levels. The 100-yr series was incrementally adjusted for each half-meter SLR scenario. Each hydrodynamic model simulation produced a 100-yr 15-minute series of predicted water levels throughout the bay. Estimates of average high-water levels and annual exceedance probabilities of extreme high-water levels were determined bay-wide for each of the five SLR scenarios. For this work, results for the Year 2012 existing sea level simulations were used to represent existing coastal still water tidal elevations in Humboldt Bay adjacent to the Project Area.

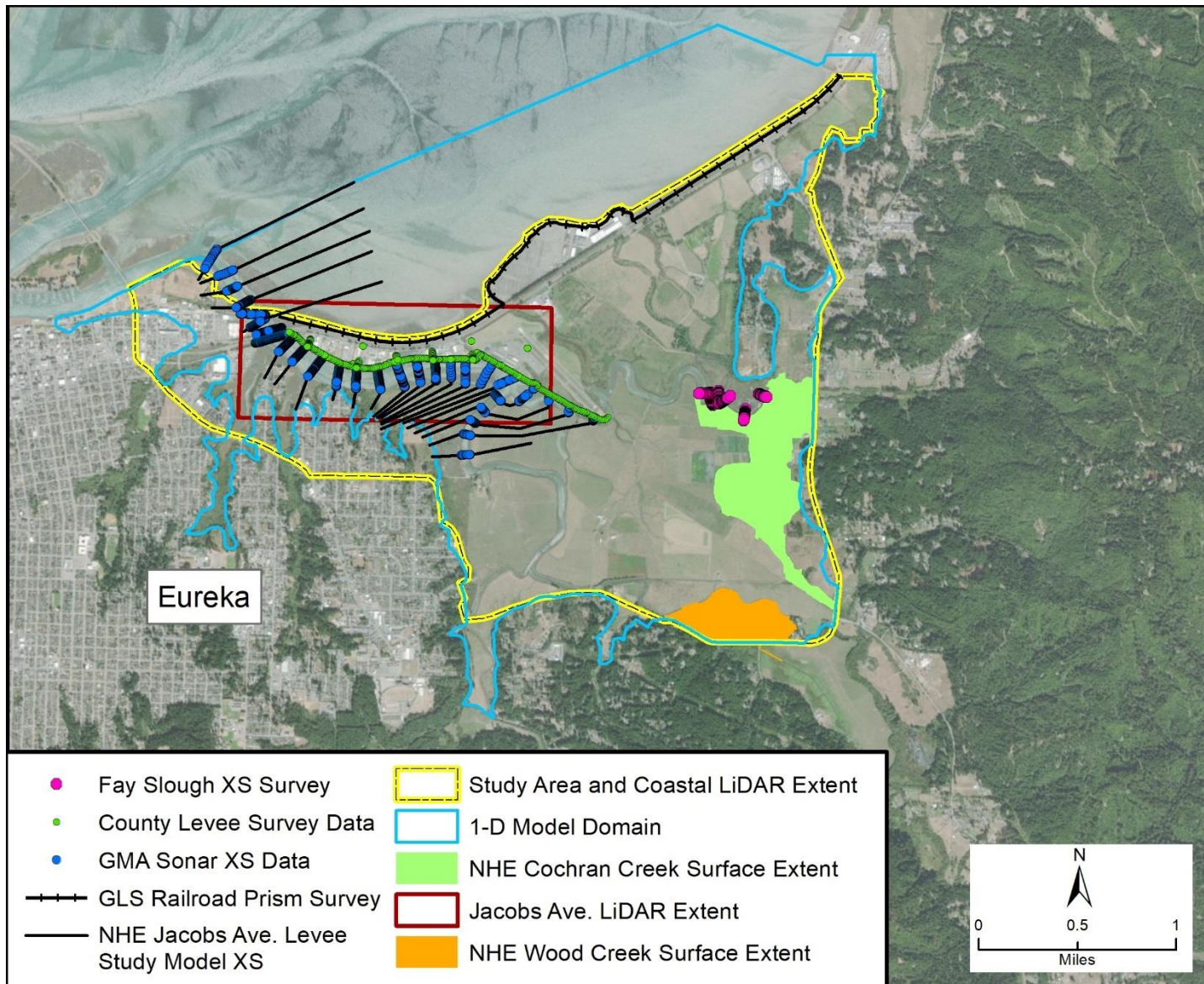


Figure 3. Map showing extent of existing data sets available for the Sea Level Rise Adaptation Plan for Humboldt County Transportation Infrastructure (Phase 1) Project Area and modeling domain.

HYDRAULIC MODEL DEVELOPMENT AND ANALYSIS

This section describes the hydraulic model development and analysis conducted for determining water surface elevations within the Project Area. Two flood/high-water event conditions were analyzed:

- Event Condition 1: riverine flooding from 2-, 10-, 100-, and 500-yr flood events from upstream riverine sources with a representative spring tide tidal series at the downstream boundary.
- Event Condition 2: coastal flooding based on representative still water tidal series for the 2-, 10-, 100-, and 500-yr extreme coastal events at the downstream boundary with a winter base flow from upstream sources.

These two event conditions were modeled for existing conditions and 1-, 2- and 3-ft sea-level rise scenarios. All presented water surface elevations are in feet referenced to NAVD88, unless noted otherwise.

One-Dimensional Hydraulic Model

The U.S. Army Corps of Engineers (COE) HEC-RAS modeling system (COE, 2016) was used to develop a one-dimensional hydraulic model (1D-Model) of the Project Area. The HEC-RAS model calculates one-dimensional water surface profiles and average channel velocities for both steady gradually varied flow and unsteady flow through a channel, two-dimensional (2D) hydraulic modeling, and combined 1D/2D hydraulic modeling. For this analysis, 1D unsteady flow modeling was used to predict flood levels within the project reach for the Project Area. Reference can be made to the HEC-RAS manual (COE, 2016) for information specific to 1D unsteady hydraulic modeling.

Model Extent and Setup

The 1D-Model reach includes 1.81 miles of Eureka Slough, approximately 3.52 miles of Freshwater Slough and lower Freshwater Creek, 2.36 miles of Fay Slough, and 1.12 miles of lower Ryan Slough. Within the 1D-Model, the creek and slough channels were represented as cross-sections between levees, levees were represented as lateral structures, and the large flood cell basins were represented as storage areas with level pool routing (Figure 4).

To generate the 1D-Model geometry, a geo-referenced HEC-RAS geometry file was created using HEC-RAS and ArcGIS. The centerline alignments were digitized from the Coastal LiDAR surface and ESRI imagery. Geo-referenced surveyed cross-section data from previous HEC-RAS modeling efforts within the Project Area (NHE 2008, 2016, 2018) were directly imported into the 1D-Model. Imported channel cross-sections were truncated just below levee tops as needed, and in some cases the cross-section spatial location was slightly adjusted to better align with the Coastal LiDAR surface. Additional channel cross-sections were digitized in HEC-RAS and extracted from the Coastal LiDAR surface or the Wood Creek topographic surface (NHE, 2008) when coverage overlapped cross-sections. For the additional cross-sections extracted from the Coastal LiDAR, the hydro-flattened data points were removed and replaced with a V-shaped channel with the lowest elevation linearly interpolated between bounding surveyed cross-section thalweg points.

All levees were modeled as lateral structures or storage area connections with weir overtopping flow. Lateral structure lines were digitized in HEC-RAS along the levee high points and elevations were extracted from the Coastal LiDAR surface. For the Jacobs Avenue levee and railroad grade between Humboldt Bay and Highway 101, the lateral structure elevations were based on surveyed crest elevations by the County (2016) for Jacobs Avenue and GLS (2017) for the railroad. As required, the lateral structure elevation points were filtered in HEC-RAS to a maximum number of 500 points.

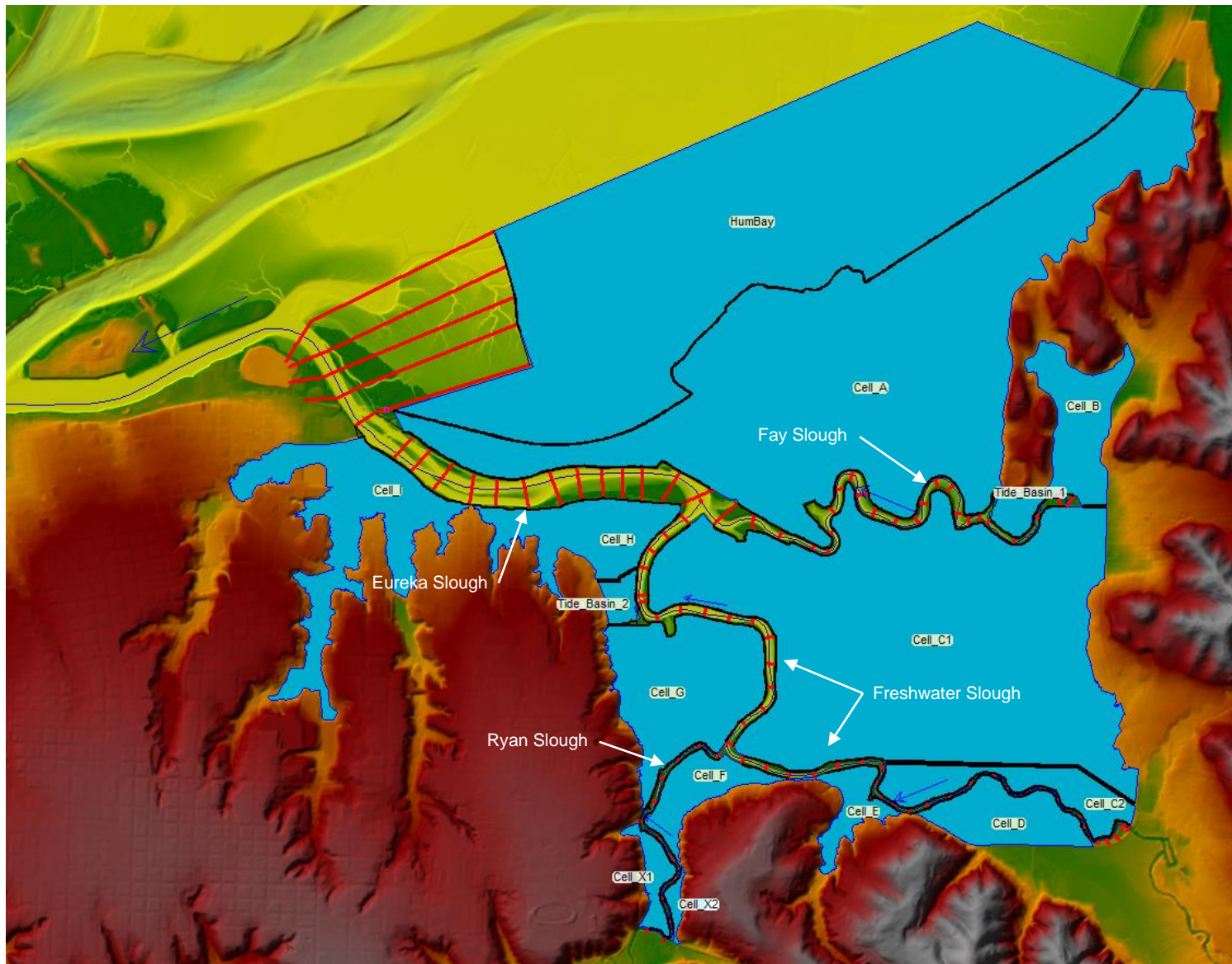


Figure 4. Geometric configuration of 1D-Model for the Sea Level Rise Adaptation Plan for Humboldt County Transportation Infrastructure (Phase 1) Project Area. Cross-section lines are red, lateral structures are black lines, and storage areas are blue.

Storage areas were established by digitizing polygons in HEC-RAS representing each storage area basin between bounding levees and topographic features. Each storage area elevation versus volume relationship was extracted from the Coastal LiDAR surface and edited it HEC-RAS to provide adequate low elevation points. The storage areas were connected to adjoining lateral structures and, as required, storage area/2D flow area boundary condition lines representing storage area inflow or stage boundary conditions were added.

Tide gate structures were incorporated into levee lateral structures, based on survey data for the Wood Creek, Cochran Creek and Redmond Creek tide gate structures, or based on tide gate data from FWS (2007). The USFWS tide gate data did not provide elevations, only dimensions, and the tide gate invert elevations were set approximately equal to the lowest channel bed elevation at the nearest channel cross-section.

For this analysis, the Highway 101 and Railroad Bridges were not incorporated into the 1D-Model. Due to the wide, slow velocity nature of Eureka Slough it was assumed that the bridge structures would not have a significant effect on predicted water surface elevations. Furthermore, the skewed bathymetric cross-sections at the Highway 101 Bridge and Railroad Bridge were not incorporated into the 1D-Model. A sensitivity analysis conducted by NHE (2016) showed that water surface elevations varied by only 0.01 ft when the skewed cross-sections were included into the 1D-Model.

Model Parameters

Manning's roughness coefficients (n values) were determined based on prior modeling experience, professional judgment and field observations. Model n values were 0.03 for the mud-dominated slough channels, 0.035 for the upstream mud/gravel riverine cross-sections, and 0.05 for the tidal wetland, levee and pasture surfaces. Contraction and expansion energy loss coefficients were set at 0.1 and 0.3, respectively, for all cross-sections.

For all tide gate structures n values were set to 0.013 for concrete box structures and 0.02 for round culverts. The culvert entrance and exit loss coefficients were set to 0.3 and 1.0, respectively.

Boundary Conditions

Boundary conditions (BC) for the 1D-Model were based on the flow condition analyzed. For Flow Condition 1, the upstream BC consisted of riverine flood hydrographs and the downstream BC consisted of a representative spring tide series. For Flow Condition 2 the downstream BC consisted of a representative tidal series that contained an extreme high-water level event and the upstream BC consisted of winter base flows for all streams. For this analysis the 2-, 10-, 100-, and 500-yr extreme events were analyzed.

Coastal Extreme Water-Level Event and Mean Monthly Maximum Water Estimates

The downstream BCs for the 1D-Model were representative tidal series containing the target extreme high-water level events and spring tide level. Spring tide was represented as the mean monthly maximum water (MMMW) tide level. All representative tidal series were from the Humboldt Bay sea-level rise 2D model (NHE, 2015) predicted 100-yr 15-min water levels extracted at the grid cell (grid L = 1031) closest to the downstream end of 1D-Model. Table 1 lists the estimated tidal datums and extreme high-water level probabilities for existing conditions (Year 2012) at the 1D-Model downstream BC (grid L = 1031).

A process was developed to determine an average (typical) representative tidal series for each event level of interest (Table 1) from the 100-yr 15-min record. The following outlines the general process steps:

1. Determine the maximum daily tide series from the 100-yr 15-min record.
2. Detrend the daily tide series.
3. Use a declustering algorithm to determine the number of maximum daily tide levels (cluster) equal to or exceeding the event level of separated by a minimum of 1 day.
4. Determine the number of days (counts) in each cluster equal to or exceeding the event level.
5. Using the average counts, determine the dates of the highest maximum daily tide for each cluster.
6. Extract a 42-day 15-min tidal series from the 100-yr 15-min record centered on each date (Step 5).
7. As needed, visually select the best tidal series that represents the extreme event of interest and develop a 21-day 15-min tidal series boundary condition for the 1D-Model.

Table 1. Summary of tidal levels and annual extreme high-water level probability estimates extracted from the NHE (2015) 2D model results (grid L = 1031) for Year 2012 at the 1D-Model downstream BC.

Tidal Value or Percent Probability of Exceedance	Return Interval (yr)	Predicted Water Levels for Year 2012 (ft, NAVD88)
Mean higher high water (MHHW)	--	7.00
Mean monthly maximum water (MMMW)	--	8.33
Mean annual maximum water (MAMW)	--	9.36
50	2	9.30
20	5	9.70
10	10	9.94
4	25	10.22
2	50	10.41
1	100	10.59
0.2	500	10.96

Table 2 lists the number of clusters, and the average, minimum and maximum counts per cluster for each boundary condition tidal event determined from the 100-year 15-min record. It's interesting to note that on average the number of days per cluster exceeding the event level of interest is approximately 2 days, except for the 500-yr event. This indicates that flooding from an extreme high-water event could occur on multiple days from the same storm. For large coastal events there can be numerous days per cluster that exceed the more frequent extreme high-water level events (e.g. 2-yr event).

Table 2. Summary of cluster and counts per cluster for each 1D-Model downstream boundary condition tidal event extracted from the NHE (2015) 2D model results (grid L = 1031) for Year 2012¹.

1D-Model Downstream Boundary Condition Tidal Event	Number of Clusters from 100-yr Record	Counts per Cluster			
		Average	Median	Minimum	Maximum
Mean monthly maximum water (MMMW)	631	3	2	1	15
2-yr or 50% Exceedance	72	2	1	1	5
10-yr or 10% Exceedance	8	2	2	1	4
100-yr or 1% Exceedance	1	2	2	2	2
500-yr or 0.2% Exceedance	1	1	1	1	1

1) The 100- and 500-yr extreme high-water level events were the same tidal series, and only one series existed.

Figure 5 shows the representative tidal series for the MMMW, 2-, 10-, 100- and 500-yr events used for the 1D-Model downstream BCs. The North Spit observed water levels corrected for local sea-level rise are included on Figure 5A, demonstrating that the representative MMMW tidal series tracks observations well although tidal amplification occurs at this location of the bay compared to North Spit. It should be noted that the predicted 23 January to 22 February 1983 tidal series contains both the 100-yr and 500-yr extreme high-water level events.

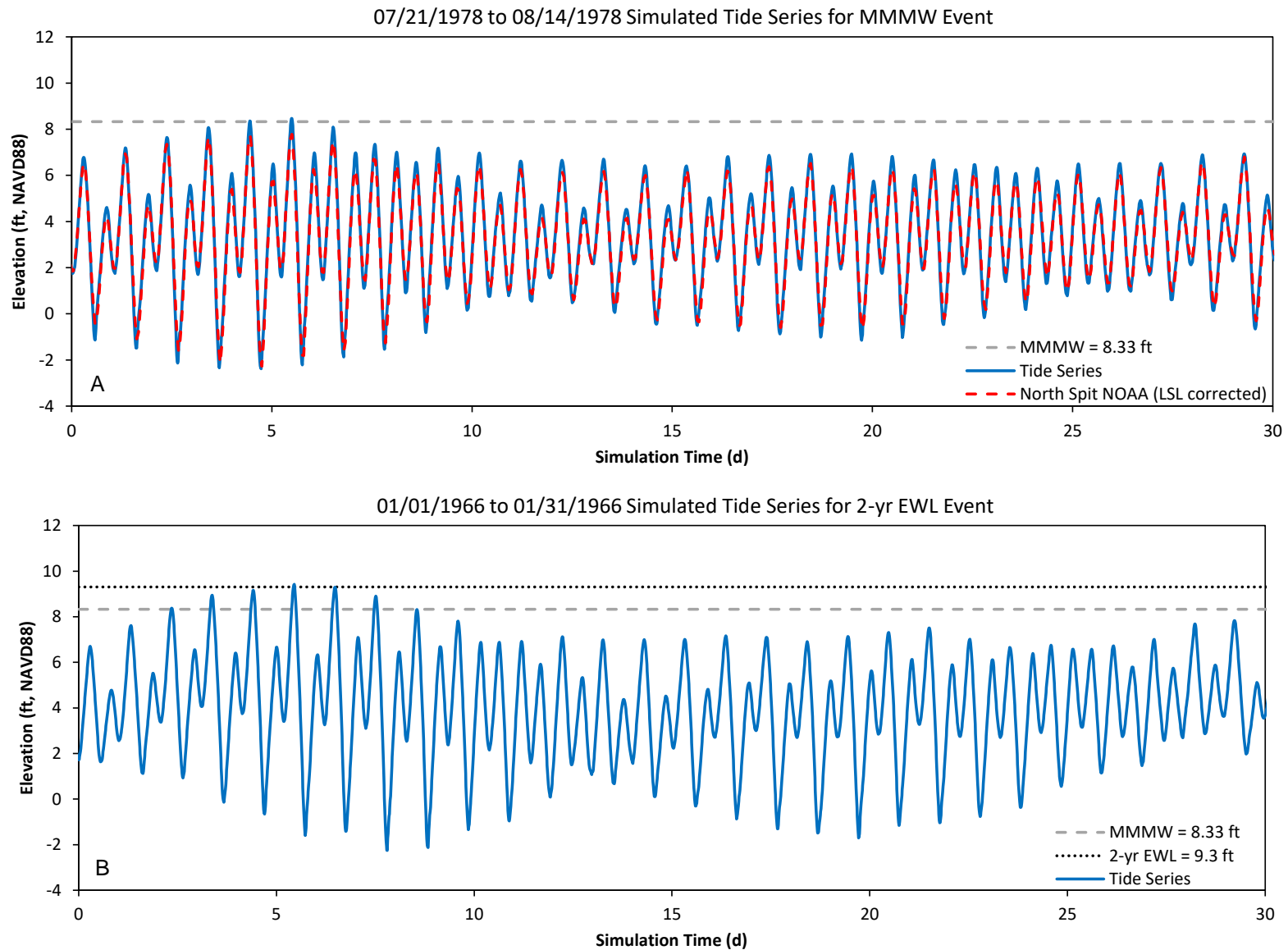


Figure 5. Representative tidal series for the 1D-Model downstream boundary condition for spring tide (mean monthly maximum water (MMMW)) (A), and 2-yr (B), 10-yr (C), and 100- and 500-yr (D) extreme high-water level events. North spit observed tidal levels rise are included on plot A.

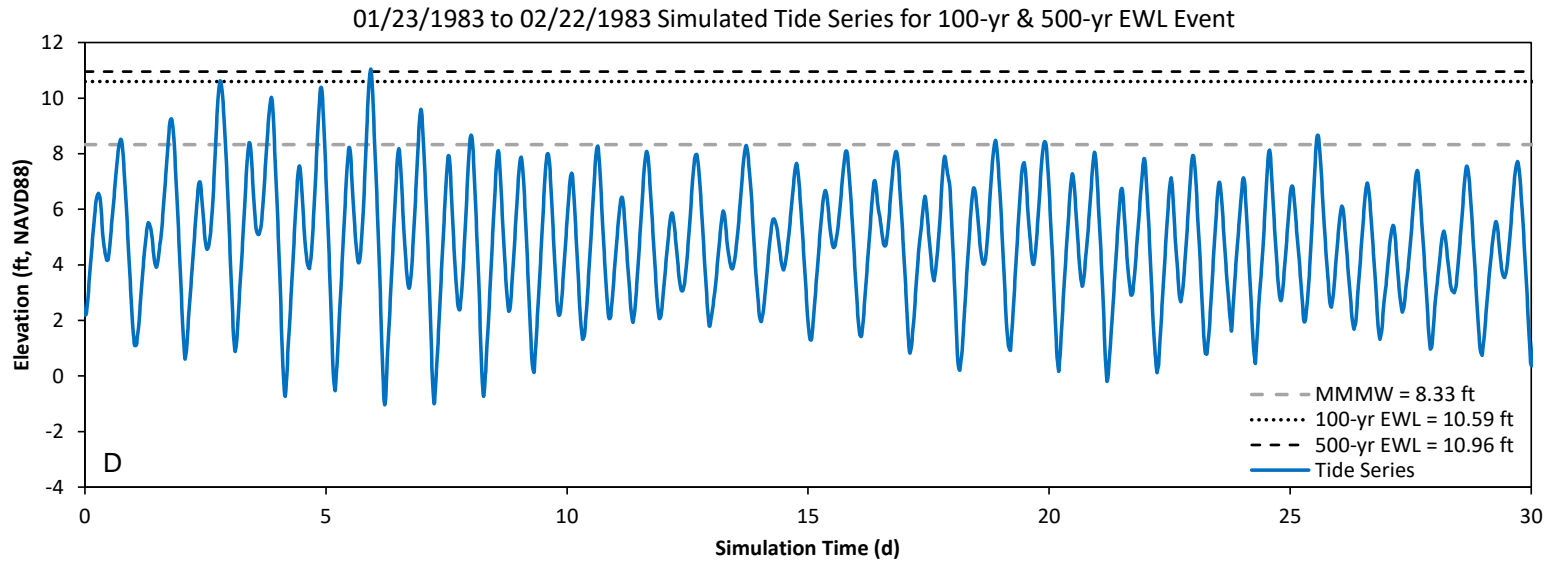
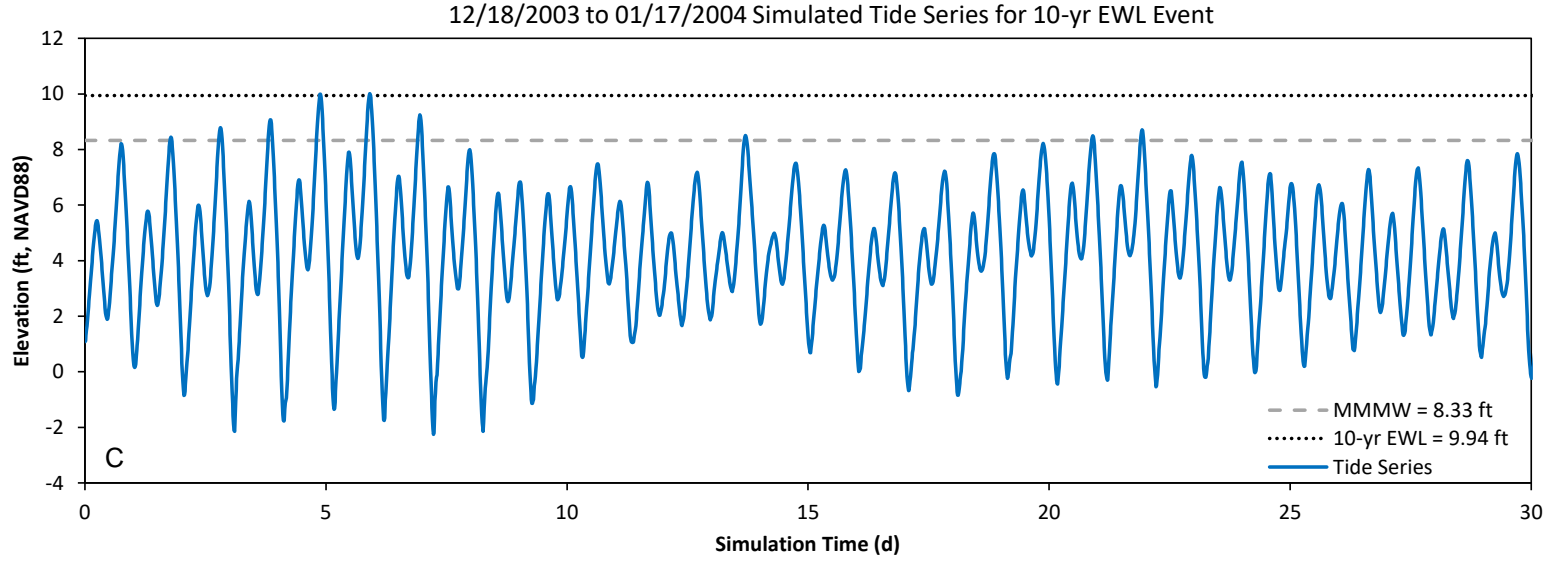


Figure 5 (continued).

Riverine Flood Events and Winter Base Flow Estimates

The upstream BCs for the 1D-Model were riverine flood hydrographs for five streams entering the model domain (Freshwater Creek, Ryan Slough, Wood Creek, Cochran Creek and Redmond Creek). Streamflow data for streams above the Project Area are limited and were not used in this work. For this analysis, flood flow estimates were developed using the regional flood-frequency equations for California (Gotvald et al., 2012). Winter base flows were determined for Project Area streams by scaling estimates for the Little River.

Flood-Frequency Estimates

Peak-flood estimates were determined for the 2-yr, 10-yr, 100-yr and 500-yr events at numerous locations within the model domain (Table 3) using the USGS online StreamStats program (<http://water.usgs.gov/osw/streamstats/>). Following FEMA (2016) guidelines, coincident tributary peak-flows was not assumed, and the BC flows were determined by differencing peak-flow estimates from Table 3 in a downstream direction.

Table 3. Summary of flood-frequency estimates for the Sea Level Rise Adaptation Plan for Humboldt County Transportation Infrastructure (Phase 1) Project Area.

Tributary and Location	Basin Area (mi ²)	Flood-Frequency Estimate (cfs) by return interval and exceedance probability						
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
		50%	20%	10%	4%	2%	1%	0.2%
Freshwater Slough above model domain	30.4	2,140	3,820	5,000	6,540	7,690	8,870	11,500
Freshwater Slough downstream Wood Creek	32.1	2,220	3,980	5,210	6,810	8,010	9,240	11,900
Freshwater Slough downstream Ryan Slough	48.4	3,020	5,440	7,150	9,360	11,000	12,700	16,500
Freshwater Slough downstream Fay Slough	53.2	3,230	5,840	7,680	10,100	11,800	13,700	17,700

Table 4 summarizes the tributary peak-flows used for the upstream BCs in the 1D-Model. Basin areas and 1.111-yr peak-flows for Cochran Creek/Quail Slough and Redmond Creek are from NHE (2018). The Cochran Creek/Quail Slough and Redmond Creek 2-, 10-, 100- and 500-yr peak-flows were determined by scaling the Fay Slough peak-flows by watershed area ratios. Peak-flows for the Cochran Creek/Quail Slough and Redmond Creek to Storage Area are flows that discharge directly into the downstream storage area (Cell C1) and were determined by differencing the Fay Slough peak-flows from the summed Cochran Creek/Quail Slough and Redmond Creek 1.111-yr peak flows. Winter base flow estimates for each tributary were scaled from the Little River near Trinidad station (USGS 11481200) winter base flow estimate (243 cfs) by averaging the period of record (1955 to 2019) monthly flows for November, December, January, February, March, and April.

Table 4. Summary of tributary peak-flows used as upstream boundary conditions for the 1D-Model.

1D-Model Upstream Boundary Condition Peak-Flow Event	Basin Area (mi ²)	Winter Base Flow (cfs) ¹	Peak-flows (cfs) used for upstream boundary conditions by return interval and exceedance probability				
			1.111-yr	2-yr	10-yr	100-yr	500-yr
			90%	50%	10%	1%	0.2%
Freshwater Slough above model domain	30.4	182	--	2,140	5,000	8,870	11,500
Wood Creek	1.7	10.2	--	80	210	370	400
Ryan Slough	15.1	90.5	--	800	1,940	3,460	4,600
Fay Slough ²	4.2	--	--	210	530	1,000	1,200
Cochran Creek/Quail Slough ³	1.4	8.3	29.6	87.7	266	529	641
Redmond Creek ³	1.1	6.6	23.4	69.3	211	418	507
Cochran Creek/Quail Slough and Redmond Creek to Storage Area ⁴	--	--	--	157.1	477	947	1,147
Little River near Trinidad (USGS 11481200)	40.5	242.7	--	--	--	--	--

- 1) Tributary Winter base flow estimates were determined by scaling Little River flow by watershed area ratios.
- 2) Fay Slough flows were not directly used in the 1D-Model, but flows are provided for consistency.
- 3) Cochran Creek/Quail Slough and Redmond Creek basin areas and 1.111-yr peak-flows from NHE (2018).
- 4) Cochran Creek/Quail Slough and Redmond Creek to Storage Area are the peak-flow boundary conditions that discharge directly into Cell C1 and were determined by differencing the Fay Slough peak-flows from the summed Cochran Creek/Quail Slough and Redmond Creek 1.111-yr peak flows.

Flood Hydrographs

Simple triangle shaped flood hydrographs were developed for each peak-flow in Table 4. The hydrograph time-base was 48-hrs (2-days), with an 8-hr rising limb, the peak lasting for 1-hr, and the falling limb lasting 39-hrs. Each flood hydrograph starts and ends at the winter base flow.

Due to the poor channel conditions in Cochran Creek/Quail Slough and Redmond Creek only the most frequent flood events stay contained within the channel. Larger flood events tend to flow overbank and into the large storage area (Cell D). For this analysis it was assumed that only the Cochran Creek/Quail Slough and Redmond Creek hydrograph flows below the 1.111-yr peak-flow remain in channel and flows above these peak-flows are combined into the Cochran Creek/Quail Slough and Redmond Creek to Storage Area hydrograph.

Based on initial model runs, it was determined that the Freshwater Slough peak-flows entering the model domain were probably too high. Field observations indicate that Freshwater Creek high flows above Myrtle Avenue likely overflow the left bank and flow into the large southerly floodplain. This floodplain flow moves west under Myrtle Avenue through a high-flow causeway crossing and flows into the Wood Creek storage basin area (Cell D). To account for this high-flow condition, the Freshwater Slough above model domain hydrographs were altered by reducing flows above the 2-yr peak-flow of 2,140 cfs using a reduction factor. A reduction factor was determined for each peak-flow by taking the ratio of the peak flow overtopping the first lateral structure downstream of the Freshwater Slough BC and the associated Freshwater Slough above model domain peak-flow. The reduction factor was linearly interpolated between zero at the 2,140 cfs flow (2-yr event) and a maximum at the hydrograph peak-flow. The reduction factors were 0.291 for the 10-yr flow, 0.444 for 100-yr flow, and 0.505 for the 500-yr flow. The reduced flow from the Freshwater Slough hydrographs were added to the Wood Creek hydrographs. Figure 6 shows the 2-, 10-, 100- and 500-yr flood hydrographs for each tributary BC with the MMMW tidal series.

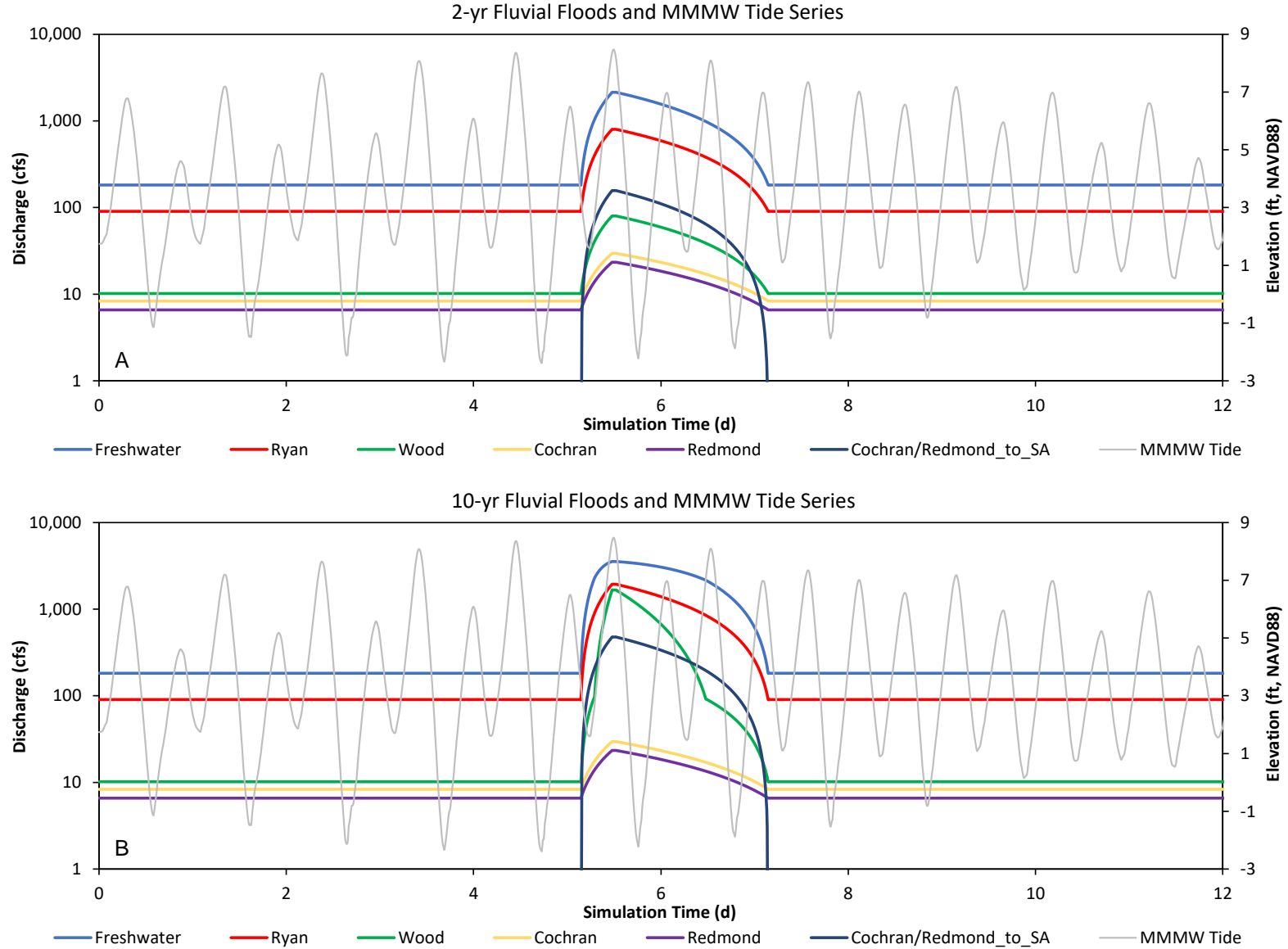


Figure 6. Flood hydrographs for the 1D-Model upstream boundary condition (BC) for 2-yr (A), 10-yr (B), 100-yr (C), and 500-yr (D) events (log scale), and the MMMW tidal series (arithmetic scale) for the 1D-Model downstream BC. Note how the flood peaks align with the maximum tidal level.

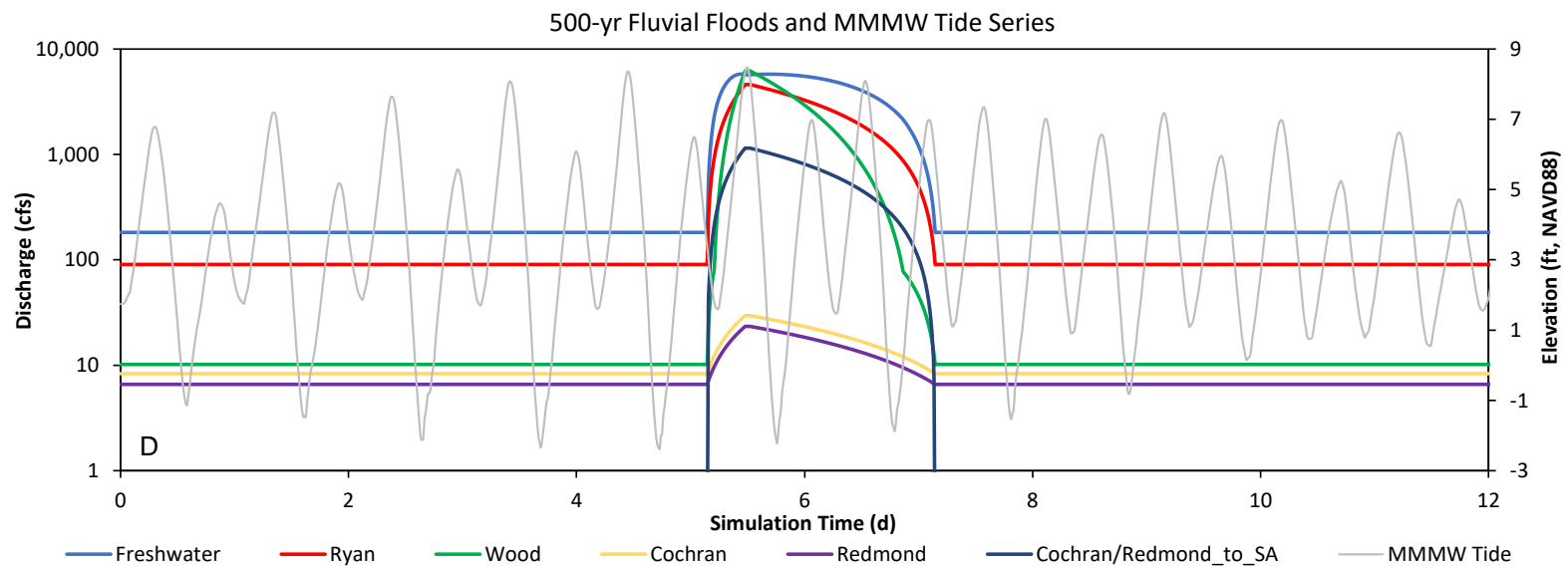
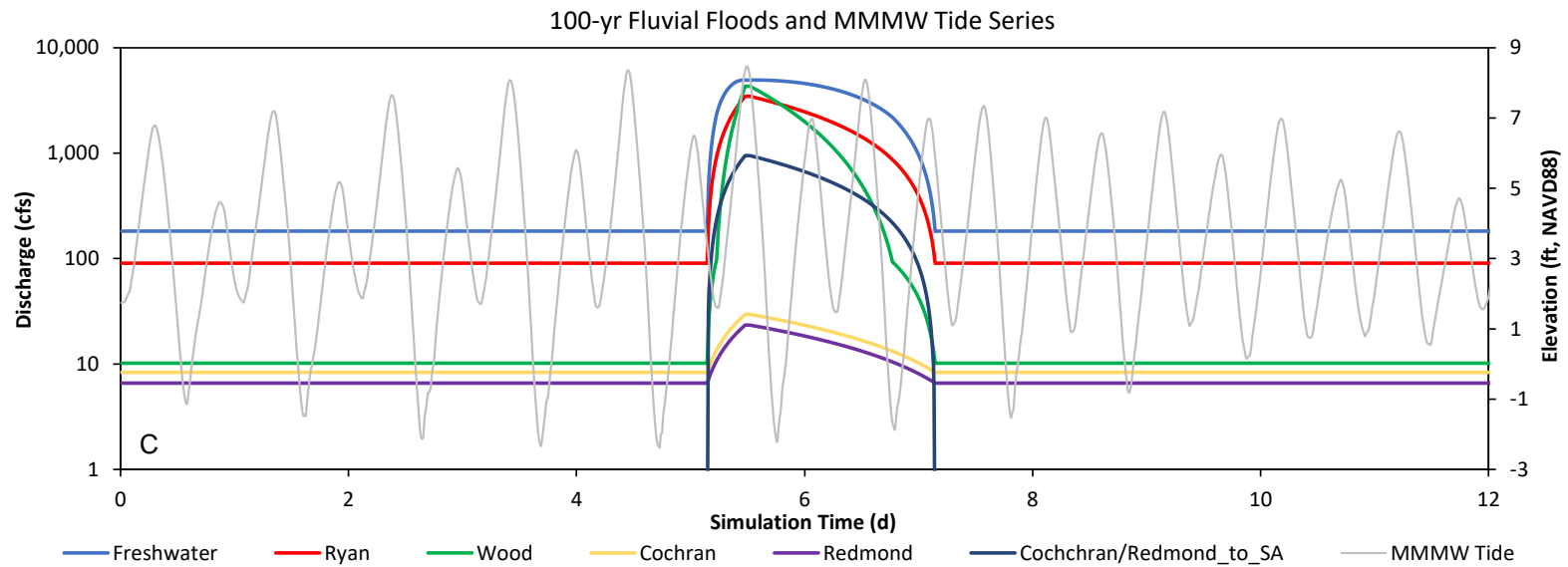


Figure 6 (continued).

Application of Boundary Conditions to Flow Condition Scenarios

The developed 1D-Model was used to predict water surface elevations within the Project Area from upstream riverine flooding and coastal extreme high-water level events. This section describes how the boundary conditions are applied to the 1D-Model domain for the two flood/high-water event conditions described above.

Event Condition 1

Event Condition 1 predicts water levels from riverine flooding for the 2-, 10-, 100- and 500-yr flood events on the upstream model boundary and a representative spring tide tidal series on the downstream boundary. For this event condition the boundary conditions (Figure 5, Table 4 and Figure 6) were applied to the 1D-Model domain (Figure 4) as outlined below:

- Freshwater Slough and Ryan Slough flood hydrographs were applied at each tributary on the upstream boundary of the model domain.
- Wood Creek flood hydrographs were applied at the upstream end of the Wood Creek storage area (Cell D).
- Cochran Creek/Quail Slough and Redmond Creek hydrographs below the 1.111-yr peak-flows were applied at each tributary outlet into Fay Slough.
- Cochran Creek/Quail Slough and Redmond Creek to Storage Area hydrographs above the 1.111-yr peak-flows were applied at the upstream end of the large agricultural storage area (Cell C1).
- MMMW tidal series was applied at the downstream boundary of the model domain.

Event Condition 2

Event Condition 2 predicts water levels from coastal extreme high-water levels for the 2-, 10-, 100- and 500-yr events at the downstream model boundary and winter base-flows on the upstream boundary for each tributary. For this event condition the boundary conditions (Figure 5, Table 4 and Figure 6) were applied to the 1D-Model domain (Figure 4) as outlined below:

- The extreme high-water level tidal series are applied at the downstream boundary of the model domain.
- Constant winter base-flow series for Freshwater Slough (182 cfs) and Ryan Slough (90.5 cfs) were applied at each tributary on the upstream boundary of the model domain.
- Wood Creek constant winter base-flow (10.2 cfs) was applied at the upstream end of the Wood Creek storage area (Cell D).
- Constant winter base-flow series for Cochran Creek/Quail Slough (8.3 cfs) and Redmond Creek (6.6 cfs) were applied at each tributary outlet into Fay Slough.
- A zero (0 cfs) winter base-flow for Cochran Creek/Quail Slough and Redmond Creek to Storage Area was applied at the upstream end of the large agricultural storage area (Cell C1).

Event Condition 1 and Event Condition 2 were modeled for existing conditions and 1-, 2- and 3-ft sea-level rise scenarios. The existing conditions tidal series BCs were increased by 1-, 2- and 3-ft for each sea-level rise scenario.

HYDRAULIC MODELING RESULTS

The developed 1D-Model for the Project Area was used to predict water surface elevations from upstream riverine flooding and downstream coastal extreme high-water level events for existing conditions, and 1-, 2- and 3-yr local sea-level rise scenarios. The remainder of this memo provides several flooding and inundation results for the slough channel reaches and storage area cells. Other hydraulic modeling results are provided in the main report.

Overall results indicate that downstream coastal high-water events control flood levels in the lower reaches of the Project Area, and riverine flooding controls levels in the upper reaches. However, as sea-levels rise the coastal events (downstream conditions) begin to control flood levels over riverine flooding in the Project Area. By approximately 3-ft of local sea-level rise, flooding in the Project Area is dominated by coastal extreme high-water level events.

Independence of Coastal (Surge) and Riverine Events

The Project Area is subject to flooding from by both coastal extreme high-water level (surge) and riverine flood events. These processes can happen independently or simultaneously occur creating combined flood level effects from both coastal and riverine events. Along much of the U.S. Pacific Coast, which includes the Project Area, storm systems that produce extreme coastal surge events are not the same storm systems that produce extreme rainfall and 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 and Little River and the coincident maximum daily tide level at Crescent City was conducted (Figure 7). This evaluation used the Eel River at Scotia (USGS 11477000) and the Little River near Trinidad (USGS 11481200) annual peak discharge data, and the maximum daily tide level that occurred on the same day as the peak discharge from the Crescent City tide gauge (NOAA 94119750) on station datum (STND). 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 are from NHE (2015).

Over the period of record for both river locations simultaneous coastal and riverine events exceeding 10-year probabilities have not occurred. Although a limited number of simultaneous events did occur between 2-yr and 10-yr probabilities at both locations. Results indicate that coastal and riverine extreme events generally appear independent (i.e. don't occur simultaneously) or can be assumed widely separated in time (Figure 7). This independence allows a simplified approach (FEMA, 2005) for computing the probabilities of combined coastal surge and riverine flood events in the Project Area.

Figure 7 also demonstrates that coastal water levels were between MHHW and the 2-yr extreme event for most annual peak-flows at both river locations. This indicates that the assumption of using a MMMW (or spring tide) tidal series as a typical downstream boundary condition for riverine flood events is reasonable.

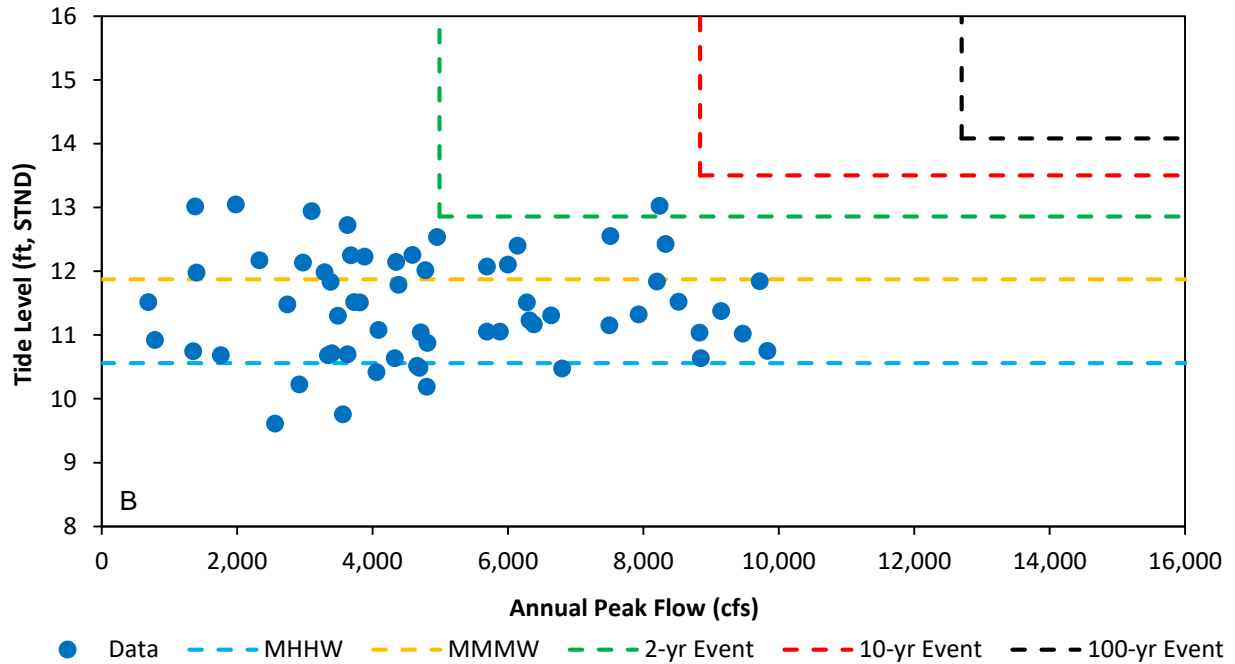
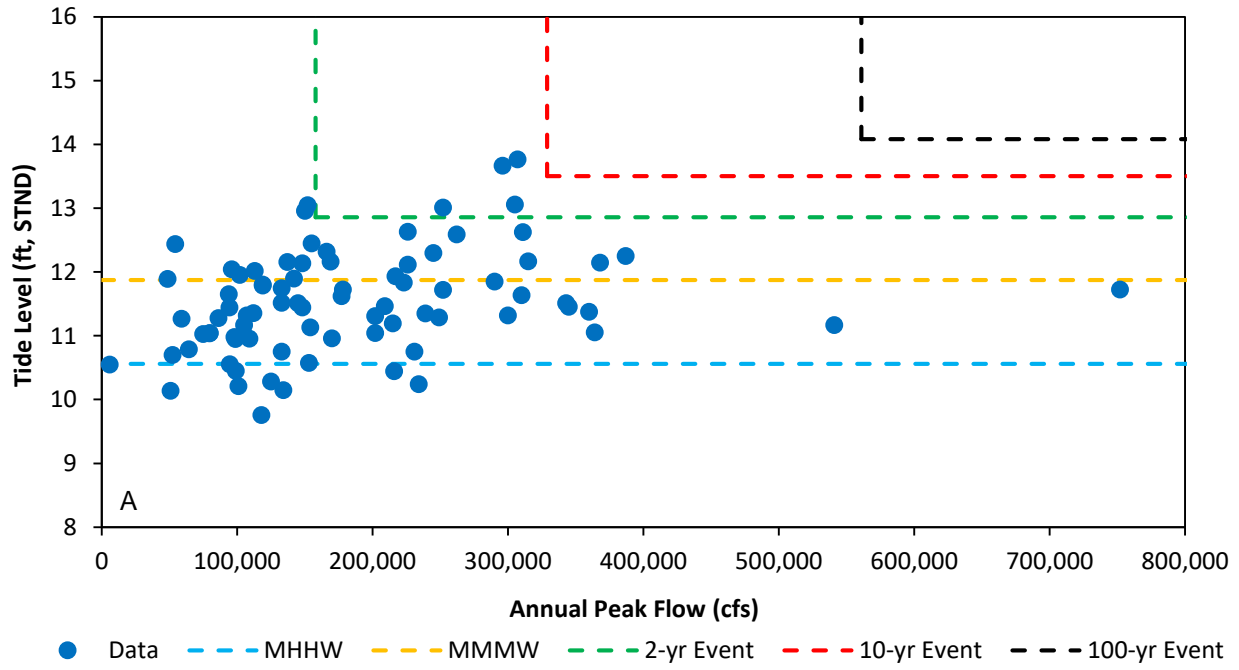


Figure 7. Comparison of (A) Eel River at Scotia (USGS 11477000) and (B) Little River near Trinidad (USGS 11481200) annual peak flows and coincident maximum daily tide levels for Crescent City (NOAA 94119750) tide gauge reported on station datum (STND). Extreme high-water level event probabilities and 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).

Flood Profiles for Combined Coastal and Riverine Events

Predicted existing condition 100-yr coastal and fluvial flood profiles are provided in Figure 8 for Freshwater Slough, Ryan Slough, and Fay Slough from the lower end of Eureka Slough to the upper end of each reach. For all profile plots the coastal water levels are shown as blue lines, the riverine levels as red lines, the bed elevation as a black dashed line, and the right and left levee crest elevations as gray and light-brown lines, respectively. These profiles show which event (coastal or fluvial) controls 100-yr water levels within each reach, and how these controls change with distance upstream from Humboldt Bay. The 100-yr coastal flood level is higher than the 100-yr riverine level in Eureka Slough and the lower portion of Freshwater Slough, and then transitions to the riverine level being higher in the upstream reaches. The 100-yr coastal flood level is higher than the riverine level along the entire Fay Slough reach.

To demonstrate how sea-level change affects profiles in each reach, results for the coastal and riverine 2-, 10-, 100- and 500-yr events for existing conditions, and the 1-, 2- and 3-ft local sea-level rise (LSLR) scenarios are provided for Freshwater Slough (Figure 9), Ryan Slough (Figure 10) and Fay Slough (Figure 11). For these plots the water level profiles are combined and only show the maximum coastal (blue line) or riverine (red line) levels along each slough reach. In Freshwater Slough and Ryan Slough, the extent of coastal flooding increases upstream for each sea-level rise scenario. As described above, Fay Slough is only affected by coastal flooding. In general, at 2-ft LSLR most of the Project Area is controlled by coastal flood levels for all events, apart from the 2-yr event in Freshwater Slough. With 3-ft LSLR the entire Project Area is controlled by coastal event, except for the very upstream reaches of Freshwater Slough near the model domain boundary.

Profiles in all reaches (Figure 9, Figure 10, and Figure 11) for the 10-, 100- and 500-yr coastal events demonstrate a drawdown at the upper extent of coastal flooding for existing conditions and the 1-ft LSLR scenario. This drawdown occurs as water overtops the levees, flowing from the channel into the storage area cells, and fills the cells to a level lower than which occurs in the adjacent channels. The fluvial floods also fill the storage area cells, but the rate of discharge in the channel is high enough that a drawdown does not occur; riverine water levels appear constant along stretches of channel where levee overtopping occurs. By 2-ft and 3-ft LSLR the drawdown of the coastal profiles no longer occur as channel water levels are high enough to provide adequate flow to fill the storage cells to the same level as in the channels. Under 2-ft and 3-ft LSLR conditions the entire Project Area appears flooded to approximately the same water level.

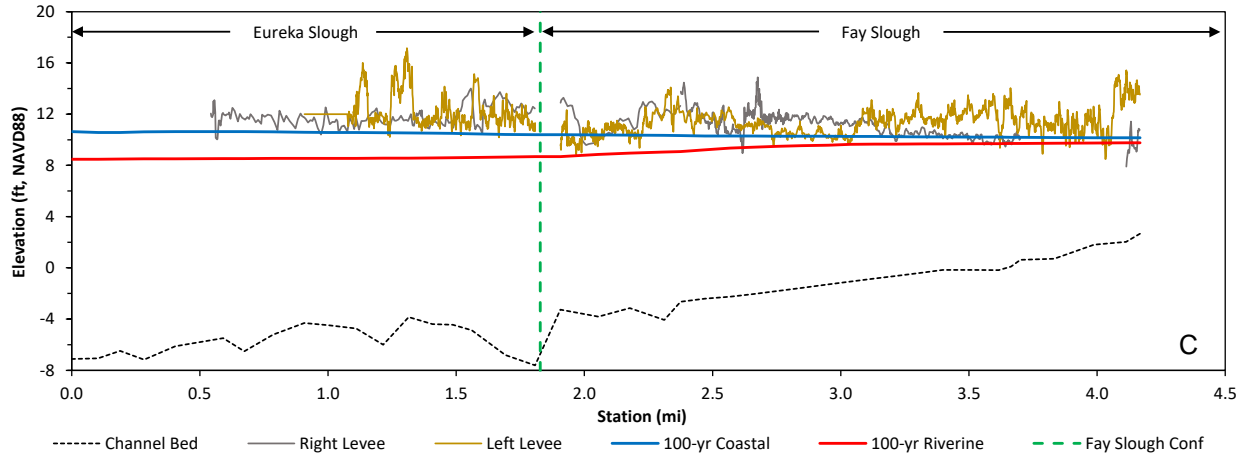
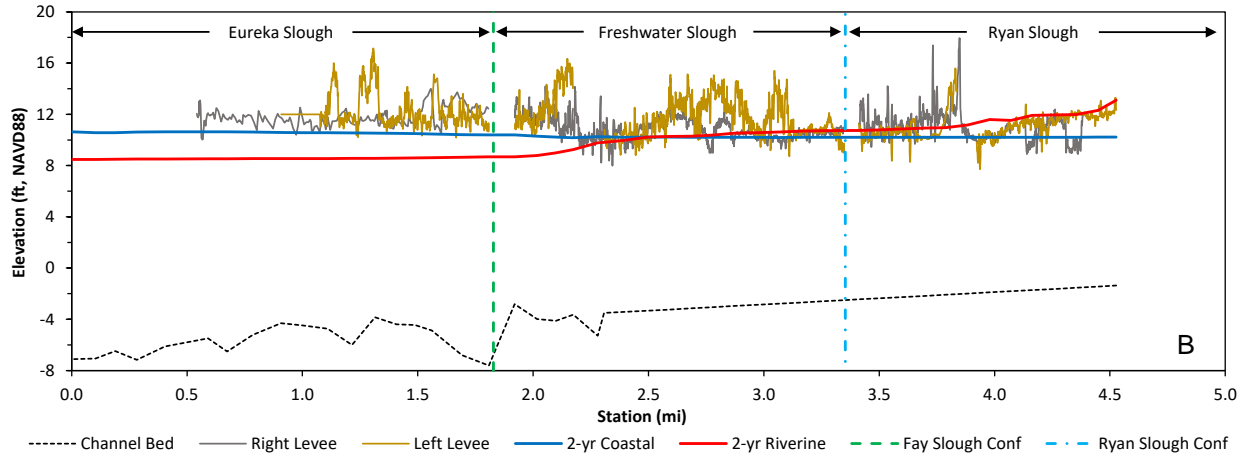
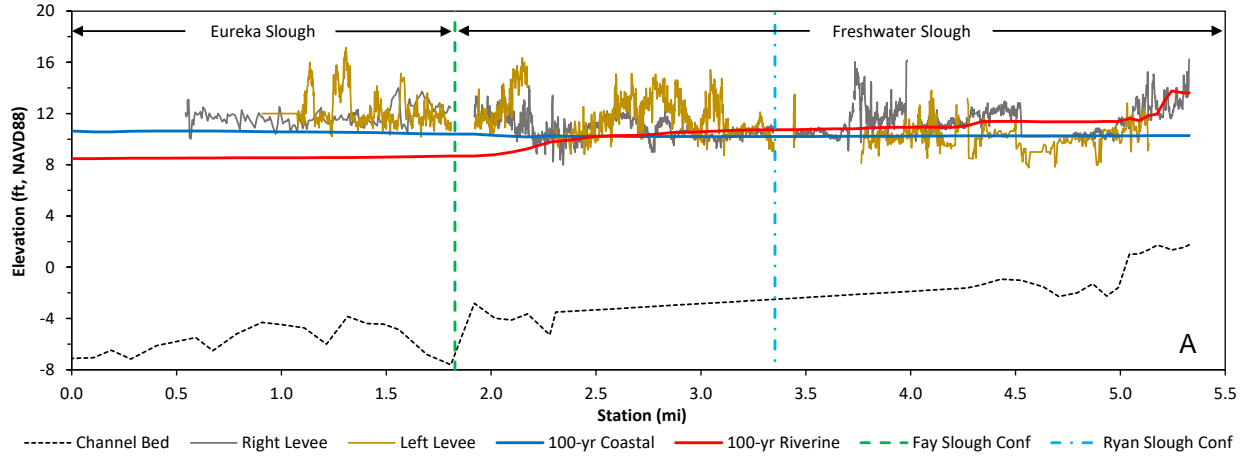


Figure 8. Predicted existing condition 100-yr coastal high-water level and riverine flood profiles for Freshwater Slough (A), Ryan Slough (B) and Fay Slough (C).

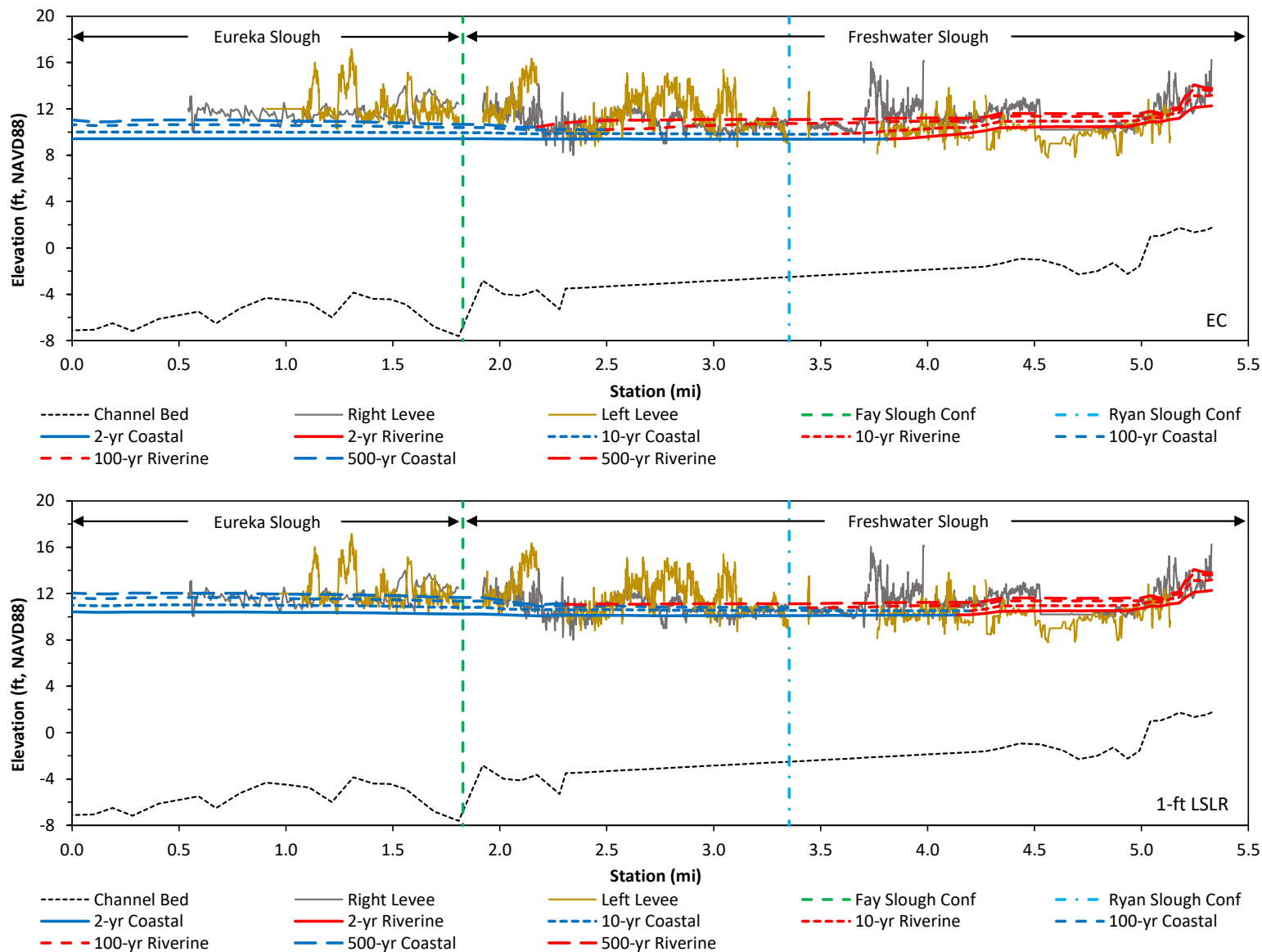


Figure 9. Freshwater Slough predicted 2-, 10-, 100- and 500-yr coastal high-water level and riverine flood profiles for existing conditions (EC), 1-ft local sea-level rise (1-ft LSLR), 2-ft LSLR, and 3-ft LSLR. Only the maximum coastal (blue line) or riverine (red line) water levels are shown.

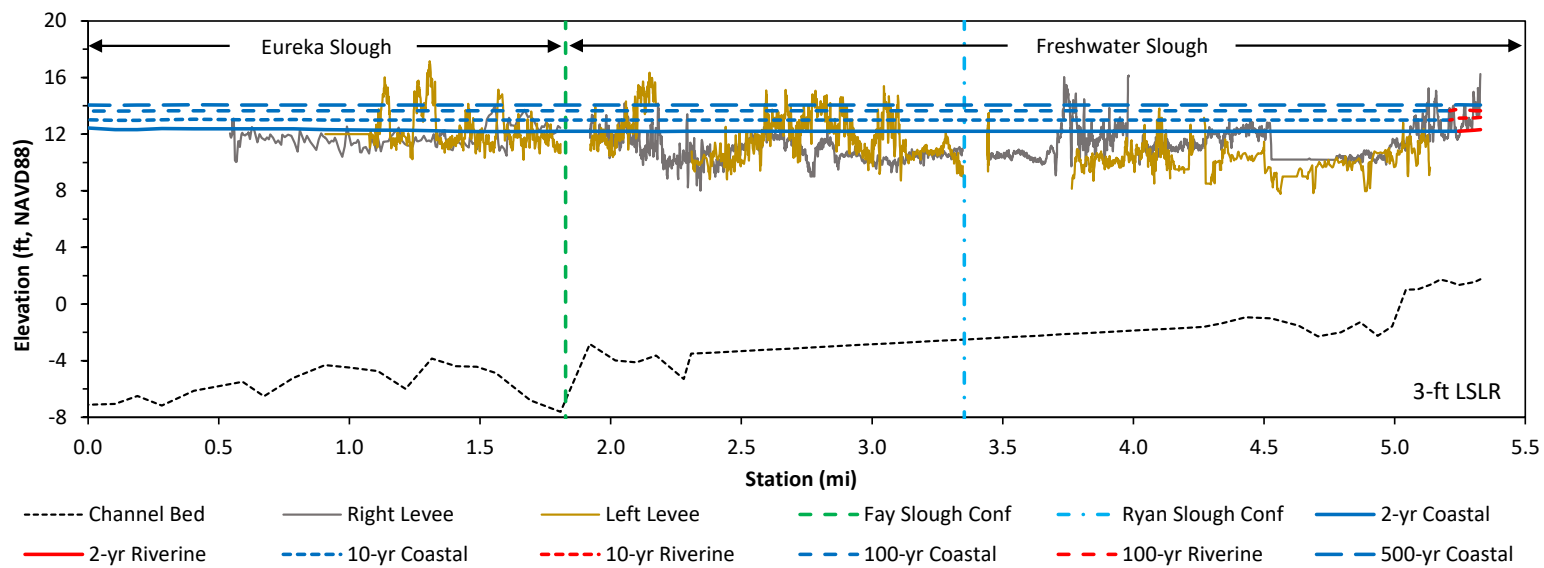
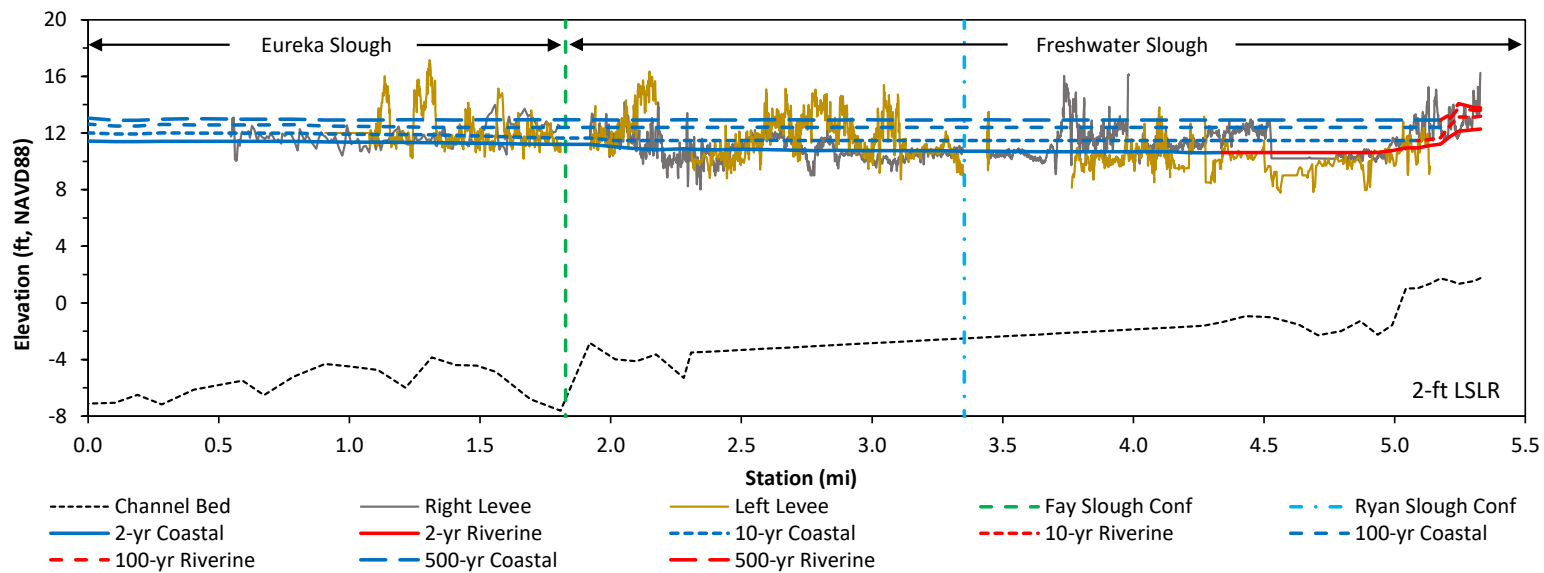


Figure 9 (continued).

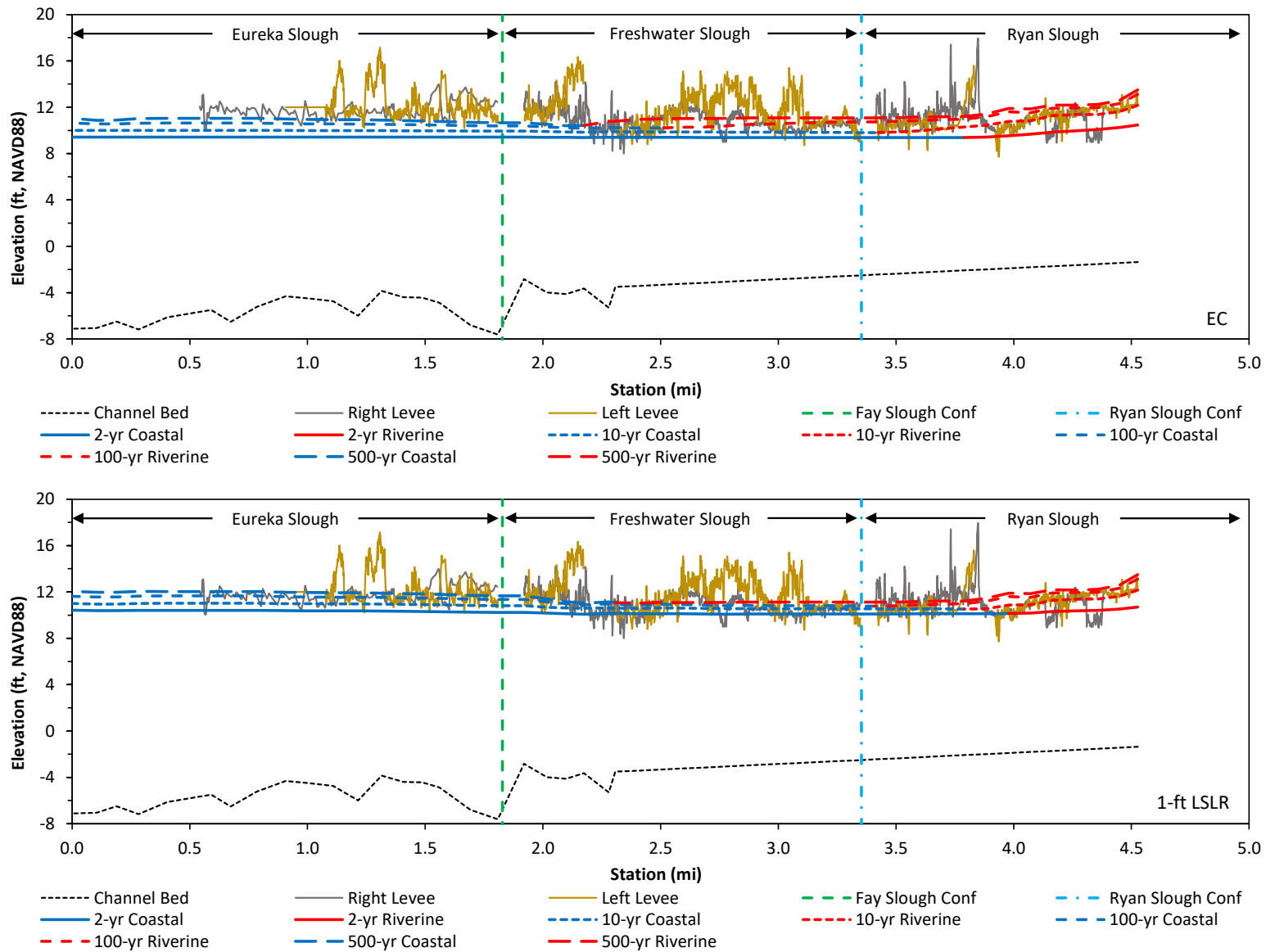


Figure 10. Ryan Slough predicted 2-, 10-, 100- and 500-yr coastal high-water level and riverine flood profiles for existing conditions (EC), 1-ft local sea-level rise (1-ft LSLR), 2-ft LSLR, and 3-ft LSLR. Only the maximum coastal (blue line) or riverine (red line) water levels are shown.

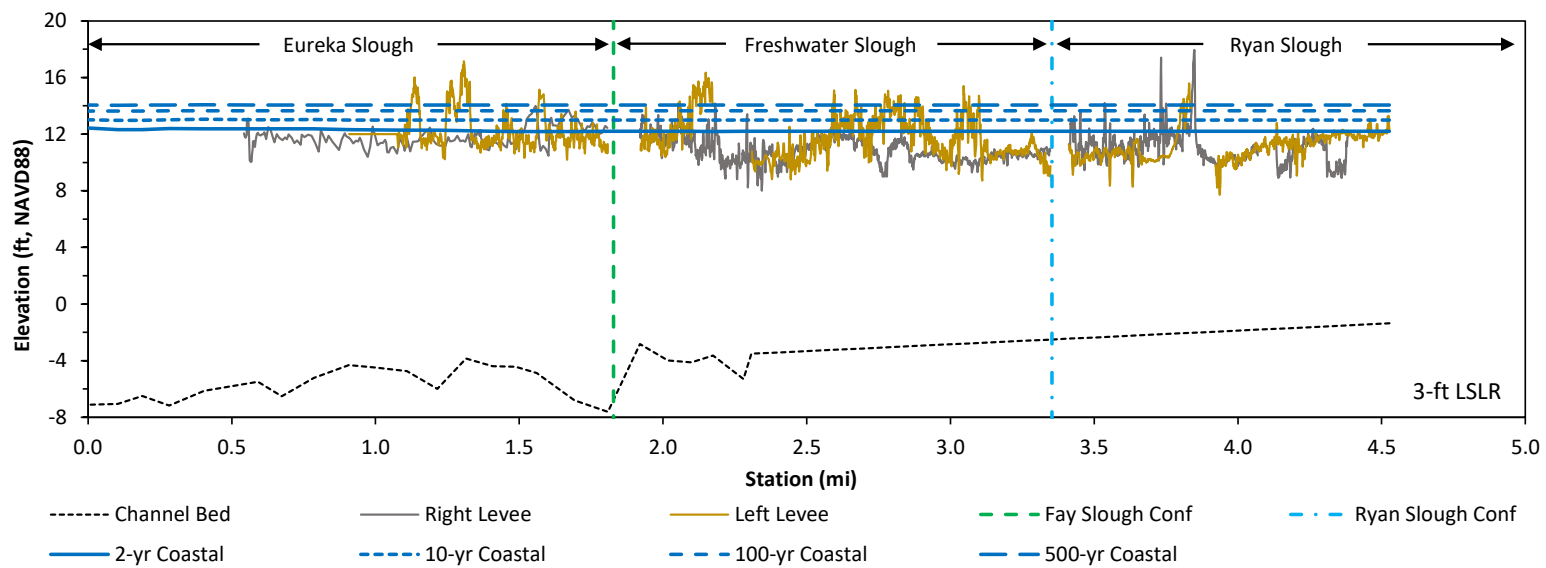
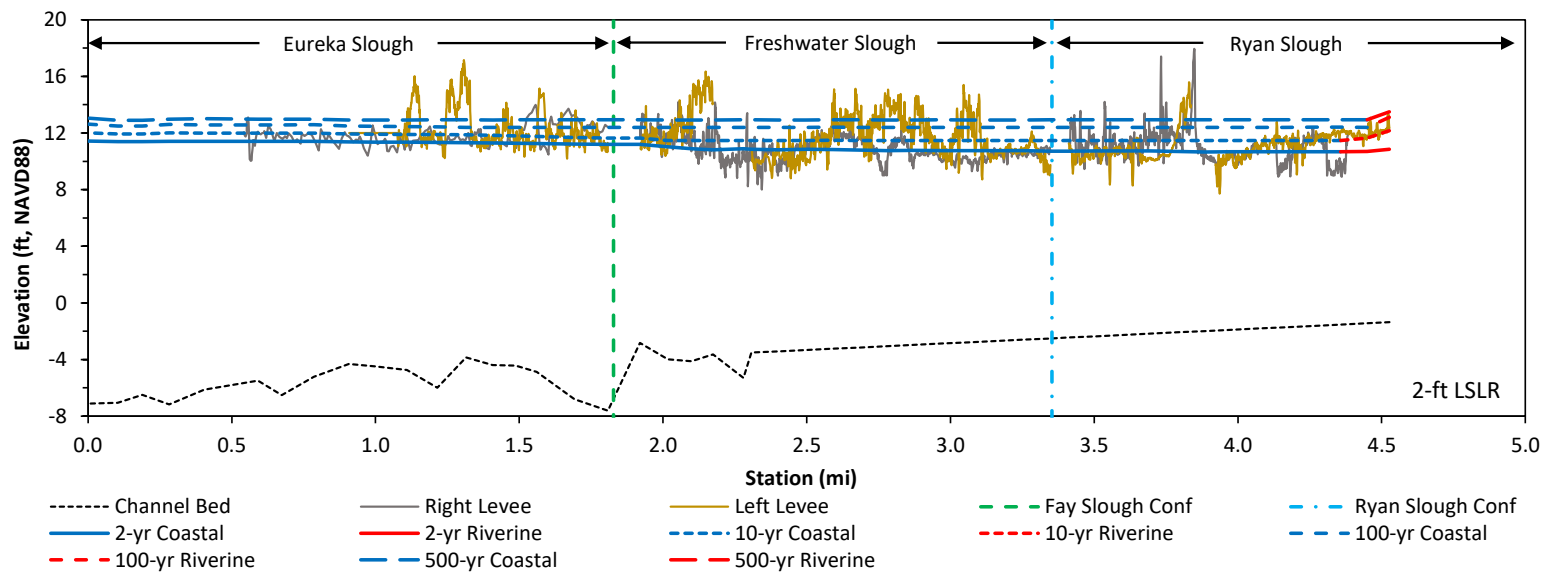


Figure 10 (continued).

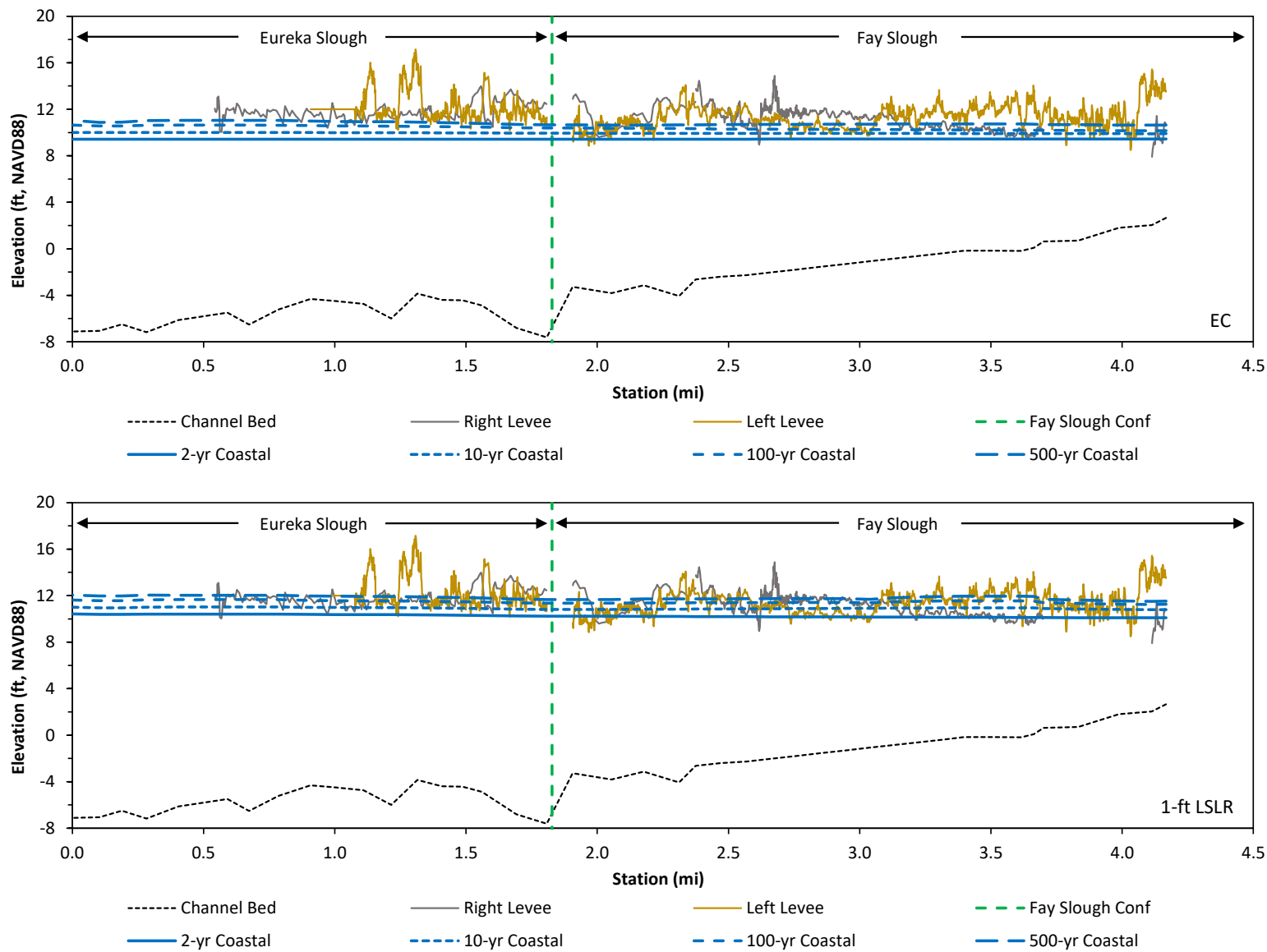
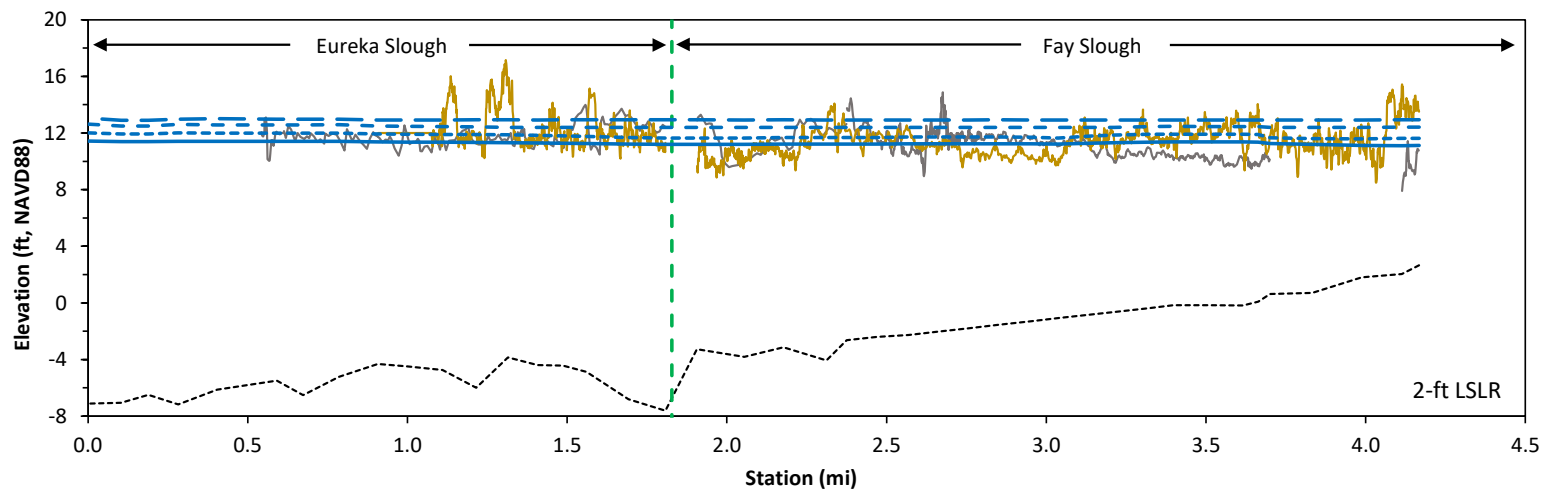
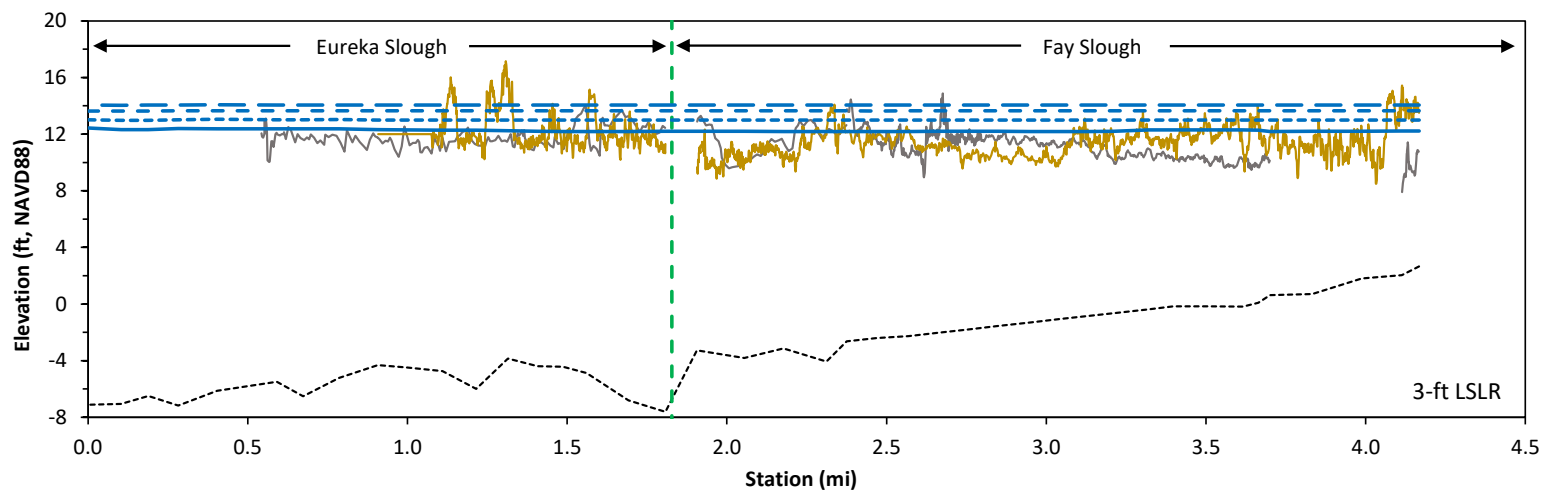


Figure 11. Fay Slough predicted 2-, 10-, 100- and 500-yr coastal high-water level and riverine flood profiles for existing conditions (EC), 1-ft local sea-level rise (1-ft LSLR), 2-ft LSLR, and 3-ft LSLR. Only the maximum coastal (blue line) or riverine (red line) water levels are shown.



- Channel Bed
- Right Levee
- Left Levee
- Fay Slough Conf
- 2-yr Coastal
- 10-yr Coastal
- 100-yr Coastal
- 500-yr Coastal



- Channel Bed
- Right Levee
- Left Levee
- Fay Slough Conf
- 2-yr Coastal
- 10-yr Coastal
- 100-yr Coastal
- 500-yr Coastal

Figure 11 (continued).

Combined Probabilities of Coastal and Riverine Extreme Water Levels within the Slough Channels

This section describes the determination of combined probabilities of coastal extreme high-water and riverine flood levels at specific cross-section locations within the slough channels using the 1D-Model predictions. Based on the independence assumption of coastal and riverine events described earlier, FEMA (2005) provides a simplified approach for determining the combined probabilities of coastal and riverine water levels. In brief, predicted water levels for the 2-, 10-, 100- and 500-yr coastal and riverine events are extracted from the 1D-Model at specific cross-section locations, and tabulated as water level versus rate of occurrence. The rate of occurrence (frequency) is the number of events per year determined as the inverse of recurrence interval. Log-log relationships of water level and frequency are linearly interpolated over a range of water levels to determine separate frequency estimates for both the coastal and riverine results. These separate frequencies are then added for the same levels to determine the total combined probabilities of coastal and riverine water levels.

Combined probability curves were developed at several locations in Freshwater Slough, Ryan Slough and Fay Slough (Figure 12) for existing conditions, and the 1-, 2- and 3-ft LSLR scenarios. The combined probability curves along with the coastal and riverine curves are provided at five locations in Freshwater Slough (Figure 13 to Figure 17), two locations in Ryan Slough (Figure 18 to Figure 19), and three locations in Fay Slough (Figure 20 to Figure 22). These probability curves demonstrate where in the slough channel reaches flooding is controlled by either the coastal or riverine event alone, or how these events combine to affect overall flood probabilities.

Eureka Slough, Fay Slough and the lower reaches of Freshwater Slough are dominated by coastal flooding for existing conditions and all sea-level rise scenarios. In the middle reach of Freshwater Slough and the lower reach of Ryan Slough flood levels are controlled by the combined event curves for existing condition and the 1-ft LSLR scenario. Likewise, in the upper reaches of Freshwater Slough and Ryan Slough flood levels are controlled by riverine events for existing condition and the 1-ft LSLR scenario. However, with 2-ft LSLR these reaches become more affected by coastal flood events, and by 3-ft LSLR all slough channel reaches are controlled by coastal flooding.

The combined probability curves at a specific location can be used to develop asset exposure plots, which show an assets elevation against the combined probability water levels to understand how the assets inundation vulnerability changes with sea-level rise. Asset exposure plots are included in the main report.

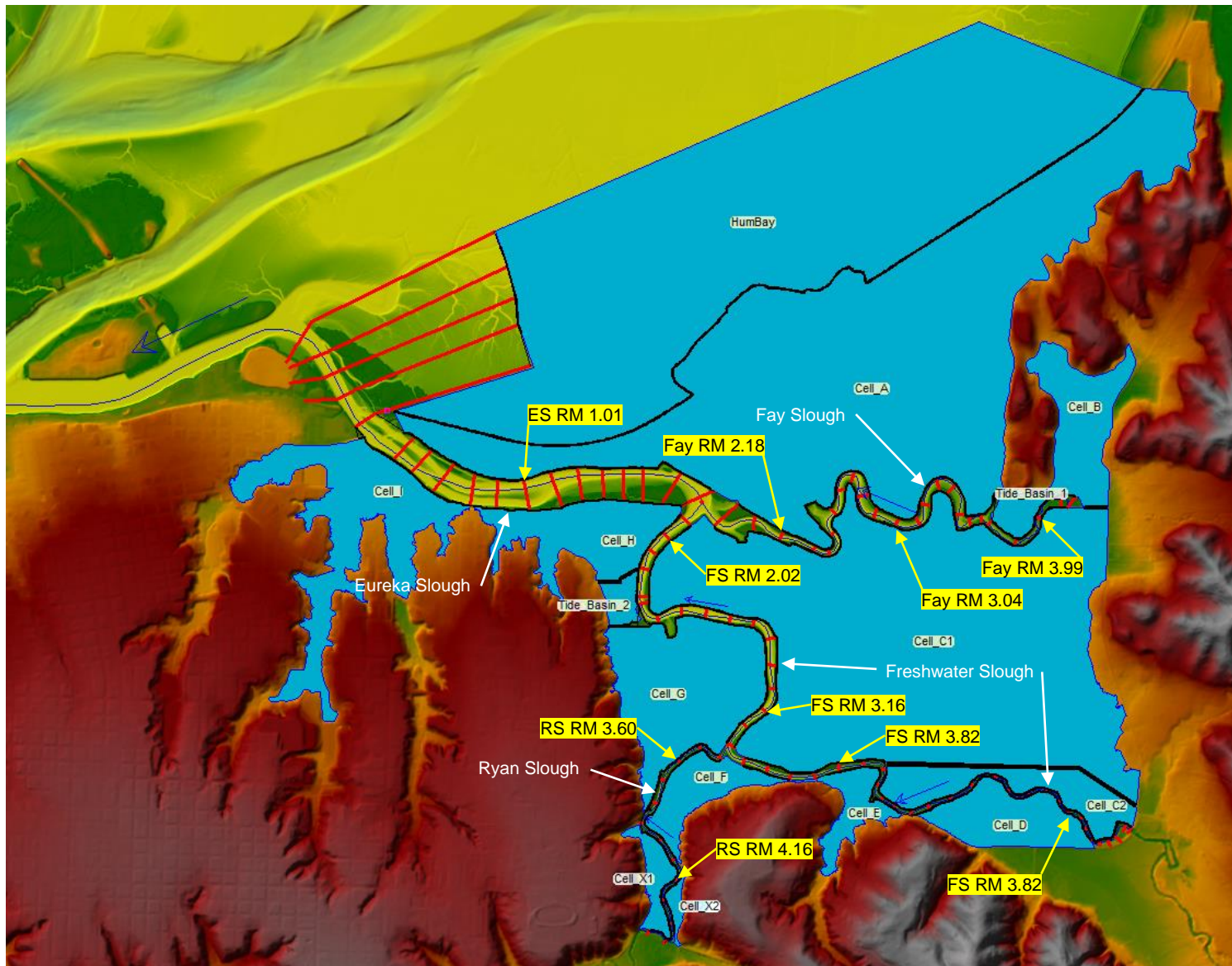


Figure 12. Cross-section locations (highlighted in yellow) of coastal (surge) extreme high-water, riverine flood, and combined level probabilities by river mile (RM) in Eureka Slough (ES), Freshwater Slough (FS), Ryan Slough (RS) and Fay Slough (Fay).

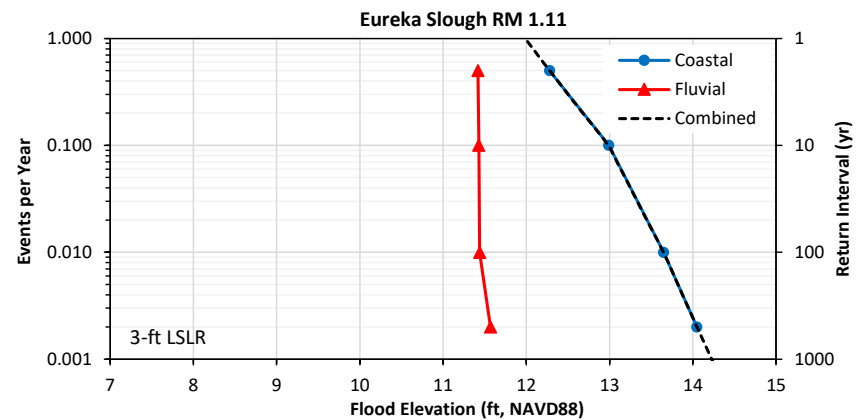
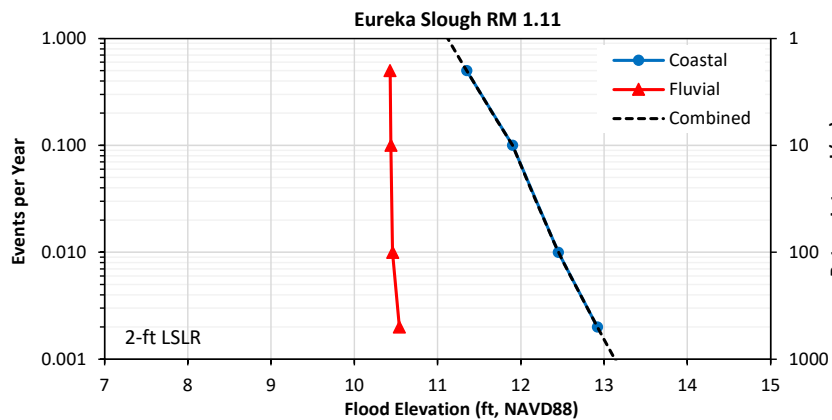
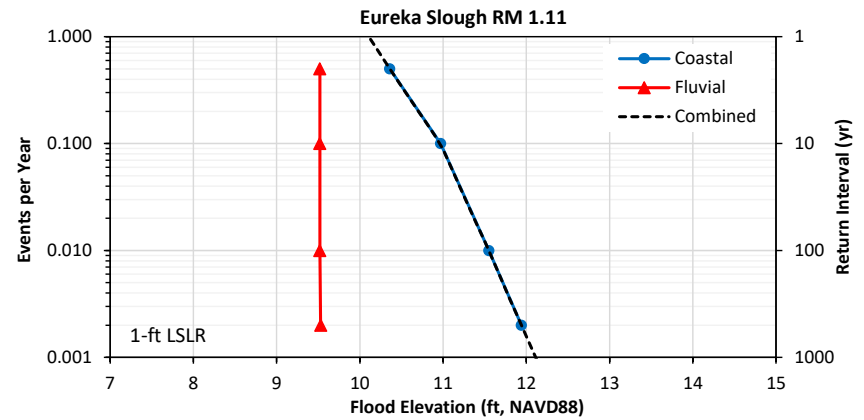
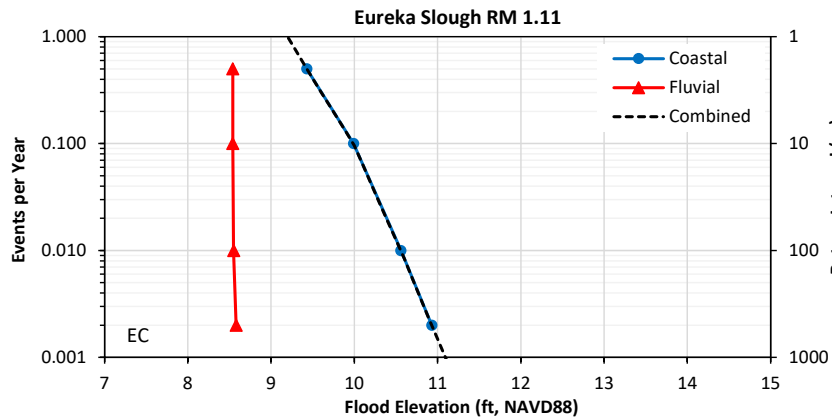


Figure 13. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Eureka Slough at River Mile (RM) 1.11. Probabilities are provided as events per year and return interval.

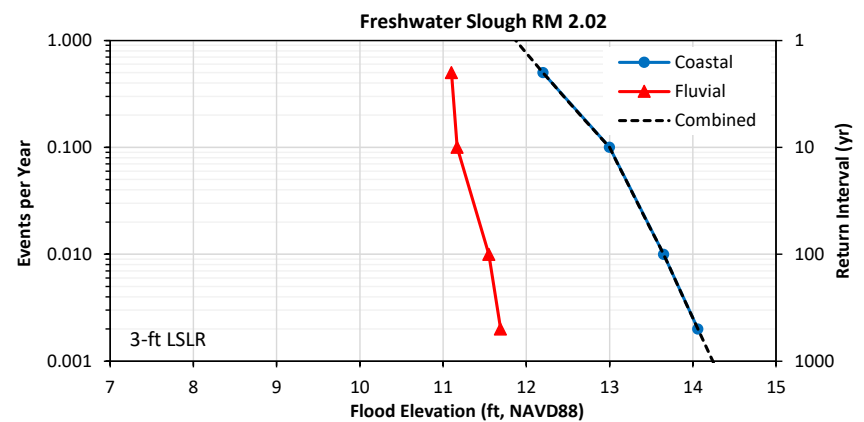
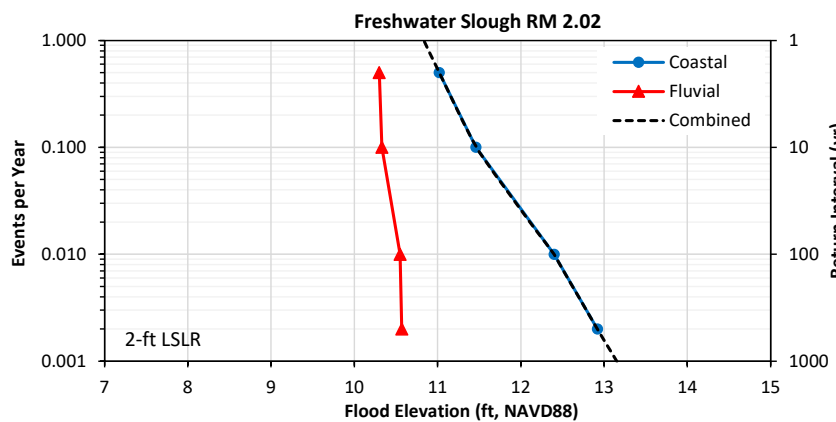
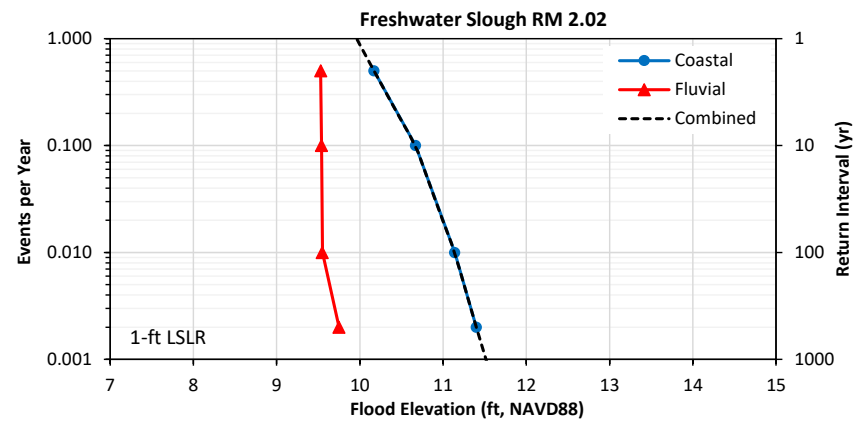
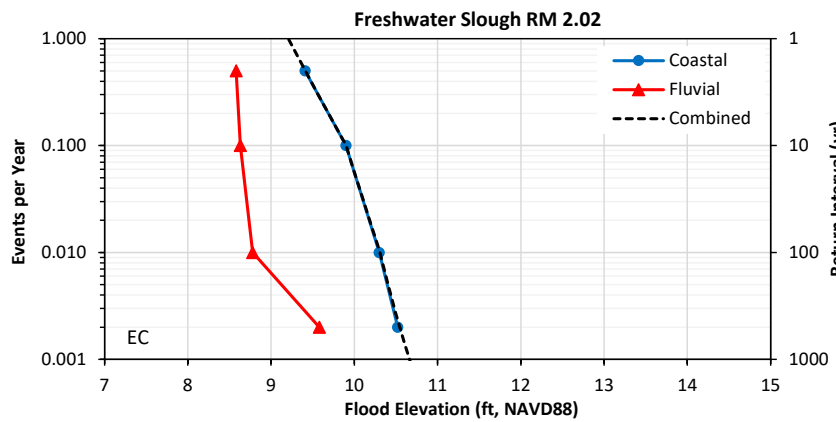


Figure 14. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Freshwater Slough at River Mile (RM) 2.02. Probabilities are provided as events per year and return interval.

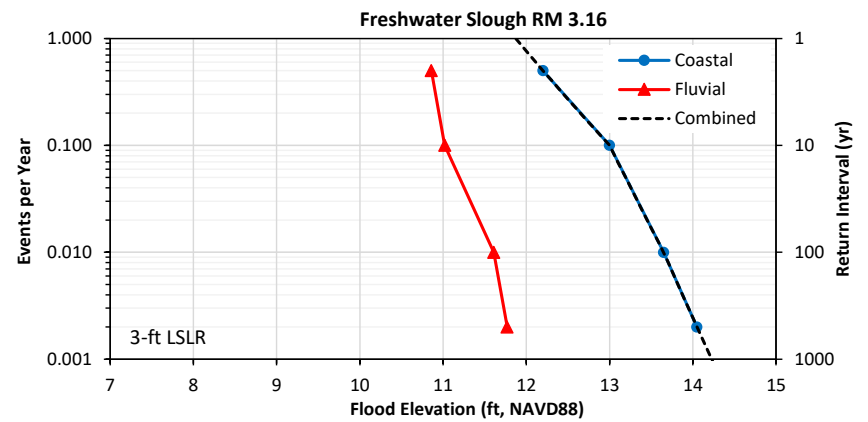
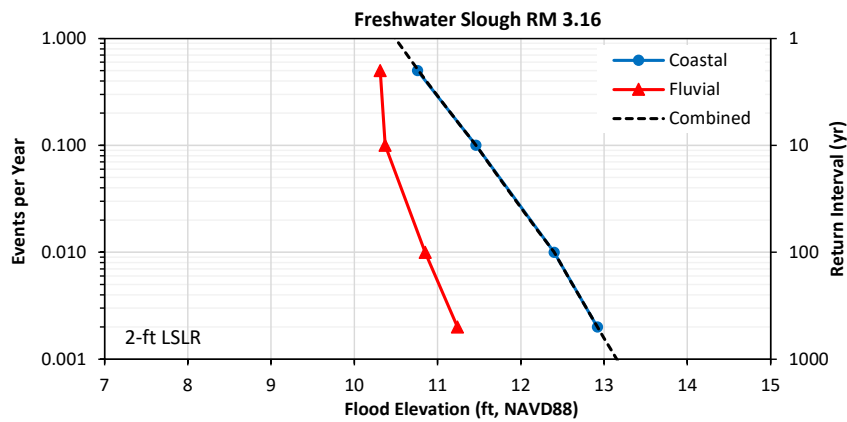
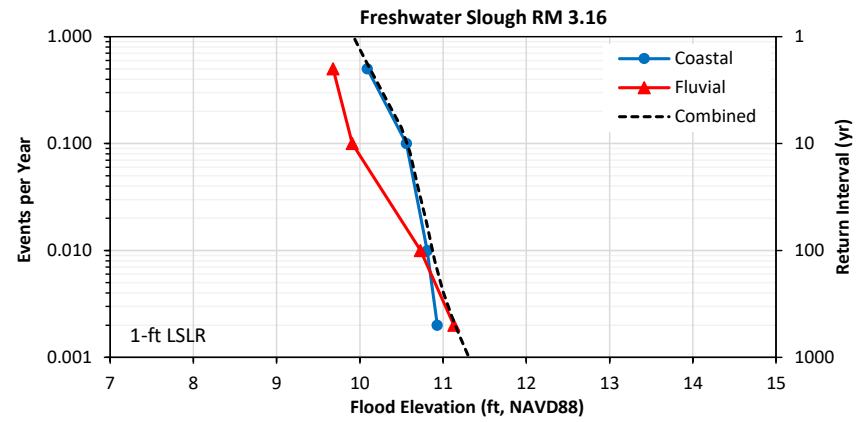
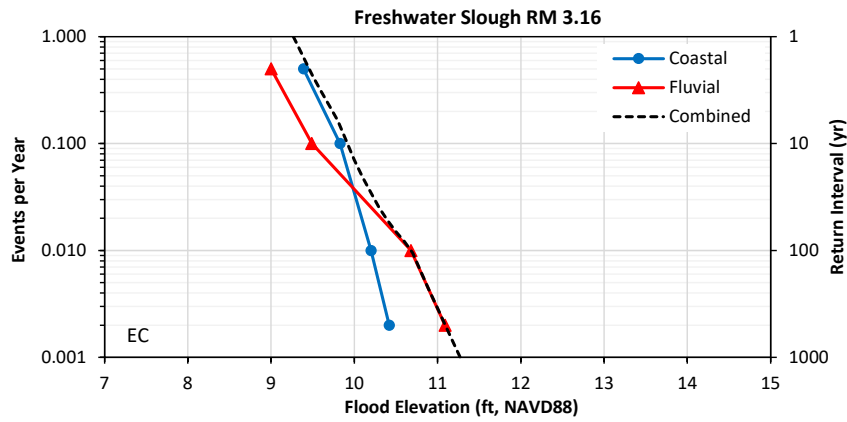


Figure 15. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Freshwater Slough at River Mile (RM) 3.16. Probabilities are provided as events per year and return interval.

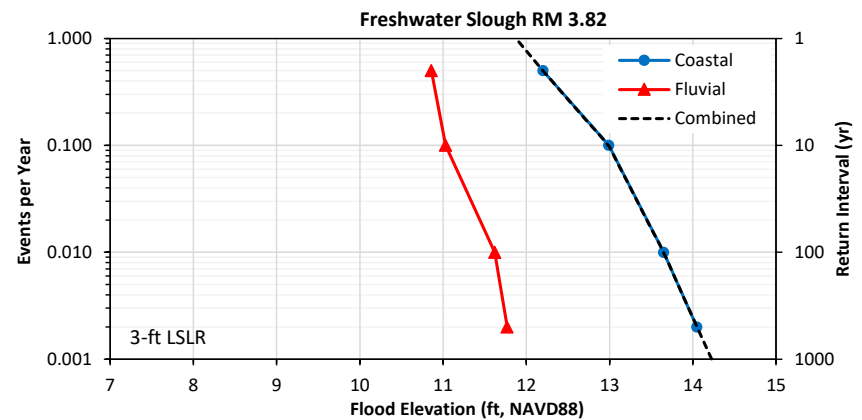
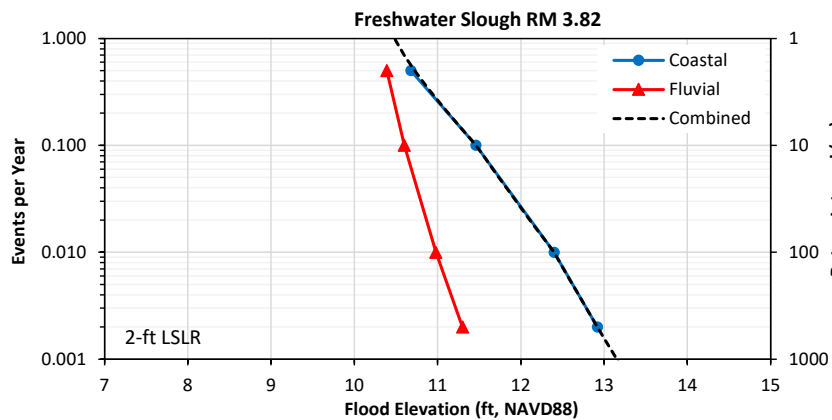
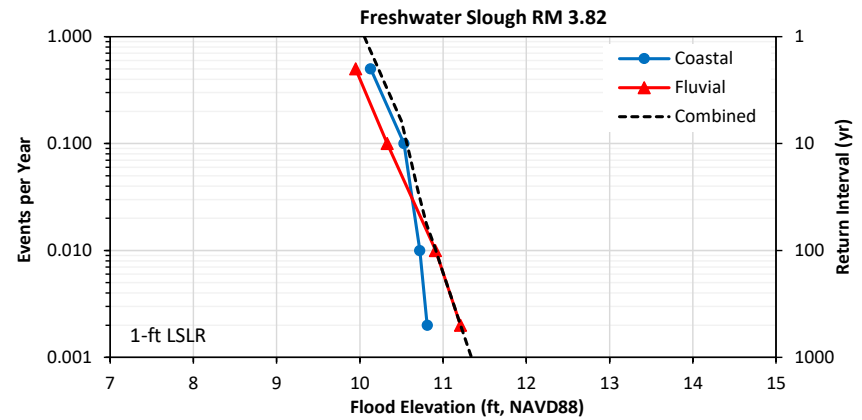
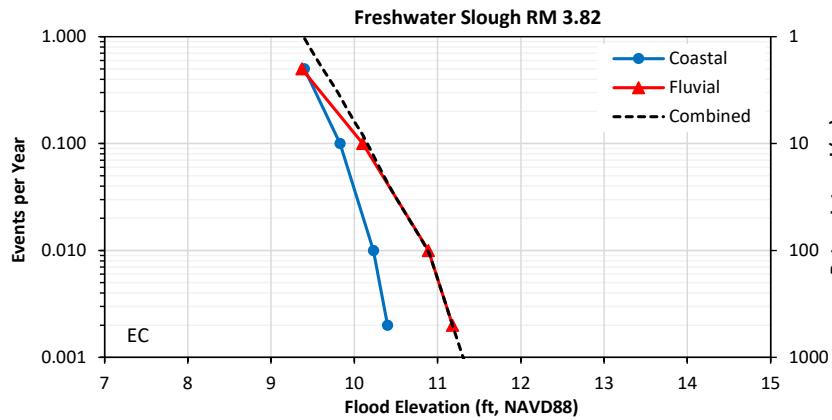


Figure 16. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Freshwater Slough at River Mile (RM) 3.82. Probabilities are provided as events per year and return interval.

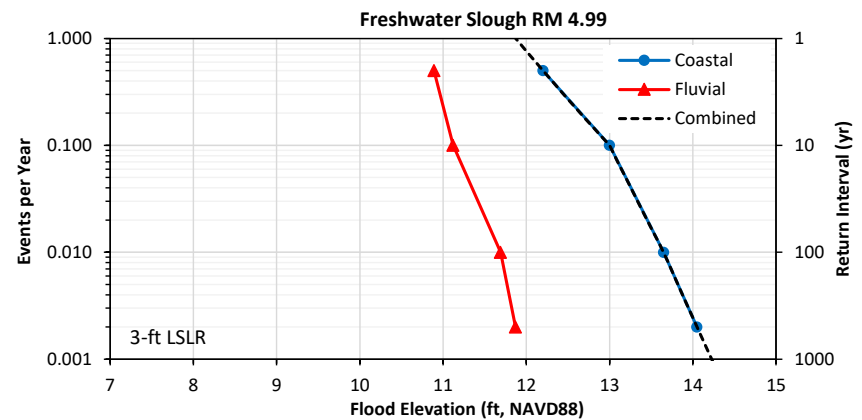
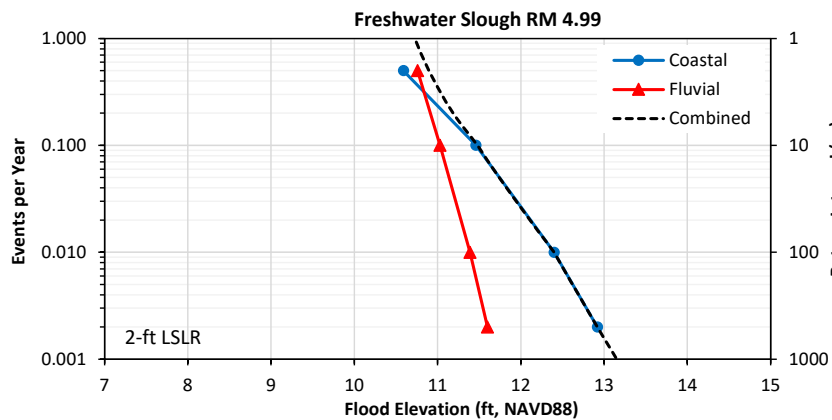
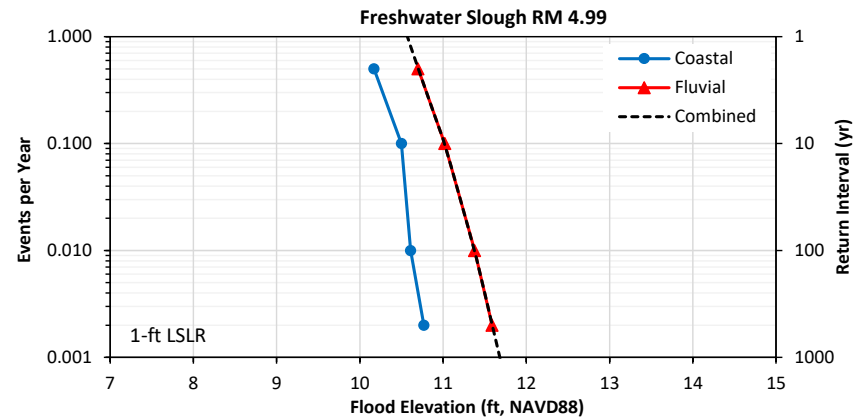
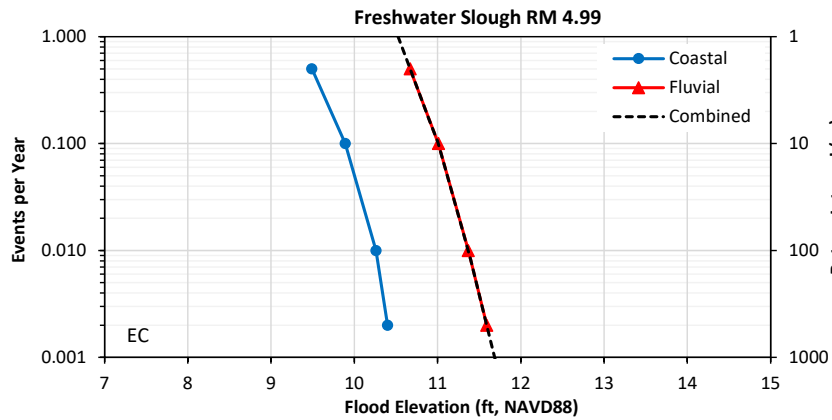


Figure 17. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Freshwater Slough at River Mile (RM) 4.99. Probabilities are provided as events per year and return interval.

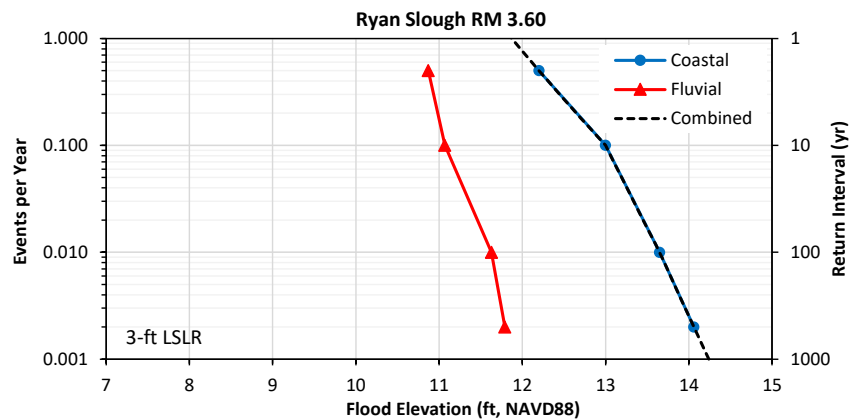
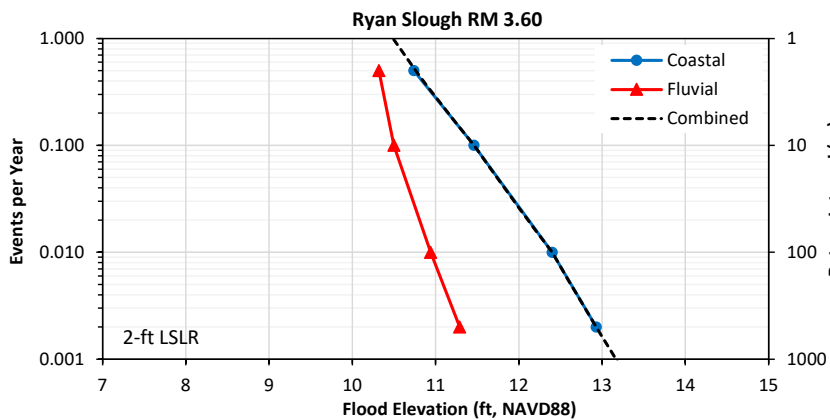
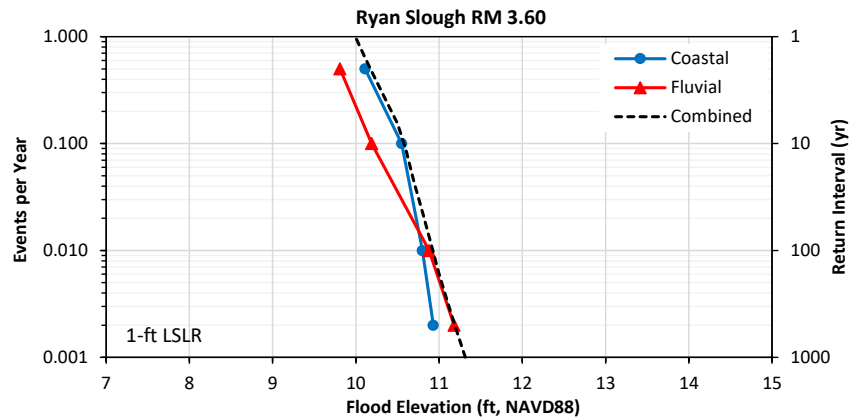
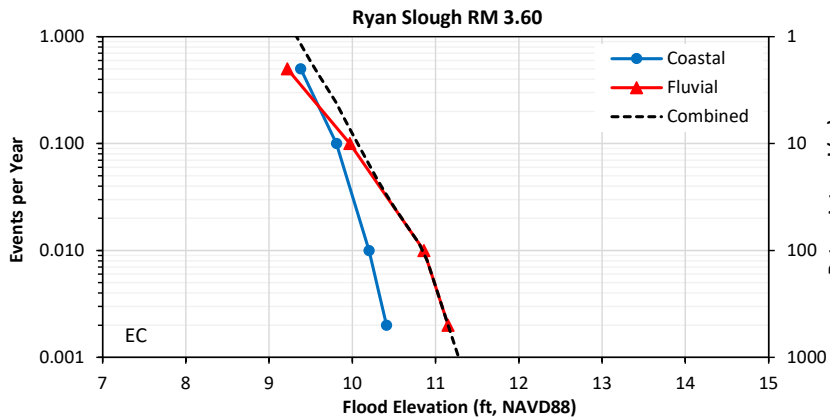


Figure 18. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Ryan Slough at River Mile (RM) 3.60. Probabilities are provided as events per year and return interval.

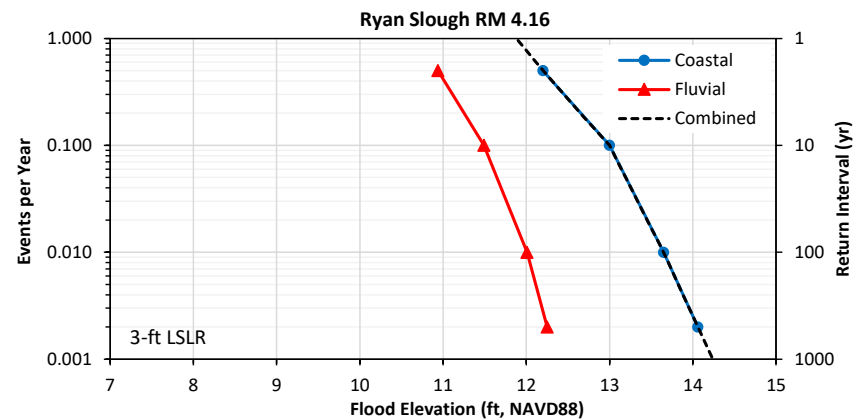
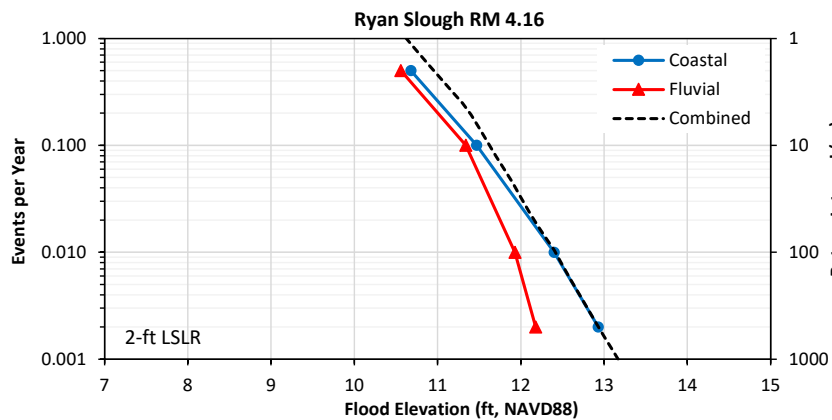
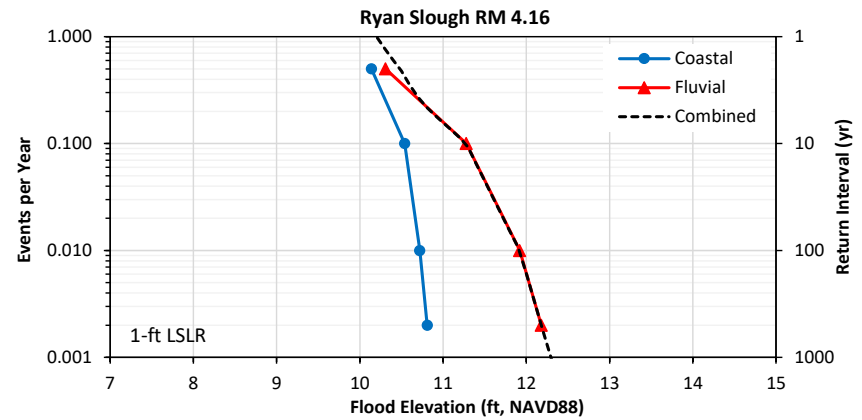
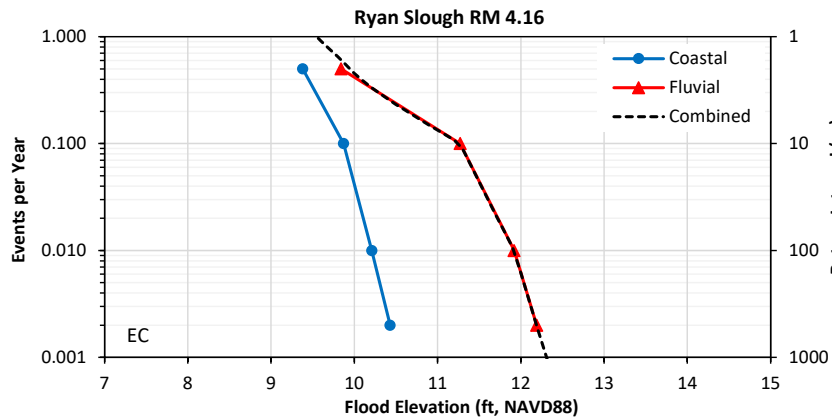


Figure 19. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Ryan Slough at River Mile (RM) 4.16. Probabilities are provided as events per year and return interval.

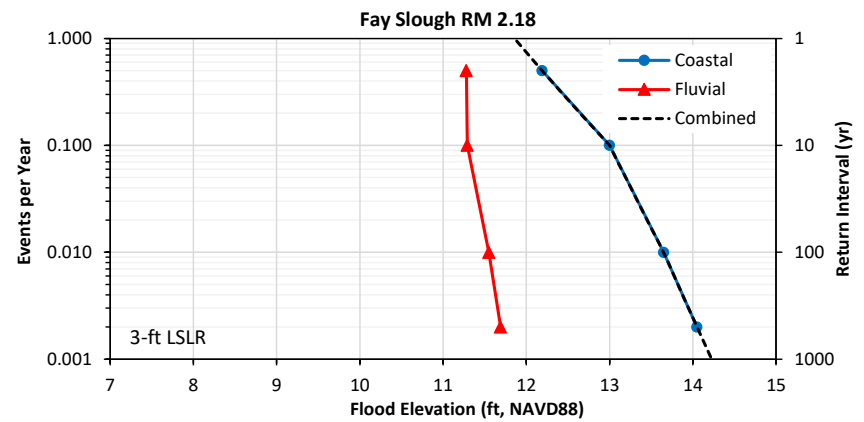
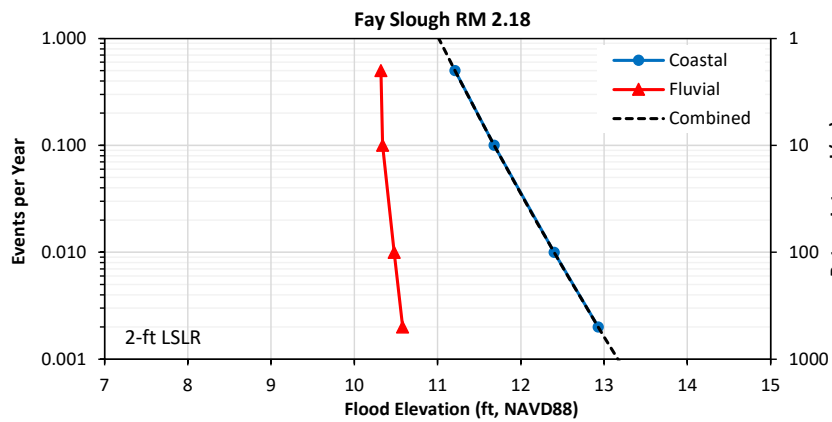
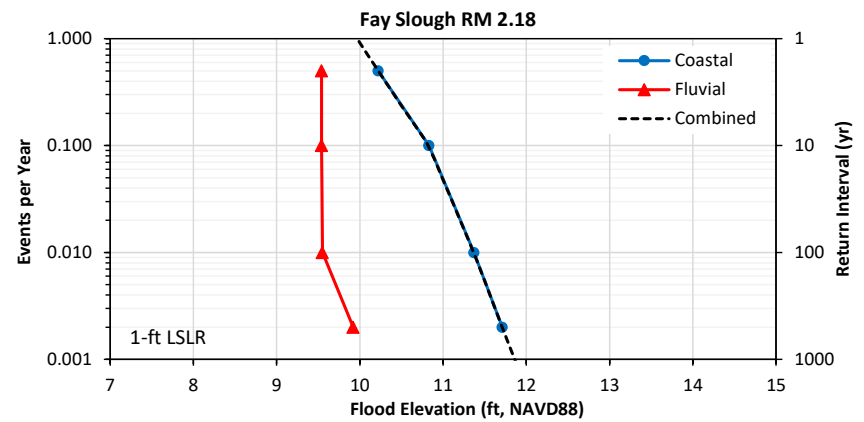
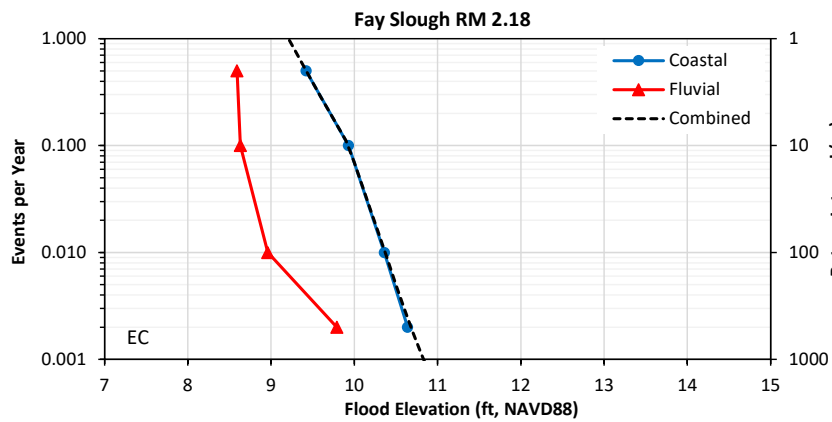


Figure 20. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Fay Slough at River Mile (RM) 2.18. Probabilities are provided as events per year and return interval.

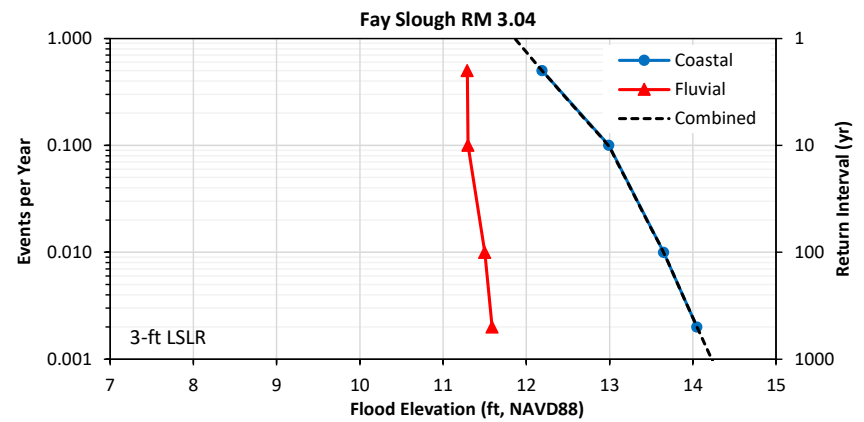
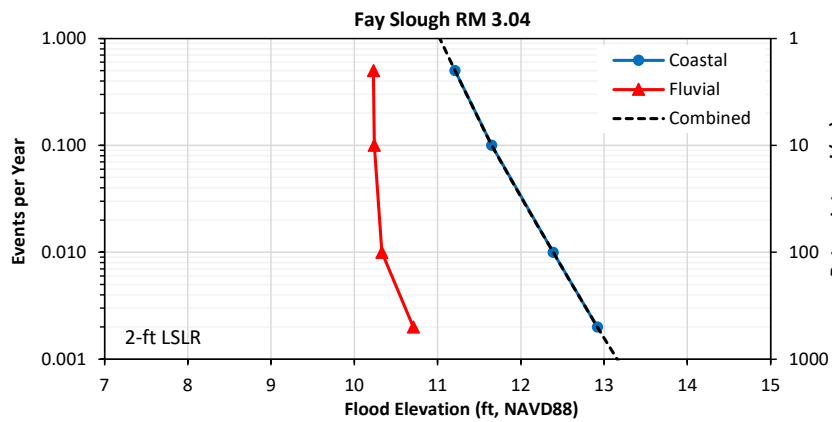
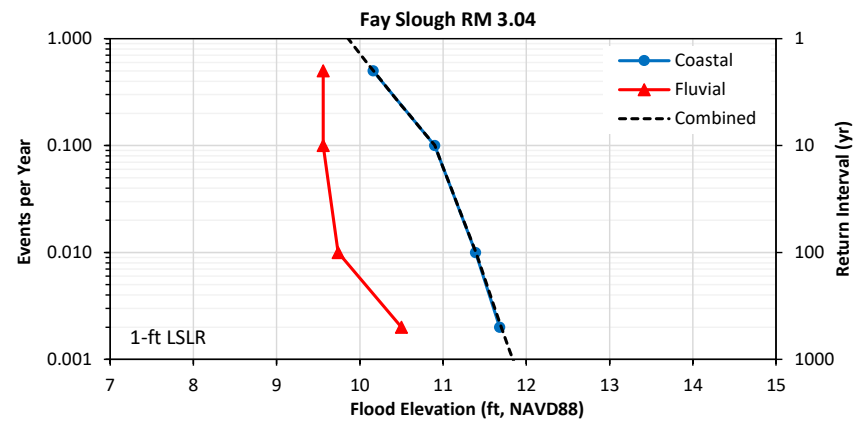
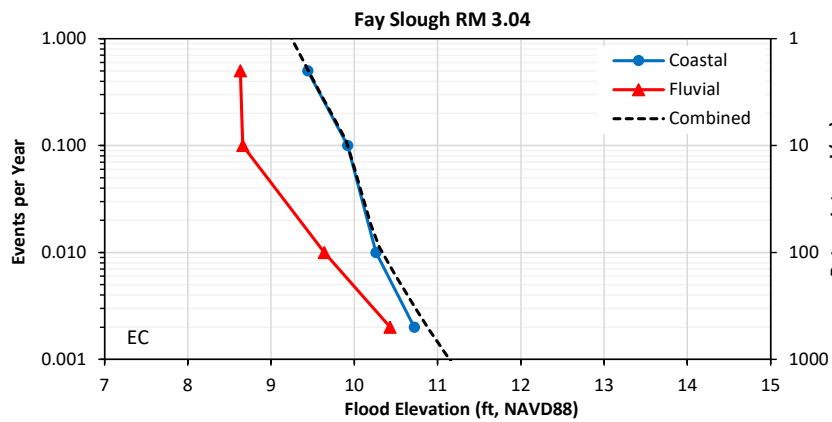


Figure 21. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Fay Slough at River Mile (RM) 3.04. Probabilities are provided as events per year and return interval.

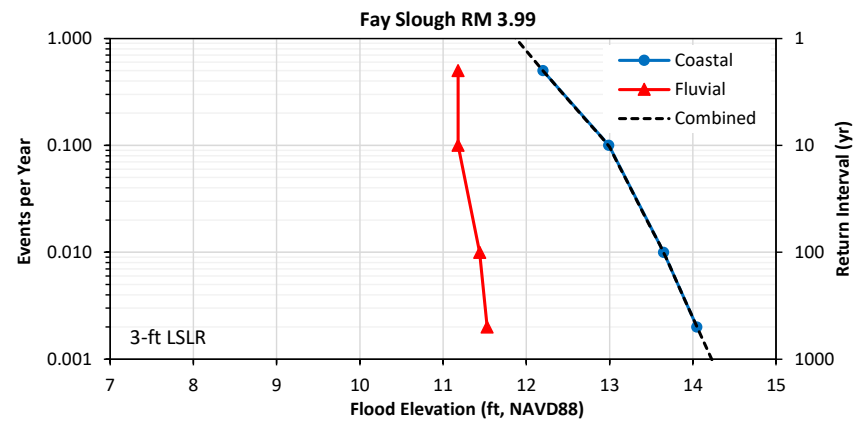
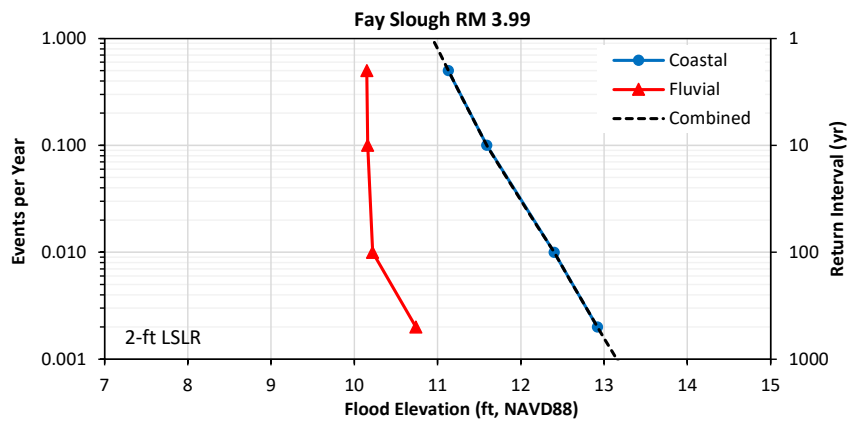
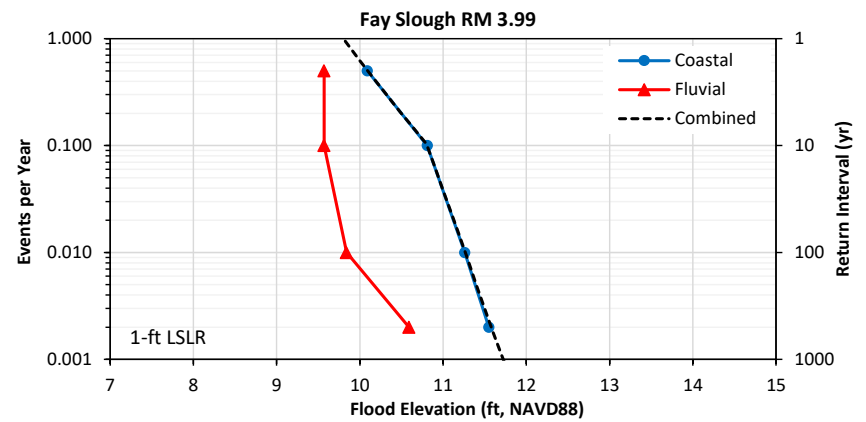
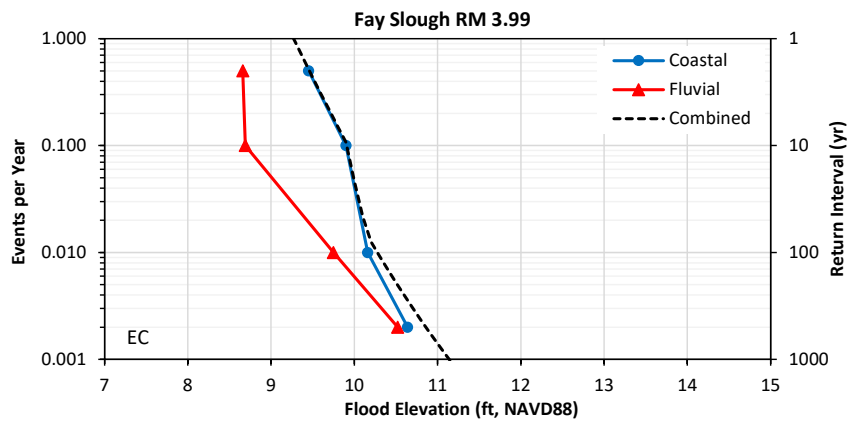


Figure 22. Coastal (surge) extreme high-water level (blue line), riverine flood level (red line), and combined level probabilities (black dashed line) in Fay Slough at River Mile (RM) 3.99. Probabilities are provided as events per year and return interval.

Storage Area Cells Inundation Water Level Time Series

The developed 1D-Model was used to predict inundation levels within storage area cells (Figure 4 or Figure 12) from the coastal and riverine events for existing conditions and the LSLR scenarios. Although the storage areas are simplistically represented in the 1D-Model with level pool routing, results are still informative to understand how inundation changes in each cell with sea-level rise.

The coastal and riverine 2-yr and 100-yr inundation time series for the first 20-days of the 30-day simulation period for existing conditions and the 1-, 2- and 3-ft LSLR scenarios were developed for Cell A (Figure 23) and Cell C1 (Figure 24). For these simulations, the cell initial conditions were set as dry or the cells minimum elevation plus the amount of LSLR. Also included in these figures are the area-weighted average ground elevation in each cell below approximately 12-ft, and the average levee elevation surrounding each cell.

Maximum inundation levels in cell A (Figure 23) are controlled by coastal events over riverine events for the same return levels for existing conditions and LSLR scenarios. For Cell C1 (Figure 24) maximum inundation levels are from riverine events for existing conditions and the 1-ft LSLR scenario but shift to maximum levels from coastal events for the 2- and 3-ft LSLR scenarios. For both cells, the duration of inundation increases with sea-level rise indicating how drainage patterns will change with sea-level rise. Similar inundation patterns occur for the other storage area cells.

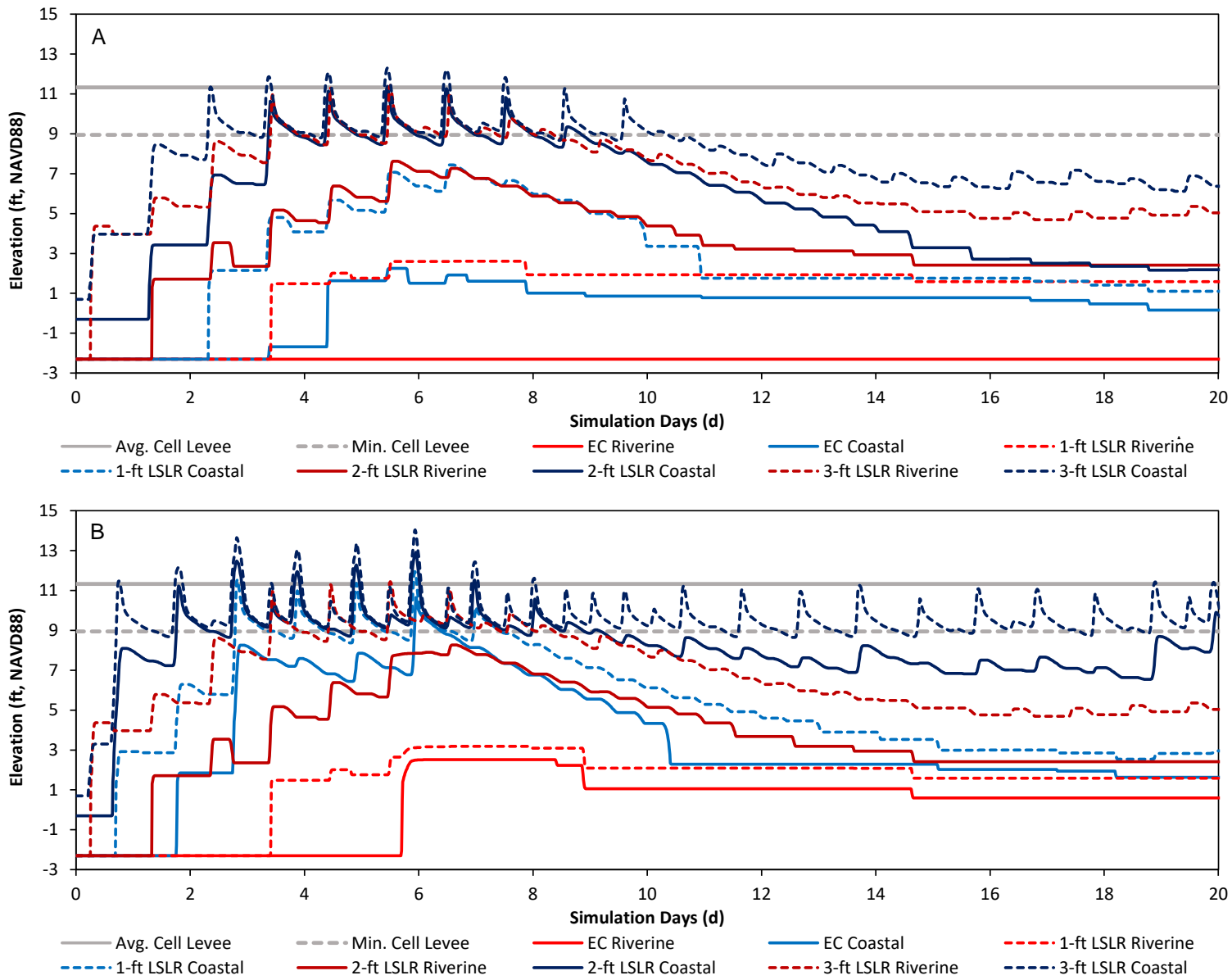


Figure 23. Cell A predicted water levels for 2-yr coastal (surge) and riverine events (A), and 100-yr and 500-yr coastal and 100-yr riverine events (B).

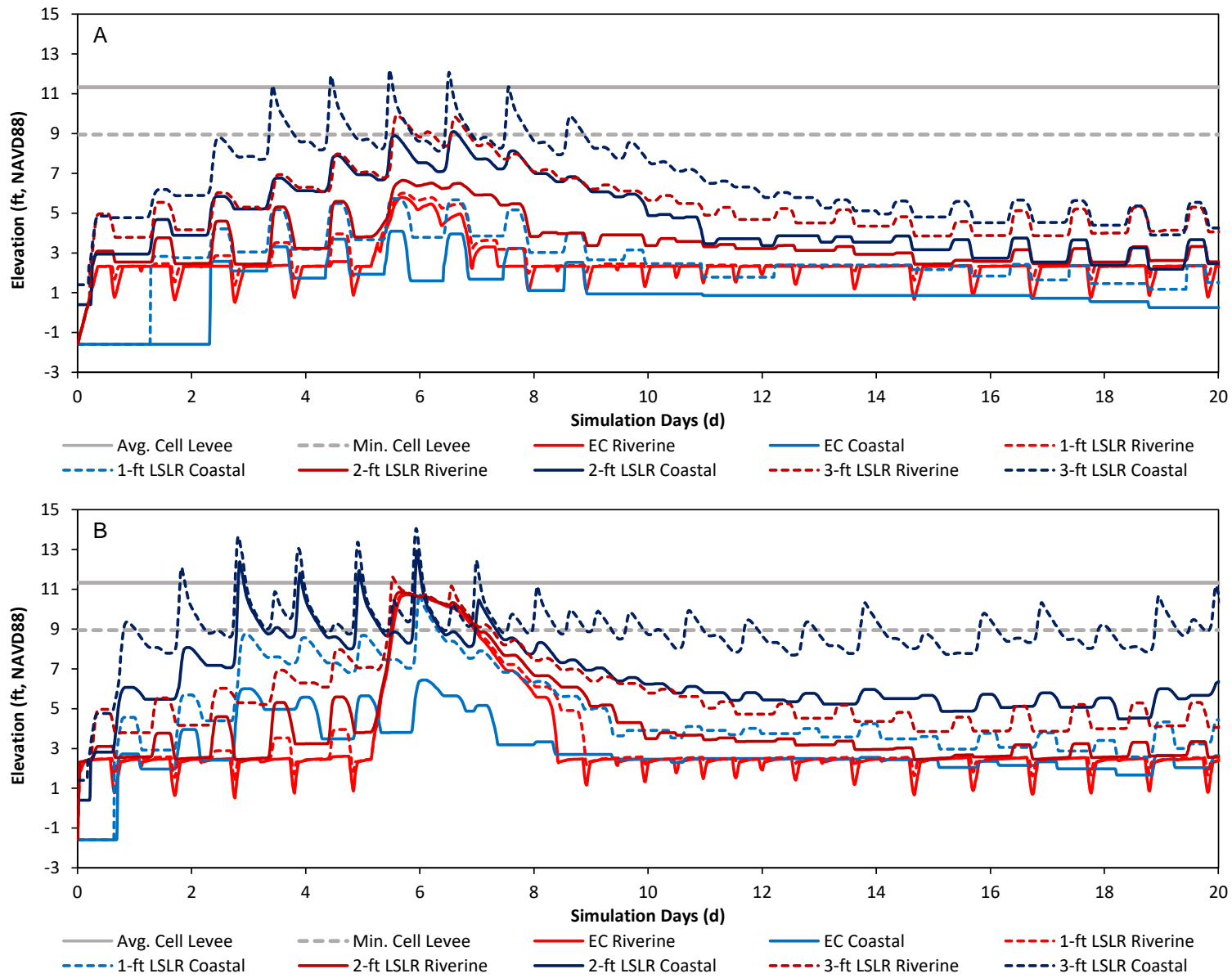


Figure 24. Cell C1 predicted water levels for 2-yr coastal (surge) and riverine events (A), and 100-yr and 500-yr coastal and 100-yr riverine events (B).

Combined Probabilities of Coastal and Riverine Inundation Levels within Storage Area Cells

Combined probability inundation levels curves for the 2-, 10-, 100- and 500-yr coastal and riverine events were developed for each storage area cell using the same approach described above for the slough channels. Figure 25 and Figure 26 show the combined probability curves and the coastal and riverine curves for Cell A and Cell C1, respectively. These probability curves demonstrate how the levees surrounding each cell affect inundation levels from overtopping by elevated water levels in adjacent slough channels and Humboldt Bay. In Cell A the fluvial curve for existing conditions only has two points as inundation occurred from the 100-yr and 500-yr fluvial floods only. These combined probability figures also demonstrate whether inundation levels in the storage area cells are controlled by coastal or riverine events alone, or by the combined probabilities.

Maximum inundation levels in Cell A (Figure 25) are controlled by coastal events for existing conditions and all LSLR scenarios. For Cell C1 (Figure 26), inundation levels are initially controlled by fluvial flooding for existing conditions and the 1-ft LSLR scenario but shifts to coastal flooding with the 2- and 3-ft LSLR scenarios.

The combined probabilities were used to develop exposure summary figures for each storage area cell for existing conditions and the LSLR scenarios (Figure 27). Included in these figures are the area-weighted average ground elevation in each cell below approximately 12ft, and the average levee elevation surrounding each cell. These exposure summary figures can be used to understand the vulnerability of each storage area cell to inundation from extreme events changes with sea-level rise.

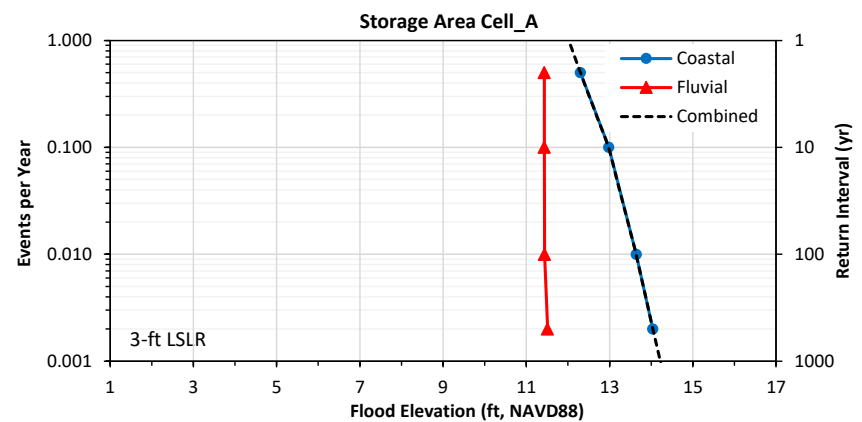
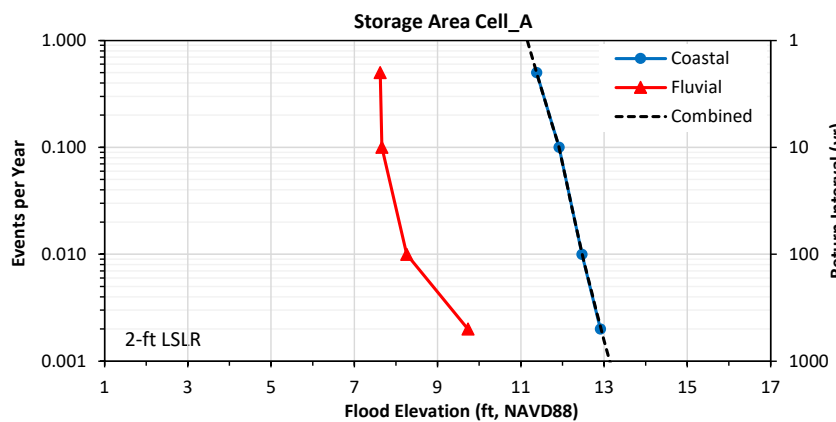
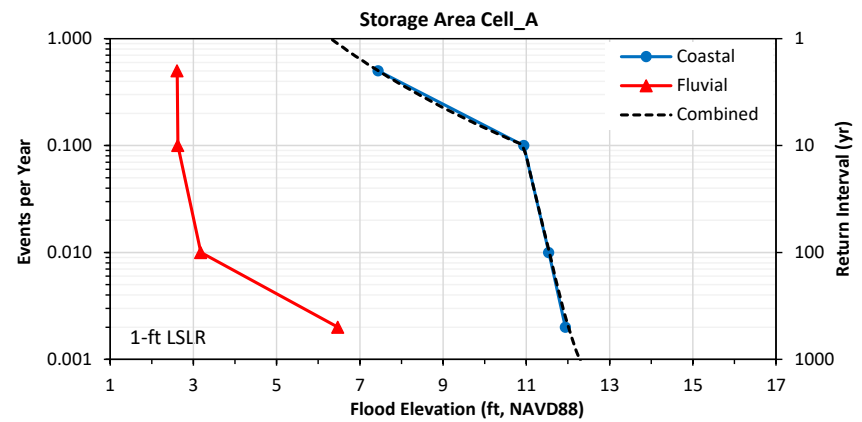
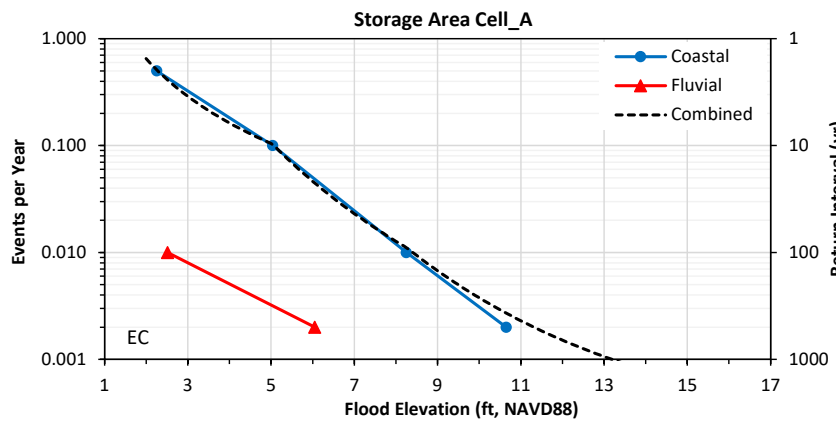


Figure 25. Coastal (blue line), riverine (red line) and combined inundation water level probabilities (black dashed line) in storage area Cell A from coastal (surge) extreme high-water and riverine flood events that overtop levees surrounding each cell. Probabilities are provided as events per year and return interval.

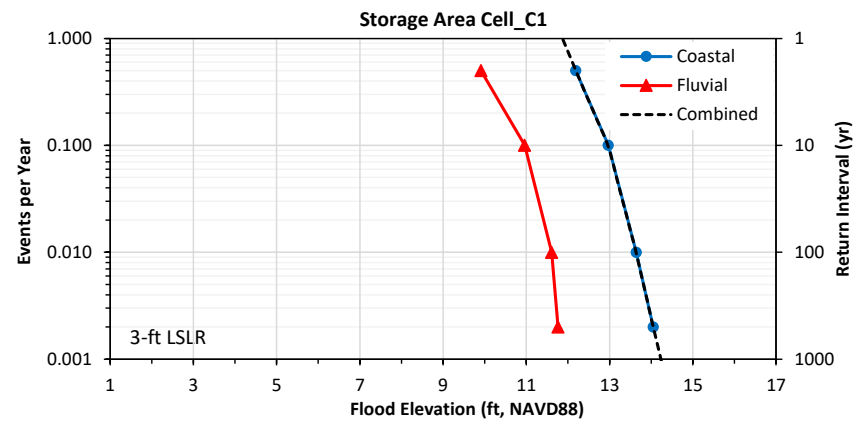
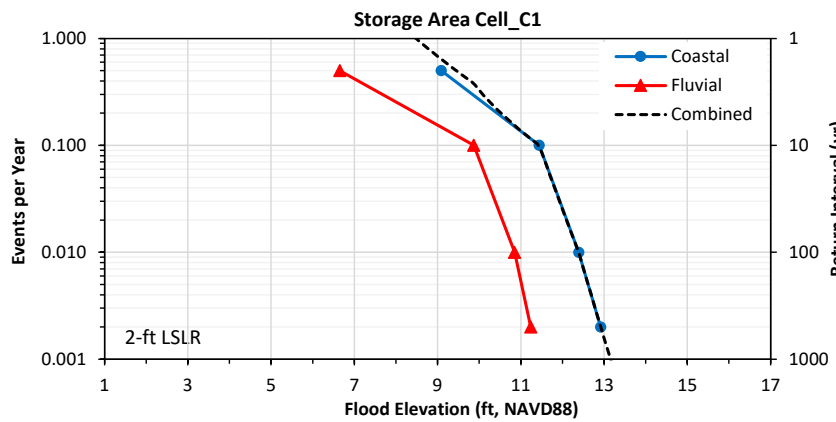
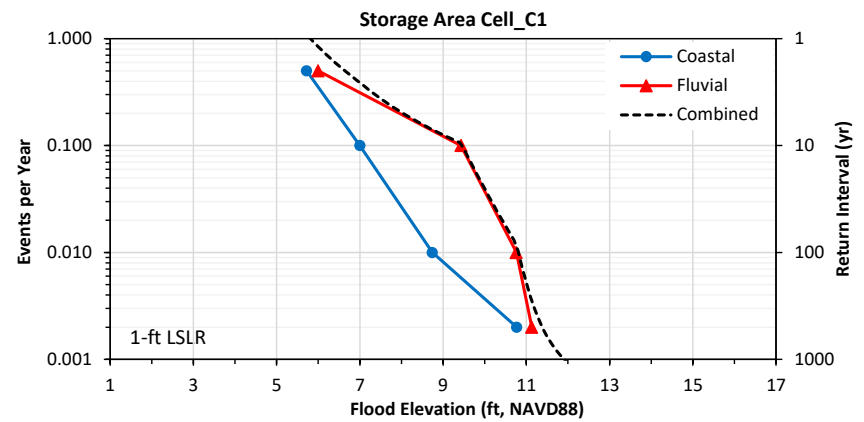
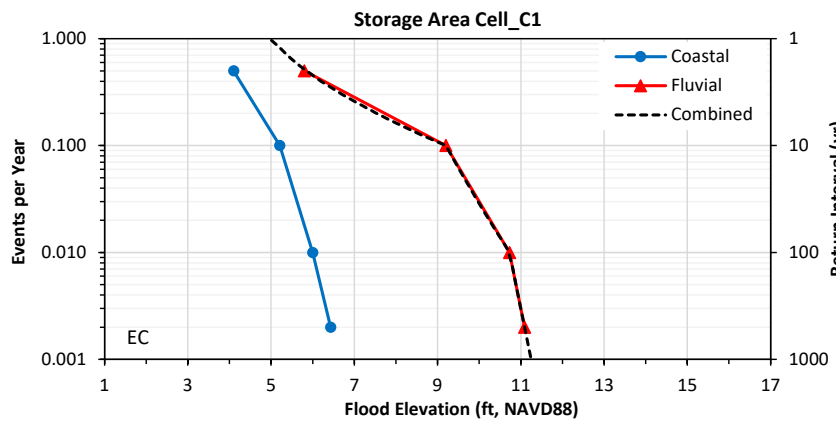


Figure 26. Coastal (blue line), riverine (red line) and combined inundation water level probabilities (black dashed line) in storage area Cell C1 from coastal (surge) extreme high-water and riverine flood events that overtop levees surrounding each cell. Probabilities are provided as events per year and return interval.

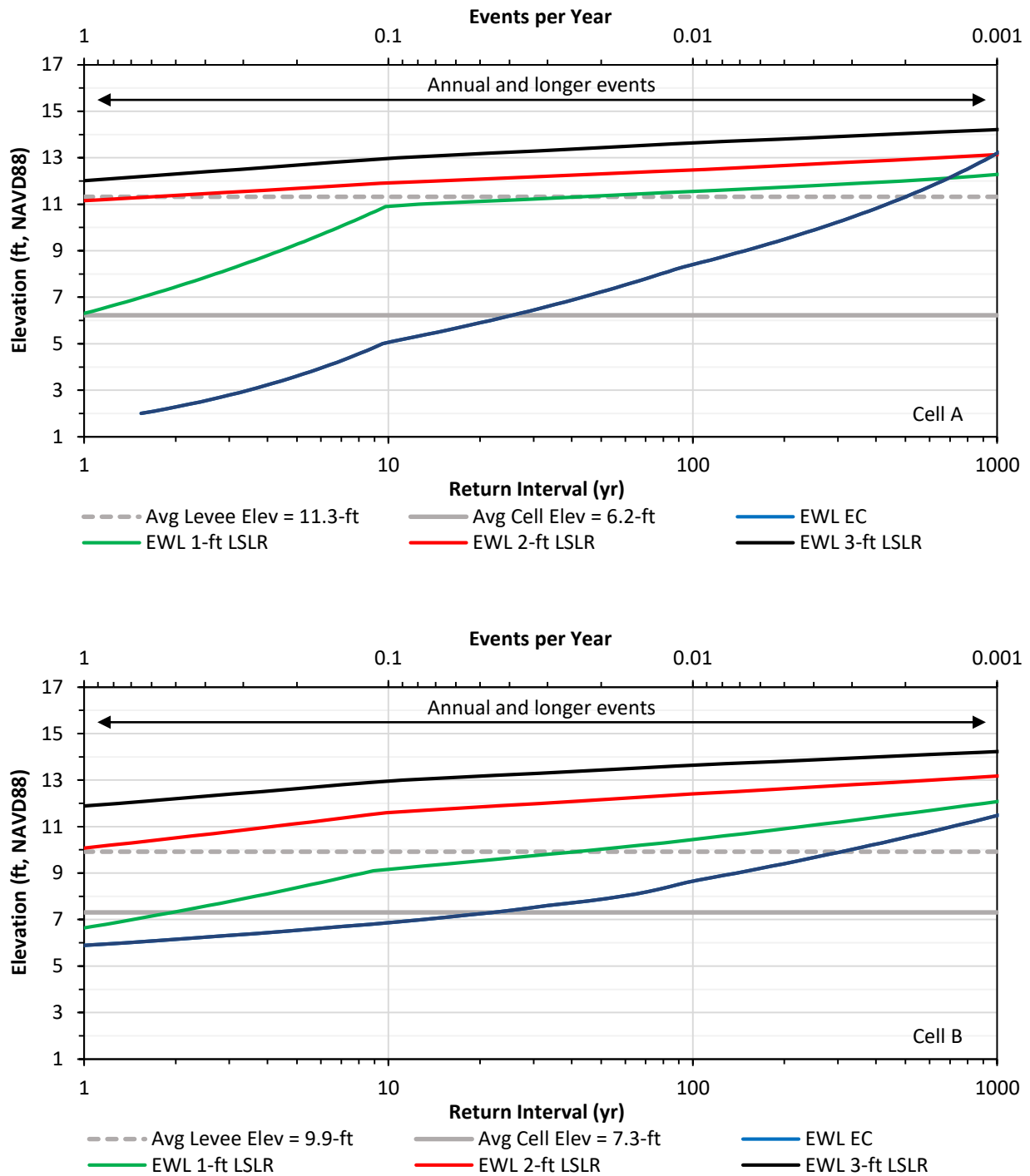


Figure 27. Exposure summary for each storage area cell compared to the average cell ground and levee elevations by inundation from levee overtopping for existing conditions (EC) and 1-, 2- and 3-ft local sea level rise (LSLR). Events per year and return interval are for combined coastal extreme high-water and riverine flood levels.

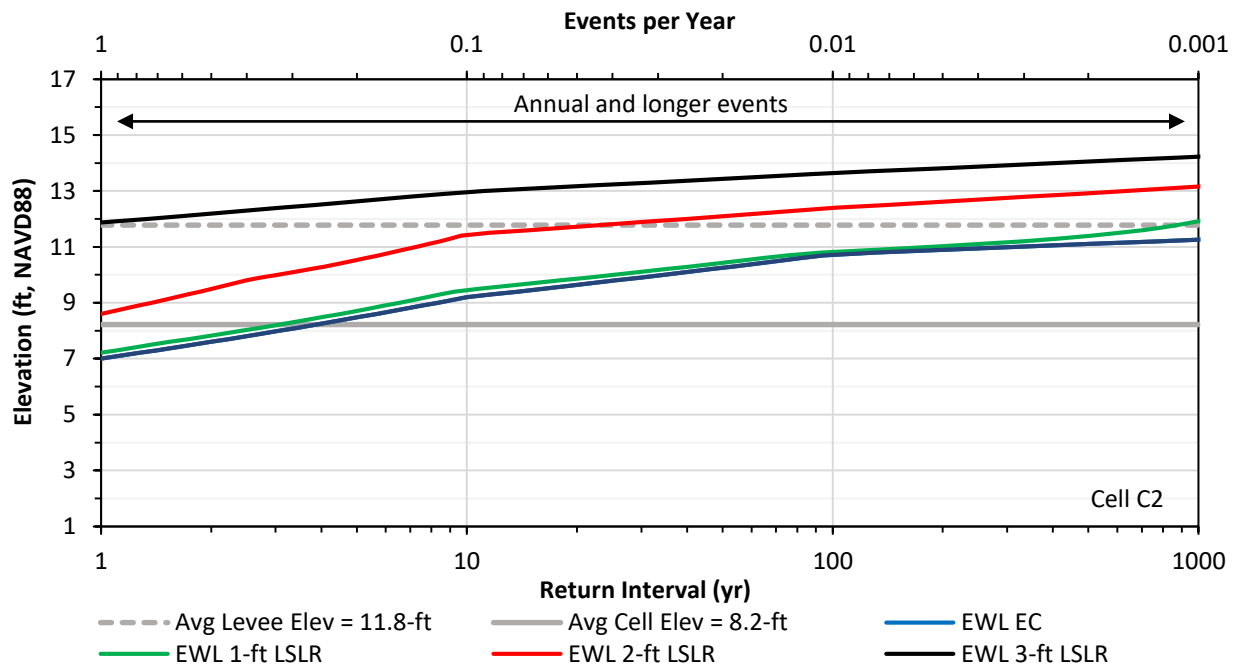
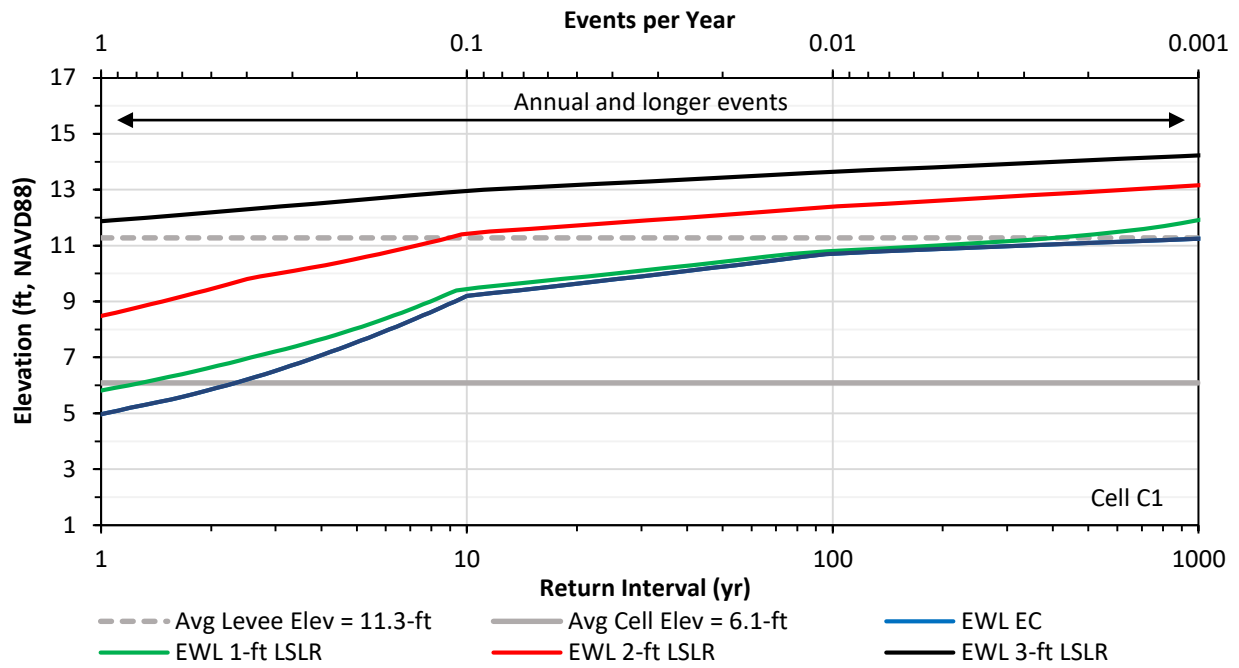


Figure 27. (continued).

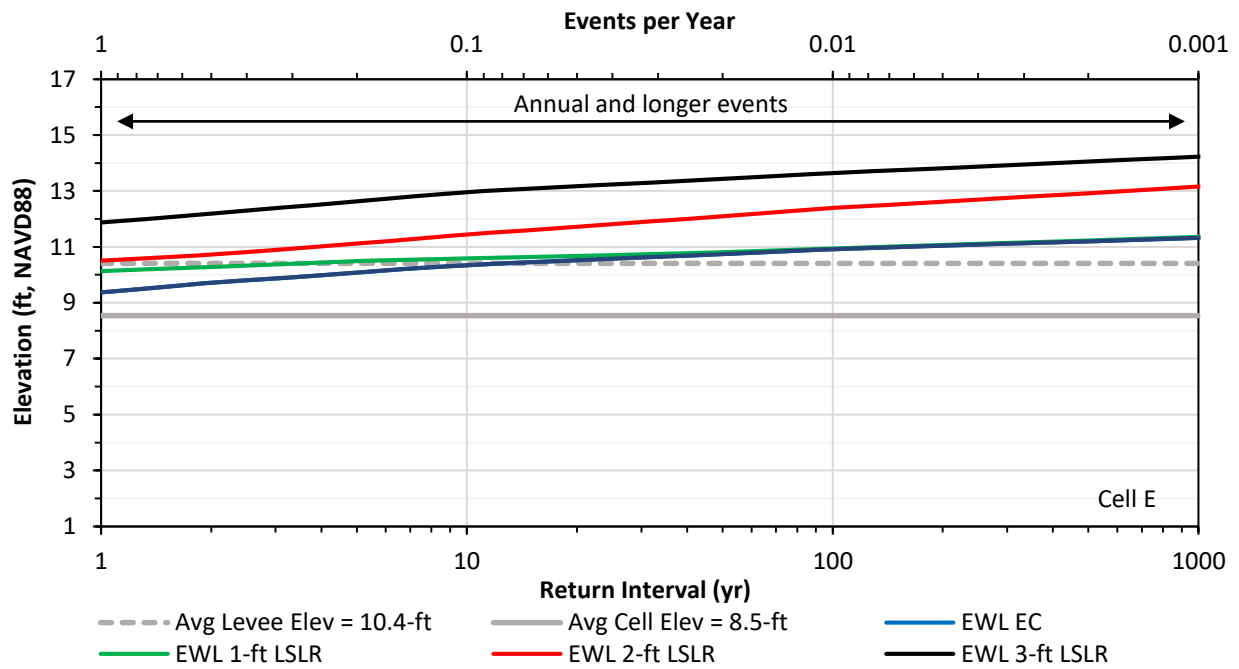
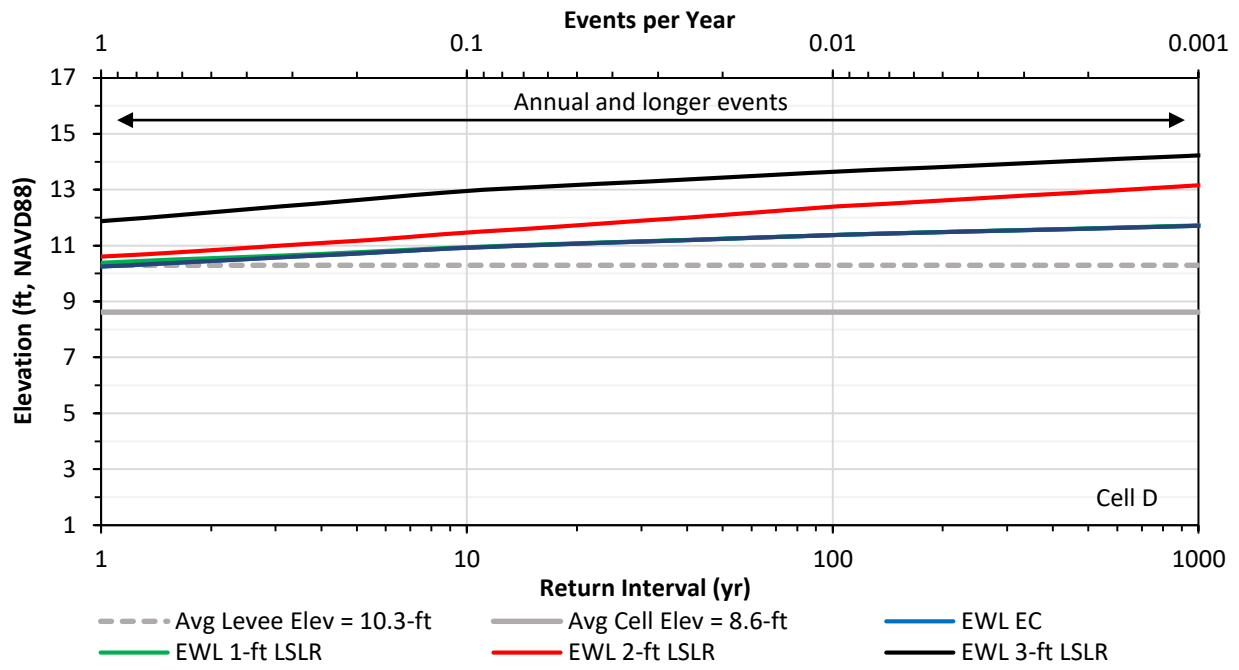


Figure 27. (continued).

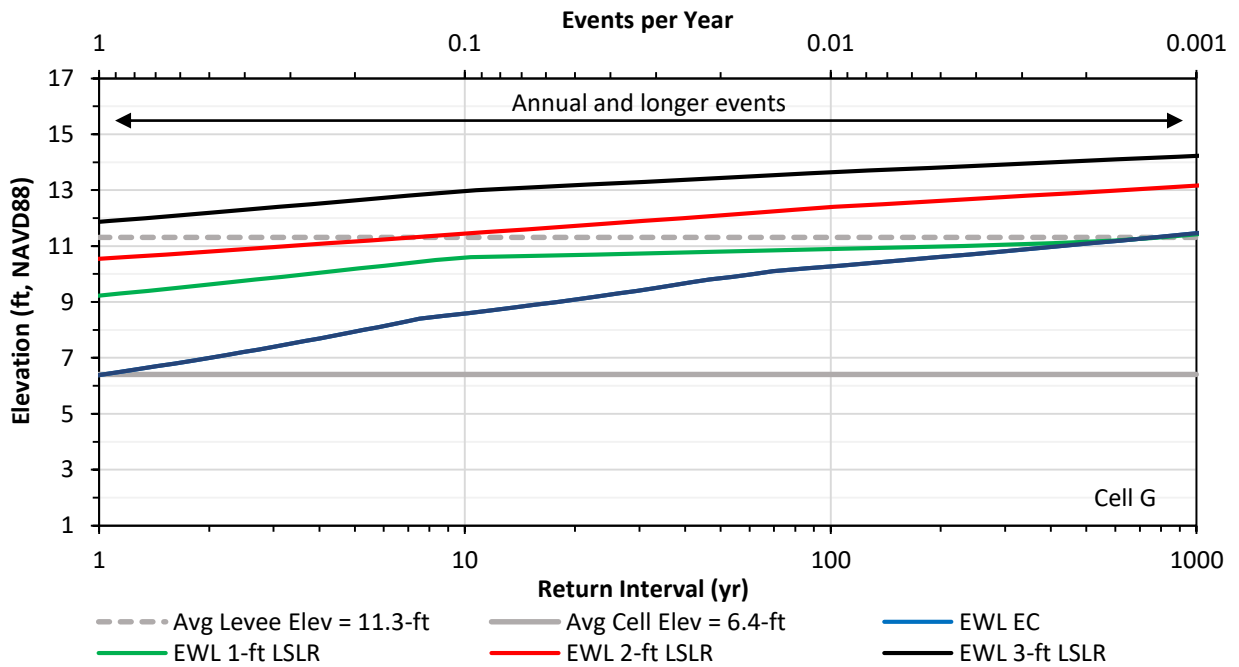
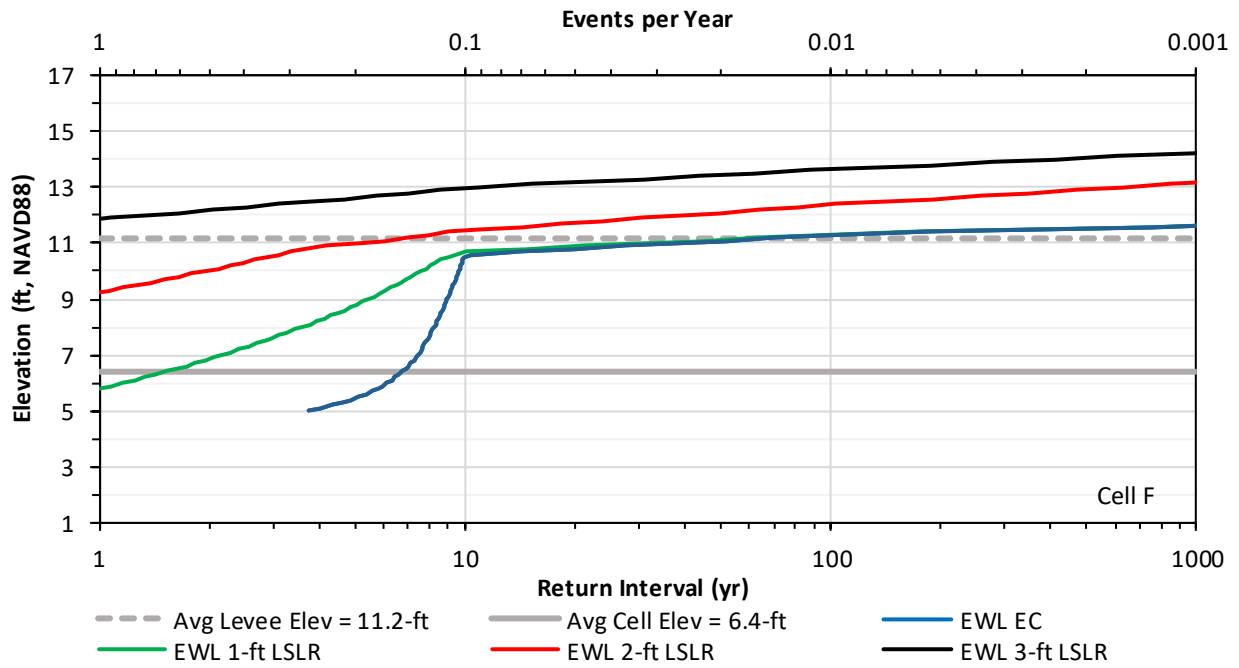


Figure 27. (continued).

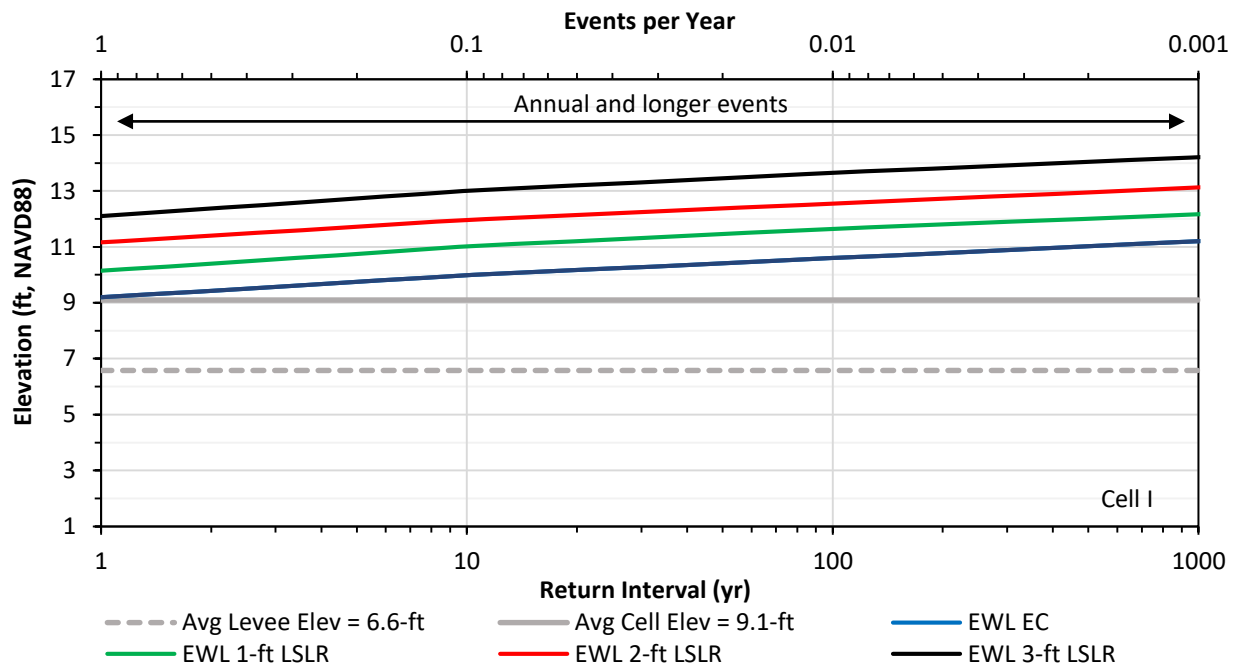
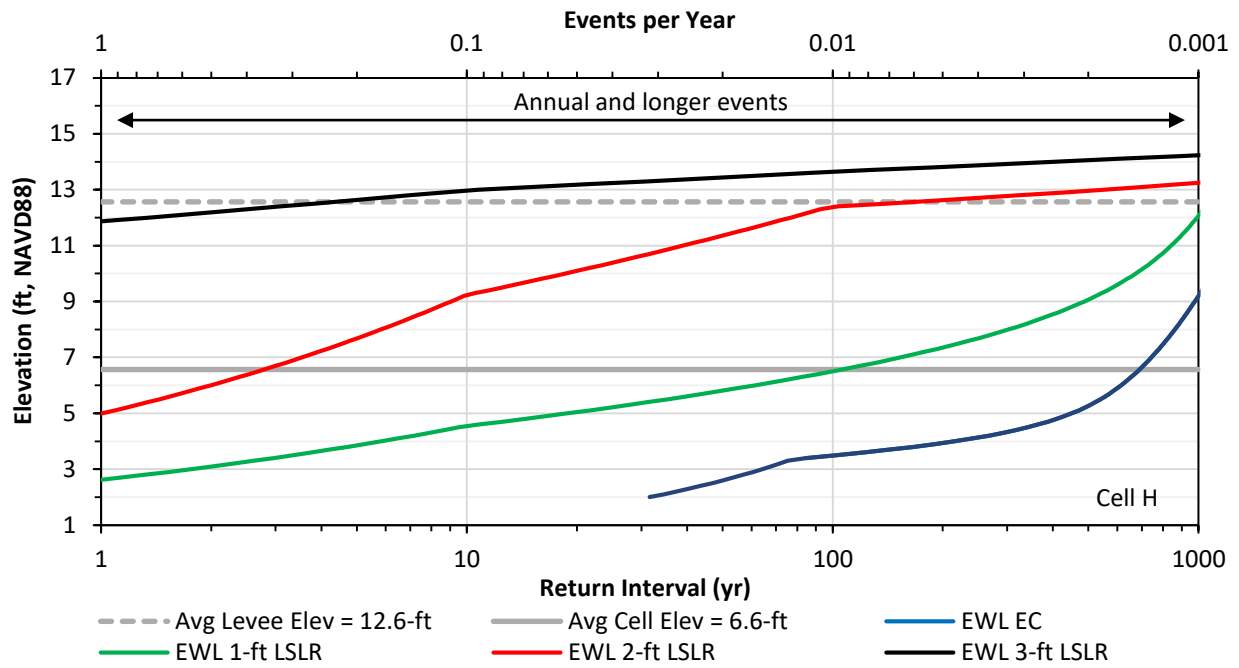


Figure 27. (continued).

Storage Area Cell Minimum Water Levels

Minimum water levels in each storage area cell were extracted from the 1D-Model for the last 7-days of each 30-day simulation for the 2-, 10-, 100- and 500-yr coastal and riverine events for existing conditions and the LSLR scenarios. These minimum water levels and the area-weighted average ground elevation in each cell below approximately 12ft are shown in Figure 28 for each storage area cell. It should be noted that the minimum water levels are not an indication of potential groundwater elevations in each cell, but how drainage of each cell will be affected by sea-level rise. The minimum water levels are a function of each storage area cells levee configuration (i.e. enclosed, open or no levee), drainage infrastructure, and adjacent slough channel bed elevations.

In general, minimum water levels for all storage area cells increase with sea-level rise but are still below average ground elevations. However, at 3-ft LSLR minimum water levels approach the average ground elevation in Cells A, B and E, and exceed the average ground elevation in Cell G. The differences between the coastal and riverine minimum water levels for each simulation are due to the different tidal series used as downstream boundary conditions in the 1D-Model. The large differences between the coastal and riverine minimum water levels in some storage area cells for the 3-ft LSLR scenario is due to the cells inability to completely drain during the 30-day simulation.

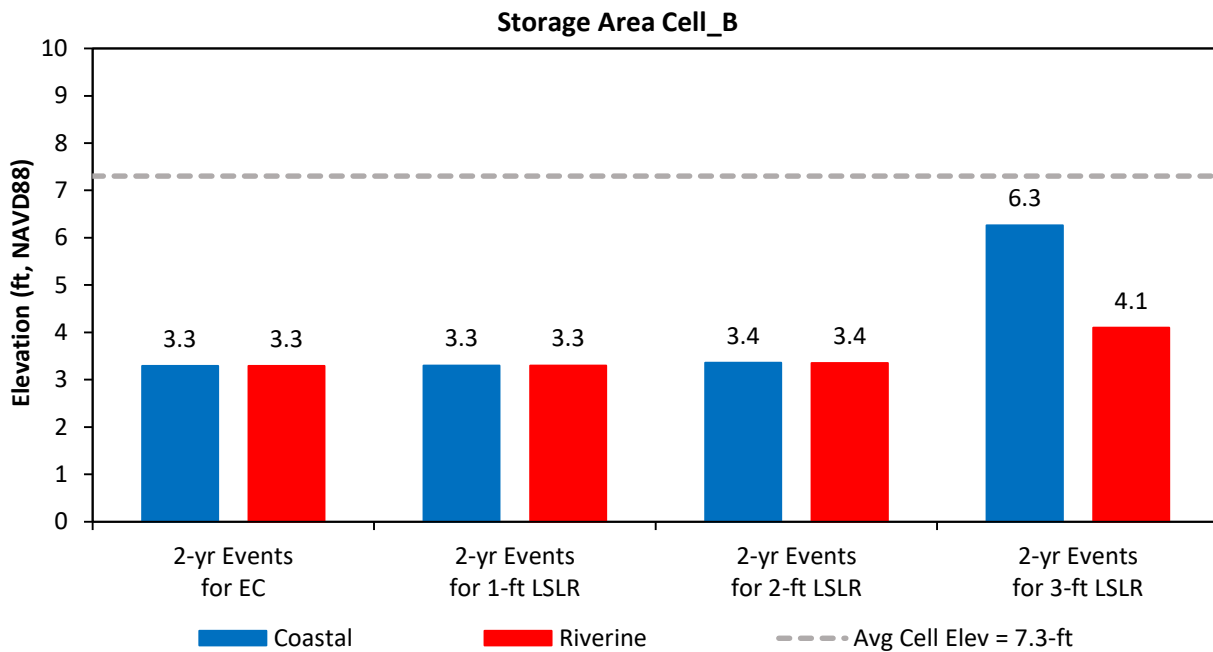
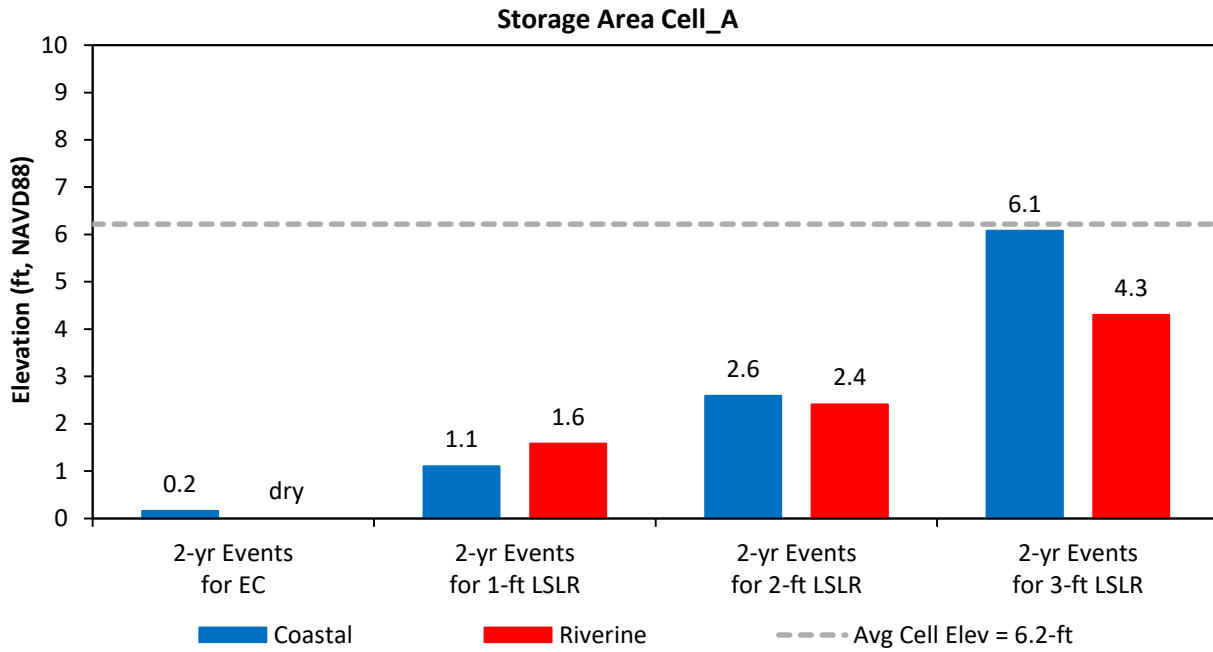


Figure 28. Minimum water levels for each storage area cell compared to the average cell ground elevation from the last 7 days of the 1D-Model simulations for the 2-yr coastal extreme high-water and riverine flood events for existing conditions (EC) and the 1-, 2- and 3-ft local sea level rise (LSLR) scenarios.

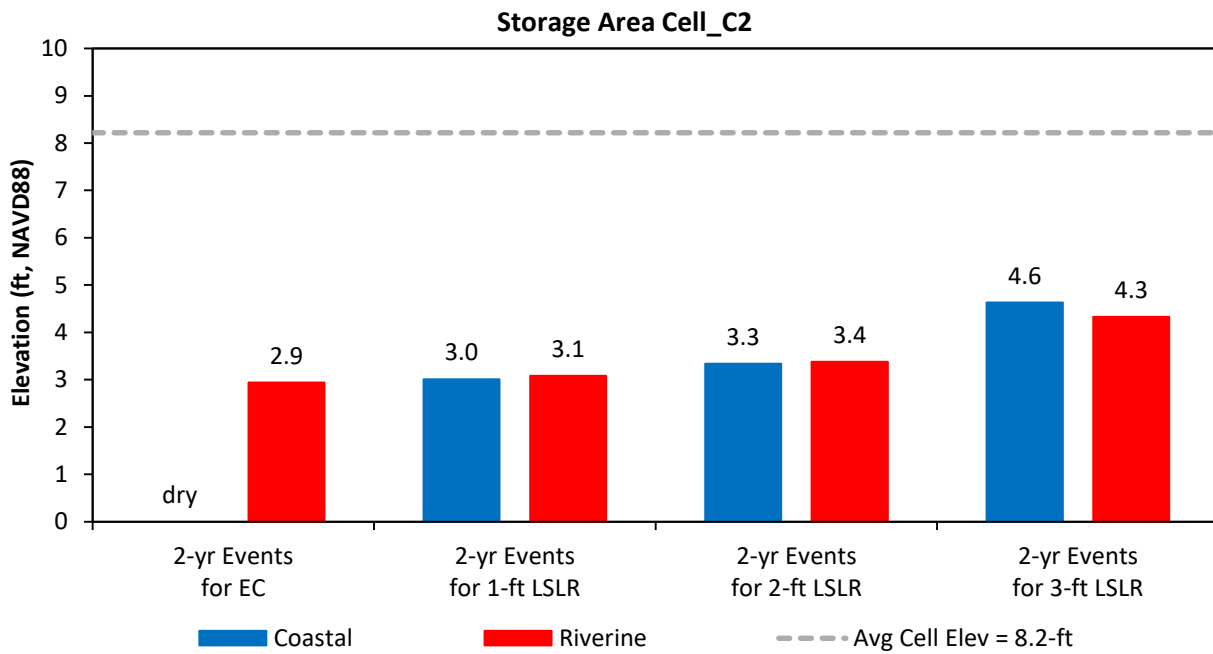
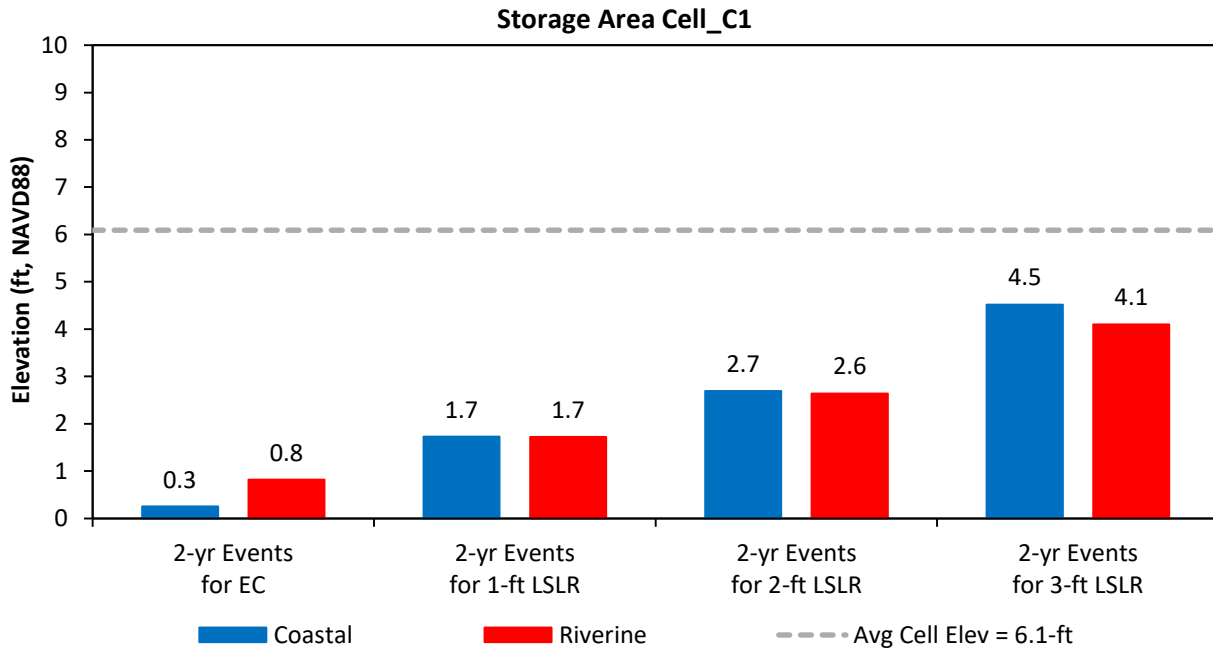


Figure 28. (continued).

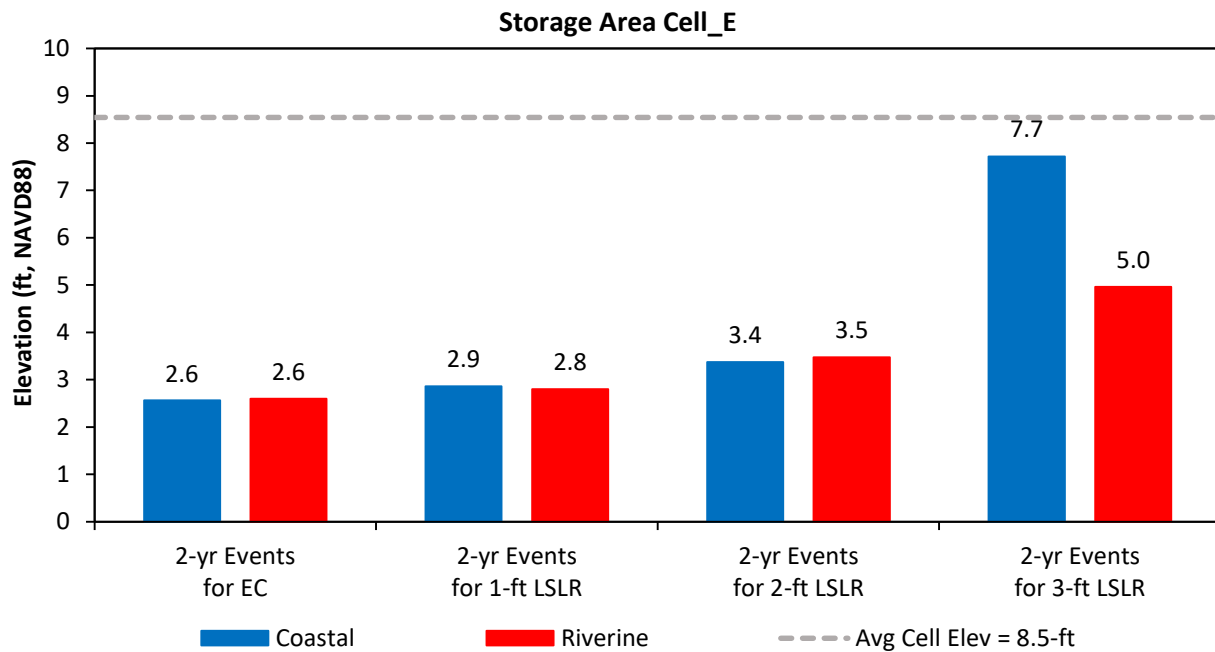
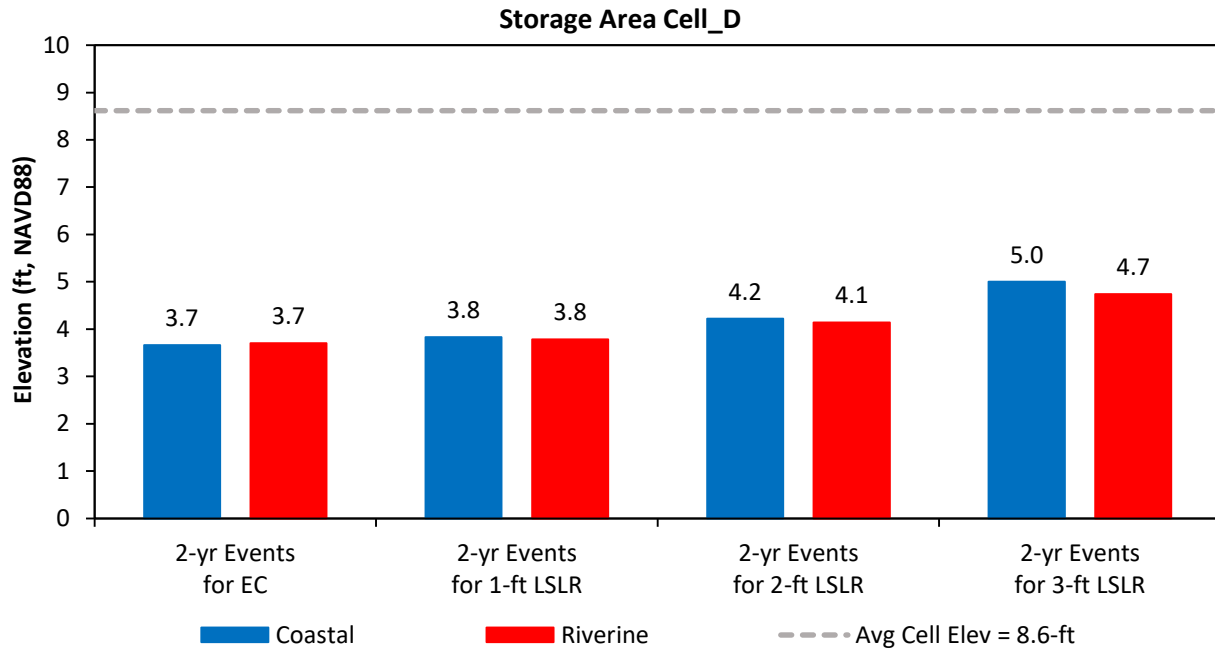


Figure 28. (continued).

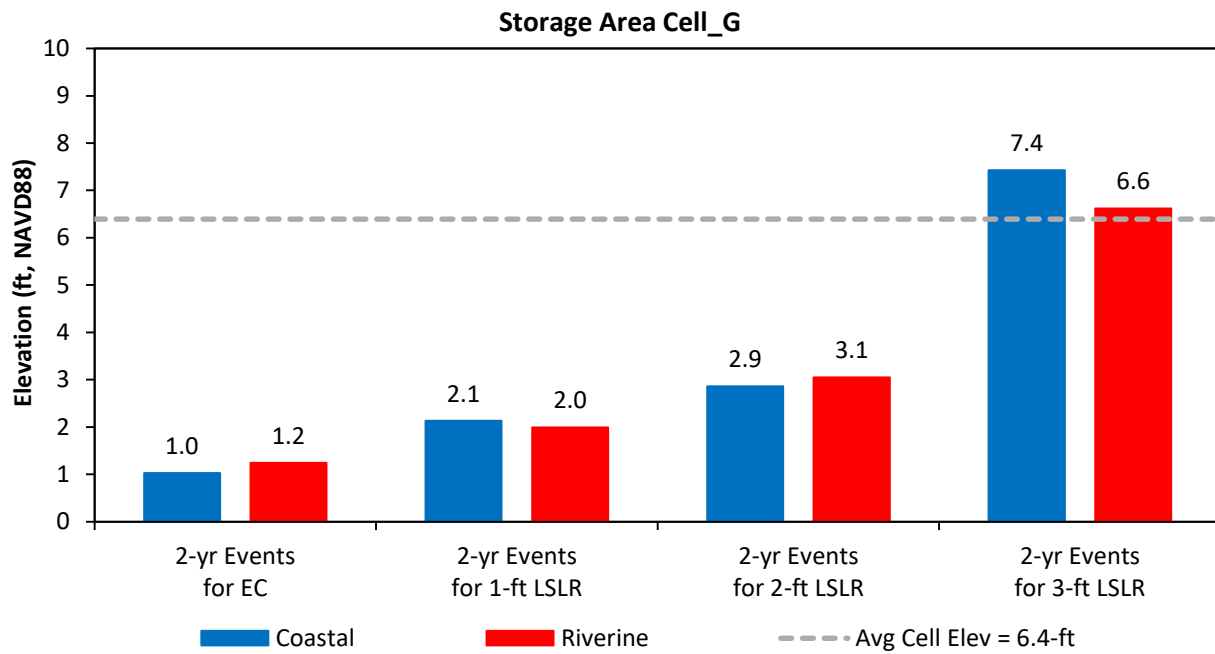
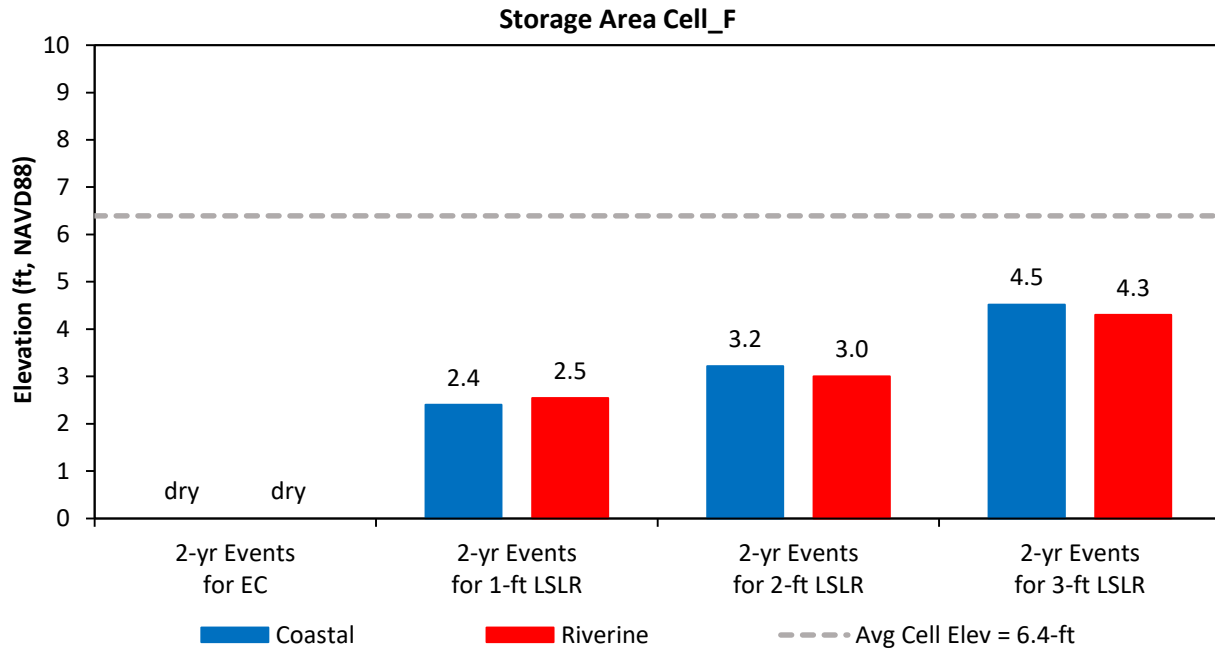


Figure 28. (continued).

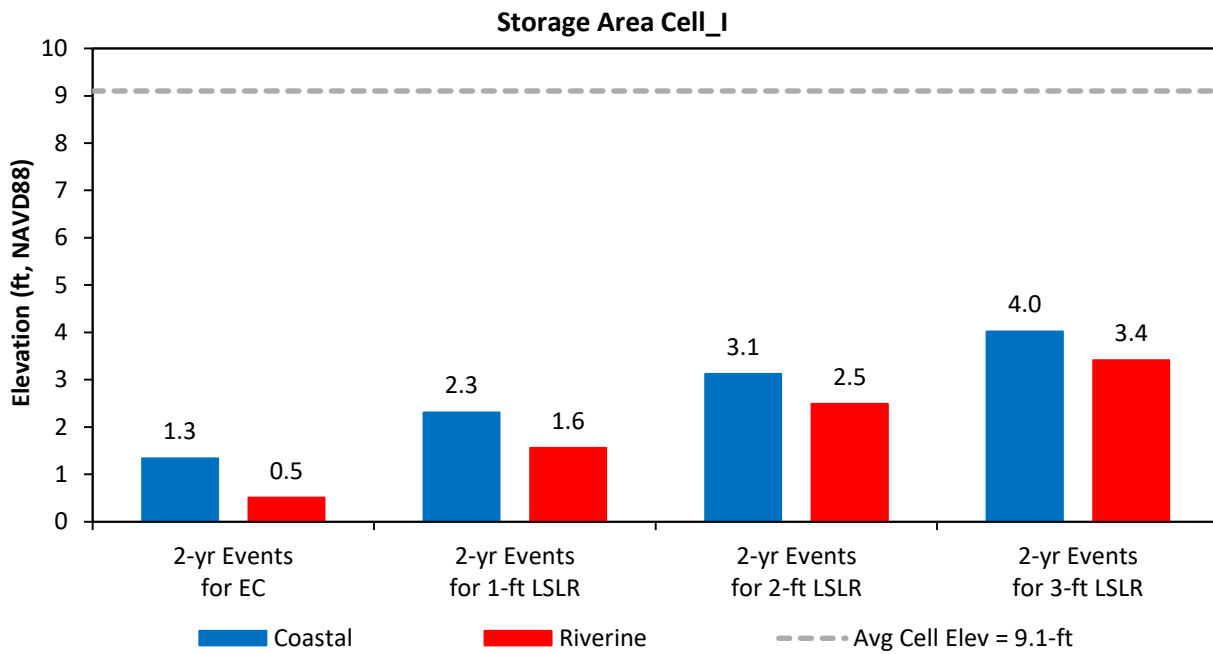
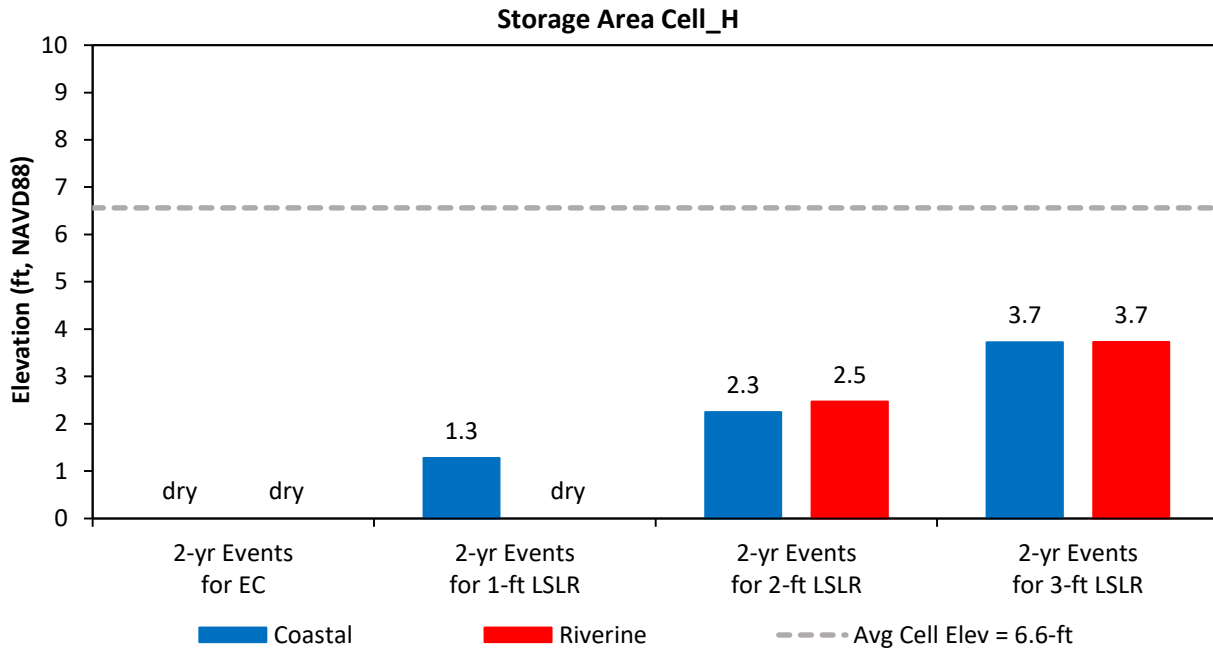


Figure 28. (continued).

REFERENCES

- County of Humboldt (County), 2016. Jacobs Avenue Levee and Murray Field Levee crest topographic field surveys. Topographic data available from County upon request. County, Eureka, CA.
- Federal Emergency Management Agency (FEMA), 2005. Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States. Joint Project by FEMA Region IX, FEMA Region X, and FEMA Headquarters. FEMA Region IX, Oakland, CA.
- Federal Emergency Management Agency (FEMA), 2016. Guidance for Flood Risk Analysis and Mapping, Hydraulics: One-Dimensional Analysis. Guidance Document 80 dated November 2016. FEMA.
- Gotvald, A.J., Barth, N.A., Veilleux, A.G. and C. Parrett. 2012. Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p., 1 pl., available online only at <http://pubs.usgs.gov/sir/2012/5113/>.
- GMA Hydrology, Inc. (GMA), 2015. Bathymetric Survey Report, Jacobs Avenue Levee Evaluation, Eureka, CA. Prepared for Northern Hydrology and Engineering as part of Humboldt County Jacobs Avenue Levee Study. GMA, Arcata, CA.
- Gutierrez Land Surveying (GLS), 2017. Humboldt Bay Trail South, Humboldt Bay Trail: Eureka Slough Railroad Bridge to Bracut Topographic Survey. Prepared for GHD Inc. Data available from GHD upon request. GLS, Eureka, CA.
- Northern Hydrology & Engineering (NHE), 2008 (original reference Jeff Anderson & Associates, 2008). Wood Creek Tidal Marsh Design Report, for the Wood Creek Tidal Marsh Enhancement Project. Prepared for Northcoast Regional Land Trust. NHE, McKinleyville, CA.
- Northern Hydrology & Engineering (NHE), 2015. Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping. Prepared for State Coastal Conservancy and Coastal Ecosystems Institute of Northern California. NHE, McKinleyville, CA. Report available at <http://www.coastalecosystemsinstitute.org>.
- Northern Hydrology & Engineering (NHE), 2016. Technical Memorandum: Jacobs Avenue Levee Bathymetric, Hydrologic and Hydraulic Study, Humboldt County, CA. Prepared for Humboldt County to support Jacobs Avenue Levee Study. NHE, McKinleyville, CA.
- Northern Hydrology & Engineering (NHE), 2018. Draft Engineering Design Technical Memorandum: Cochran Creek Fish Passage and Channel Restoration Project. Prepared for California State Coastal Conservancy, California Department of Fish and Wildlife, Coastal Ecosystems Institute of Northern California, and Thomas Gast & Associates Environmental Consultants. NHE, McKinleyville, CA.
- Sousa Land Surveys, Inc. (Sousa), 2011. LiDAR based topographic survey of the Jacobs Avenue Levee Project Area. Prepared for the County of Humboldt. Data available from the County upon request. Sousa, Fairfield, CA.
- U.S. Fish and Wildlife Service (FWS), 2007. Humboldt Bay Water Control Structure Assessment, and Mapping Project, Final Report. FWS, Arcata, CA.

U.S. Army Corps of Engineers (COE), 2016. HEC-RAS, River Analysis System – User’s Manual and Hydraulic Reference Manual, Version 5.0. U.S. Army Corps of Engineers, Institute of Water Resources, Hydraulic Engineering Center, Davis, California, CPD-68 and CPD-69.