Table D-1. Summary of Hazard Scenarios

Tidal Hydraulics, Wind, Sea Level Rise, Resource Response and Impacts

SCENARIO ELEMENTS	Tidal Extreme Events with Fluvial Winter Base Flow, Variable Wind, and Shoreline Conditions									
	1 Typical King Tide with Wind	2 Extreme Tide	3 Extreme Tide with Wind	4 Extreme Tide	5 Extreme Tide	5a Armored and Elevated Shoreline	6 Extreme Tide	6a Armored and Elevated Shoreline	7 Extreme Tide	8 Extreme Tide
HYDRAULICS AND SEA LEVEL RISE (SLR)										
Tidal Still Water Level (NAVD)	**8.3ft**	**9.3ft**	**9.3ft**	**9.9ft**	**10.6ft**	**10.6ft**	**11.6ft**	**11.6ft**	**12.6ft**	**13.6ft**
Wind Set-up	0.5ft (**8.8ft NAVD**)	0	1ft (**10.3ft NAVD**)	0	0	0	0	0	0	0
Wind Wave Height	1ft	0	2.4ft	0	0	0	0	0	0	0
Wave Runup	0.5ft – 1ft	0	1.5ft – 4.5ft	0	0	0	0	0	0	0
Total Water Level (TWL) NAVD (Bay Shoreline)	**9.3-10.3ft**	9.3ft	**12-15ft**	9.9ft	10.6ft	10.6ft	11.6ft	11.6ft	12.6ft	13.6ft
Approximate Equivalent Still Water Event with SLR	King Tide + 0ft SLR 2-yr + 0.5ft SLR MHHW + 2ft SLR MHW + 3ft SLR	2-yr + 0ft SLR MMMW + 1ft SLR MHHW + 2.5ft SLR MHW + 3.5ft SLR	50-yr + 0ft SLR 10-yr + 0.5ft SLR 2-yr + 1.0ft SLR MMMW + 2.0ft SLR MHHW + 3.5ft SLR	10-yr + 0ft SLR 2-yr + 0.5ft SLR MMMW + 1.5ft SLR MHHW + 3.0ft SLR	100-yr + 0ft SLR 10-yr + 0.5ft SLR 2-yr + 1.0ft SLR MMMW + 2.0ft SLR MHHW + 3.5ft SLR		100-yr + 1ft SLR 10-yr + 1.5ft SLR 2-yr + 2.0ft SLR MMMW + 3.0ft SLR MHHW + 4.5ft SLR		100-yr + 2ft SLR 10-yr + 2.5ft SLR 2-yr + 3.0ft SLR MMMW + 4.0ft SLR MHHW + 5.5ft SLR	100-yr+ 3ft SLR 10-yr+ 3.5ft SLR 2-yr+ 4.0ft SLR MMMW+ 5.0ft SLR MHHW+ 6.5ft SLR
RESOURCE RESPONSE & IMPACT SUMMARY (see case study descriptions)										
Overtopping	Limited, Select, Isolated Locations	Limited, Select, Isolated Locations	Rail Prism, Brainard, Interior Levees	Rail Prism, Brainard, Interior Levees	Rail Prism, Brainard, Interior Levees	Interior Levees	Rail Prism, Brainard, Interior Levees	Rail Prism, Brainard, Interior Levees	Rail Prism, Interior Levees	Rail Prism, Interior Levees
Cell A Bay Shoreline	< 0.1 mi, < 0.1 ac-ft	< 0.1 mi, < 0.1 ac-ft	1.9 mi, 460 ac-ft	1 mi, 37 ac-ft	2.2 mi, 940 ac-ft	0	2.7 mi, 4,700 ac-ft	1.4 mi, 10 ac-ft	3.0 mi, 6,300 ac-ft	3.3 mi, 6,600 ac-ft
Cell A Interior Shoreline	0	30 ft, 0.7 ac-ft	1,300 ft, 60 ac-ft	900 ft, 12 ac-ft	2,200 ft, 110 ac-ft	2,200 ft, 110 ac-ft	1.7 mi, 300 ac-ft	1.7 mi, 300 ac-ft	2.6 mi, 2,300 ac-ft	2.9 mi, 4,900 ac-ft
All other Cells	< 0.1 mi	0.5 mi	1.6 mi	1.2 mi	2.6 mi	2.6 mi	5.4 mi	5.4 mi	9.8 mi	10.6 mi
Shoreline Erosion Potential – Low	Wind Waves	N/A	Wind Waves	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shoreline Erosion Potential – Moderate	Rill	Rill	Wind Waves, Rill	Rill	Rill	Rill	Rill	Rill	Rill	Rill
Shoreline Erosion Potential – High	None	None	Wind Waves, Potential Breach-75ft, Cells A,B,C,E,G	Potential Breach-75ft, Cells B,C,E,G	Potential Breach-270ft, Cells A,B,C,E,G	Potential Breach-270ft, Cells A,B,C,E,G	Potential Breach-4,000ft, Cells A,B,C,E,F,G	Potential Breach-1,200ft, Cells A,B,C,E,F,G	Potential Breach-4 miles, Cells A,B,C,E,F,G	Potential Breach-5 miles, Cells A,B,C,E,F,G
Transportation Resources Impacted	Usability Disruption: Park Street	Usability Disruption: Park Street	Usability Disruption: Tydd Street Jacobs Avenue Murray Field Access 2nd and Y Street Repair/Closure: Hwy 101 SB Park Street	Usability Disruption: Murray Field Access 2nd and Y Street Tydd Street Repair/Closure: Hwy 101 SB Park Street	Partial/Temp Closure: Jacobs Ave Hwy 255 (Alt Route) 2nd and Y Street Tydd Street Repair/Closure: Hwy 101 SB Murray Field Access Hoover Street Park Street	Partial/Temp Closure: Murray Field Access 2nd and Y Street Tydd Street Hwy 255 (Alt Route) Repair/Closure: Hoover Street Park Street	Partial/Temp Closure: Myrtle Ave 4th Street Repair/Closure: Hwy 101 SB & NB Murray Field Access Jacobs Ave Hoover Street Tydd Street 2nd and Y Street Indianola Cutoff Park Street Hwy 255 (Alt Route)	Partial/Temp Closure: Murray Field Access Myrtle Ave 4th Street Repair/Closure: Hoover Street Tydd Street 2nd and Y Street Park Street Hwy 255 (Alt Route)	Partial/Temp Closure: 4th, 5th & 6th Streets Repair/Closure: Hwy 101 SB &NB Murray Field Access Jacobs Ave Hoover Street Tydd Street 2nd and Y Street Indianola Cutoff Park Street Myrtle Ave Hwy 255 (Alt Route)	Partial/Temp Closure: 4th, 5th & 6th Streets Repair/Closure: Hwy 101 SB & NB Murray Field Access Jacobs Ave Hoover Street Tydd Street 2nd and Y Street Indianola Cutoff Park Street Myrtle Ave Hwy 255 (Alt Route)
Other Critical Resources Impacted	No Significant, Observable Impacts	Minor: Underground Utilities Moderate: Agricultural Lands	Minor: Underground Utilities Water Booster Station Moderate: Sewer Pump Stations Moderate to Major: Agricultural Lands	Minor: Underground Utilities Sewer Pump Stations Moderate to Major: Agricultural Lands	Minor to Major: Underground Utilities Moderate: Sewer Pump Stations Water Booster Station Moderate to Major: Residential Areas Commercial Areas Agricultural Lands	Minor to Major: Underground Utilities Moderate: Sewer Pump Stations Water Booster Station Residential Areas Commercial Areas Moderate to Major: Agricultural Lands	Moderate to Major: Underground Utilities Sewer Pump Stations Water Booster Station Major: Residential Areas Commercial Areas Agricultural Lands	Moderate: Residential Areas Commercial Areas Moderate to Major: Underground Utilities Sewer Pump Stations Water Booster Station Major: Agricultural Lands	Major: Residential Areas Commercial Areas Agricultural Lands Underground Utilities Sewer Pump Stations Water Booster Station	Major: Residential Areas Commercial Areas Agricultural Lands Underground Utilities Sewer Pump Stations Water Booster Station
Key Findings and Conclusions	No significant episodic impacts. Typical long-term erosion and geomorphic processes. Minor flooding of Park Street.	Approximate elevation when overtopping begins. Existing drainage infrastructure has capacity to convey overtopping flow.	Temporary closure of Hwy 101 southbound. Alternate route required. Significant damage to shoreline rail prism	Hazardous Conditions/ Temporary closure of Hwy 101 southbound. Alternate route required.	Temporary closure of Hwy 101 southbound. Alternate route required. Widespread damage to shoreline structures and flooding.	Overtopping along Bay Shoreline does not occur, preventing closure of Hwy 101 and significantly reducing flooding of Cell A.	Closure of Hwy 101 and alternate routes around Humboldt Bay. Widespread damage to shoreline structures Major flooding of all Protected Lands.	Overtopping along Bay Shoreline is reduced, preventing closure of Hwy 101 and significantly reducing flooding of Cell A.	Closure of Hwy 101 and alternate routes around Humboldt Bay. Widespread damage to shoreline structures Major flooding of all Protected Lands.	Closure of Hwy 101 and alternate routes around Humboldt Bay. Widespread damage to shoreline structures Major flooding of all Protected Lands.

All Elevations in NAVD88
MHHW: 7 feet
MMMW: 8.3 feet

Table D-2. Summary of Hazard Scenarios

Fluvial Hydraulics, Resource Response and Impacts

SCENARIO ELEMENTS		Extreme Fluvial Events with Typical High Tides		
		9	10	11
HYDRAULICS AND SEA LEVEL RISE (SLR)				
Fluvial Flow Recurrence		**2-yr**	**10-yr**	**100-yr**
Tidal Still Water Level (NAVD)		**8.3ft**	**8.3ft**	**8.3ft**
Wind Set-up		0	0	0
Wind Wave Height		0	0	0
Wave Runup		0	0	0
Total Water Level (TWL) NAVD (Bay Shoreline)		8.3ft	8.3ft	8.3ft
Approximate Equivalent Still Water Event with SLR		Not Applicable	Not Applicable	Not Applicable
RESOURCE RESPONSE & IMPACT SUMMARY (see case study descriptions)				
Overtopping		Freshwater and Ryan Sloughs	Freshwater and Ryan Sloughs	Freshwater, Ryan and Fay Sloughs
Cell A Bay Shoreline		< 0.1 mi, < 0.1 ac-ft	< 0.1 mi, < 0.1 ac-ft	< 0.1 mi, < 0.1 ac-ft
Cell A Interior Shoreline		0	0	1 location
All other Cells		1.6 mi	2.5 mi	5.6 mi
Shoreline Erosion Potential	Low	None	None	None
	Moderate	Rill	Rill	Rill
	High	Potential Breach-9ft, Cells C and E	Potential Breach-1,200ft, Cells C,E,F,G and Ryan Slough	Potential Breach-6,700ft, Cells A,B,C,E,F,G and Ryan Slough
Transportation Resources Impacted		None*	None*	None*
Other Critical Resources Impacted		Delayed Access	Delayed Access	Delayed Access
Key Findings and Conclusions		Flooding typically <1ft in diked former tidelands adjacent to Freshwater Slough	Flooding does not affect Cell A and Hwy 101	Flooding does not affect Cell A and Hwy 101

* Hydraulic modeling of fluvial events did not assess flows and inundation upstream of and including Myrtle Avenue.

Table D-3. Critical Resource Impact Thresholds

Resource Response and Impacts Due to Tidal and Fluvial Flooding

Asset or Land Use		Physical Process	Asset Impacts: Initiation of Impacts	Asset Impacts: Increasing	Asset Impacts: Most Severe
			Increasing Water Levels →		
INFRASTRUCTURE	**Earthen Levee/ Dike/ Rail Prism [1]**	Overtopping	No Overtopping, Water-side Erosion	>1ft for <2hrs, or <1ft for >0hrs Minor Erosion/Repairs	>1ft for >2hrs Breach/Reconstruction
INFRASTRUCTURE	**Roads and Trails**	Flood Depth/ Duration	<3 inch depth Usability Distribution with Minor Clean-up	3-12 inch depth Temporary Closure with Minor Damage/Repairs	>12 inch depth Closure with Permanent Damage/Reconstruction
INFRASTRUCTURE	**Storm Drain System and Tide Gates**	Conveyance and Storage	System capacity sufficient but requires increased maintenance frequency	System conveyance insufficient, however system storage volume sufficient	System conveyance and storage volume insufficient
UTILITIES	**Lift or Pump Stations**	Surface Flooding	Infrequent flooding temporarily delay access. Wet-wells and electrical controls above flood elevation	Frequent flooding delays regular access/limits routine maintenance/repairs. In-kind replacement would be difficult. Wet-wells and electrical controls at flood elevation	Permanent tidal inundation prevents access for maintenance/repairs. In-kind replacement not feasible. Inundation elevation exceeds wet-wells and electrical controls
UTILITIES	**Sewer or Water Pressure Main**	Surface Flooding and Groundwater	Infrequent flooding temporarily delay access for maintenance/repairs	Frequent freshwater flooding or infrequent tidal inundation delays regular access/limits routine maintenance/repairs. In-kind replacement would be difficult. Increase pipe corrosion potential.	Permanent tidal inundation prevents access for maintenance/repairs. In-kind replacement not feasible. Pipe corrosion could lead to failure.
UTILITIES	**Sewer Gravity Main and Manholes**	Surface Flooding and Groundwater	Infrequent flooding temporarily delay access for maintenance/repairs	Frequent freshwater flooding or infrequent tidal inundation delays regular access/limits routine maintenance/repairs. In-kind replacement would be difficult. Increase pipe corrosion potential. Increase infiltration/inflow (I&I) into system. Manhole lids at flood elevation.	Permanent tidal inundation prevents access for maintenance/repairs. In-kind replacement not feasible. Increase infiltration/inflow (I&I) into system. Pipe corrosion could lead to failure. Inundation elevation exceeds manhole lid elevation. Increase infiltration/inflow (I&I) results in system overload.
UTILITIES	**Gas Main**	Surface Flooding and Groundwater	Infrequent flooding temporarily delay access for maintenance/repairs	Frequent freshwater flooding or infrequent tidal inundation delays regular access/limits routine maintenance/repairs. In-kind replacement would be difficult. Increase pipe buoyancy and corrosion potential.	Permanent tidal inundation prevents access for maintenance/repairs. In-kind replacement not feasible. Pipe buoyancy and corrosion could lead to failure.
UTILITIES	**Communication Towers/Poles**	Surface Flooding	Infrequent flooding temporarily delay access for maintenance/repairs	Frequent freshwater flooding or infrequent tidal inundation delays regular access/limits routine maintenance/repairs. In-kind replacement would be difficult.	Permanent tidal inundation prevents access for maintenance/repairs. In-kind replacement not feasible.
LAND USE	**Residential/ Commercial/ Industrial**	Surface Flooding	<3 inch depth Usability Distribution with Minor Clean-up	3-12 inch depth Minor Damage/Repairs	>12 inch depth Major Damage/Reconstruction
LAND USE	**Agricultural Land and Wildlife Areas**	Surface Flooding and Groundwater	Infrequent freshwater flooding similar to current conditions with minor increases in depth/duration. Vegetation types are not quantifiably altered.	Frequent freshwater flooding, infrequent tidal flooding and minor increase in groundwater elevations. Vegetation types alter at low elevations.	Permanent tidal inundation converts vegetation types

References: [1] ACOE, EurOtop 2016, HUD

HAZARD SCENARIO 1

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
8.8 feet NAVD	**Existing (2012 baseline)** King Tide (~1-yr) 99% chance per year	**1 foot** MMMW 5 to 6 events per year	**2 feet** MHHW Daily - Weekly	**3 feet** MHW Daily

Introduction (See Exhibit HS 1-1):

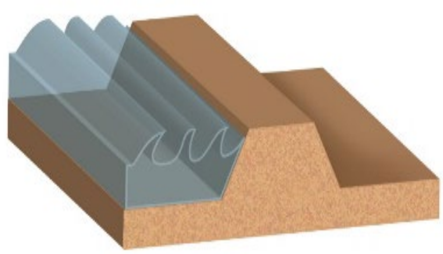
This case study describes a scenario characterized by typical hydraulic conditions that occur from November through January, when the highest tide of the year, a King Tide, coincides with a wind event from the west-northwest. Winds elevate water levels (wind setup) along eastern Arcata Bay, in addition to producing waves. Waves either dissipate as they travel across the salt marsh or uprush on the rail prism (wave runup) which increases erosion potential. Shallow, short duration overtopping occurs in limited locations, where previous erosion has decreased rail prism elevation and where wave runup splashes over. The King Tide overtops the low elevation area of Park Street, which is typical of tides above 8.0 feet (NAVD) that occur multiple times a year. Little to no overtopping occurs throughout the rest of the study area.

Example King Tide with Wind Wave Runup on Rail Prism

Highlighted shoreline processes and responses in this scenario include wind wave erosion, overtopping with rill erosion on the land-facing slope, and typical roadway flooding. Conceptual examples shown below.

Wind Waves

Arcata Bay Shoreline
Minor Erosion and Overtopping



Concept Shoreline Wind Wave Erosion (National Science Foundation, 2020)

Overtopping and Erosion

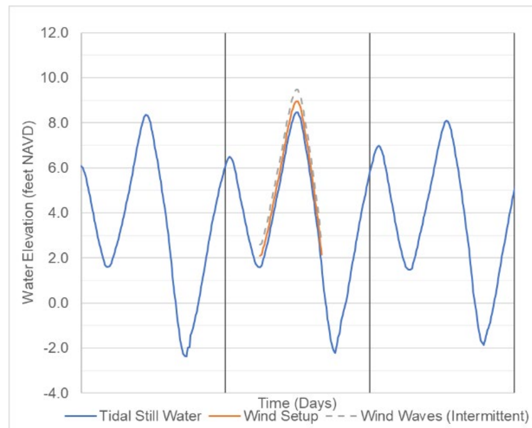
2 locations Arcata Bay Shoreline
<1% of Interior Slough Levees

Typical Roadway Flooding

Park Street

Hydraulics and Sea Level Rise:

This scenario combines the highest spring tides that occur during the year, typically from November through January, during average meteorological conditions and any combination of astronomical conditions with continuous winds from the west. High spring tides of similar elevation occur multiple days in a row on separate occasions during this time of year and are not considered extreme. Certain meteorological conditions may increase water levels, as represented by the strong winds. Increases may be modest to extreme. The modest increase associated with this scenario is intended to represent common meteorological conditions and the highest tide of the year, also known as the King Tide. Based on observations made on January 11, 2020 during a King Tide, strong winds generated waves across Arcata Bay and elevated water levels along the eastern shore. Predicted high tides leading up to the King Tide, exceed 8 feet for three days prior to the peak and one day following[1]. The peak tide of 8.3 feet is increased within the study area due to wind set-up and waves. Wind setup increases water levels by 0.5 feet (8.8 feet NAVD), throughout the study area and waves runup the rail prism and levees along Arcata Bay for hours, intermittently increasing water levels to between 9.3 and 10.3 feet (NAVD). Based on modeled wind speeds from the west/northwest in Eureka Slough, wind waves in the sloughs are not a significant erosional process on interior levees[2]. Water levels are referenced to the 2012 baseline and ground elevations are referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 8.8 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 1 Hydraulics and Sea Level Rise		
Tidal Still Water Level	8.3 ft NAVD	
Wind Set-up	0.5 ft (8.8 ft NAVD bay shoreline and sloughs)	
Wind Wave Height	Height: 1 ft	
Wave Runup Range	0.5 – 1.0 ft	
Total Water Level (TWL)	9.3 – 10.3 ft NAVD Tidal still water, wind setup and wave uprush along bay shoreline	
Fluvial Flows	Winter Base Flow from tributaries	

Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018. Tidal marsh along the eastern bay shoreline is assumed to match the extent shown in **Exhibit G-1** geomorphic trends.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, similar hydraulic conditions were observed on January 11, 2020 by GHD. Photos and observations from this event were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 1-1 and described in this case study. Exhibit HS 1-1 shows the approximate, observed wave height and modeled overtopping depth and duration of the interior and bay shoreline. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4, at the end of this case study, and are based on the hydraulic modeling results and associated physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

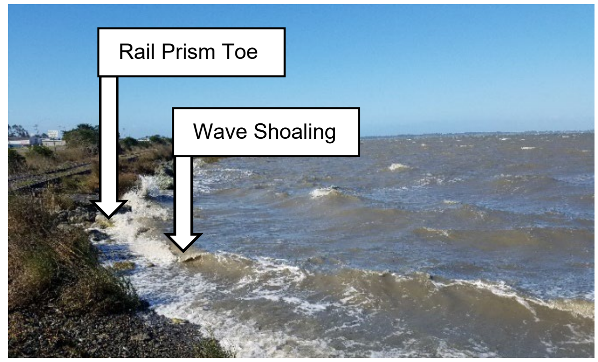
[2] NHE 2016, Jacobs Avenue Levee Bathymetric, Hydrologic and Hydraulic Study,Humboldt County, CA March 2016.

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101. The extent of overtopping for the Bay Shoreline is summarized in Table 2, at the end of this case study.

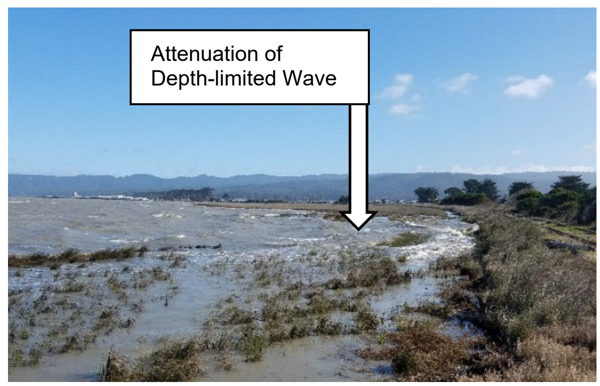
Hydraulic Conditions:

In the days leading up to and following the peak tide event, high tides rise to within one foot of the rail prism crest. On the day of the peak tide, high winds occur throughout the tidal cycle. As the tide rises and water depth increases, incident wave heights increase. Waves eventually begin to shoal and dissipate over tidal marshes and the toes of the rail prism and Brainard levee. The shallow depths over the marshes cause the waves to attenuate and decrease as they propagate toward the shore.



Example Wave Shoaling Along Toe of Rail Prism Where Salt Marsh is Absent South of Brainard

As the tide continues to rise, the water depth over the tidal marsh increases. When the depth exceeds 0.8 feet, the ability of the tidal marsh to attenuate waves diminishes and waves are not depth-limited. Therefore, at a water level above 8.3 feet (NAVD), waves are expected to rush up on the rail prism, inducing wave runup, elevating peak water levels 0.5 to 1.0 feet. Peak water levels are momentary but repetitive over multiple hours, as the waves break and splash vertically and landward. The extent of continuous overtopping, when still water levels are above the rail prism crest, is limited to one location north of Brainard and one south (Exhibit HS1-1). The location south of Brainard is not hydraulically connected to the Cell A interior, as the Highway 101 prism provides an elevation barrier, similar to a levee. Wave runup, along the entirety of the rail prism contributes minor, intermittent sprays of tidal waters above and potentially over the rail prism.



Example Attenuation of Wave Height by Tidal Marsh South of Brainard

The Brainard levee bay-facing slope induces peak wave runup. However, the top elevation is typically higher relative to the rail prism and prevents overtopping.

Following the peak event, the ebb tide reduces water levels and winds speeds decrease, reducing wind-wave exposure along the shoreline. The extent of Bay Shoreline overtopping is summarized in Table 2.

Resource Response and Impacts:

The physical response of the Bay Shoreline under this scenario varies based on existing shoreline condition, presence/absence of adjacent tidal marsh, and wind-wave exposure. Anticipated responses are described below.

Rail Prism and Brainard Levee: In areas of intact tidal marsh, wave height is dampened by the tidal marsh for water levels less than 8.3 feet (NAVD), reducing wave energy and erosion potential on the rail prism. Under these conditions, wave-induced erosion along the rail prism is limited to approximately 400 linear feet of rail prism south of Brainard and approximately 5,000 linear feet north of Brainard. Areas of poorly graded rock and concrete rubble have increased erosion potential within the larger voids. As water levels increase above 8.3 feet (NAVD), the tidal marsh no longer dampens wave height and wave runup occurs directly on the rail prism, increasing erosive forces on the bay-facing slope and top. The drainage channel

Wave-induced Lateral Erosion along Rail Prism.

between the southbound travel lanes of Highway 101 and the rail prism has adequate capacity to store and convey all overtopping flow to the drainage channel within the interior of Cell A, discharging to Eureka Slough.

The Brainard levee slope is armored with well-graded rock slope protection and vegetation. While the steep slopes increase wave runup height, erosion potential even in the absence of tidal marsh, is minimal due to the size and gradation of the rock slope protection.

In areas where tidal marsh is absent or fragmented, with historical erosion and overtopping of rail prism observable, continued lateral erosion occurs. Although shallow (less than 1 foot) and short (less than 2 hours), overtopping of the rail prism results in rill erosion across the top and land-facing slope. This erosion reduces the crest elevation and provides a pathway for future inundation and is subject to increased failure potential as rills can deepen and widen. The damaged rail prism requires repair to maintain the same level of flood protection and stability prior to the event.

Overtopping Flow at Lowest Point of Rail Prism

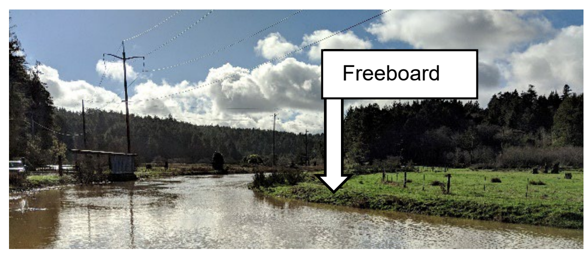
Highway 101: All lanes of Highway 101 remain dry and travel is not affected by the event.

Interior Shoreline

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Levee crest elevations throughout the Interior Shoreline typically provide freeboard, separation between the levee crests and tidal water level. Overtopping is limited to a few locations on Fay Slough protecting Cell B, Freshwater Slough protecting Cell C and Cell E, and Ryan Slough protecting Cells G and the area upstream of Myrtle Avenue. Overtopping occurs at the peak of the highest tides prior to, during and following the event, and is shallow (less than 1 foot) and short (less than 2 hours).



Freeboard between Levee Crest and Tidal Water.

Resource Response and Impacts:

Although limited in extent, duration and depth, overtopping of unarmored earthen levees induces rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

Example Levee Crest Erosion from Repetitive Overtopping (Laird, 2013)

The extent of Interior Shoreline overtopping for each cell is summarized in Table 2 and Table 3. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area,

HAZARD SCENARIO 1

Indianola Cutoff, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions:

The limited extent of overtopping contributes a minimal amount of tidal flooding to Protected Lands, as shown in Exhibit HS 1-1. Tidal flooding across Park Street remains within existing drainage channels and within Cell G. Overtopping of Cell C and upstream of Myrtle Avenue on Ryan Slough is limited and contained within existing drainage channels. Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient. Residential communities, commercial development, and public utility infrastructure exist between elevation 9 and 11 feet (NAVD). Tidal water levels are generally within 1 to 2 feet of flooding the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, and HCSD's sewer pump station and residences on Bay Street.

High Tides Encroach on the Shoreline RV Park

Public Utility Infrastructure within one to two feet of high tides

Protected Lands with fluvial sources, such as Cell C, impound the fluvial flow when water levels in the slough channels are greater than water levels within the protected lands. Due to the magnitude, frequency and duration of high tides, combined with lower land elevation protected by levees, favorable drainage conditions typically last for only a few hours each day.

Resource Response and Impacts:

No flooding of Protected Lands is observed under these hydraulic conditions, with the exception of Park Street, which commonly floods when tidal water levels are above 8.0 feet (NAVD).

The limited extent of overtopping results in all tidal flooding and impounded fluvial flows to be stored and conveyed within existing drainage channels. However increases in fluvial flows, groundwater elevation, or precipitation, that is common during this time of year, results in impoundment and typically shallow flooding of low-lying areas. Sea level rise is expected to increase low tide and ground water elevations, which will reduce the duration of favorable drainage conditions and increase the volume of impounded water and flood depth.

Inundation Due to Impoundment of Fresh Water

HAZARD SCENARIO 1

Scenario Summary:

The multiple days of high spring tides and single day of strong winds have few significant, observable impacts within the Study Area. The appearance of the landscape is typical of winter conditions in the Study Area, with large tidal ranges, windy conditions, and minor flooding of the lowest elevation lands.

Along the Bay Shoreline, the interaction between the salt marsh, rail prism and waves is observable. In areas where salt marsh exists, waves dissipate at water levels below 8.3 feet (NAVD), reducing wave runup and resulting erosion potential on the rail prism. Where salt marsh is not present, wave erosion persists throughout the wind event, slowly decreasing the width and elevation of the rail prism. Overtopping of the rail prism is limited to a single location with hydraulic connection to the Cell A interior Protected Lands (Table 2). The existing drainage ditch between Highway 101 and the rail prism has adequate capacity to store and convey the overtopping. Although shallow (less than 1 foot) and short (less than 2 hours), overtopping of the rail prism results in rill erosion across the top and land-facing slope. This erosion reduces the crest elevation and provides a pathway for future inundation and is subject to increased failure potential as rills can deepen and widen. The damaged rail prism requires repair to maintain the same level of flood protection and stability prior to the event.

The Interior Shoreline is overtopped in limited locations (Table 3). Overtopping volume is contained within the existing, low elevation drainage channels within Protected Lands. Although limited in extent, overtopping of unarmored earthen levees induces rill erosion across the top and land-facing slope of earthen levees. Damaged levees require repair to maintain the same level of flood protection and stability prior to the event.

No flooding of Protected Lands is observed under these hydraulic conditions, with the exception of Park Street, which commonly floods during this time of year. However, high tides and typical fluvial, groundwater and precipitation in winter months typically result in flooding of low-lying lands, as favorable drainage conditions are limited to a few hours per day. Sea level rise is expected to increase low tide and ground water elevations, which will further reduce the duration of favorable drainage conditions and increase the volume, depth, and duration of impounded water. A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 1

Table 2. Overtopping Summary for Cell A Bay and Slough Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	-	-	Contained within Ditch	-	-
		Rail Prism	50	<1%	-			
	Brainard Levee	Levee	-	-	-	-		
	Brainard to Indianola Cutoff	Rail Prism	10	<1%	-	< 0.1 ac-ft, Contained within Ditch		
Slough	Fay Slough	Levee	-	-	-	-		
	Eureka Slough	Levee	-	-	-	-		

[1]LF=Lineal Feet

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)[4]	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	10	4%	-	-	-
C1	Fay Slough	-	-	-	-	-
	Freshwater Slough	13	-	-		
C2	Freshwater Slough	-	-	-	-	-
D[2]	Freshwater Slough	200	4%	-	0 to 1.3	8.8
E	Freshwater Slough	3	-	-	-	-
F	Ryan Slough	-	-	-	-	-
	Freshwater Slough	-	-	-		
G	Freshwater Slough	-	-	-	-	-
	Park Street	151	25%	-		
	Ryan Slough	6	-	-		
H	Freshwater Slough	-	-	-	-	-
	Eureka Slough	-	0%	-		
I[3]	Eureka Slough	-	-	-	-	-
Myrtle	Ryan Slough	32	1%	-	-	-

[2]Cell Subject to Daily Tidal Inundation
[3]No Shoreline Structure, Protected by Natural Elevation Gradient
[4]LF=Overtopping >1 foot and > 2hrs

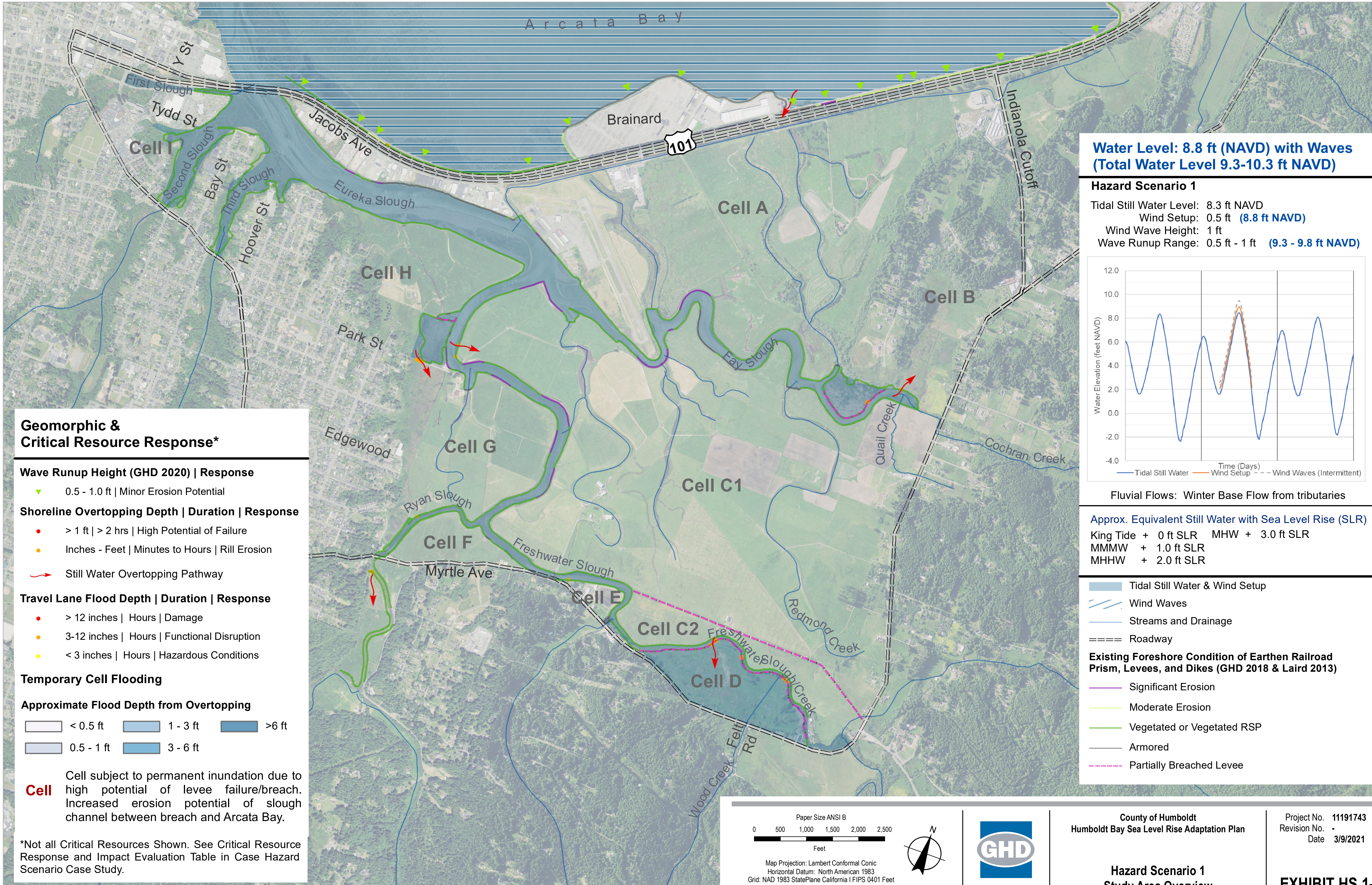
HAZARD SCENARIO 1

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/Extent	Impact to Resource
Shoreline Protection	Earthen Levees	Overtopping (depth and time)	Cell A	none	None Observed
			Cell B	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell C	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell E	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell F	none	None Observed
			Cell G	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell H	none	None Observed
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay	1 ft	Land-slide Slope Erosion
		Overtopping (depth and time)	Cell A- Arcata Bay	none	None Observed
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	none	none
	Hwy 101 Northbound		Cell A - Arcata Bay	none	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	-	none
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	0.8	**Closure**
	Hoover Street		Cell I	-	none
	2nd and Y Streets		Cell I	-	none
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alt Route)		Arcata Bay	-	none
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	-	none
			Humboldt CSD Hoover Street	-	none
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	-	none

HAZARD SCENARIO 1

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/Extent	Impact to Resource
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	-	none
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell I Hoover St - HCSD	-	none
	Sewer Gravity Main	Surface Flooding (Hours)	Cell I Hoover St - HCSD	-	none
	Gas Main	Surface Flooding (Hours)	Cell G	-	none
	Gas Main	Surface Flooding (Hours)	Cell C	-	none
	Gas Main	Surface Flooding (Hours)	Cell A	-	none
	Communications (Underground)	Surface Flooding (Hours)	Cell A	-	none
	Communication Towers/Poles	Surface Flooding (Hours)	Cell H	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Murray Field	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Harper Motors	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Brainard	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Rainbow Storage Indianola Cutoff	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	2nd and Y Street	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	6th and Tydd Street	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Hoover Street	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Park Street	0.8	Shallow Flooding
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Edgewood	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell A	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell B	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell C	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell E	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell F	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell G	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Cell H	-	none
Protected Lands	**Agricultural Land and Wildlife Areas**	Surface Flooding (hrs)	Ryan Slough Upstream of Myrtle	-	none



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Print date: 09 Mar 2021 - 12:51

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 2

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
9.3 feet NAVD	**Existing (2012 baseline)** 2-yr 50% chance per year	**1 foot** MMMW 5 to 6 events per year	**2.5 feet** MHHW Daily - Weekly	**3.5 feet** MHW Daily

Introduction (See Exhibit HS 2-1):

This case study describes a scenario characterized by an extreme tide in the absence of local wind effects that further increase water levels. Overtopping occurs in limited locations of the rail prism along Arcata Bay and levees along the interior slough channels. Overtopping is shallow (less than 1 foot) and/or of short duration (less than 2 hours). Tidal waters flood Park Street, which typically occurs multiple times a year, and Cells B, E, G and the area upstream of Myrtle Avenue on Ryan Slough.

Highlighted shoreline processes and responses in this scenario include overtopping and rill erosion of land-facing slope, tidal flooding of protected lands, and typical roadway flooding. Examples shown below.

Overtopping and Erosion
4% Arcata Bay Shoreline
2% of Interior Slough Levees

Tidal Flooding of Protected Lands
Cells B, E, G, and Ryan Slough

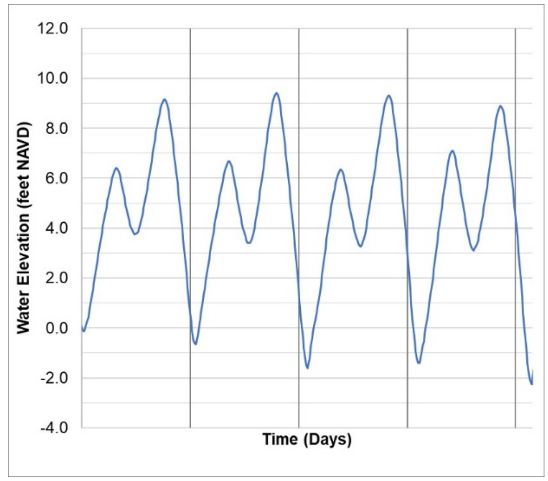
Typical Roadway Flooding
Park Street

Hydraulics and Sea Level Rise:

This scenario combines the highest spring tides that occur during the year, from November through January, with meteorological conditions, such as storm surge, that further increase tidal elevations. High spring tides occur multiple days in a row on separate occasions during this time of year. The increase due to storm surge is intended to represent conditions that typically occur, on average, every couple years under existing conditions (2012 baseline). Based on predicted tides leading up to water level event of 9.3 feet (NAVD), high tides exceed 9.0 feet (NAVD) the day prior to the peak and the day following[1]. Calm conditions, without wind effects that increase water levels and produce waves, exist throughout the duration of peak tides. Water levels are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 9.3 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 2 Hydraulics and Sea Level Rise		
Tidal Still Water Level	9.3 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	9.3 ft NAVD	
Fluvial Flows	Winter Base Flow from tributaries	

Antecedent Shoreline Conditions:

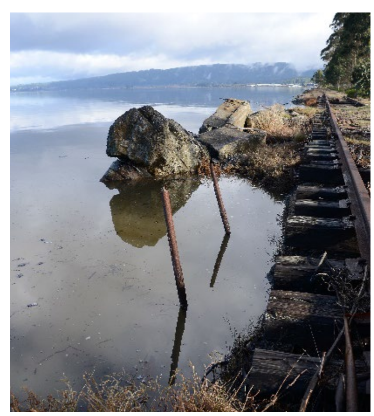
This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, similar hydraulic conditions occur, on average, every couple years. Photos and observations of similar events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 2-1 and described in this case study. Exhibit HS 2-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.



Example High Tide during Calm Conditions

<u>**Hydraulic Conditions:**</u>

High tides above 9.0 feet (NAVD) occur for multiple days, with the peak reaching 9.3 feet (NAVD). As the tide rises, water levels approach the crest and move into low elevation areas of the rail prism created by previous high tide and storm events. Erosion of the rail prism and levee is not typically observable under these conditions, as still water levels rise. Only the highest peak water level, on the day of the event overtops the rail prism. The extent of overtopping is limited to two locations north of Brainard, where previous storms have lowered crest elevation, and several south of Brainard (Exhibit HS2-1). Overtopping north of

HAZARD SCENARIO 2

Brainard is conveyed into a drainage ditch that flows into the interior of Cell A, while overtopping south of Brainard is captured in a drainage channel that not hydraulically connected to the interior of Cell A, as the Highway 101 prism provides an elevation barrier, similar to a levee. Overtopping at all Bay Shoreline locations is shallow (less than 1 foot) and short (less than 2 hours). Following the peak tide event, water levels remain below the rail prism and Brainard levee crest elevations.

Resource Response and Impacts:
The physical response of the Bay Shoreline under this scenario varies based on existing shoreline condition. Anticipated responses are described below.

Rail Prism and Brainard Levee: Although the depth of overtopping is shallow and duration short, rill erosion occurs across the top and land-facing slope, creating new paths erosional pathways, exacerbating locations of previous overtopping erosion, and reducing the previous level of flood protection. Overtopping of the rail prism south of Brainard flows into the drainage ditch between the rail prism and highway, where it is stored until tidal water levels decrease and the channel drains toward Eureka Slough and back to Arcata Bay through culverts. Overtopping flow north of Brainard is captured within the existing drainage ditch between the rail prism and highway, and conveyed to the drainage system in Cell A with outlet to Eureka Slough.

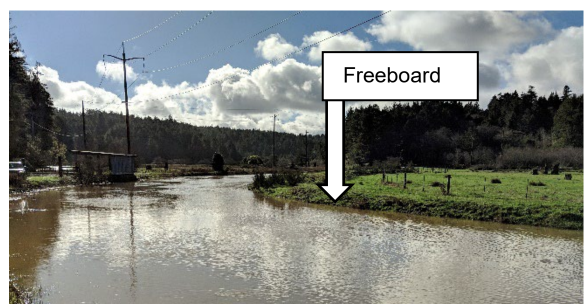
Overtopping Flow at Lowest Point of Rail Prism

Highway 101: All lanes of Highway 101 remain dry and travel is not affected by the event.

Interior Shoreline

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

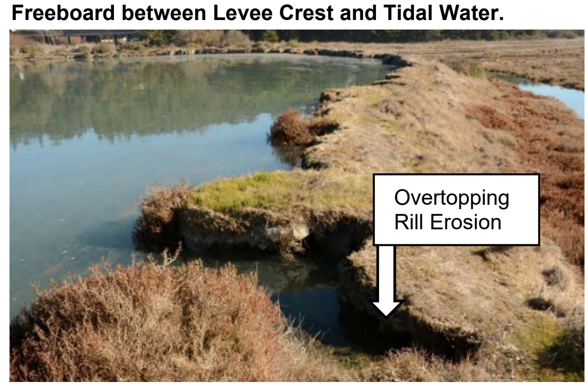
Hydraulic Conditions:
Levee crest elevations throughout the Interior Shoreline typically provide freeboard, separation between the levee crests and tidal water level. However, overtopping occurs at a number of locations on Fay Slough protecting Cells A, B, and C; Freshwater Slough protecting Cells C, E, F, G and H; and Ryan Slough protecting Cell G and the area upstream of Myrtle Avenue. Overtopping occurs at the peak of the highest tides prior to, during and following the event, and is shallow (less than 1 foot) and short (less than 2 hours).



Freeboard between Levee Crest and Tidal Water.

Resource Response and Impacts:
Overtopping occurs at numerous locations throughout the Interior Shoreline. Although limited in duration and depth, overtopping of unarmored earthen levees induces rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.



Example Levee Crest Erosion from Repetitive Overtopping (Laird, 2013)

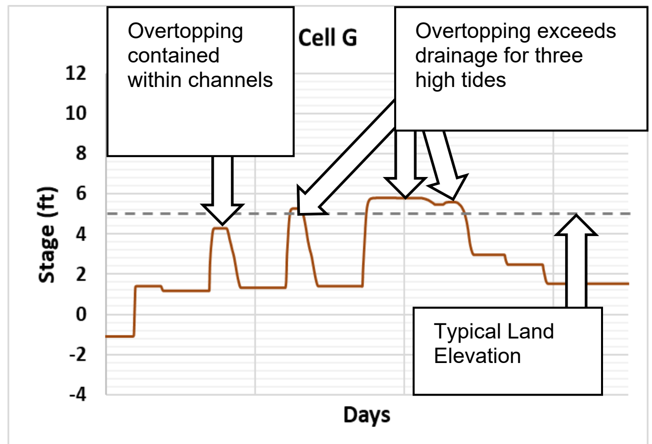
The extent of Interior Shoreline overtopping for each cell is summarized in Table 2 and Table 3. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions:

Overtopping occurs during multiple high tides on sequential days. The extent of levee, rail prism and roadway (Park Street) overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells B, E, G and the area upstream of Myrtle on Ryan Slough, as shown in Exhibit HS 2-1. Overtopping is otherwise contained within existing low elevation drainage channels.



Example Hydrograph of Flooding within Cell

Protected Lands with fluvial sources, such as Cell C, impound the fluvial flow when water levels in the slough channels are greater than water levels within the protected lands. Due to the magnitude, frequency and duration of high tides, combined with lower land elevation protected by levees, favorable drainage conditions typically last for only a few hours each day.

Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient. Residential communities, commercial development, and public utility infrastructure exist between elevation 9 and 11 feet (NAVD). Tidal water levels are generally within 1 foot of flooding the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, and HCSD's sewer pump station and residences on Bay Street.

Example Shallow Flooding of Agricultural Lands

Resource Response and Impacts:

Shallow, tidal flooding of Cells B, E, G and the area upstream of Myrtle on Ryan Slough are not likely to have lasting impacts on agricultural lands with respect to conversion of vegetation types if limited to isolated, infrequent events. The shallow flooding persists for one to two days due to the magnitude, frequency and duration of high tide levels and overtopping, combined with lower land elevation and hydraulic conditions not favorable for drainage. Sea level rise is expected to increase low tide and ground water elevations, which will reduce the duration of favorable drainage conditions and increase the volume of impounded water and flood depth.

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Scenario Summary:

The multiple days of high spring tides and storm surge result in limited, shallow, short duration overtopping in the study area. The appearance of the landscape is generally similar to typical winter conditions in the Study Area, when large swings from high tide to low tide occur and standing water fills low-lying, saturated lands.

Along the Bay Shoreline, overtopping of the rail prism is limited to two locations with hydraulic connection to the Cell A interior Protected Lands (Table 2). The existing drainage ditch between Highway 101 and the rail prism has adequate capacity to store and convey the overtopping. Although shallow (less than 1 foot) and short (less than 2 hours), overtopping of the rail prism results in rill erosion across the top and land-facing slope. This erosion reduces the crest elevation and provides a pathway for future inundation and is subject to increased failure potential as rills can deepen and widen. The damaged rail prism requires repair to maintain the same level of flood protection and stability prior to the event.

Overtopping occurs at a number of locations along the Interior Shoreline, on Fay Slough protecting Cells A, B, and C; Freshwater Slough protecting Cells C, E, F, G and H; and Ryan Slough protecting Cell G and the area upstream of Myrtle Avenue (Table 3). Overtopping occurs during multiple high tides on sequential days, prior to, during and following the event, and is shallow (less than 1 foot) and short (less than 2 hours).

Shallow, tidal flooding of Cells B, E, G and the area upstream of Myrtle on Ryan Slough persists for one to two days and is not likely to have lasting impacts on agricultural lands with respect to conversion of vegetation types if limited to isolated, infrequent events. Flooding of Park Street also occurs, which commonly floods during this time of year. High tides limit favorable drainage conditions to a few hours per day. Sea level rise is expected to increase low tide and ground water elevations, which will further reduce the duration of favorable drainage conditions and increase the volume, depth, and duration of impounded water. A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 2

Table 2. Overtopping Summary for Cell A Bay and Slough Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	0%	-	-	-	-
		Rail Prism	597	9%	-			
	Brainard Levee	Levee	-	0%	-	0		
	Brainard to Indianola Cutoff	Rail Prism	83	1%	-	0		
Slough	Fay Slough	Levee	28	0%	-	1		
	Eureka Slough	Levee	-	0%	-	-		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	139	50%	-	0 to 0.7	6.1
C1	Fay Slough	137	1%	-	-	-
	Freshwater Slough	256	2%	-		
C2	Freshwater Slough	-	0%	-	-	-
D[2]	Freshwater Slough	1,255	28%	-	0 to 2	9.5
E	Freshwater Slough	143	6%	-	0.2 to 1.2	7.1
F	Ryan Slough	-	0%	-	-	-
	Freshwater Slough	-	0%	-		
G	Freshwater Slough	127	2%	-	0.8 to 1.3	6.8
	Park Street	207	34%	-		
	Ryan Slough	45	2%	-		
H	Freshwater Slough	-	0%	-	-	-
	Eureka Slough	-	0%	-		
I[2]	Eureka Slough	-	-	-	0 to 0.5	9.4
Myrtle	Ryan Slough	322	8%	-	1.4 to 3.4	9.4

HAZARD SCENARIO 2

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/Extent	Impact to Resource
Shoreline Protection	**Earthen Levees**	Overtopping (depth and time)	Cell A	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell B	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell C	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell E	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell F	none	None Observed
			Cell G	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell H	none	None Observed
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay	-	N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
Transportation	**Hwy 101 Southbound**	Surface Flooding (ft)	Cell A - Arcata Bay	none	none
	Hwy 101 Northbound		Cell A - Arcata Bay	none	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	-	none
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	1.3	**Closure & Damage**
	Hoover Street		Cell I	-	none
	2nd and Y Streets		Cell I	-	none
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alternate Route)		Arcata Bay	-	none
Utilities	**Sewer Lift Stations**	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	-	none
			Humboldt CSD Hoover Street	-	none

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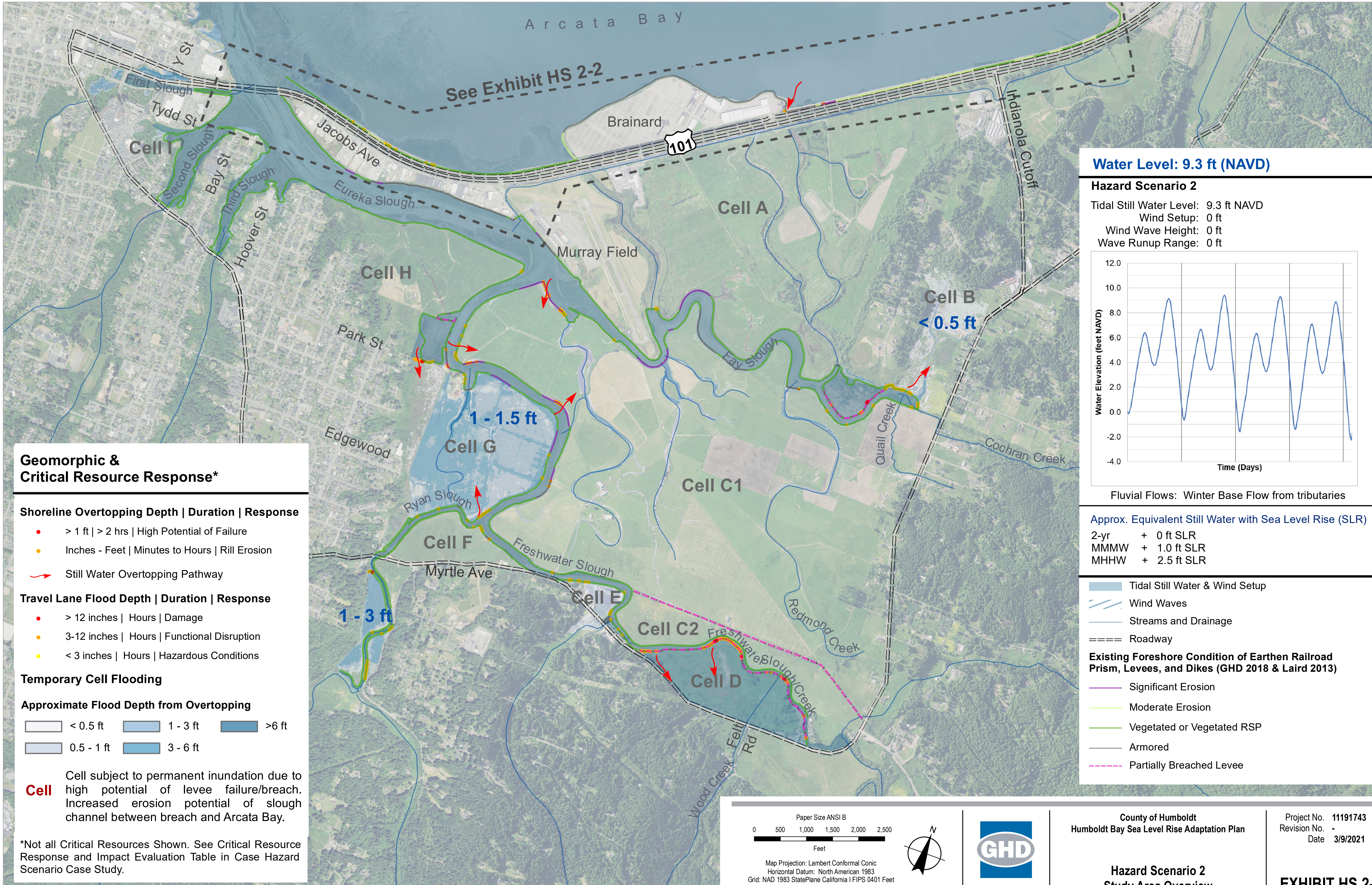
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	-	none
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	-	none
			Cell I Hoover St - HCSD	4	Limited Access < 1 Day
	Sewer Gravity Main		Cell I Hoover St - HCSD	4	Limited Access < 1 Day
	Gas Main		Cell G	47	**Limited Access Multiple Days**
			Cell C	-	none
			Cell A	-	none
	Communications (Underground)		Cell A	-	none
	Communication Towers/Poles		Cell H	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	-	none
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	-	none
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	-	none
			6th and Tydd Street	-	none
			Hoover Street	-	none
			Park Street	1.3	**Damage/Stranding**
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	-	none
			Cell B	27	**Limited Access Multiple Days**
			Cell C	-	none
			Cell E	33	**Limited Access Multiple Days**
			Cell F	-	none
			Cell G	47	**Limited Access Multiple Days**
			Cell H	-	none



County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 2
Study Area Overview

Project No. 11191743
Revision No. -
Date 3/9/2021

EXHIBIT HS 2-1

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Print date: 09 Mar 2021 - 14:24

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

Water Level: 9.3 ft (NAVD)

Hazard Scenario 2
See Exhibit HS 2-1 for Water Level Detail

Tidal Still Water & Wind Set-up
Wind Waves
Streams and Drainage
Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee

Drainage

Drainage Swale/Ditch
Culvert
Culvert with Flash Board Riser
Drop Inlet
Culvert with Flap Gate or Tide Gate

Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion

Travel Lane Flood Depth | Duration | Response

- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

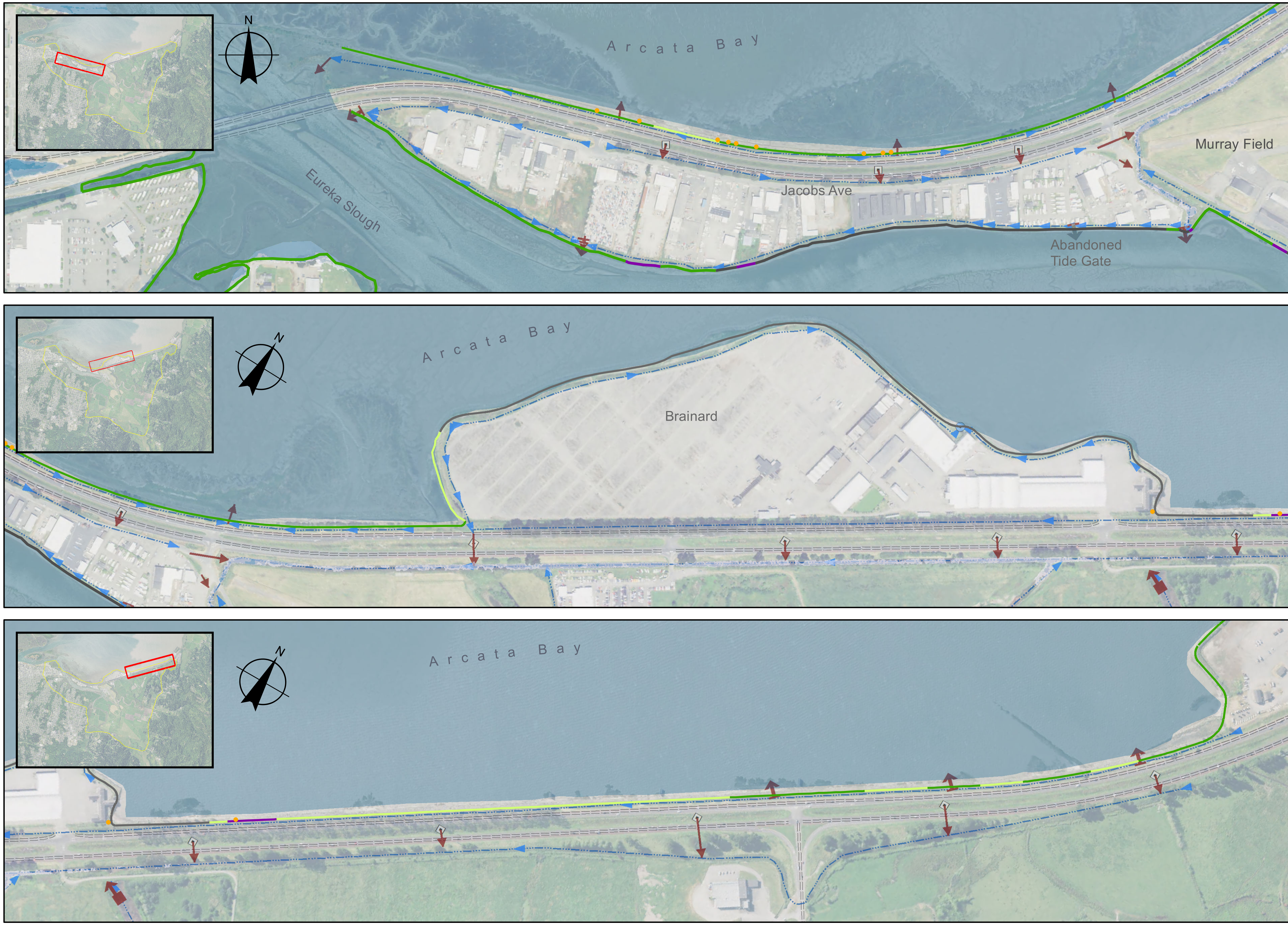
Temporary Cell Flooding

Approximate Flood Depth from Overtopping

< 0.5 ft
1 - 3 ft
>6 ft
0.5 - 1 ft
3 - 6 ft

Cell Cell subject to permanent inundation due to high potential of levee failure/breach. Increased erosion potential of slough channel between breach and Arcata Bay.

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.



Paper Size ANSI B
0 250 500 750 1,000
Feet
Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 2
Bay Shoreline

Project No. 11191743
Revision No. -
Date 3/9/2021

EXHIBIT HS 2-2

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Print date: 09 Mar 2021 - 14:25

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 3

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
10.3 feet NAVD	**<u>Existing (2012 baseline)</u>** ~50-year 2% chance per year	**<u>1 foot</u>** 2-year 50% chance per year	**<u>2 feet</u>** MMMW 5 to 6 events per year	**<u>3.5 feet</u>** MHHW Daily - Weekly

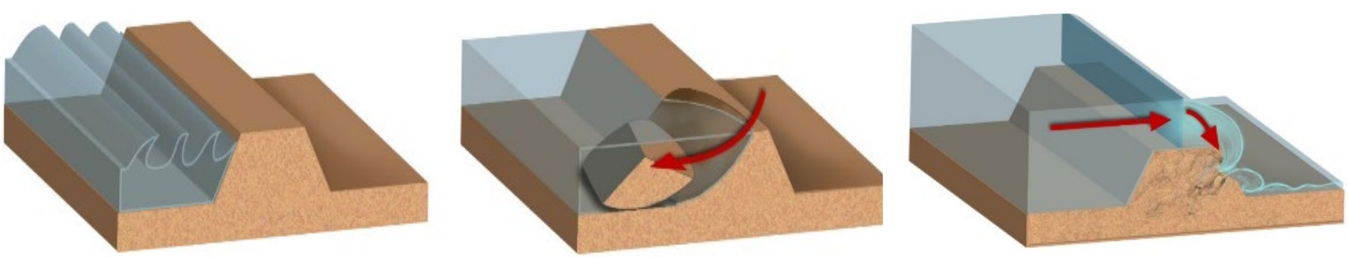
Introduction (See Exhibit HS 3-1):

Photo of December 31, 2005 storm from Highway 101 Southbound.

This case study describes a scenario characterized by similar hydraulic conditions observed on December 31, 2005, the highest observed tide affecting the Study Area[1]. An extreme high tide coincided with a high wind event from the west-southwest. The strong winds elevated water levels (wind setup) along eastern Arcata Bay, in addition to producing waves. Water levels overtopped large sections of the rail prism, which exceeded the capacity of the adjacent drainage channel, flooding the southbound travel lanes of Highway 101. Flood waters entered the median drainage ditches and were conveyed into the drainage network east of the highway. Northbound travel lanes were not flooded. The storm impacts resulted in flooding throughout the Study Area; hazardous conditions for motorists traveling southbound on Highway 101 and eventual closure of the highway for multiple hours; damage to the rail prism requiring repairs to restore pre-event flood protection; and extensive post storm cleanup of roadways, drainage channels and flooded areas.

Highlighted shoreline processes in this scenario include wave erosion, slope failure/erosion of bay- and slough-facing slopes, and overtopping with land-facing slope erosion. Conceptual examples shown below.

<u>Wind Waves</u>	**<u>Slope Failure/Erosion</u>**	**<u>Overtopping and Erosion</u>**
Arcata Bay Shoreline Erosion and Overtopping	Arcata Bay Shoreline Rail Prism	53% of Arcata Bay Shoreline 15% of Interior Slough Levees



Example Shoreline Structure Responses (National Science Foundation, 2020)

Hydraulics and Sea Level Rise:

This scenario combines extreme spring tides that typically occur in the months from November through January, with a low-pressure system (storm surge) that increases predicted tidal water levels entering Humboldt Bay and strong, continuous winds from the west that elevate water levels along the eastern shore of Arcata Bay and generate waves. Based on predicted tides leading up to a still water level event of 9.3 feet (NAVD), high tides exceed 9.0 feet (NAVD) the day prior to the peak and the day following[2]. On the day of the 9.3 foot (NAVD) peak tide, wind setup increases water levels by 1 foot throughout the Study Area, to 10.3 feet (NAVD). The wind produces a significant waves height of 2.4 feet, which intermittently increase water levels to between 12 and 15 with wave runup on the rail prism and levees. Based on modeled wind speeds of 45 mph from the west/southwest in Eureka Slough, wind waves in the sloughs are not a significant erosional process and are therefore not added

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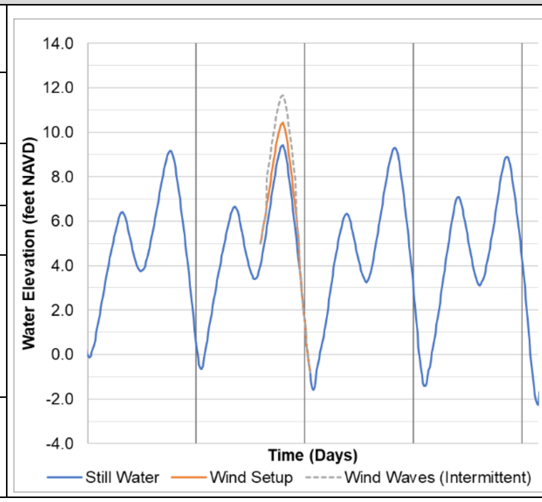
[1]NOAA 2020, Datums for 9418767, North Spit CA

[2] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

to water levels within sloughs[3]. Water levels are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. An approximate 45 mph sustained wind event (similar to FEMA's 50-year event used in the Coastal Flood Study[4]). The water level of 10.3 feet is an approximate 50-year still water recurrence. However, the event was also analyzed as part of the *Humboldt Bay Trail South Project*, which found that the combined water level and wave event resulted in more frequent storm conditions, with an approximate 5- to 10-year recurrence or greater[5]. Approximate equivalent recurrences for this still water level scenario of 10.3 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 3 Hydraulics and Sea Level Rise

Tidal Still Water Level	9.3 ft NAVD
Wind Set-up	1 ft (10.3 ft NAVD bay shoreline and sloughs)
Wind Wave Height	Height: 2.4 ft
Wave Runup Range	1.5 – 4.5 ft
Total Water Level (TWL)	12-15 ft NAVD Tidal still water, wind setup and wave uprush along bay shoreline
Fluvial Flows	Winter Base Flow from tributaries



Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018. Tidal marsh along the eastern bay shoreline is assumed to match the extent shown in **Exhibit G-1** geomorphic trends.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, a historical event with similar hydraulic conditions to this scenario occurred on December 31, 2005. Photos and observations from this event were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 3-1. Exhibit HS 3-1 shows the modeled wave height and overtopping depth and duration of the Interior and Bay Shoreline, as well as, the maximum inundation depth associated with predicted tidal still water and wave overtopping into Protected Lands. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

[3] NHE 2016, Jacobs Avenue Levee Bathymetric, Hydrologic and Hydraulic Study,Humboldt County, CA March 2016.

[4] FEMA 2014, Intermediate Data Submittal #3, Nearshore Hydraulics, Humboldt County, California, FEMA Region IX California Coastal Analysis and Mapping Project / Open Pacific Coast Study, prepared by BakerAECOM, September 2014.

[5] ESA 2018, Sea-Level Rise Vulnerability and Adaptation Report, Humboldt Bay Trail South, Prepared for County of Humboldt and GHD, June 2018.

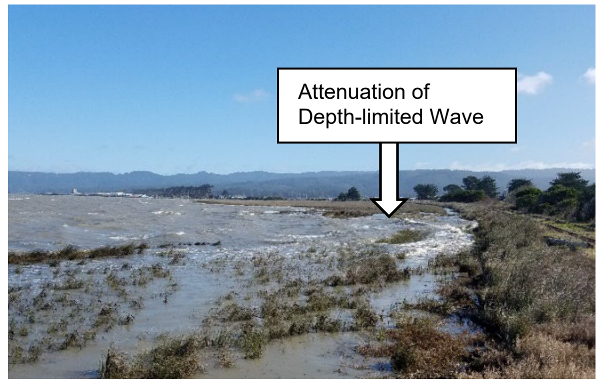
HAZARD SCENARIO 3

Bay Shoreline

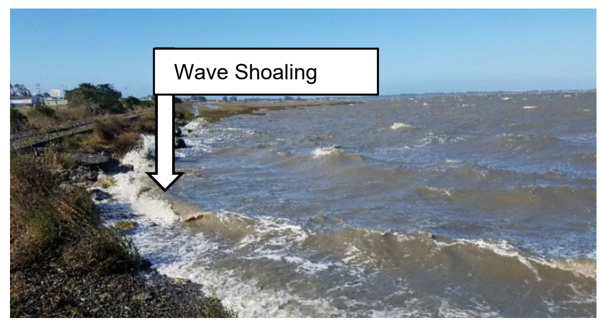
This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

Hydraulic Conditions:

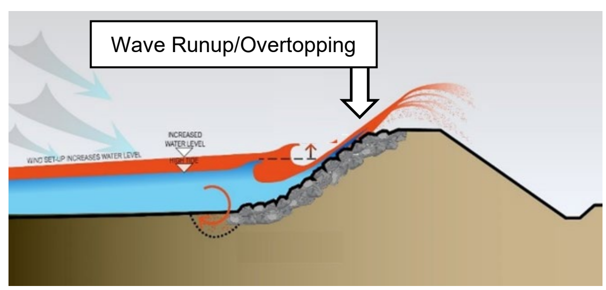
High tides above 9.0 feet (NAVD) occur on the day prior and following the peak water level. These high tides overtop limited portions of the rail prism and are characterized in Scenario 2. On the day of the peak tide, high winds occur throughout the tidal cycle. As the tide rises and water depth increases, incident wave heights increase. Waves eventually begin to shoal and dissipate over tidal marshes and the toes of the rail prism and Brainard levee. The shallow depths over the marshes cause the waves to attenuate and decrease as they propagate toward the shore.



Example Attenuation of Wave Height by Tidal Marsh South of Brainard



Example Wave Shoaling Along Toe of Rail Prism Where Salt Marsh is Absent South of Brainard



Example of Wave Runup

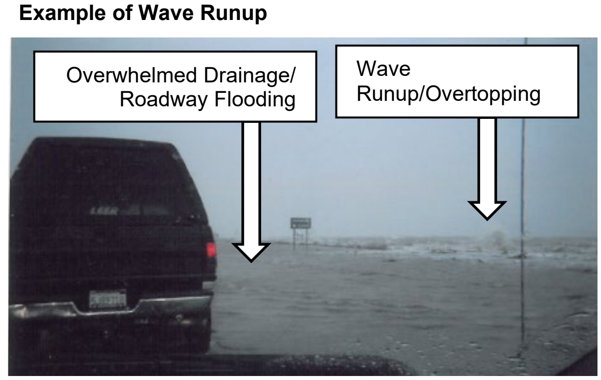


Photo from Similar Event with Inundation of Hwy 101

As the tide continues to rise, the water depth over the tidal marsh increases. When the depth exceeds approximately 2 feet, the ability of the tidal marsh to attenuate waves diminishes, and waves are not depth-limited. Therefore, at a water level above approximately 9.5 feet (NAVD), waves are expected to rush up on the rail prism, inducing wave runup, elevating peak water levels 1.5 to 4.5 feet. Peak water levels are momentary but repetitive over multiple hours, as the waves break and splash vertically and landward. Overtopping of the rail prism begins with wave runup, contributing intermittent discharges of tidal waters above and over the rail prism. The drainage channel between the southbound travel lanes of Highway 101 and the rail prism fills with the overtopping flow. When tide water elevation peaks at 10.3 feet (NAVD) due to tide, storm surge and wind, water levels exceed the entire rail prism elevation and continuous overtopping occurs. Overtopping flow exceeds the capacity of the drainage channel and floods the Highway 101 southbound travel lanes along Brainard and north. During continuous overtopping, waves travel from the bay, across the rail prism, to the highway. Tidal waters flow into the median ditch, and then conveyed east through culverts to the interior drainage channel along the highway. Limited conveyance to the northbound lanes occurs across at-grade crossings connecting travel lanes. Continuous overtopping at all Bay Shoreline locations is shallow (less than 1 foot) and/or short (less than 2 hours), while wave runup overtopping occurs for 4 to 8 hours leading up to and following the peak tide.

The Brainard levee top elevation is typically higher relative to the rail prism and overtopping is limited to the southern leveed shore. Wave runup results in splashing above the top of the levee, with limited overtopping flow and associated erosion.

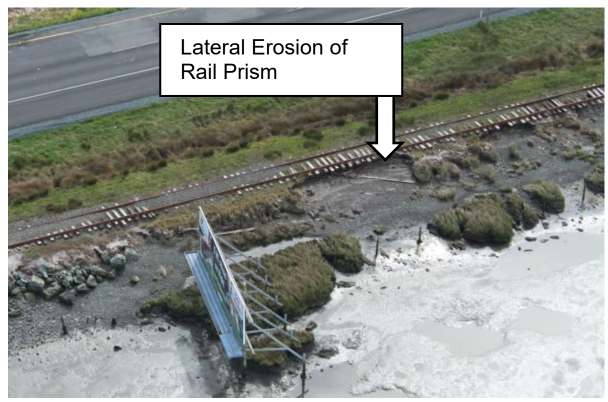
Following the peak event, the ebb tide reduces water levels and wind-wave exposure along the shoreline.

Resource Response and Impacts:

The physical response of the bay shoreline under this scenario varies based on existing shoreline condition, presence/absence of adjacent tidal marsh, and wave exposure. Anticipated responses are described below.

Rail Prism and Brainard Levee: In areas of intact tidal marsh, wave height is dampened by the tidal marsh for water levels less than 9.0 feet (NAVD), reducing wave energy and erosion potential on the rail prism. Under these conditions, wave-induced erosion along the rail prism is limited to approximately 400 linear feet of rail prism south of Brainard and approximately 5,000 linear feet north of Brainard. Erosion occurs in the larger voids of poorly graded rock and concrete rubble. As water levels increase above 9.0 feet (NAVD), the tidal marsh no longer dampens wave height and wave runup dissipates energy directly on the rail prism, increasing erosive forces on the bay-facing slope and top. The Brainard levee slope is armored with well-graded rock slope protection and vegetation. While the steep slopes increase wave runup height, erosion potential, even in the absence of tidal marsh, is minimal due to the size and gradation of the rock slope protection.

Example Wave-Induced Erosion of Rail Prism Resulting in Displacement of Ballast and Undermined Tracks



Example Wave-Induced Erosion of Tidal Marsh and Rail Prism

In areas where tidal marsh is absent or fragmented, with historical erosion and overtopping of rail prism observable, continued lateral erosion occurs. Although considered to be shallow (less than 1 foot) and/or short (less than 2 hours), overtopping of the rail prism results in significant rill erosion across the top and land-facing slope. This erosion reduces the crest elevation and provides a pathway for future inundation and is subject to increased failure potential as rills can deepen and widen. The damaged rail prism requires repair to maintain the same level of flood protection and stability prior to the event.

Highway 101: The southbound lanes of Highway 101 are inundated with up to 1 foot of tidal waters when the capacity of the ditch between the rail prism and Highway (30 acre-feet) is exceeded by overtopping (940 acre-feet). Several hours of dangerous conditions exist which eventually result in closures of the southbound lanes. Closure conditions are estimated to last 6 hours. Debris and sediment deposited across the roadway requires cleanup prior to the roadway opening. Erosion along the landward slope of the southbound Highway prism is likely, similar to levee rill erosion, and require repairs. Drainage channels and control structures require inspection and removal of debris.

Example Rill Erosion on Rail Prism Top and Backslope Due to Overtopping

Interior Shoreline

HAZARD SCENARIO 3

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:
Overtopping occurs throughout the Interior Shoreline of the Study Area, on every slough and every cell, typically totaling hundreds to thousands of feet of levee protecting each cell (Exhibit HS3-1). The lowest levee crest elevations of Cells B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping that exceeds 1 foot of depth and 2 hours in duration.

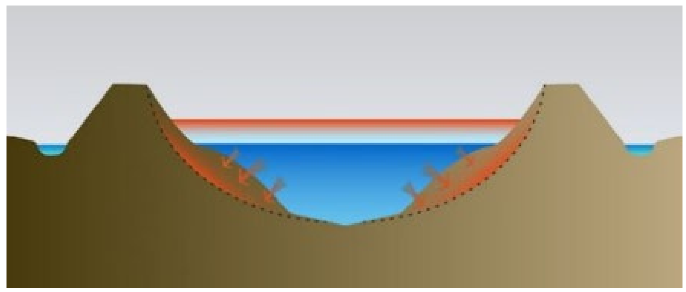
Resource Response and Impacts:
Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.

Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:

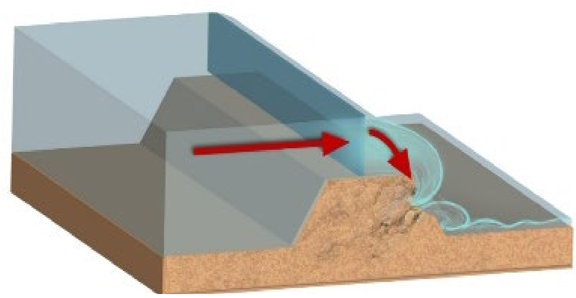
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

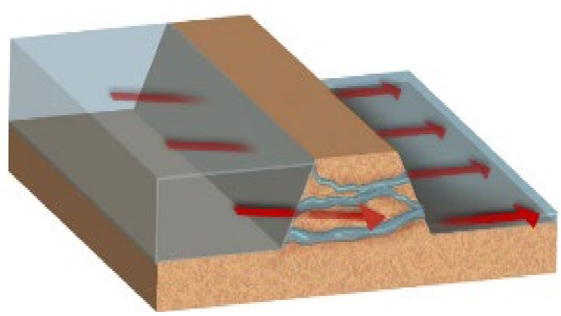
Example Levee Crest Erosion from Overtopping (Laird, 2013)



Conceptual Channel Adjustment with Breach Event



Overtopping creates erosion on top and backside (above) (National Science Foundation, 2020)



Sustained erosion, differentials in water levels, and levee material can contribute to internal erosion and piping
(National Science Foundation, 2020)

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions:

Overtopping occurs during multiple high tides on sequential days. The extent of levee, rail prism and roadway (Park Street) overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells A, B, E, G, the area upstream of Myrtle Avenue on Ryan Slough and to a lesser extent Cell C. The depth and water surface elevation of flooding for each cell are summarized in Table 3, at the end of this case study. Flooding is typically 1 to 3 feet deep and requires multiple days to drain.

Nearly 90% of the 520 acre-feet of tidal flooding in Cell A overtops the Bay Shoreline and highway is conveyed to the interior of Cell A, flooding low elevation lands below elevation 5.5 ft (NAVD) (Table 2). Flooding affects Airport Drive and extends to the lowest elevations of Jacobs Avenue roadway and developed areas.

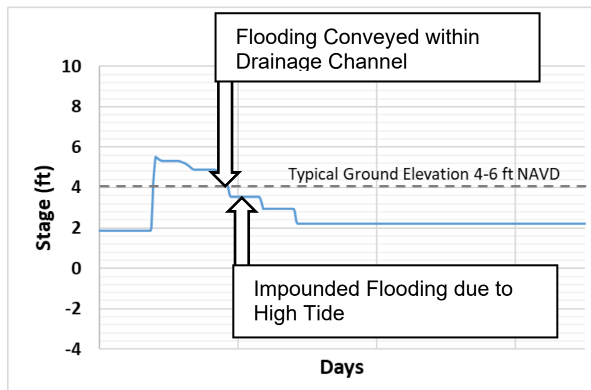
In other cells repetitive tidal inundation occurs during the peak tide and high tides overtopping lower elevation levees in the day leading up and following the event. In Cells B and C1, flooding is typically less than 1 foot and retreats to within existing drainage channels within 12 to 24 hours, while flooding in Cells E and G is multiple feet and is flooded for 24 to 36 hours (Table 3). Due to the magnitude, frequency and duration of high tides, combined with lower land elevation protected by levees, favorable drainage conditions typically last for only a few hours each day and is otherwise impounded within the cells.

Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient. Residential communities, commercial development, and public utility infrastructure exist between elevation 9 and 11 feet (NAVD). Tidal water levels begin to flood these areas, resulting in 3 to 12 inches of flooding at the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, HCSD's sewer pump station and residences on Bay Street, as well as Y Street and 2nd Street.

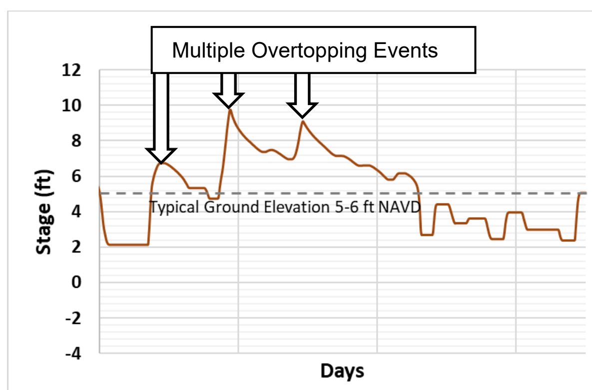
Resource Response and Impacts:

Flooding of developed areas along Jacobs Avenue, Murray Field and Brainard is typically less than six inches and limited to the lowest elevations temporarily restricting access. Vehicle ingress and egress may be limited at the roadway access to Murray Field and Brainard due to ponded or flowing water between 6-inches and 1-foot. The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, largely restricting access temporarily.

Example Inundation of low-lying lands



Overtopping Followed by Delayed Drainage Due to Tides



Example Multiple Overtopping Events

HAZARD SCENARIO 3

Throughout the Study Area, temporary flooding disrupts access to repair levees or tend to utilities. Dangerous conditions exist during each high tide when overtopping occurs if property owners or maintenance crews attempt to access or assess damages. Drainage of interior areas may be delayed by accumulation of debris carried and deposited in drainage ditches by flooding. Short duration flooding of tidal waters do not result in lasting impacts to pastures or utilities.

The levees protecting cells B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

Scenario Summary:

The multiple days of high tides, and single day of storm surge and strong winds result in dangerous conditions and functional disruption of Highway 101; a high potential for levee failure in select locations; dangerous conditions near overtopping levees and in the lowlands they protect; significant erosion of tidal marsh, the rail prism, and interior levees; and extensive cleanup throughout the Study Area.

Along the Bay Shoreline, nearly the entire rail prism is overtopped (Table 2). The rail prism experiences significant erosion and reduction of future flood protection while the Brainard Levee remains largely unaffected. Overtopping north of Brainard overwhelms the capacity of the drainage channel, flooding Highway 101 southbound and flowing into the interior Protected Lands via the median drainage ditch. South of Brainard, overtopping of the rail prism remains below the southbound highway road elevation and does not contribute to interior flooding. Dangerous conditions exist over multiple hours for motorists and progress into temporary closure of Highway 101 southbound for multiple hours. Myrtle Avenue/Old Arcata Road and Highway 255 provide alternate travel routes around the bay. Ingress and egress routes from Highway 101 to Murray Field are flooded. Access to Indianola Cutoff is limited to Highway 101 northbound or Myrtle Avenue/Old Arcata Road.

Overtopping along the Interior Shoreline is widespread (Table 3). The lowest levee crest elevations of Cells B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping that exceeds 1 foot of depth and 2 hours in duration. These conditions pose a high potential for levee failure and breaching. In the event of a levee breach, the cell may be subject to inundation from daily tides and increase erosive forces along the interior shoreline, between the breach and Arcata Bay.

Nearly 90% of the 520 acre-feet of tidal flooding in Cell A overtops the Bay Shoreline, mostly over the rail prism north of Brainard. Flooding of developed areas along Jacobs Avenue, Murray Field and Brainard is typically less than six inches and limited to the lowest elevations temporarily restricting access. The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, with temporary restricted access.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 3

Table 2. Overtopping Summary for Cell A Bay and Slough Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	0%	-	-	Jacobs Ave 0 to 0.1 ft, Fay Slough Wildlife Area 0.6 to 1.6 ft	6
		Rail Prism	4,065	63%	-			
	Brainard Levee	Levee	98	2%	-	13		
	Brainard to Indianola Cutoff	Rail Prism	5,796	84%	-	450		
Slough	Fay Slough	Levee	1,228	8%	-	55		
	Eureka Slough	Levee	37	1%	-	1		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	202	72%	9	0.8 to 1.8	7.2
C1	Fay Slough	823	7%	-	0 to 1.3	5.7
	Freshwater Slough	1,535	15%	23		
C2	Freshwater Slough	129	2%	-	-	-
D[2]	Freshwater Slough	2,472	54%	207	0.7 to 2.7	10.2
E	Freshwater Slough	1,074	41%	3	3.2 to 4.2	10.1
F	Ryan Slough	412	12%	-	0 to 0.9	5.9
	Freshwater Slough	54	5%	-		
G	Freshwater Slough	751	13%	-	3.6 to 4.1	9.6
	Park Street	501	81%	156		
	Ryan Slough	253	11%	10		
H	Freshwater Slough	-	0%	-	-	-
	Eureka Slough	3	0%	-		
I[2]	Eureka Slough	-	-	-	0 to 1.4	10.4
Myrtle	Ryan Slough	872	21%	32	2.2 to 4.2	10.1

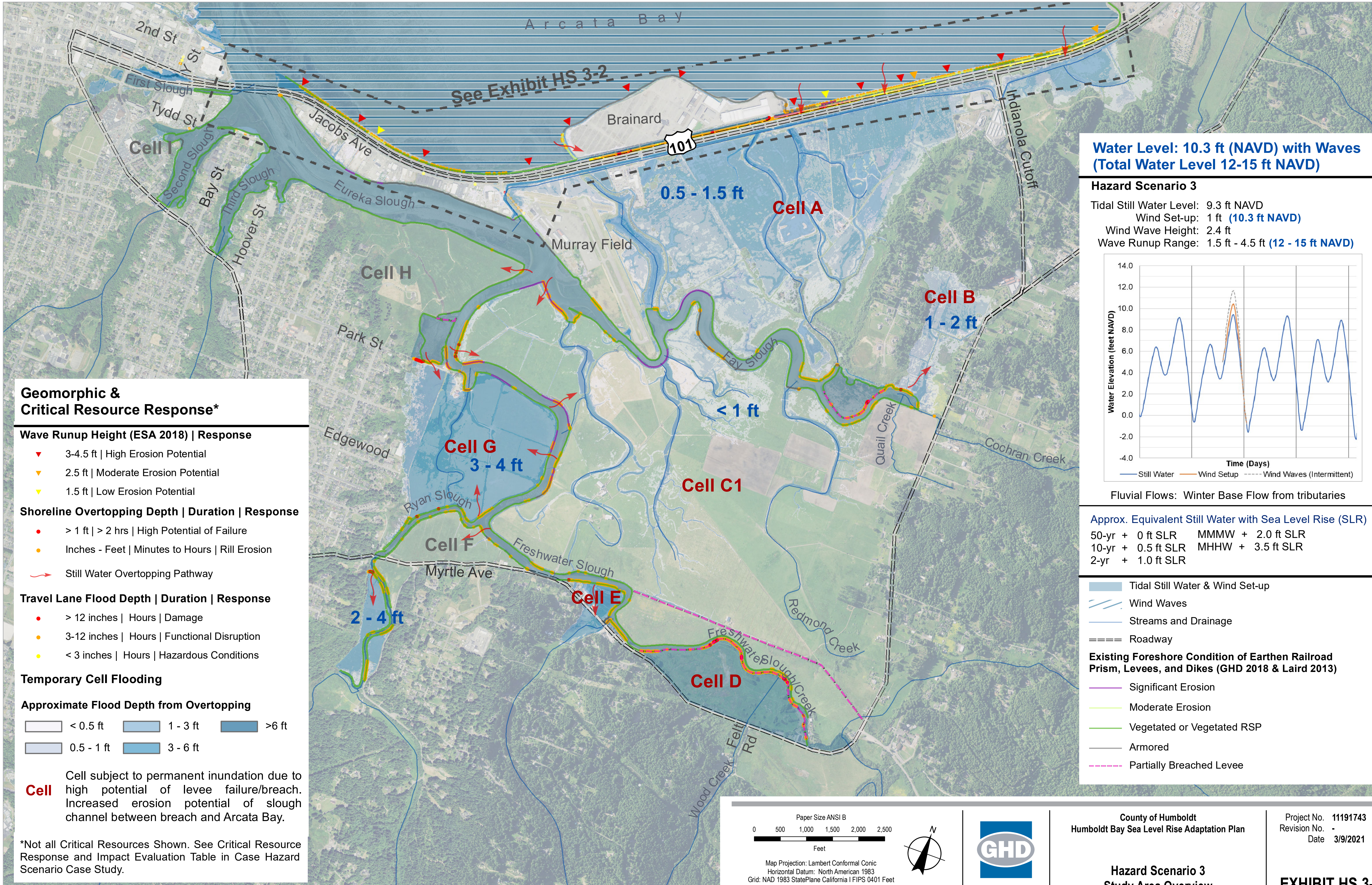
HAZARD SCENARIO 3

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees/ Dikes	Overtopping (depth and time)	Cell A	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell B	>1ft and >2 hrs	**Potential Failure**
			Cell C	>1ft and >2 hrs	**Potential Failure**
			Cell E	>1ft and >2 hrs	**Potential Failure**
			Cell F	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell G	>1ft and >2 hrs	**Potential Failure**
			Cell H	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay	1.5-4.5 ft	**Top and Land-facing Slope Rill Erosion**
		Overtopping (depth and time)	Cell A- Arcata Bay	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	2	**Closure & Damage**
	Hwy 101 Northbound		Cell A - Arcata Bay	none	none
	Jacobs Ave		Cell A (ft)	0.1	Shallow Flooding
	Airport Road		Cell A	2	**Closure & Damage**
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	2	**Closure & Damage**
	Hoover Street		Cell I	0.9	**Closure**
	2nd and Y Streets		Cell I	0.5	**Closure**
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alternate Route)		Arcata Bay	-	none
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	0.5	Shallow Flooding
			Humboldt CSD Hoover Street	0.5	Shallow Flooding
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	0.2	Shallow Flooding
	Sewer or Water Pressure Main		Cell A Jacobs Ave - COE	26	**Limited Access Multiple Days**

HAZARD SCENARIO 3

	Critical Resource	Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
		Surface Flooding (Hours)	Cell I Hoover St - HCSD	8	Limited Access < 1 Day
	Sewer Gravity Main		Cell I Hoover St - HCSD	8	Limited Access < 1 Day
	Gas Main		Cell G	101	**Limited Access Multiple Days**
			Cell C	26	**Limited Access Multiple Days**
			Cell A	26	**Limited Access Multiple Days**
	Communications (Underground)		Cell A	26	**Limited Access Multiple Days**
	Communication Towers/Poles		Cell H	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	0.1	Shallow Flooding
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	2	**Damage/Stranding**
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	0.5	Shallow Flooding
			6th and Tydd Street	-	none
			Hoover Street	0.9	Shallow Flooding
			Park Street	2	**Damage/Stranding**
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	26	**Limited Access Multiple Days**
			Cell B	45	**Limited Access Multiple Days**
			Cell C	26	**Limited Access Multiple Days**
			Cell E	70	**Limited Access Multiple Days**
			Cell F	7	Limited Access < 1 Day
			Cell G	101	**Limited Access Multiple Days**
			Cell H	-	none
			Ryan Slough Upstream of Myrtle	31	**Limited Access Multiple Days**



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Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

Water Level: 10.3 ft (NAVD) with Waves (Total Water Level 12-15 ft NAVD)

Hazard Scenario 3
See Exhibit HS 3-1 for Water Level Detail

Tidal Still Water & Wind Set-up
Wind Waves
Streams and Drainage
Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee

Drainage

Drainage Swale/Ditch
Culvert
Culvert with Flash Board Riser
Drop Inlet
Culvert with Flap Gate or Tide Gate

Geomorphic & Critical Resource Response*

Wave Runup Height (ESA 2018) | Response

3-4.5 ft | High Erosion Potential
2.5 ft | Moderate Erosion Potential
1.5 ft | Low Erosion Potential

Shoreline Overtopping Depth | Duration | Response

> 1 ft | > 2 hrs | High Potential of Failure
Inches - Feet | Minutes to Hours | Rill Erosion

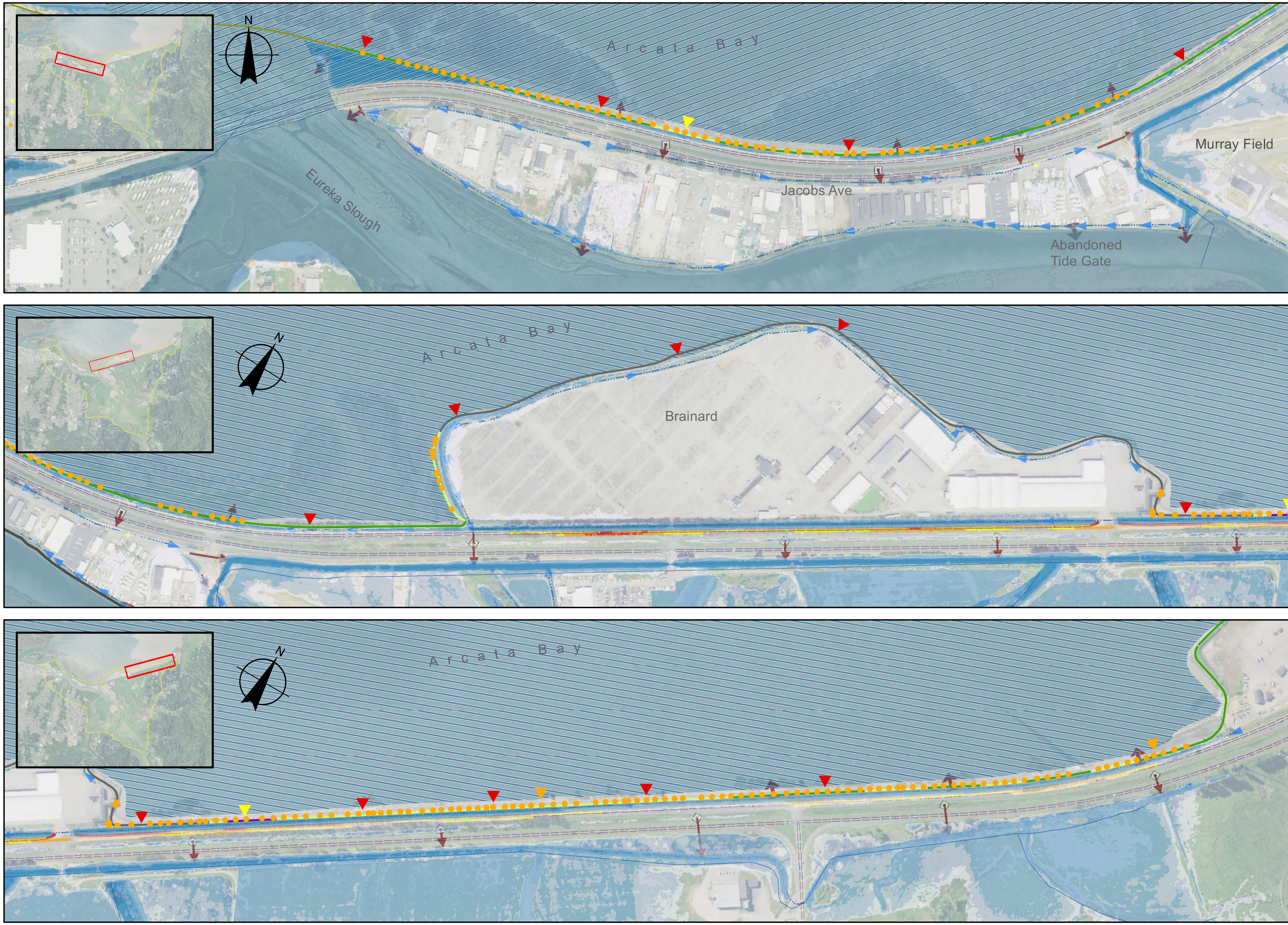
Travel Lane Flood Depth | Duration | Response

> 12 inches | Hours | Damage
3-12 inches | Hours | Functional Disruption
< 3 inches | Hours | Hazardous Conditions

Approximate Flood Depth from Overtopping

< 0.5 ft
0.5 - 1 ft
1 - 3 ft
3 - 6 ft
>6 ft

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.



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County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 3
Bay Shoreline

Project No. **11191743**
Revision No. **-**
Date **3/9/2021**

EXHIBIT HS 3-2

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Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 4

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
9.9 feet NAVD	**Existing (2012 baseline)** 10-year 10% chance per year	**0.5 foot** 2-year 50% chance per year	**1.5 feet** MMMW 5 to 6 events per year	**3 feet** MHHW Daily - Weekly

Introduction (See Exhibit HS 4-1):

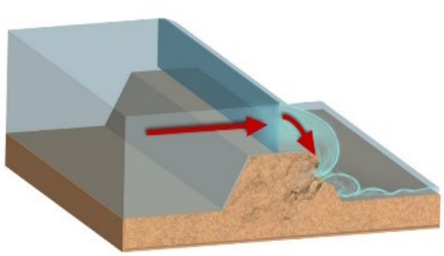
Rill Erosion of Railroad Prism Top and Backslope Due to Overtopping

This case study describes a scenario characterized by two extreme tides occurring on consecutive days in the absence of local wind effects that further increase water levels. The extreme tides overtop large sections of the rail prism along Arcata Bay. Overtopping is shallow and brief, and the drainage channel between the rail prism and Highway 101 maintains capacity to store and convey the flow. Overtopping of levees occurs throughout the study area and is typically shallow and/or of short duration. Short sections of levees in Cells B, C, E, G, and upstream of Myrtle on Ryan Slough experience overtopping exceeding 1 foot and 2 hours, creating conditions with a high potential for failure and subsequent daily tidal inundation with increased slough channel erosion. Tidal flooding of protected lands is variable. Developed areas are typically unaffected or experience shallow flooding. Tidal flooding of agricultural lands varies by cell with some cells experiencing less than 1 inch and others experiencing 4 feet.

Highlighted shoreline processes and responses in this scenario overtopping and landward slope erosion, flooding of agricultural lands, and flooding of roadways, leading to closure. Conceptual examples shown below.

Overtopping and Erosion

26% Arcata Bay Shoreline
6% of Interior Slough Levees



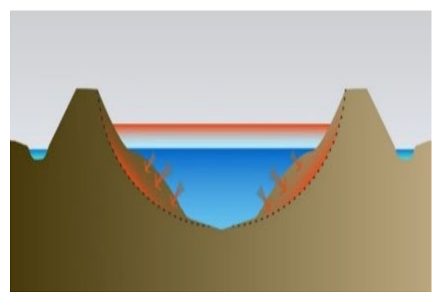
Example Shoreline Overtopping (National Science Foundation, 2020)

Tidal Flooding of Agricultural Lands

Cells A, B, C, E, G, and Ryan Slough

Channel Adjustment Due to Failure

Interior Levees
Cells B, C, E, G, Ryan Slough



Hydraulics and Sea Level Rise:

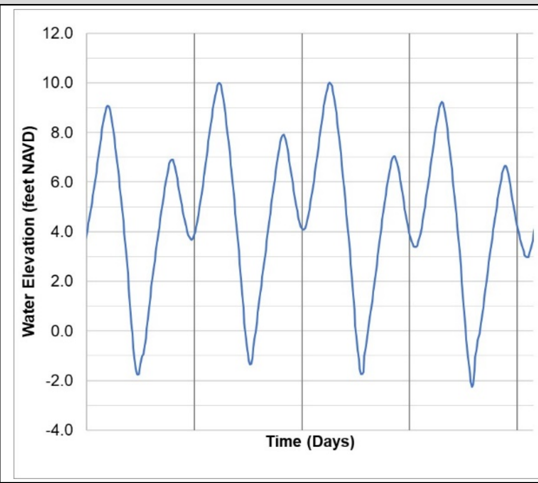
This scenario combines the highest spring tides that occur during the year, from November through January, with meteorological conditions, such as storm surge, that further increase tidal elevations. High spring tides occur multiple days in a row on separate occasions during this time of year. The increase due to storm surge is intended to represent conditions that are relatively infrequent under existing conditions (2012 baseline). Based on predicted tides, two water level events of 9.9 feet (NAVD) occur on consecutive days and 9.0 feet (NAVD) on the day prior to and following the peak tides[1]. Calm conditions, without wind effects that increase water levels and produce waves, exist throughout the duration of peak tides. Water levels are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

equivalent recurrences for this still water level scenario of 9.9 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 4 Hydraulics

Tidal Still Water Level	9.9 ft NAVD
Wind Set-up	0 ft
Wind Wave Height	Height: 0 ft
Wave Runup Range	0 ft
Total Water Level (TWL)	9.9 ft NAVD
Fluvial Flows	Winter Base Flow from tributaries



Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, similar hydraulic conditions occur, on average, every couple years. Photos and observations of similar events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 4-1 and described in this case study. Exhibit HS 4-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

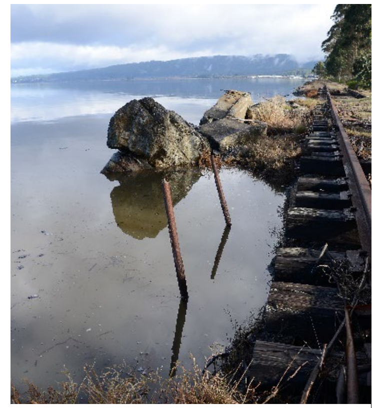
HAZARD SCENARIO 4

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101.

<u>Hydraulic Conditions:</u>

Two successive days of extreme tidal water levels, reaching 9.9 feet (NAVD), overtop the rail prism at numerous locations north of Brainard. Overtopping of the railroad prism is typically less than 1 foot and occurs on two occasions for 1 to 2 hours, at the peak tides. Overtopping flow enters the drainage channel between Highway 101 and the rail prism and is conveyed to the interior drainage network of Cell A that outlets to Eureka Slough. Overtopping of the rail prism also occurs in numerous locations south of Brainard, but does not overtop the Highway and the drainage is not hydraulically connected to the interior of Cell A. Exhibit HS 4-1 shows the locations, depth and duration of shoreline overtopping associated with peak water levels for this scenario. The Brainard levee top elevation is higher relative to the rail prism and would not be subject to the same extent or duration of overtopping.



Example High Tide during Calm Conditions, Prior to Overtopping

<u>Resource Response and Impacts:</u>

The physical response of the Bay Shoreline under this scenario will vary based on the existing shoreline condition. The anticipated responses are described below. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

<u>Rail Prism:</u> Although relatively short and shallow, overtopping of the rail prism, creates numerous locations of rill due to the composition of the prism consisting largely of ballast material and exhibiting existing erosional pathways. Rill erosion reduces the elevation of the rail prism and provides a pathway for future flooding. Future overtopping at these locations are subject to increased failure potential as rills can deepen and widen. If unrepaired following the event, the protection to future events is effectively reduced.

Rill Erosion of Railroad Prism Top and Land-Facing Slope Due to Overtopping

<u>Brainard Levee:</u> While generally higher elevation than the rail prism, the southern area of the Brainard Levee is overtopped. Similar to the rail prism, rill erosion across the top and land-facing slope occurs, reducing the elevation and creating pathways for future flooding.

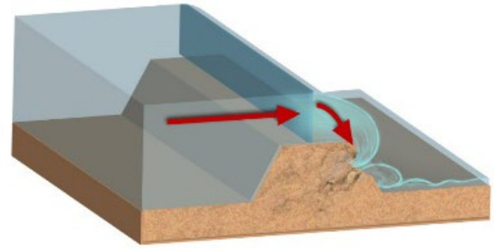
<u>Highway 101:</u> Shallow flooding may occur along low elevation areas of the highway shoulder and edge of the western southbound travel lane, but is brief, likely lasting less than 1 hour. Drainage channels require inspection and removal of debris and sediment at drainage structures such as culverts and tide gates.

Interior Shoreline

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

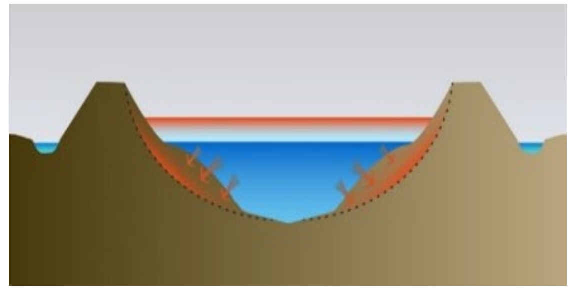
<u>Hydraulic Conditions:</u>

Overtopping occurs along all slough channels and all cells on consecutive days. Exhibit HS 4-1 shows the locations, depth and duration of shoreline overtopping associated with tidal still water elevations for interior slough channels. The extent of overtopping to each cell ranges from 100 to 2,000 feet. Significant overtopping of greater than 1 foot for more than 2 hours occurs in select locations along short (3 to 20 feet) sections protecting Cells B, C, E, G and the area upstream of Myrtle Avenue on Ryan Slough.



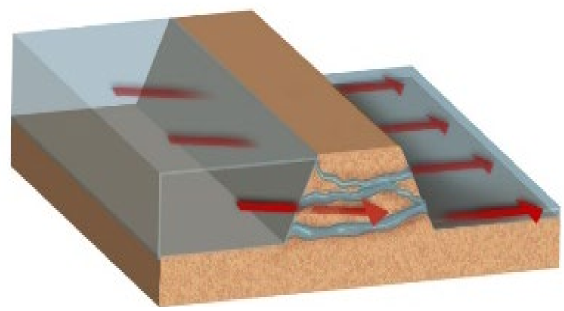
Example Shoreline Overtopping (National Science Foundation, 2020)

Resource Response and Impacts:
Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.



Conceptual Channel Adjustment with Breach Event

Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:



Example Internal Erosion/Seepage of Levees (National Science Foundation, 2020)

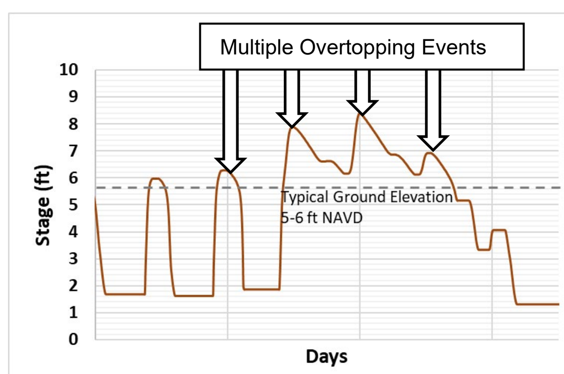
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

Protected Lands

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions:
Overtopping occurs during multiple high tides on sequential days. The extent of levee, rail prism and roadway (Park Street) overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells B, E, G, and upstream of Myrtle on Ryan Slough and to a lesser extent Cells A and C. The depth and water surface elevation of flooding for each cell are summarized in Table 3, at the end of this case study. Flooding is typically 0.5 to 4.5 feet deep and varies throughout the study area. Multiple cycles of flooding and draining occur in each cell.



Multiple Overtopping Events Occur in Most Cells

Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient. Residential communities, commercial development, and public utility infrastructure exist between elevation 9 and 11 feet (NAVD). Tidal water levels begin to flood these areas, resulting in 1 to 9 inches of flooding at the Shoreline RV Park at the end of 6th Street, the City of Eureka's

Waterfront Trail and Hill Street sewer pump station off Tydd Street, HCSD's sewer pump station and residences on Bay Street, as well as 2nd Street.

Resource Response and Impacts:

Shallow flooding of the developed areas adjacent to First, Second and Third Slough temporarily restricts access temporarily.

Example Inundation of low-lying lands

Throughout the Study Area, temporary flooding disrupts access to repair levees or tend to utilities. Dangerous conditions exist during each high tide when overtopping occurs if property owners or maintenance crews attempt to access or assess damages. Drainage of interior areas may be delayed by accumulation of debris carried and deposited in drainage ditches by flooding. Short duration flooding of tidal waters do not result in lasting impacts to pastures or utilities.

The levees protecting cells B, C, E, G and the area upstream of Myrtle Avenue on Ryan Slough are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

Scenario Summary:

The multiple days of extreme tides result in multiple overtopping events of shoreline structures and tidal flooding throughout the Study Area. Short sections of levee along the interior shoreline are subject to overtopping conditions that pose a high potential for failure. Dangerous conditions exist near overtopping levees and in the lowlands they protect.

Along the Bay Shoreline, overtopping flow enters the drainage channel between Highway 101 and the rail prism and is conveyed to the interior drainage network of Cell A that outlets to Eureka Slough. Shallow flooding may occur along low elevation areas of the highway shoulder and edge of the western southbound travel lane, but is brief, likely lasting less than 1 hour.

Significant overtopping of greater than 1 foot for more than 2 hours occurs in select locations of the Interior Shoreline, along short (3 to 20 feet) sections protecting Cells B, C, E, G and the area upstream of Myrtle Avenue on Ryan Slough. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay.

Shallow flooding of developed areas disrupts access and requires temporary retreat. More substantial, repetitive flooding of agricultural lands requires multiple days to drain but does not likely cause lasting impacts to land management. However, in the event of a breach due to significant overtopping, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 4

Table 2. Overtopping Summary for Bay Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	0%	-	-	-	4
		Rail Prism	2,966	46%	-			
	Brainard Levee	Levee	39	1%	-	2		
	Brainard to Indianola Cutoff	Rail Prism	1,989	29%	-	35		
Slough	Fay Slough	Levee	894	6%	-	12		
	Eureka Slough	Levee	-	0%	-	-		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	187	67%	9	0.3 to 1.3	6.7
C1	Fay Slough	553	5%	-	0 to 0.8	5.2
	Freshwater Slough	686	7%	23		
C2	Freshwater Slough	9	0%	-	-	-
D[2]	Freshwater Slough	1,925	42%	207	0.4 to 2.4	9.9
E	Freshwater Slough	810	31%	3	2.8 to 3.8	9.7
F	Ryan Slough	90	3%	-	0 to 0.1	5.0
	Freshwater Slough	22	2%	-		
G	Freshwater Slough	405	7%	-	2.4 to 2.9	8.4
	Park Street	416	68%	156		
	Ryan Slough	70	3%	10		
H	Freshwater Slough	-	0%	-	-	-
	Eureka Slough	-	0%	-		
I[2]	Eureka Slough	-	-	-	0 to 1	10.0
Myrtle	Ryan Slough	681	16%	32	2.3 to 4.3	10.3

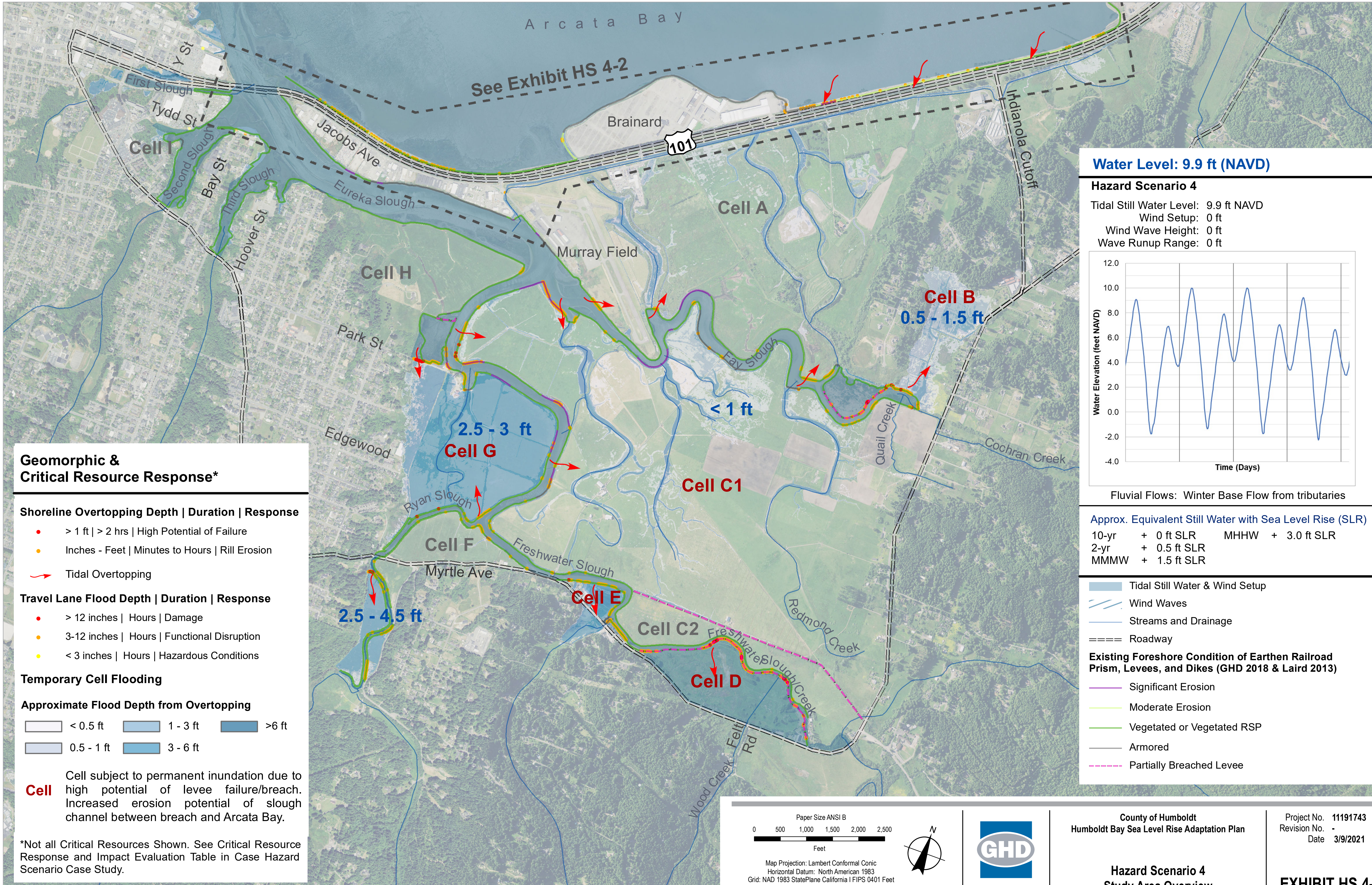
HAZARD SCENARIO 4

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees/ Dikes	Overtopping (depth and time)	Cell A	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
			Cell B	>1ft and >2 hrs	Potential Failure
			Cell C	>1ft and >2 hrs	Potential Failure
			Cell E	>1ft and >2 hrs	Potential Failure
			Cell F	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
			Cell G	>1ft and >2 hrs	Potential Failure
			Cell H	none	None Observed
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	1.7	Closure & Damage
	Hwy 101 Northbound		Cell A - Arcata Bay	none	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	0.3	Closure
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	1.9	Closure & Damage
	Hoover Street		Cell I	0.5	Closure
	2nd and Y Streets		Cell I	0.1	Shallow Flooding
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alternate Route)		Arcata Bay	-	none
UTILITIES	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	0.1	Shallow Flooding
			Humboldt CSD Hoover Street	0.1	Shallow Flooding
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	-	none
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	6	Limited Access < 1 Day
			Cell I Hoover St - HCSD	7	Limited Access < 1 Day

HAZARD SCENARIO 4

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
	Sewer Gravity Main		Cell I Hoover St - HCSD	7	Limited Access < 1 Day
	Gas Main		Cell G	91	**Limited Access Multiple Days**
			Cell C	14	Limited Access < 1 Day
			Cell A	6	Limited Access < 1 Day
	Communications (Underground)		Cell A	6	Limited Access < 1 Day
	Communication Towers/Poles		Cell H	-	none
PROTECTED LANDS	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	-	none
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	1.7	**Damage/Stranding**
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	0.1	Shallow Flooding
			6th and Tydd Street	-	none
			Hoover Street	0.5	Shallow Flooding
			Park Street	1.9	**Damage/Stranding**
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	6	Limited Access < 1 Day
			Cell B	37	**Limited Access Multiple Days**
			Cell C	14	Limited Access < 1 Day
			Cell E	71	**Limited Access Multiple Days**
			Cell F	5	Limited Access < 1 Day
			Cell G	92	**Limited Access Multiple Days**
			Cell H	-	none
			Ryan Slough Upstream of Myrtle	70	**Limited Access Multiple Days**



Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 4
Study Area Overview

Project No. 11191743
Revision No. -
Date 3/9/2021

EXHIBIT HS 4-1

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Created by: bvivyan

Water Level: 9.9 ft (NAVD)

Hazard Scenario 4
See Exhibit HS 4-1 for Water Level Detail

Tidal Still Water
(Wind Setup and Wind Waves Not Present)
Streams and Drainage
Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee

Drainage

Drainage Swale/Ditch
Culvert
Culvert with Flash Board Riser
Drop Inlet
Culvert with Flap Gate or Tide Gate

Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion

Travel Lane Flood Depth | Duration | Response

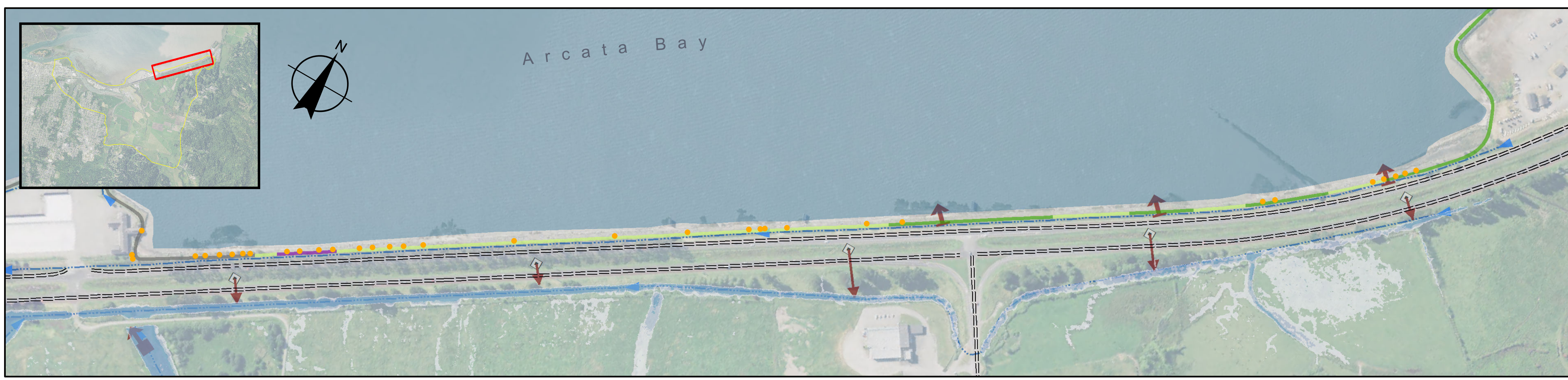
- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

Temporary Cell Flooding

Approximate Flood Depth from Overtopping

< 0.5 ft
0.5 - 1 ft
1 - 3 ft
3 - 6 ft
>6 ft

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.



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County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 4
Bay Shoreline

Project No. **11191743**
Revision No. **-**
Date **3/9/2021**

EXHIBIT HS 4-2

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Print date: 09 Mar 2021 - 14:37
Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 5

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
10.6 feet NAVD	<u>Existing (2012 baseline)</u> 100-year 1% chance per year	<u>1 foot</u> 2-year 50% chance per year	<u>2 feet</u> MMMW 5 to 6 events per year	<u>3.5 feet</u> MHHW Daily - Weekly

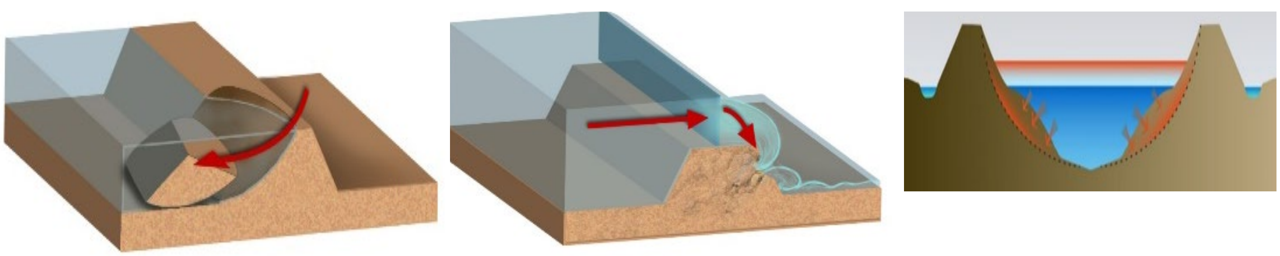
Introduction (See Exhibit HS 5-1):

Example Highway 101 Southbound Flooding (Source)

This case study describes a scenario characterized by an extreme high tide, exceeding the highest observed tide affecting the Study Area[1], and an additional extreme tide following the peak event, without significant wind or fluvial flood effects. The extreme tide overtops nearly the entire rail prism and a portion of the Brainard levee along Arcata Bay, damaging large sections of rail prism. Overtopping exceeds the capacity of the drainage channel between the rail prism and Highway 101, flooding the southbound lanes, resulting in closure of the highway. Overtopping of levees along slough channels occurs on all sloughs, protecting all cells. Nearly all cells experience significant overtopping, greater than 1 foot for greater than 2 hours, indicating a high potential for failure and subsequent daily tidal inundation with increased slough channel erosion. Overtopping results in tidal flooding throughout the Study Area, with developed areas typically experiencing less than 1 foot of flood depth, and agricultural areas experiencing 2 to 5 feet. Approximately 90% of the flooding volume to Cell A occurs along the Bay Shoreline.

Highlighted shoreline processes in this scenario include slope failure/erosion of bay/slough facing slopes, overtopping and landward slope erosion, and channel adjustment due to high breach potential. Conceptual examples shown below.

<u>Slope Failure/Sloughing</u>	<u>Overtopping/Erosion</u>	<u>Channel Adjustment with Breach</u>
Arcata Bay Shoreline Rail Prism	61% of Arcata Bay Shoreline 24% of Interior Slough Levees	270 feet of Significant Overtopping resulting in High Potential for Breach and downstream channel adjustment



Example Shoreline Structure Responses (National Science Foundation, 2020)

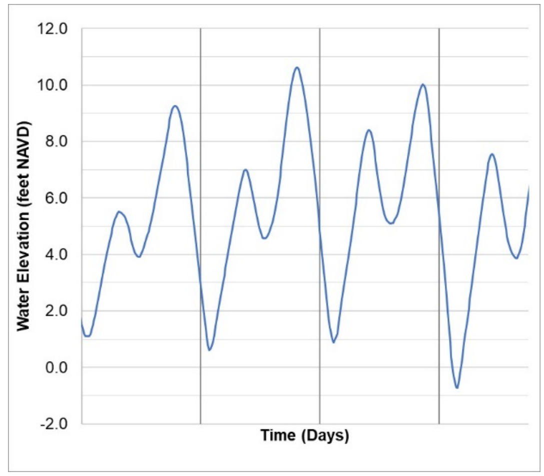
Hydraulics and Sea Level Rise:

This scenario combines the highest spring tides that occur during the year, from November through January, with meteorological conditions, such as storm surge, that further increase tidal elevations. High spring tides occur multiple days in a row on separate occasions during this time of year. The increase due to storm surge is intended to represent conditions that are rare under existing conditions (2012 baseline). Based on predicted tides, the peak water level of 10.6 feet (NAVD) is followed by another tide reaching nearly 10 feet (NAVD)[2]. Calm conditions, without wind effects that increase water levels and produce waves, exist throughout the duration of peak tides. Water levels are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences

[1] NOAA 2020, Datums for 9418767, North Spit CA

[2] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

for this still water level scenario of 10.6 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 5 Hydraulics		
Tidal Still Water Level	10.6 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	Height: 0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	10.6 ft NAVD	
Fluvial Flows	Winter Base Flow from tributaries	

Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, these hydraulic conditions are considered to be rare, exceeding the highest observed tide affecting the Study Area. Photos and observations of similar, but smaller events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 5-1 and described in this case study. Exhibit HS 5-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

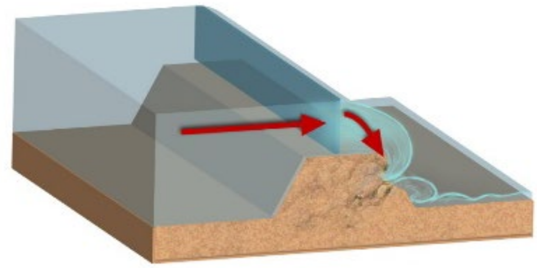
HAZARD SCENARIO 5

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101.

Hydraulic Conditions:

In the days leading up to the peak tidal water level, overtopping and flooding is limited, similar to Scenarios 1 and 2. The peak tidal still water level reaches 10.6 feet (NAVD) and is followed by a tide of 10 feet (NAVD). Nearly the entire railroad prism from Eureka Slough north and a short section of the southern Brainard levee. The capacity of the drainage channel between the southbound travel lanes of Highway 101 and the rail prism is exceeded. North of Brainard, all or portions of the Highway 101 southbound travel lanes are flooded during the peak tide and the lowest elevations are likely flooded during the peak tide on the following day. Flooding flows into the median ditch, where it is conveyed east to the ditch east of the highway, preventing northbound lanes from significant flooding. Limited conveyance, resulting in ponding on the northbound lanes occurs across in areas of at grade crossings connecting the travel lanes. South of Brainard, highway elevations are greater than peak water levels. Overtopping of the railroad prism is typically less than 1 foot and occurs for 2 to 3 hours at each highest tide, resulting in 940 acre feet of tidal waters flowing into the interior of Cell A. Exhibit HS 5-1 shows the locations, depth and duration of shoreline overtopping associated with peak water levels for this scenario.



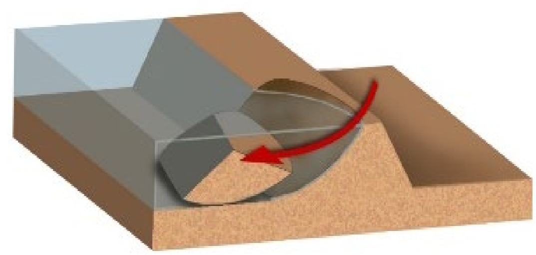
Example Overtopping and Erosion (National Science Foundation, 2020)

Resource Response and Impacts:

The physical response of the Bay Shoreline under this scenario will vary based on the existing shoreline condition. Anticipated responses are described below. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

Rail Prism: The extensive overtopping of the rail prism and observed composition, results in expected slope failures and significant rill erosion. The lack of cohesion within the ballast material would likely cause sloughing of the bank and movement of material down the slope. Overtopping of the rail prism by continuous flow will result in rill erosion across the top and land-facing slope. Damages that go unrepaired are subject to the following:

- Increased potential of saturation/seepage due to reduced levee width.
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.



Example Slope Failure from Sloughing (National Science Foundation, 2020)

Highway 101: Overtopping results in flooding of the southbound lanes of Highway 101 with more than 1 foot depth of tidal waters. Dangerous conditions and eventually closure result for up to two days. Erosion along the landward slope of the southbound Highway prism is likely, requiring repairs. Significant clean up is required following the event. Drainage channels require inspection and removal of debris and sediment at drainage structures such as culverts and tide gates.

Rill Erosion of Railroad Prism Top and Backslope Due to Overtopping

HAZARD SCENARIO 5

Interior Shoreline

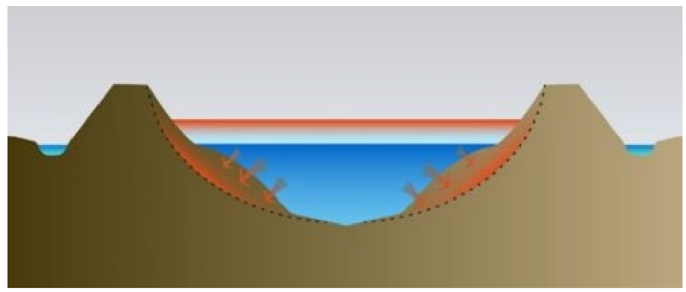
This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Overtopping of tidal waters occurs along all slough channels and all cells, typically totaling hundreds to thousands of feet protecting each cell. Exhibit HS 5-1 shows the locations, depth and duration of shoreline overtopping. Levees protecting Cells A, B, C, E, G and the area upstream of Myrtle are all subject to significant overtopping, exceeding 1 foot of depth and 2 hours in duration. The extent of significant overtopping is typically 50 feet or less.

Resource Response and Impacts:

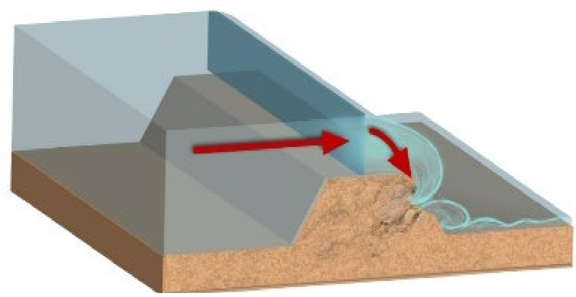
Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.



Conceptual Channel Adjustment with Breach Event

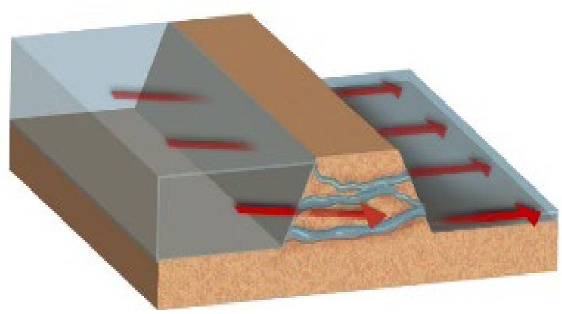
Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.



Overtopping creates erosion on top and backside (above) (National Science Foundation, 2020)

The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.



Sustained erosion, differentials in water levels, and levee material can contribute to internal erosion and piping

(National Science Foundation, 2020)

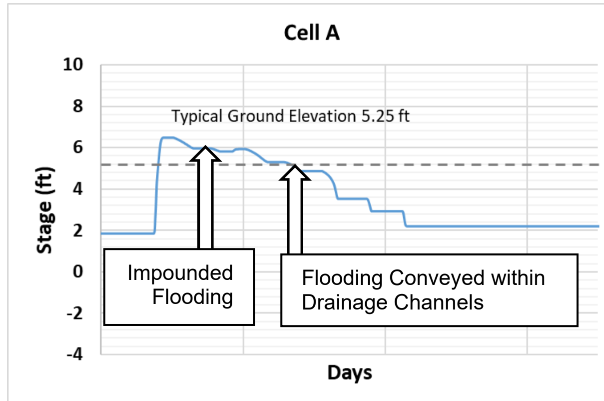
HAZARD SCENARIO 5

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

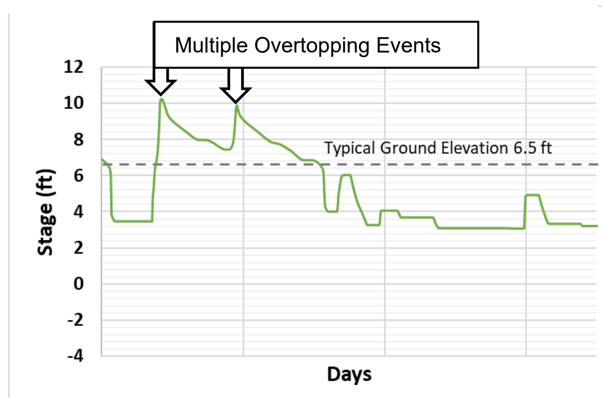
Hydraulic Conditions:

Overtopping occurs during multiple high tides on sequential days. The extent of levee, rail prism and roadway overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells A, B, C, E, G, and upstream of Myrtle on Ryan Slough. The depth and water surface elevation of flooding for each cell are summarized in Table 3, at the end of this case study. Flooding is typically between 1 to 4 feet deep, with multiple cycles of flooding and draining occurring in each cell. Subsequent high tides and limited duration of low tides impound stall and slow drainage.



Overtopping Events, Followed by Stalled Drainage

Flooding of Cell A occurs during the peak event with a predicted 940 acre-feet of tidal waters flowing over the rail prism and highway to the median drainage ditch that conveys flooding to the interior of Cell A. The capacity of the drainage ditch along the eastern edge of Highway 101 is exceeded and floods the low lying areas, combined with 110 acre-feet of tidal overtopping along Fay Slough. Flooding affects areas below elevation 6.5 feet (NAVD) and lasts up to 60 hours. Developed areas, roadways, and sewer pump stations located along Jacobs Avenue and Brainard experience up to 1 foot of flooding, while Airport Road and Murray Field experience more than 1 foot.



Multiple Overtopping Events

In other cells, repetitive tidal inundation occurs during the peak tide and following high tide(s). Tidal flooding in Cell G reaches the higher elevation areas at the end of Edgewood Road. Multiple days are required to drain the tidal flooding due to the limited duration of favorable drainage conditions.

Flooding encroaches on the developed areas adjacent to First, Second and Third Slough, protected by a natural elevation gradient. Up to 1 foot of flooding affects the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street and 2nd Street. HCSD's sewer pump station and residences on Bay Street experience more than 1 foot of flooding.

Example Inundation of low-lying lands

Resource Response and Impacts:

Flooding of developed areas along Jacobs Avenue and Brainard is typically less than 1 foot and Airport Road is flooded by more than 1 foot, impacting ingress and egress to Highway 101 and causing damage to at-grade facilities, including two City of Eureka sewer pump stations. The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, largely restricting access and causing damage to at grade facilities.

HAZARD SCENARIO 5

Dangerous conditions exist during each high tide when overtopping occurs if property owners or maintenance crews attempt to access or assess damages. Drainage of interior areas may be delayed by accumulation of debris carried and deposited in drainage ditches by flooding. Short duration flooding of tidal waters do not result in lasting impacts to pastures or utilities.

The levees protecting cells A, B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

Scenario Summary:

The multiple days of extreme tides and peak day result in dangerous conditions and closure of Highway 101, and smaller local roadways. Dangerous conditions exist near overtopping levees and the lowlands they protect. The rail prism experiences slope failure and erosion. Rill erosion on the tops and land-facing slopes of levees is widespread. Approximately 270 feet of interior slough levees are exposed to a high potential for failure and breaching. Extensive repairs and cleanup to restore pre-event conditions and flood protection throughout the Study Area are required.

Along the Bay Shoreline, nearly the entire rail prism is overtopped (Table 2). The rail prism experiences significant erosion and reduction of future flood protection while the Brainard Levee remains largely unaffected. Overtopping north of Brainard overwhelms the capacity of the drainage channel, flooding Highway 101 southbound and flowing into the interior Protected Lands via the median drainage ditch. South of Brainard, overtopping of the rail prism remains below the southbound highway road elevation and does not contribute to interior flooding. Dangerous conditions exist over multiple hours for motorists and progress into temporary closure of Highway 101 southbound for multiple hours to days. Myrtle Avenue/Old Arcata Road and Highway 255 provide alternate travel routes around the bay. Ingress and egress routes from Highway 101 to Murray Field are flooded. Access to Indianola Cutoff is limited to Highway 101 northbound or Myrtle Avenue/Old Arcata Road.

Overtopping along the Interior Shoreline is widespread (Table 2 and Table 3). Levees protecting Cells A, B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping that exceeds 1 foot of depth and 2 hours in duration. These conditions pose a high potential for levee failure and breaching. In the event of a levee breach, the cell may be subject to inundation from daily tides and increase erosive forces along the interior shoreline, between the breach and Arcata Bay.

Nearly 90% of the 1,050 acre-feet of tidal flooding in Cell A overtops the Bay Shoreline, mostly over the rail prism north of Brainard. Flooding of developed areas along Jacobs Avenue, Murray Field and Brainard is typically around 1 foot deep causing damage to at-grade structures, including the City of Eureka sewer pump stations. The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, including the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street and 2nd Street. HCSD's sewer pump station and residences on Bay Street experience more than 1 foot of flooding. Low elevation lands within the other cells experience multiple feet of flooding and do not result in lasting impacts to pastures or utilities.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 5

Table 2. Overtopping Summary for Bay Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	20	0%	-	-	Jacobs Ave 0 to 1 ft Fay Slough Wildlife Area 1.5 to 2.5 ft	6.5
		Rail Prism	4,844	75%	-			
	Brainard Levee	Levee	240	4%	-	26		
	Brainard to Indianola Cutoff	Rail Prism	6,495	94%	-	916		
Slough	Fay Slough	Levee	2,124	14%	3	104		
	Eureka Slough	Levee	100	2%	-	3		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	205	74%	31	1.2 to 2.2	7.7
C1	Fay Slough	1,587	14%	38	0 to 1.5	6.0
	Freshwater Slough	2,071	20%	55		
C2	Freshwater Slough	1,623	28%	-	0 to 0.2	6.6
D[2]	Freshwater Slough	2,827	62%	488	0.8 to 2.8	10.3
E	Freshwater Slough	1,341	51%	34	3.3 to 4.3	10.2
F	Ryan Slough	638	19%	-	0.3 to 1.3	6.3
	Freshwater Slough	69	7%	-		
G	Freshwater Slough	946	16%	28	3.8 to 4.3	9.8
	Park Street	509	83%	179		
	Ryan Slough	522	22%	29		
H	Freshwater Slough	-	0%	-	-	0.0
	Eureka Slough	26	1%	-		
I[2]	Eureka Slough	-		-	0 to 1.6	10.6
Myrtle	Ryan Slough	1,010	24%	50	2.9 to 4.9	10.9

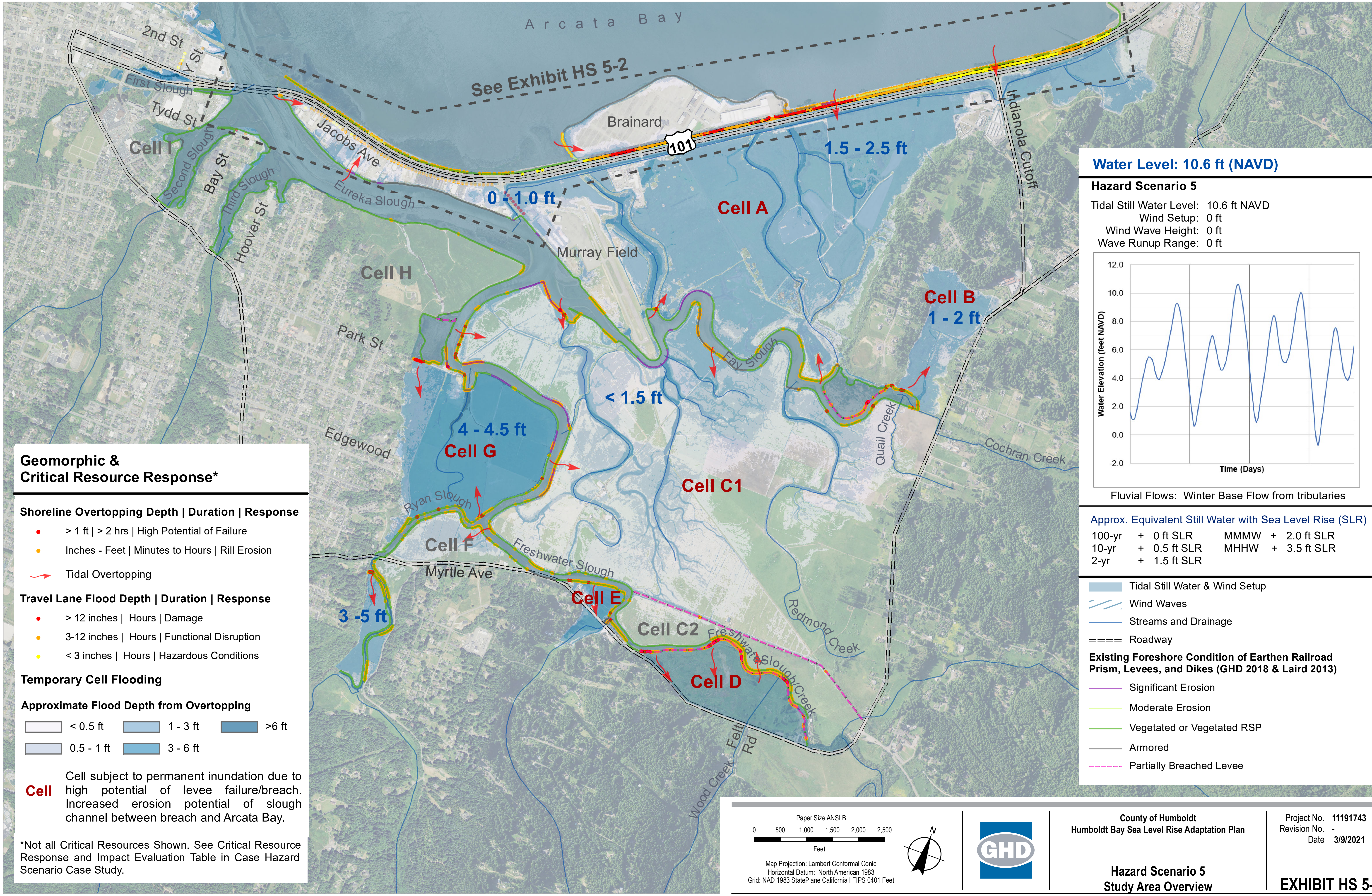
HAZARD SCENARIO 5

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	**Earthen Levees/ Dikes**	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	**Potential Failure**
			Cell B	>1ft and >2 hrs	**Potential Failure**
			Cell C	>1ft and >2 hrs	**Potential Failure**
			Cell E	>1ft and >2 hrs	**Potential Failure**
			Cell F	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell G	>1ft and >2 hrs	**Potential Failure**
			Cell H	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
Transportation	**Hwy 101 Southbound**	Surface Flooding (ft)	Cell A - Arcata Bay	2.4	**Closure & Damage**
	Hwy 101 Northbound		Cell A - Arcata Bay	-	none
	Jacobs Ave		Cell A (ft)	1.0	**Closure**
	Airport Road		Cell A	2.7	**Closure & Damage**
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	2.6	**Closure & Damage**
	Hoover Street		Cell I	1.1	**Closure & Damage**
	2nd and Y Streets		Cell I	0.7	**Closure**
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alternate Route)		Arcata Bay	0.2	Shallow Flooding
Utilities	**Sewer Lift Stations**	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	0.7	**Limited Access**
			Humboldt CSD Hoover Street	0.7	**Limited Access**
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	0.3	Shallow Flooding
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	60	**Limited Access Multiple Days**
			Cell I Hoover St - HCSD	9	Limited Access < 1 Day
	Sewer Gravity Main		Cell I Hoover St - HCSD	9	Limited Access < 1 Day
	Gas Main		Cell G	103	**Limited Access Multiple Days**

HAZARD SCENARIO 5

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
			Cell C	34	**Limited Access Multiple Days**
			Cell A	60	**Limited Access Multiple Days**
	Communications (Underground)		Cell A	60	**Limited Access Multiple Days**
	Communication Towers/Poles		Cell H	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	1.0	Shallow Flooding
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	2.4	**Damage/Stranding**
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	0.7	Shallow Flooding
			6th and Tydd Street	-	none
			Hoover Street	1.1	**Damage/Stranding**
			Park Street	2.6	**Damage/Stranding**
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	60	**Limited Access Multiple Days**
			Cell B	52	**Limited Access Multiple Days**
			Cell C	34	**Limited Access Multiple Days**
			Cell E	71	**Limited Access Multiple Days**
			Cell F	14	Limited Access < 1 Day
			Cell G	103	**Limited Access Multiple Days**
			Cell H	-	none
			Ryan Slough Upstream of Myrtle	135	**Limited Access Multiple Days**



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Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

Water Level: 10.6 ft (NAVD)

Hazard Scenario 5
See Exhibit HS 5-1 for Water Level Detail

Tidal Still Water
(Wind Setup and Wind Waves Not Present)
Streams and Drainage
Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

- Significant Erosion
- Moderate Erosion
- Vegetated or Vegetated RSP
- Armored
- Partially Breached Levee

Drainage

- Drainage Swale/Ditch
- Culvert
- Culvert with Flash Board Riser
- Drop Inlet
- Culvert with Flap Gate or Tide Gate

Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion

Travel Lane Flood Depth | Duration | Response

- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

Temporary Cell Flooding

Approximate Flood Depth from Overtopping

- < 0.5 ft
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 6 ft
- >6 ft

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.

Paper Size ANSI B
0 250 500 750 1,000
Feet
Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
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County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 5
Bay Shoreline

Project No. **11191743**
Revision No. **-**
Date **3/9/2021**

EXHIBIT HS 5-2

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Print date: 09 Mar 2021 - 14:40

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 5A

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
10.6 feet NAVD	**Existing (2012 baseline)** 100-year 1% chance per year	**1 foot** 2-year 50% chance per year	**2 feet** MMMW 5 to 6 events per year	**3.5 feet** MHHW Daily - Weekly

Introduction (See Exhibit HS 5A-1):

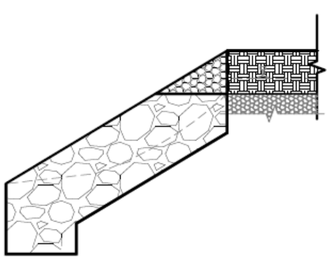
This case study describes a scenario that incorporates planned future conditions of the Arcata Bay shoreline with the rail prism elevated to 11.5 feet (NAVD) and rock slope protection along the bay-facing bank. Hydraulic conditions are the same as Scenario 5 with an extreme high tide and no significant wind or fluvial flood conditions. This extreme tide no longer overtops the rail prism along Arcata Bay, which prevents flooding of Highway 101 and significantly reduces flooding of the Cell A interior. The extreme tide affects other cells along interior sloughs, similar to Scenario 5, with widespread overtopping of levees, flooding of multiple smaller roadways, developed and agricultural areas. Approximately 270 feet of interior slough levees are exposed to high potential of failure and breaching conditions with overtopping of greater than 1 foot for greater than 2 hours.

The Planned Humboldt Bay Trail South will Increase the Elevation and Improve Rock Slope Protection Along the Bay Shoreline.

Highlighted shoreline processes in this scenario include slope failure/erosion of bay/slough facing slopes, overtopping and landward slope erosion, and channel adjustment due to high breach potential. Conceptual examples shown below.

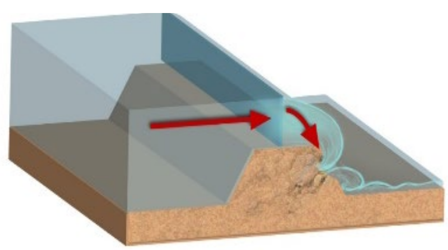
Revetment and Elevation

Arcata Bay Shoreline
Rail Prism



Overtopping/Erosion

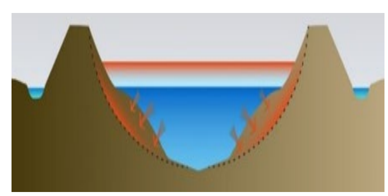
0% of Arcata Bay Shoreline
24% of Interior Slough Levees



Example Overtopping and Erosion (National Science Foundation, 2020)

Channel Adjustment with Breach

270 feet of Significant Overtopping resulting in High Potential for Breach and downstream channel adjustment



Hydraulics and Sea Level Rise:

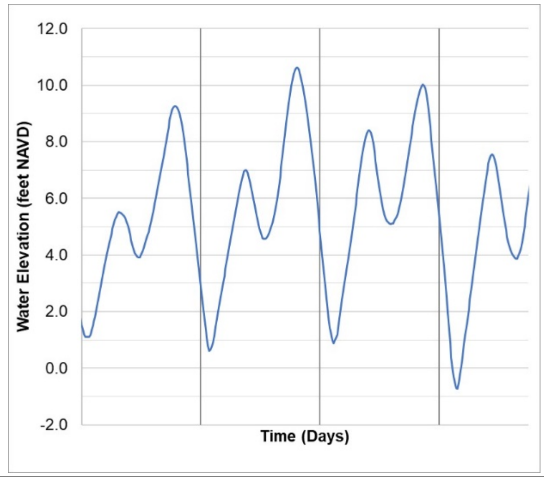
This scenario combines the highest spring tides that occur during the year, from November through January, with meteorological conditions, such as storm surge, that further increase tidal elevations. High spring tides occur multiple days in a row on separate occasions during this time of year. The increase due to storm surge is intended to represent conditions that are rare under existing conditions (2012 baseline). Based on predicted tides, the peak water level of 10.6 feet (NAVD) is followed by another tide reaching nearly 10 feet (NAVD)[1]. Calm conditions, without wind effects that increase water levels and produce waves, exist throughout the duration of peak tides. Water levels are referenced to 2012 baseline and ground elevations referenced to the

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 10.6 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 5A Hydraulics

Tidal Still Water Level	10.6 ft NAVD
Wind Set-up	0 ft
Wind Wave Height	Height: 0 ft
Wave Runup Range	0 ft
Total Water Level (TWL)	10.6 ft NAVD
Fluvial Flows	Winter Base Flow from tributaries



Antecedent Shoreline Conditions:

This scenario assumes planned shoreline elevations and condition associated with the County's Humboldt Bay Trail South Project along Arcata Bay. For all other shorelines, existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, these hydraulic conditions are considered to be rare, exceeding the highest observed tide affecting the Study Area. Photos and observations of similar, but smaller events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 5A-1 and described in this case study. Modeled overtopping volume of the Bay Shoreline was removed to represent future conditions. Exhibit HS 5A-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

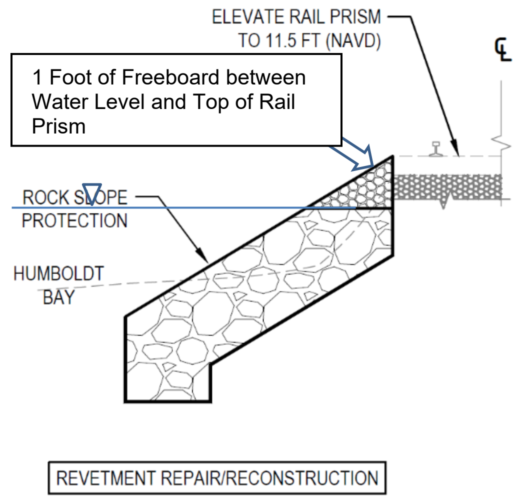
HAZARD SCENARIO 5A

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101.

Hydraulic Conditions:

The proposed elevation increase of the rail prism along the Bay Shoreline provides protection up to 11.5 feet (NAVD) and provides approximately 1 foot of freeboard in this scenario water level. The elevated rail prism prevents 940 acre feet of tidal overtopping compared to existing conditions.



Resource Response and Impacts:

The physical response of the bay shoreline under this scenario is estimated based on future, proposed conditions. The anticipated responses are described below. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

Rail Prism: The planned elevation and rock slope protection along the rail prism, no overtopping nor erosion of the bay – facing slope occurs. The response is similar to that of the existing Brainard levee where levee crest elevations are higher than water levels and banks are protected with rock slope protection.

Highway 101: No overtopping occurs at the rail prism and highway flooding is prevented.

Interior Shoreline

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Overtopping of tidal waters occurs along all slough channels and all cells, typically totaling hundreds to thousands of feet protecting each cell. Exhibit HS 5-1 shows the locations, depth and duration of shoreline overtopping. Levees protecting Cells A, B, C, E, G and the area upstream of Myrtle are all subject to significant overtopping, exceeding 1 foot of depth and 2 hours in duration. The extent of significant overtopping is typically 50 feet or less.

Resource Response and Impacts:

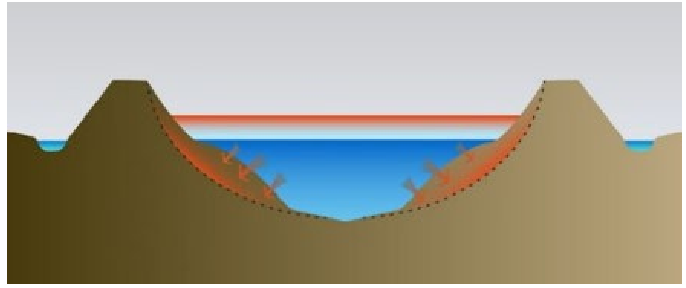
HAZARD SCENARIO 5A

Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.

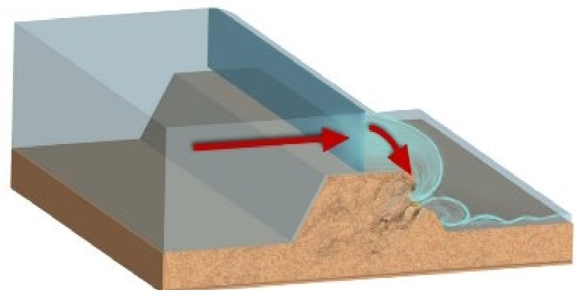
Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

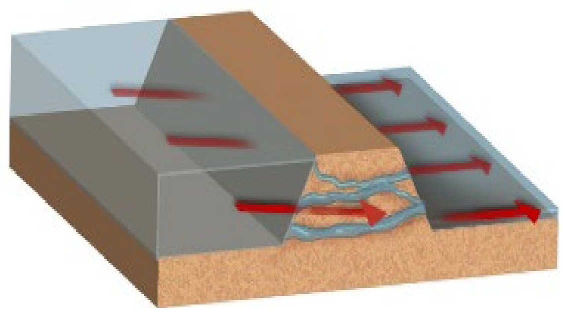
The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.



Conceptual Channel Adjustment with Breach Event



Overtopping creates erosion on top and backside (above) (National Science Foundation, 2020)



Sustained erosion, differentials in water levels, and levee material can contribute to internal erosion and piping

(National Science Foundation, 2020)

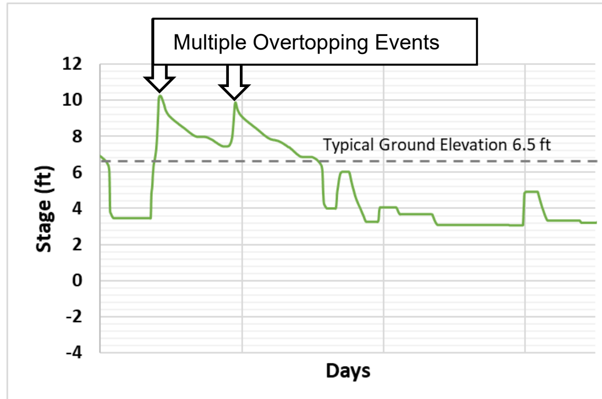
HAZARD SCENARIO 5A

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

<u>Hydraulic Conditions:</u>

Overtopping occurs during multiple high tides on sequential days. However, overtopping does not occur along the rail prism and highway. The extent of levee overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells A, B, C, E, G, and upstream of Myrtle on Ryan Slough. The depth and water surface elevation of flooding for each cell are summarized in Table 3, at the end of this case study. Flooding is typically between 0.5 to 4 feet deep, with multiple cycles of flooding and draining occurring in each cell, and subsequent high tides and limited duration of low tides impounding flooding until drained to within drainage channels.



Multiple Overtopping Events

Flooding of Cell A is reduced by 940 acre-feet to 110 acre-feet, significantly reducing the extent and depth of flooding. Flooding is reduced to only the lowest elevations, typically in undeveloped areas. Water levels are reduced from 6.5 feet to 4.4 feet (NAVD). Flooding is prevented from reaching developed areas, roadways, and sewer pump stations located along Jacobs Avenue, Brainard, Airport Road and Murray Field.

In other cells repetitive tidal inundation occurs during the peak tide and following high tide(s). Tidal flooding in Cell G reaches the higher elevation areas at the end of Edgewood Road. Multiple days are required to drain the tidal flooding due to the limited duration of favorable drainage conditions.

Flooding encroaches on the developed areas adjacent to First, Second and Third Slough, protected by a natural elevation gradient. Up to 1 foot of flooding affects the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street and 2nd Street. HCSD's sewer pump station and residences on Bay Street experience more than 1 foot of flooding.

<u>Resource Response and Impacts:</u>

Dangerous conditions exist during each high tide when overtopping occurs if property owners or maintenance crews attempt to access or assess damages. Drainage of interior areas may be delayed by accumulation of debris carried and deposited in drainage ditches by flooding. Short duration flooding of tidal waters do not result in lasting impacts to pastures or utilities.

The levees protecting cells A, B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

Example Inundation of low-lying lands

HAZARD SCENARIO 5A

Scenario Summary:

The planned elevation and rock slope protection along the rail prism prevents overtopping and erosion along the Bay Shoreline. This future, proposed conditions also prevents highway flooding. However, The multiple days of extreme tides and peak day result in dangerous conditions and closure of smaller local roadways. Dangerous conditions exist near overtopping levees and the lowlands they protect. Approximately 270 feet of interior slough levees are exposed to a high potential for failure and breaching. Extensive repairs and cleanup to restore pre-event conditions and flood protection throughout the Study Area are required.

Overtopping to Cell A is reduced by 940 acre feet, representing a 90% reduction in the volume of tidal flooding (Table 2). The remaining 110 acre feet of overtopping along the interior slough channels results in flooding in only the lowest-lying areas, below 4.4 feet (NAVD). Flooding in the developed areas along Jacobs Avenue and Murray Field is limited to the volume overtopping the adjacent levees preventing damages to at-grade structures.

Overtopping along the Interior Shoreline is widespread (Table 2 and Table 3). Levees protecting Cells A, B, C, E, G and on Ryan Slough upstream of Myrtle are subject to overtopping that exceeds 1 foot of depth and 2 hours in duration. These conditions pose a high potential for levee failure and breaching. In the event of a levee breach, the cell may be subject to inundation from daily tides and increase erosive forces along the interior shoreline, between the breach and Arcata Bay.

The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, including the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street and 2nd Street. HCSD's sewer pump station and residences on Bay Street experience more than 1 foot of flooding. Low elevation lands within the other cells experience multiple feet of flooding and do not result in lasting impacts to pastures or utilities.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 5A

Table 2. Overtopping Summary for Bay Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	0	0%	-	-	< 3 inches	4.4
		Rail Prism	0	0%	-			
	Brainard Levee	Levee	0	0%	-	-		
	Brainard to Indianola Cutoff	Rail Prism	0	0%	-	-		
Slough	Fay Slough	Levee	2,124	14%	3	104		
	Eureka Slough	Levee	100	2%	-	3		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	205	74%	31	1.2 to 2.2	7.7
C1	Fay Slough	1,587	14%	38	0 to 1.5	6.0
	Freshwater Slough	2,071	20%	55		
C2	Freshwater Slough	1,623	28%	-	0 to 0.2	6.6
D[2]	Freshwater Slough	2,827	62%	488	0.8 to 2.8	10.3
E	Freshwater Slough	1,341	51%	34	3.3 to 4.3	10.2
F	Ryan Slough	638	19%	-	0.3 to 1.3	6.3
	Freshwater Slough	69	7%	-		
G	Freshwater Slough	946	16%	28	3.8 to 4.3	9.8
	Park Street	509	83%	179		
	Ryan Slough	522	22%	29		
H	Freshwater Slough	-	0%	-	-	0.0
	Eureka Slough	26	1%	-		
I[2]	Eureka Slough	-		-	0 to 1.6	10.6
Myrtle	Ryan Slough	1,010	24%	50	2.9 to 4.9	10.9

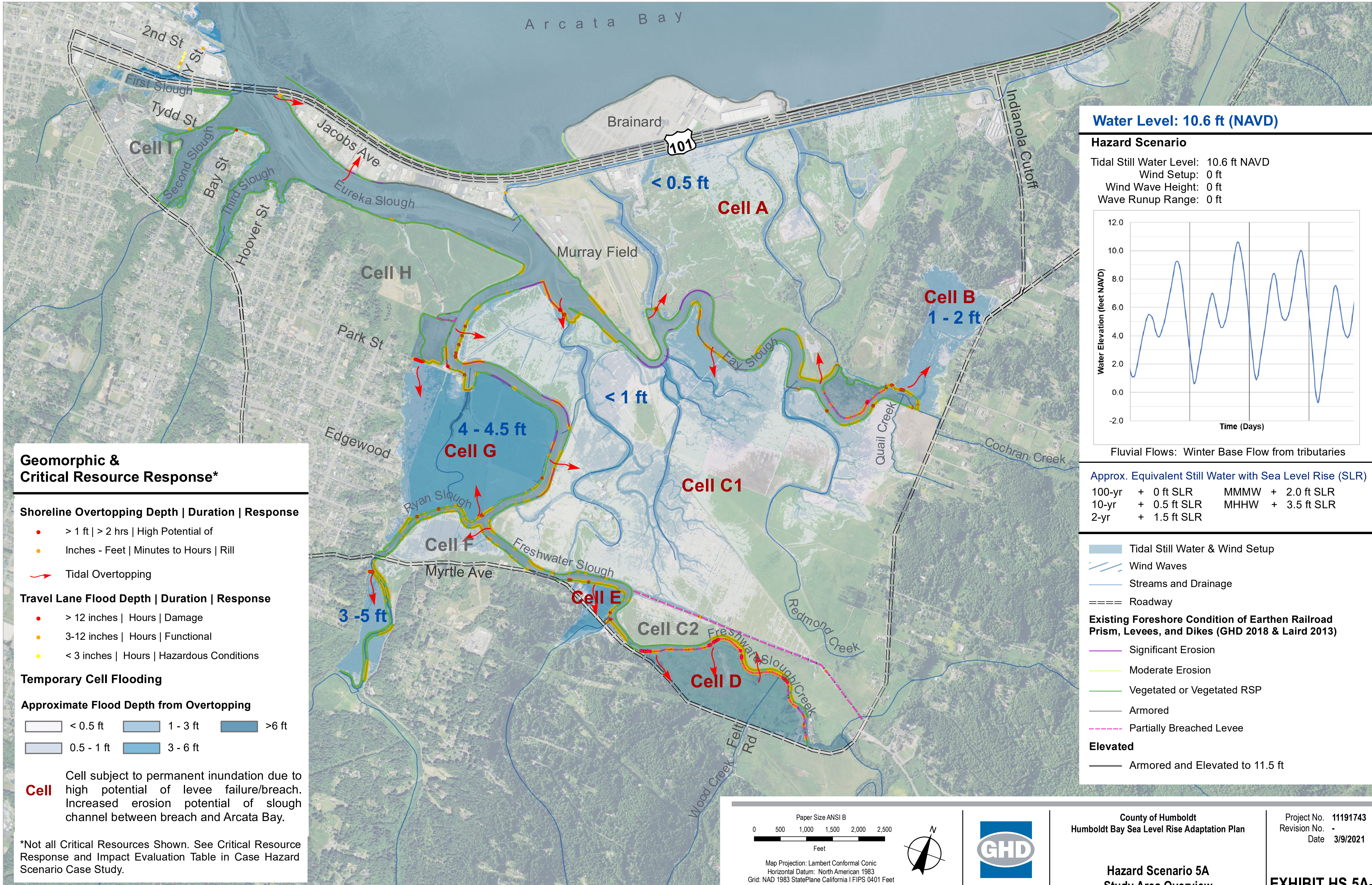
HAZARD SCENARIO 5A

Table 4. Critical Resource Response and Impact Evaluation

	Critical Resource	Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	Potential Failure
			Cell B	>1ft and >2 hrs	Potential Failure
			Cell C	>1ft and >2 hrs	Potential Failure
			Cell E	>1ft and >2 hrs	Potential Failure
			Cell F	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
			Cell G	>1ft and >2 hrs	Potential Failure
			Cell H	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	none	none observed
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	-	none
	Hwy 101 Northbound		Cell A - Arcata Bay	-	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	-	none
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	2.6	Closure & Damage
	Hoover Street		Cell I	1.053817	Closure & Damage
	2nd and Y Streets		Cell I	0.748946	Closure
	4th, 5th, 6th, V St		Cell I	0	none
	Myrtle Ave		Cells B, C, F, D	0	none
	Hwy 255 (Alternate Route)		Arcata Bay	0.2	Shallow Flooding
UTILITIES	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	0.69	Limited Access
			Humboldt CSD Hoover Street	0.69	Limited Access
			Humboldt CSD Edgewood	0	none
	Water Booster Station		City of Eureka Myrtle Ave	0.31	Shallow Flooding
			Cell A Jacobs Ave - COE	-	none

HAZARD SCENARIO 5A

	Critical Resource	Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell I Hoover St - HCSD	9	Limited Access < 1 Day
	Sewer Gravity Main		Cell I Hoover St - HCSD	9	Limited Access < 1 Day
	Gas Main		Cell G	103	Limited Access Multiple Days
			Cell C	34	Limited Access Multiple Days
			Cell A	12	Limited Access < 1 Day
	Communications (Underground)		Cell A	12	Limited Access < 1 Day
	Communication Towers/Poles		Cell H	0	none
PROTECTED LANDS	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	0	none
			Murray Field	0	none
			Harper Motors	0	none
			Brainard	0	none
			Rainbow Storage Indianola Cutoff	0	none
			2nd and Y Street	0.7	Shallow Flooding
			6th and Tydd Street	0.0	none
			Hoover Street	1.1	**Damage/Stranding**
			Park Street	2.6	**Damage/Stranding**
			Edgewood	0.0	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	12	Limited Access < 1 Day
			Cell B	52	**Limited Access Multiple Days**
			Cell C	34	**Limited Access Multiple Days**
			Cell E	72	**Limited Access Multiple Days**
			Cell F	14	Limited Access < 1 Day
			Cell G	103	**Limited Access Multiple Days**
			Cell H	0	none
			Ryan Slough Upstream of Myrtle	135	**Limited Access Multiple Days**



County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 5A
Study Area Overview

Project No. **11191743**
Revision No. **-**
Date **3/9/2021**

EXHIBIT HS 5A-1

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Print date: 09 Mar 2021 - 15:02

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 6

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
11.6 feet NAVD	**Existing (2012 baseline)** >500-year <0.5% chance per year	**1 foot** 100-year 1% chance per year	**1.5 feet** 10-year 10% chance per year	**2.5 feet** 2-year 50% chance per year

Introduction (See Exhibit HS 6-1):

This case study describes a scenario characterized by an extreme high tide, elevated low tides, and no significant wind or fluvial flood effects. An extreme tide of this magnitude is very rare. Based on historical accounts, the extent of flooding described in this scenario is similar to descriptions of the November 24, 1885 water levels that were likely a result of a tsunami, however water levels are not known. This scenario is intended to describe potential future extreme conditions that affect the entire Study Area and alternate transportation routes around Humboldt Bay. Tidal water levels of this magnitude overtop the entire rail prism along Arcata Bay and the majority of most levees along the interior slough channels. Multiple feet of flooding affect protected lands and roadways. Closure of Highway 101, alternate routes around the bay on Highway 255 and Myrtle Avenue are flooded, as well as multiple smaller roadways, such as Tydd Street, Hoover Street, Y Street, and 2nd Street. Ingress and egress routes are quickly flooded, within limited time for evacuation and approximately 4,400 feet of the Study Area shoreline experiences significant overtopping, meeting the criteria for a high probability of failure and breaching.

Highlighted shoreline processes in this scenario include slope failure/erosion of bay/slough facing slopes, overtopping and landward slope erosion, and channel adjustment due to high breach potential. Conceptual examples shown below.

Slope Failure/Sloughing

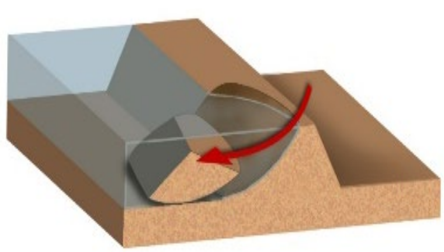
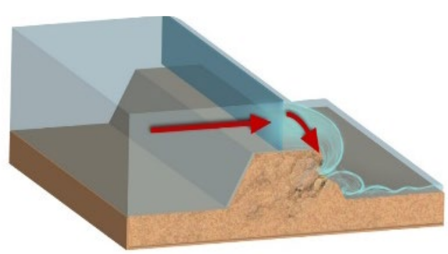
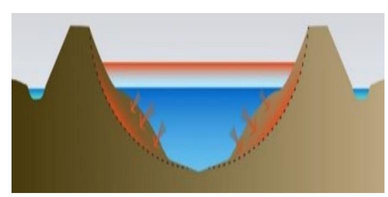
Arcata Bay Shoreline
Interior Shoreline

Overtopping/Erosion

74% of Arcata Bay Shoreline
47% of Interior Slough Levees

Channel Adjustment with Breach

4,400 feet of Significant Overtopping resulting in High Potential for Breach and downstream channel adjustment

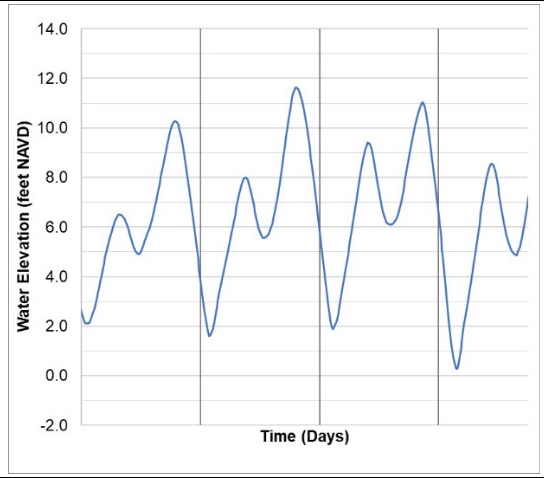
Example Shoreline Structure Responses (National Science Foundation, 2020)

Hydraulics and Sea Level Rise:

This scenario includes potential future extreme spring tides that typically occur in the months from November through January, where extreme high and low tides occur over multiple days in combination with a low-pressure system (storm surge) that increases predicted tidal water levels entering Humboldt Bay. Low tide elevations are elevated due to sea level rise. In the days preceding the storm, extreme tidal water levels are observable. Based on predicted tides by NHE 2019 leading up to the still water event, high tide reaches 10 feet (NAVD) the day prior to the peak of 11.6 feet (NAVD) and 11 feet (NAVD) the following day[1]. Water levels are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 11.6 feet (NAVD), with variable amounts of sea level rise, are presented at the top of this page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 6 Hydraulics		
Tidal Still Water Level	11.6 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	Height: 0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	11.6 ft NAVD	
Fluvial Flows	Winter Base Flow from tributaries	

Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, these hydraulic conditions are considered to be rare, exceeding the highest observed tide affecting the Study Area. Photos and observations of similar, but smaller events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 6-1 and described in this case study. Exhibit HS 6-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

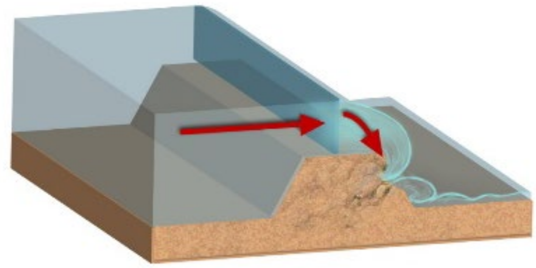
HAZARD SCENARIO 6

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101.

Hydraulic Conditions:

In the days leading up to the peak tidal water level, overtopping and flooding occur, similar to Scenario 4. The peak tidal still water level reaches 11.6 feet (NAVD) and is followed by a tide of 11 feet (NAVD). The entire railroad prism from Eureka Slough north and a short section of the southern Brainard levee. The capacity of the drainage channel between the southbound travel lanes of Highway 101 and the rail prism is exceeded. Highway 101 southbound lanes throughout the study area are flooded during the peak tides. This is the first scenario where flood of the Highway, between Eureka Slough and Brainarad occurs. Tidal flooding flows into the median ditch, where it is conveyed east to the ditch east of the highway and combines with overtopping flow from Fay Slough and Eureka Slough, eventually reaching a water level of 11.3 feet (NAVD) and flooding the northbound lanes as well. Overtopping of the railroad prism exceeds 1 foot depth and lasts for more than 2 hours resulting in a high potential for failure. Exhibit HS 6-1 shows the locations, depth and duration of shoreline overtopping associated with peak water levels for this scenario.



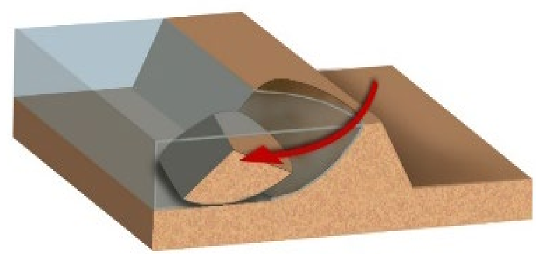
Example Overtopping and Erosion (National Science Foundation, 2020)

Resource Response and Impacts:

The physical response of the Bay Shoreline under this scenario will vary based on the existing shoreline condition. Anticipated responses are described below. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

Rail Prism: The extensive overtopping of the rail prism and observed composition, results in expected slope failures and significant rill erosion. The lack of cohesion within the ballast material would likely cause sloughing of the bank and movement of material down the slope. Overtopping of the rail prism by continuous flow will result in rill erosion across the top and land-facing slope. Damages that go unrepaired are subject to the following:

- Increased potential of saturation/seepage due to reduced levee width.
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.



Example Slope Failure from Sloughing (National Science Foundation, 2020)

Highway 101: Overtopping results in flooding of the all lanes of Highway 101 with more than 1 foot depth of tidal waters. Dangerous conditions and eventually closure result for multiple days. Erosion along the landward slope of the southbound Highway prism is likely, requiring repairs. Significant clean up is required following the event. Drainage channels require inspection and removal of debris and sediment at drainage structures such as culverts and tide gates.

Rill Erosion of Railroad Prism Top and Backslope Due to Overtopping

HAZARD SCENARIO 6

Interior Shoreline

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Overtopping of tidal waters occurs along all slough channels and all cells, typically totaling hundreds to thousands of feet protecting each cell. Exhibit HS 6-1 shows the locations, depth and duration of shoreline overtopping. Levees protecting Cells A, B, C, E, F, G and the area upstream of Myrtle are all subject to significant overtopping, exceeding 1 foot of depth and 2 hours in duration. The extent of significant overtopping is typically hundreds of feet.

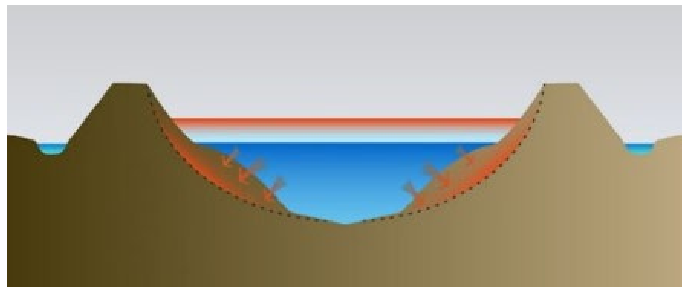
Resource Response and Impacts:

Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.

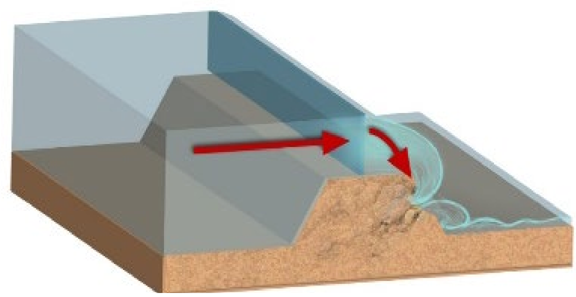
Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

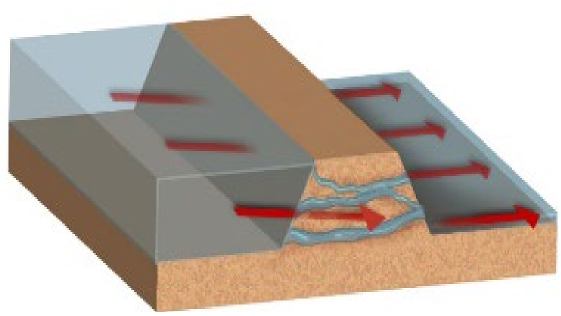
The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.



Conceptual Channel Adjustment with Breach Event



Overtopping creates erosion on top and backside (above) (National Science Foundation, 2020)



Sustained erosion, differentials in water levels, and levee material can contribute to internal erosion and piping (National Science Foundation, 2020)

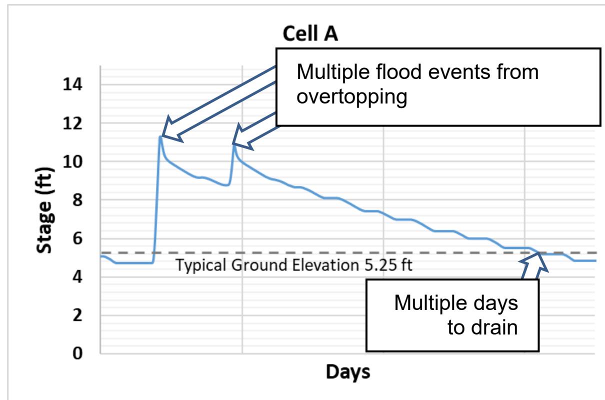
HAZARD SCENARIO 6

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions:

Overtopping occurs during multiple high tides on sequential days. The extent of levee, rail prism and roadway overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells A, B, C, E, F, G, and upstream of Myrtle on Ryan Slough. The depth and water surface elevation of flooding for each cell are summarized in Table 3, at the end of this case study. Flooding is typically between 3 to 7 feet deep, with multiple cycles of flooding and draining occurring in each cell. Subsequent high tides and limited duration of low tides impound stall and slow drainage.



Multiple Overtopping Events, Followed by Multiple Days to Drain the Protected Lands

Flooding of Cell A occurs multiple events with a predicted 4,700 acre-feet of tidal waters flowing over the rail prism and highway to the median drainage ditches that convey flooding to the interior of Cell A. The capacity of the drainage ditch along the eastern edge of Highway 101 is exceeded and floods the low lying areas, combined with 300 acre-feet of tidal overtopping along Fay Slough. Water levels within the cell reach 11.3 feet (NAVD) multiple days. Developed areas, roadways, and sewer pump stations located along Jacobs Avenue, Brainard, Airport Road, Murray Field, Harper Motors and Indianola Cutoff experience 3 to 6 feet of flooding.

In other cells, repetitive tidal inundation occurs during multiple high tides. Tidal flooding in Cell G reaches the higher elevation areas at the end of Edgewood Road. Tidal flooding of Cell B rise to the elevation of Myrtle Avenue, flooding the roadway. Multiple days are required to drain the tidal flooding due to the limited duration of favorable drainage conditions.

Flooding encroaches on the developed areas adjacent to First, Second and Third Slough, protected by a natural elevation gradient. Up to 2.5 feet of flooding affects the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street, 2nd Street and 4th Street. HCSD's sewer pump station and residences on Bay Street experience more than 2 feet of flooding

Resource Response and Impacts:

Flooding of developed areas along Jacobs Avenue, Brainard, Murray Field, and Indianola Cutoff is typically between 3 and 6 feet preventing ingress and egress to Highway 101 and Myrtle Avenue, causing significant damage to the at-grade facilities and contents, including two City of Eureka sewer pump stations. The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, largely restricting access and causing damage to facilities.

Dangerous conditions exist throughout the Study Area, throughout the duration of overtopping, flooding and draining and the ability to access or assess damages is minimal. Drainage of interior areas may be delayed by further delayed by the accumulation of debris carried and deposited in drainage ditches by flooding. Short duration flooding of tidal waters do not result in lasting impacts to pastures or utilities, however the high potential for levee failure and breaching suggest that some areas will have lasting impacts, changing the management options available for the land.

The levees protecting cells A, B, C, E, F, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

HAZARD SCENARIO 6

Scenario Summary:

The multiple days of extreme tides and peak day result in significant overtopping and flooding throughout the Study Area. All lanes of Highway 101 and smaller local roadways are flooded, requiring closure. Alternate routes around the bay are also flooded and closed. Dangerous conditions exist throughout the Study Area. Flooding of cells occurs rapidly, resulting in 3 to 7 feet of flood depth and preventing ingress and egress. Approximately 4,000 feet of shoreline structures are exposed to overtopping conditions qualified as high potential for failure and breaching. Extensive repairs and cleanup to restore pre-event conditions and flood protection throughout the Study Area are required.

Along the Bay Shoreline, the entire rail prism is overtopped (Table 2). The rail prism experiences significant erosion, reduction of future flood protection and a high potential for failure, while the Brainard Levee experiences rill erosion on the land-facing slope. Tidal overtopping of the rail prism and highway combines with overtopping along Fay Slough and Eureka Slough, resulting in a water level of 11.3 feet (NAVD) inundating nearly the entire cell, resulting in closure of Highway 101, Indianola Cutoff and all ingress and egress routes. Myrtle Avenue/Old Arcata Road and Highway 255 are not available for alternate travel routes around the bay, as they are also flooded. Drainage of the cell occurs over multiple days, adding potential failure of levees due to seepage.

Overtopping along the Interior Shoreline is widespread (Table 2 and Table 3). Levees protecting Cells A, B, C, E, F, G and on Ryan Slough upstream of Myrtle are subject to overtopping that exceeds 1 foot of depth and 2 hours in duration. These conditions pose a high potential for levee failure and breaching. In the event of a levee breach, the cell may be subject to inundation from daily tides and increase erosive forces along the interior shoreline, between the breach and Arcata Bay. Drainage of the cell occurs over multiple days, adding potential failure of levees due to seepage.

Nearly 94% of the 5,000 acre-feet of tidal flooding in Cell A overtops the Bay Shoreline rail prism and highway. Flooding of developed areas along Jacobs Avenue, Murray Field and Brainard is 3 to 6 feet deep causing damage to structures and contents, including the City of Eureka sewer pump stations. The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, including the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street and 2nd Street. HCSD's sewer pump station and residences on Bay Street experience more than 2 feet of flooding. Flooding also propagates onto Edgewood Road and Myrtle Avenue. Low elevation lands within the other cells experience multiple feet of flooding and do not result in lasting impacts to pastures or utilities. However, The levees protecting cells A, B, C, E, F, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

A summary of impacts to critical resources is presented in Table 4.

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HAZARD SCENARIO 6

Table 2. Overtopping Summary for Bay Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	4,960	82%	-	-	Jacobs Ave 3.3 to 5.8 ft, Fay Slough Wildlife Area 6.3 to 7.3 ft	11.3
		Rail Prism	6,454	99%	2,209			
	Brainard Levee	Levee	693	13%	-	245		
	Brainard to Indianola Cutoff	Rail Prism	6,923	100%	661	4,456		
Slough	Fay Slough	Levee	8,880	57%	136	216		
	Eureka Slough	Levee	2,987	45%	-	84		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	270	97%	135	3.5 to 4.5	10.0
C1	Fay Slough	6,008	54%	313	1.8 to 3.8	8.2
	Freshwater Slough	5,513	54%	308		
C2	Freshwater Slough	2,396	41%	-	0 to 1.8	8.2
D[2]	Freshwater Slough	3,431	75%	407	1.1 to 3.1	10.6
E	Freshwater Slough	2,024	78%	146	3.7 to 4.7	10.7
F	Ryan Slough	1,316	39%	-	4.3 to 5.3	10.3
	Freshwater Slough	181	18%	6		
G	Freshwater Slough	2,483	42%	35	4.9 to 5.4	10.8
	Park Street	530	86%	289		
	Ryan Slough	1,721	73%	48		
H	Freshwater Slough	289	13%	-	0 to 0.6	6.1
	Eureka Slough	294	7%	-		
I[2]	Eureka Slough	-		-	0 to 2.6	11.6
Myrtle	Ryan Slough	1,476	36%	75	2.7 to 4.7	10.7

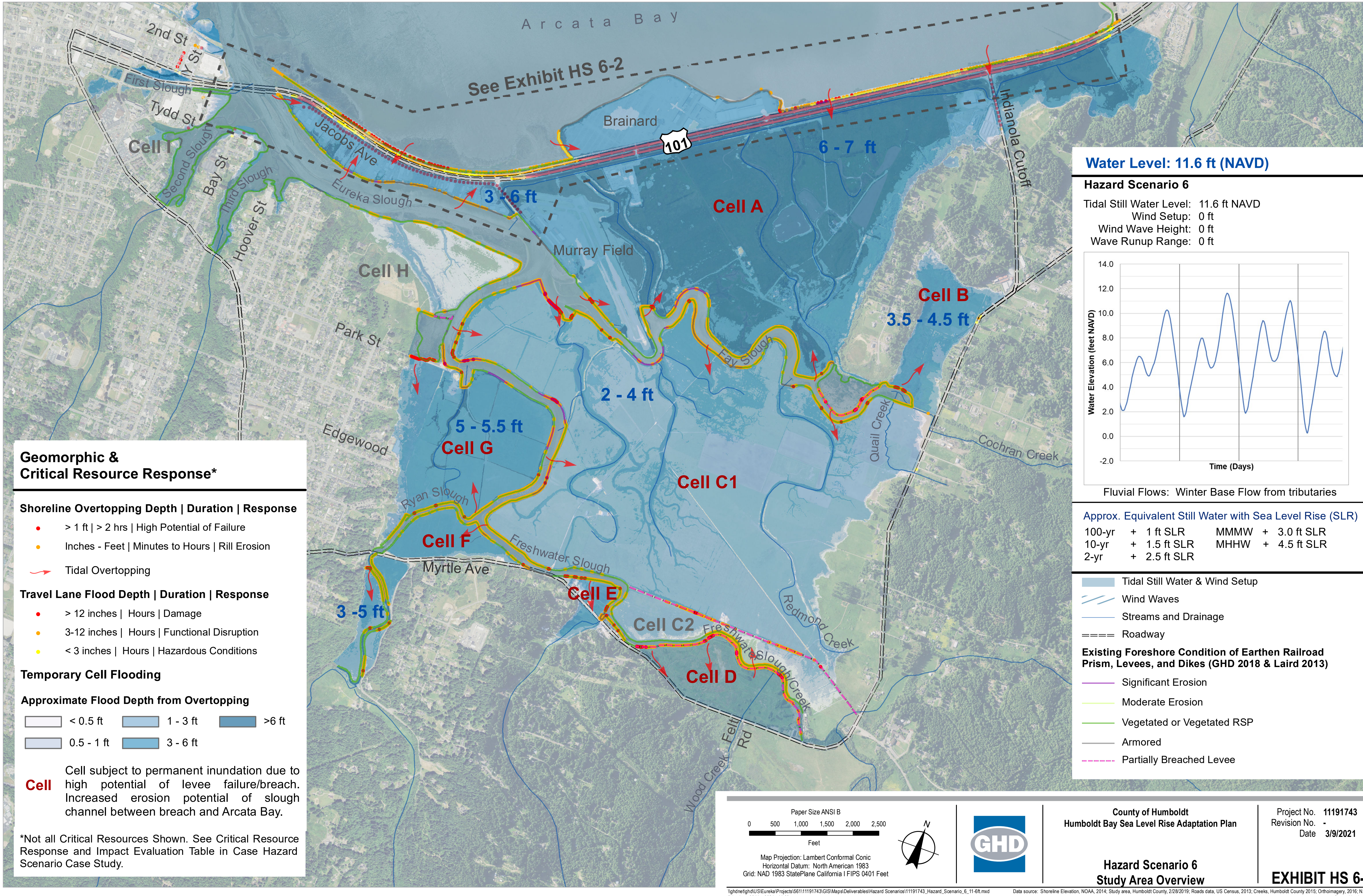
HAZARD SCENARIO 6

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	**Potential Failure**
			Cell B	>1ft and >2 hrs	**Potential Failure**
			Cell C	>1ft and >2 hrs	**Potential Failure**
			Cell E	>1ft and >2 hrs	**Potential Failure**
			Cell F	>1ft and >2 hrs	**Potential Failure**
			Cell G	>1ft and >2 hrs	**Potential Failure**
			Cell H	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	>1ft and >2 hrs	**Potential Failure**
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	3.4	**Closure & Damage**
	Hwy 101 Northbound		Cell A - Arcata Bay	2.7	**Closure & Damage**
	Jacobs Ave		Cell A (ft)	5.8	**Closure & Damage**
	Airport Road		Cell A	7.5	**Closure & Damage**
	Indianola Cutoff		Cell A	3.4	**Closure & Damage**
	Park Street		Cell G	3.6	**Closure & Damage**
	Hoover Street		Cell I	2.0	**Closure & Damage**
	2nd and Y Streets		Cell I	1.7	**Closure & Damage**
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	0.3	**Closure**
	Hwy 255 (Alternate Route)		Arcata Bay	1.2	**Closure & Damage**
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	4.6	**Potential Inflow/Overflow/Damage**
			City of Eureka Jacobs Ave #2	4.7	**Potential Inflow/Overflow/Damage**
			City of Eureka Y Street	0.6	**Limited Access**
			City of Eureka Hill Street (Tydd Street)	1.7	**Limited Access**
			Humboldt CSD Hoover Street	1.7	**Limited Access**

HAZARD SCENARIO 6

	Critical Resource	Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
			Humboldt CSD Edgewood	1	**Limited Access**
	Water Booster Station		City of Eureka Myrtle Ave	1	**Limited Access**
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	203	**Limited Access > 1 week**
			Cell I Hoover St - HCSD	18	Limited Access < 1 Day
	Sewer Gravity Main		Cell I Hoover St - HCSD	18	Limited Access < 1 Day
	Gas Main		Cell G	95	**Limited Access Multiple Days**
			Cell C	113	**Limited Access Multiple Days**
			Cell A	203	**Limited Access > 1 week**
	Communications (Underground)		Cell A	203	**Limited Access > 1 week**
	Communication Towers/Poles		Cell H	8.5	Limited Access < 1 Day
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	5.8	**Potential Loss of Property/Life**
			Murray Field	4.1	**Damage/Stranding**
			Harper Motors	4.1	**Damage/Stranding**
			Brainard	3.4	**Damage/Stranding**
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	1.7	**Damage/Stranding**
			6th and Tydd Street	-	none
			Hoover Street	2.0	**Damage/Stranding**
			Park Street	3.6	**Damage/Stranding**
			Edgewood	0.6	Shallow Flooding
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	203	**Potential Changes to Land Management**
			Cell B	79	**Limited Access Multiple Days**
			Cell C	113	**Limited Access Multiple Days**
			Cell E	89	**Limited Access Multiple Days**
			Cell F	53	**Limited Access Multiple Days**
			Cell G	95	**Limited Access Multiple Days**
			Cell H	8	Limited Access < 1 Day
			Ryan Slough Upstream of Myrtle	56	**Limited Access Multiple Days**



Arcata Bay
See Exhibit HS 6-2
2nd St
Y St
First Slough
Tydd St
Cell I
Second Slough
Bay St
Third Slough
Hoover St
Jacobs Ave
Eureka Slough
Brainard
101
6 - 7 ft
3 - 6 ft
Cell A
Indianola Cutoff
Murray Field
Cell H
Park St
Fay Slough
Cell B
3.5 - 4.5 ft
2 - 4 ft
5 - 5.5 ft
Cell G
Edgewood
Quail Creek
Cochran Creek
Cell C1
Ryan Slough
Cell F
Freshwater Slough
Myrtle Ave
Cell E
3 -5 ft
Cell C2
Redmond Creek
Freshwater Slough
Slough Creek
Cell D
Felt Rd
Wood Creek
Water Level: 11.6 ft (NAVD)
Hazard Scenario 6
Tidal Still Water Level: 11.6 ft NAVD
Wind Setup: 0 ft
Wind Wave Height: 0 ft
Wave Runup Range: 0 ft
Water Elevation (feet NAVD)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
Time (Days)
Fluvial Flows: Winter Base Flow from tributaries
Approx. Equivalent Still Water with Sea Level Rise (SLR)
100-yr + 1 ft SLR
10-yr + 1.5 ft SLR
2-yr + 2.5 ft SLR
MMMW + 3.0 ft SLR
MHHW + 4.5 ft SLR
Tidal Still Water & Wind Setup
Wind Waves
Streams and Drainage
Roadway
Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)
Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee
Geomorphic & Critical Resource Response*
Shoreline Overtopping Depth | Duration | Response
> 1 ft | > 2 hrs | High Potential of Failure
Inches - Feet | Minutes to Hours | Rill Erosion
Tidal Overtopping
Travel Lane Flood Depth | Duration | Response
> 12 inches | Hours | Damage
3-12 inches | Hours | Functional Disruption
< 3 inches | Hours | Hazardous Conditions
Temporary Cell Flooding
Approximate Flood Depth from Overtopping
< 0.5 ft
1 - 3 ft
>6 ft
0.5 - 1 ft
3 - 6 ft
Cell
Cell subject to permanent inundation due to high potential of levee failure/breach. Increased erosion potential of slough channel between breach and Arcata Bay.
*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.
Paper Size ANSI B
0 500 1,000 1,500 2,000 2,500
Feet
Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet
N
GHD
County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan
Hazard Scenario 6
Study Area Overview
Project No. 11191743
Revision No. -
Date 3/9/2021
EXHIBIT HS 6-1

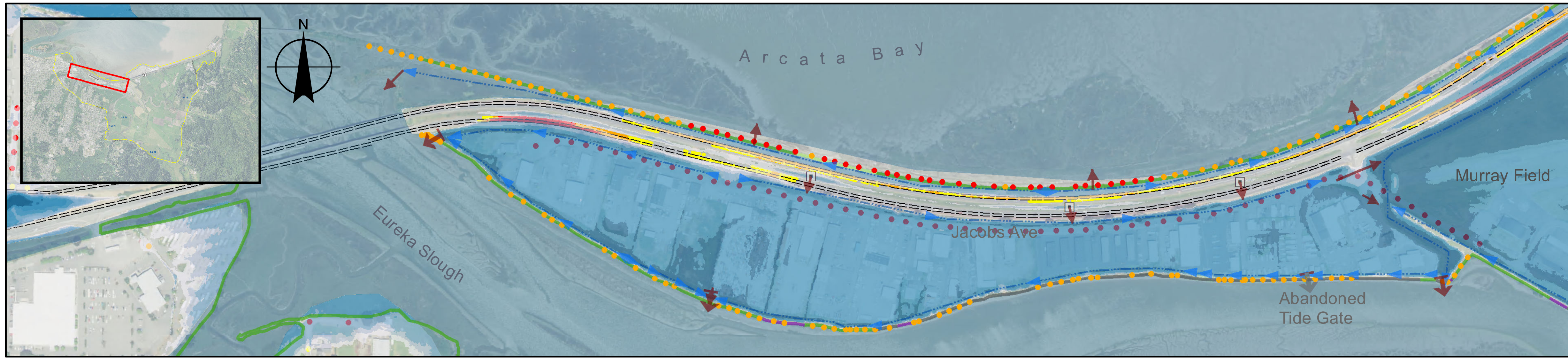
Water Level: 11.6 ft (NAVD)

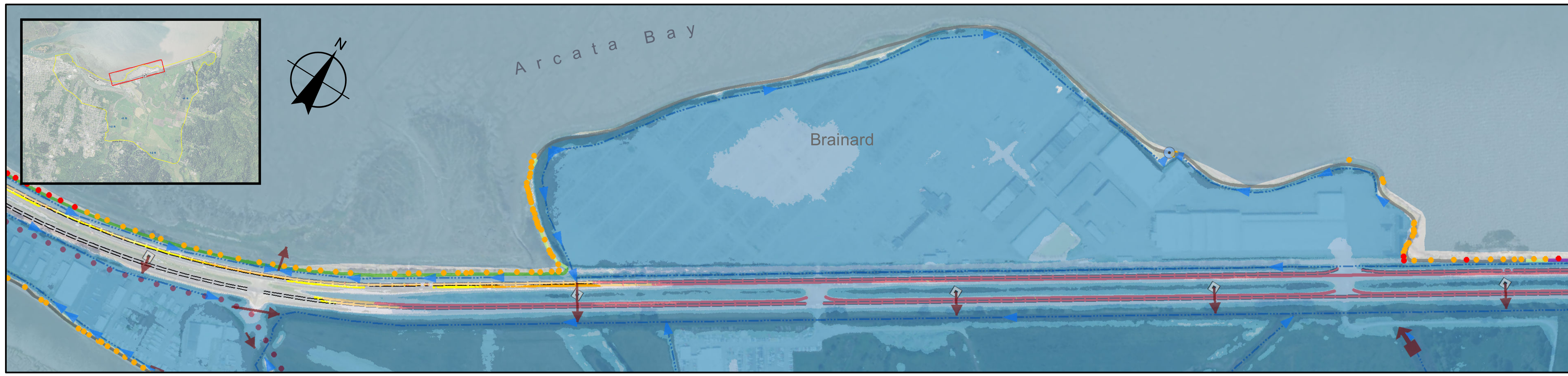
Hazard Scenario 6
See Exhibit HS 6-1 for Water Level Detail

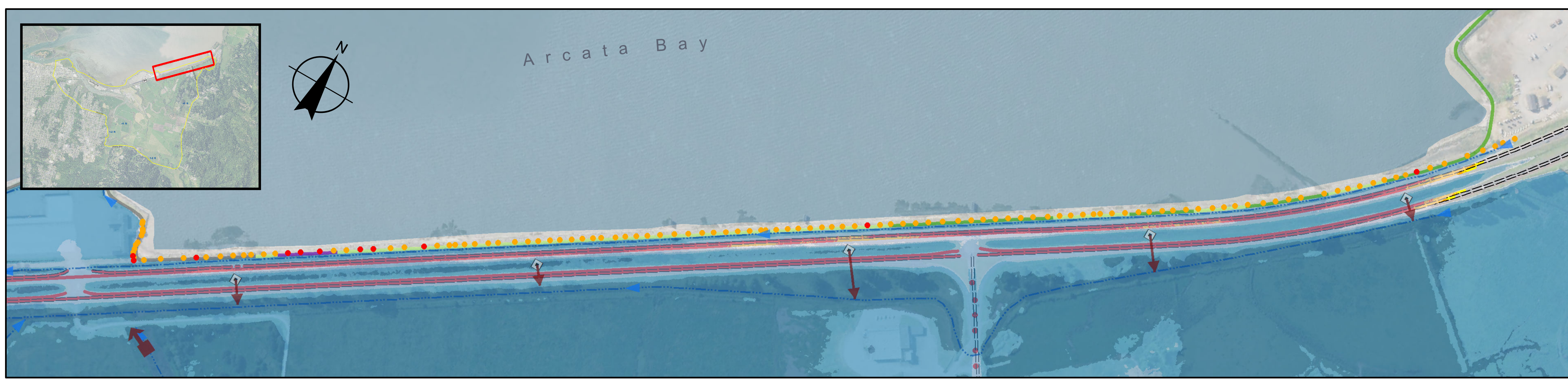
Tidal Still Water
(Wind Setup and Wind Waves Not Present)
Streams and Drainage
Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

- Significant Erosion
- Moderate Erosion
- Vegetated or Vegetated RSP
- Armored
- Partially Breached Levee







Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion

Travel Lane Flood Depth | Duration | Response

- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

Temporary Cell Flooding

Approximate Flood Depth from Overtopping

- < 0.5 ft
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 6 ft
- >6 ft

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.

Paper Size ANSI B

0 250 500 750 1,000
Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 6
Bay Shoreline

Project No. 11191743
Revision No. -
Date 3/9/2021

EXHIBIT HS 6-2

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Print date: 09 Mar 2021 - 14:52
Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 6A

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
11.6 feet NAVD	**Existing (2012 baseline)** >500-year <0.5% chance per year	**1 foot** 100-year 1% chance per year	**1.5 feet** 10-year 10% chance per year	**2.5 feet** 2-year 50% chance per year

Introduction (See Exhibit HS 6A-1):

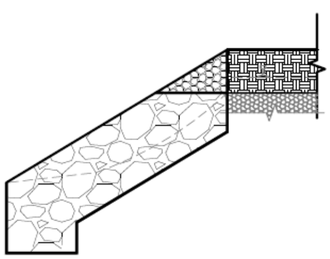
This case study describes a scenario that incorporates planned future conditions of the Arcata Bay shoreline with the rail prism elevated to 11.5 feet (NAVD) and rock slope protection along the bay-facing bank. Hydraulic conditions are the same as Scenario 6 with an extreme high tide and no significant wind or fluvial flood conditions. This extreme tide still overtops the rail prism along Arcata Bay, but prevents flooding of Highway 101 and significantly reduces flooding of the Cell A interior. The extreme tide affects other cells along interior sloughs, similar to Scenario 6, with widespread overtopping of levees, flooding of multiple smaller roadways, developed and agricultural areas. Approximately 1,800 feet of interior slough levees are exposed to high potential of failure and breaching conditions with overtopping of greater than 1 foot for greater than 2 hours.

The Planned Humboldt Bay Trail South will Increase the Elevation and Improve Rock Slope Protection Along the Bay Shoreline.

Highlighted shoreline processes in this scenario include slope failure/erosion of bay/slough facing slopes, overtopping and landward slope erosion, and channel adjustment due to high breach potential. Conceptual examples shown below.

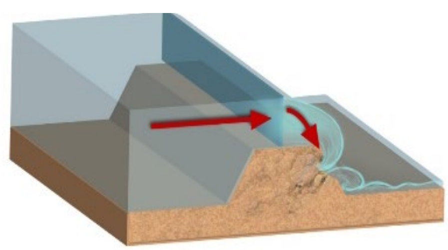
Revetment and Elevation

Arcata Bay Shoreline
Rail Prism



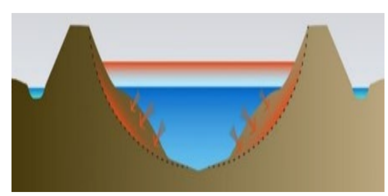
Overtopping/Erosion

Volume Reduced along Arcata Bay Shoreline
47% of Interior Slough Levees



Channel Adjustment with Breach

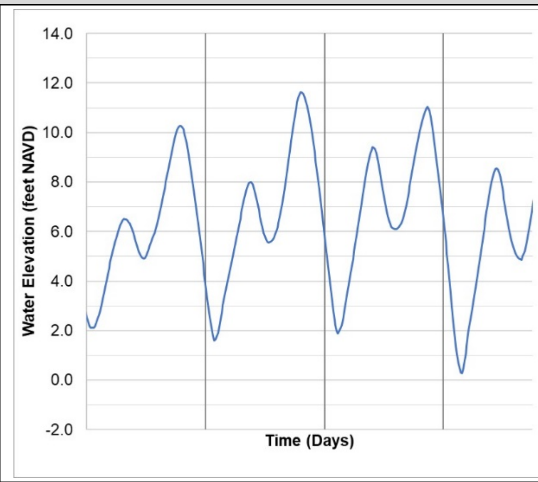
1,800 feet of Significant Overtopping resulting in High Potential for Breach and downstream channel adjustment



Example Shoreline Structure Response (National Science Foundation, 2020)

Hydraulics and Sea Level Rise:

This scenario includes potential future extreme spring tides that typically occur in the months from November through January, where extreme high and low tides occur over multiple days in combination with a low-pressure system (storm surge) that increases predicted tidal water levels entering Humboldt Bay. Low tide elevations are elevated due to sea level rise. In the days preceding the storm, extreme tidal water levels are observable. Based on predicted tides by NHE 2019 leading up to the still water event, high tide reaches 10 feet (NAVD) the day prior to the peak of 11.6 feet (NAVD) and 11 feet (NAVD) the following day.[1]. Water levels are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 11.6 feet (NAVD), with variable amounts of sea level rise, are presented at the top of this page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 6A Hydraulics		
Tidal Still Water Level	11.6 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	Height: 0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	11.6 ft NAVD	
Fluvial Flows	Winter Base Flow from tributaries	

Antecedent Shoreline Conditions:

This scenario assumes planned shoreline elevations and condition associated with the County's Humboldt Bay Trail South Project along Arcata Bay. For all other shorelines, existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, these hydraulic conditions are considered to be rare, exceeding the highest observed tide affecting the Study Area. Photos and observations of similar, but smaller events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 6A-1 and described in this case study. Modeled overtopping volume of the Bay Shoreline was removed to represent future conditions. Exhibit HS 6A-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

HAZARD SCENARIO 6A

Interior Shoreline

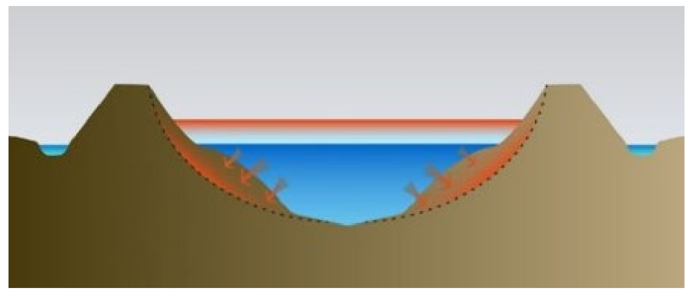
This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Overtopping of tidal waters occurs along all slough channels and all cells, typically totaling hundreds to thousands of feet protecting each cell. Exhibit HS 6-1 shows the locations, depth and duration of shoreline overtopping. Levees protecting Cells A, B, C, E, F, G and the area upstream of Myrtle are all subject to significant overtopping, exceeding 1 foot of depth and 2 hours in duration. The extent of significant overtopping is typically hundreds of feet.

Resource Response and Impacts:

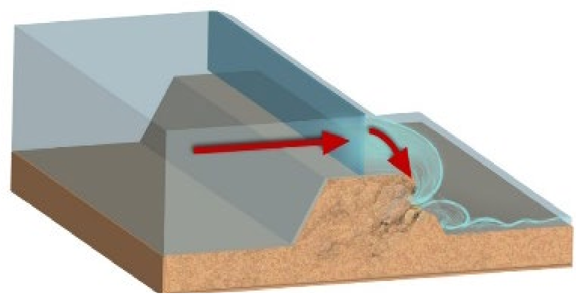
Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.



Conceptual Channel Adjustment with Breach Event

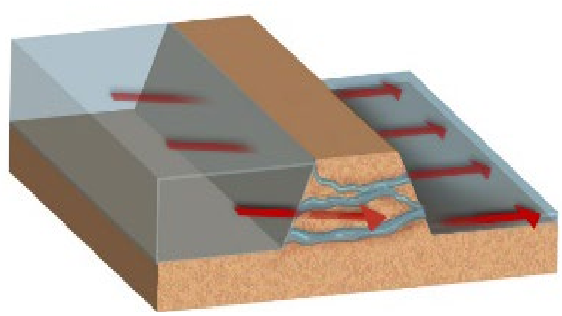
Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.



Overtopping creates erosion on top and backside (above) (National Science Foundation, 2020)

The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.



Sustained erosion, differentials in water levels, and levee material can contribute to internal erosion and piping (National Science Foundation, 2020)

HAZARD SCENARIO 6A

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

<u>Hydraulic Conditions:</u>

Overtopping occurs during multiple high tides on sequential days. The extent of levee, rail prism and roadway overtopping results in tidal waters entering all cells, and exceeds the capacity of existing drainage channels, flooding agricultural lands in Cells A, B, C, E, F, G, and upstream of Myrtle on Ryan Slough. The depth and water surface elevation of flooding for each cell are summarized in Table 3, at the end of this case study. Flooding is typically between 3 to 7 feet deep, with multiple cycles of flooding and draining occurring in each cell. Subsequent high tides and limited duration of low tides impound stall and slow drainage.

Tidal flooding of Cell A as a result of rail prism overtopping is significantly reduced, from 4,700 acre-feet to 10 acre-feet. The capacity of the drainage ditch along the eastern edge of Highway 101 has adequate capacity, and flooding of low-lying lands is largely limited to the 300 acre-feet of tidal overtopping along Fay Slough. Water levels within the cell are reduced from 11.3 feet (NAVD) to 5.1 feet. Developed areas, roadways, and sewer pump stations located along Jacobs Avenue, Brainard, Airport Road, Murray Field, Harper Motors and Indianola Cutoff no longer flood.

In other cells, repetitive tidal inundation occurs during multiple high tides. Tidal flooding in Cell G reaches the higher elevation areas at the end of Edgewood Road. Tidal flooding of Cell B rise to the elevation of Myrtle Avenue, flooding the roadway. Multiple days are required to drain the tidal flooding due to the limited duration of favorable drainage conditions.

Flooding encroaches on the developed areas adjacent to First, Second and Third Slough, protected by a natural elevation gradient. Up to 2.5 feet of flooding affects the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street, 2nd Street and 4th Street. HCSD's sewer pump station and residences on Bay Street experience more than 2 feet of flooding

<u>Resource Response and Impacts:</u>

The developed areas adjacent to First, Second and Third Slough experience 2.5 feet of flooding, largely restricting access and causing damage to facilities and contents. Dangerous conditions exist throughout the Study Area, throughout the duration of overtopping, flooding and draining and the ability to access or assess damages is minimal. Drainage of interior areas may be delayed by further delayed by the accumulation of debris carried and deposited in drainage ditches by flooding. Short duration flooding of tidal waters do not result in lasting impacts to pastures or utilities, however the high potential for levee failure and breaching suggest that some areas will have lasting impacts, changing the management options available for the land.

The levees protecting cells A, B, C, E, F, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

HAZARD SCENARIO 6A

Scenario Summary:

The planned elevation and rock slope protection along the rail prism significantly reduces the volume of overtopping and extent of erosion along the Bay Shoreline. This future, proposed condition also prevents highway flooding and reduces the depth of flooding in Cell A. However, the extreme tides result in widespread shoreline overtopping and flooding throughout the rest of the Study Area. Multiple roadways, including Myrtle Avenue and smaller local roadways including Park Street, Tydd Street, the Waterfront Trail, Hoover Street, Edgewood Road, Y Street, 2nd Street and 4th Street. Dangerous conditions exist throughout the lowlands protected by levees with flooding reaching multiple feet deep. Rill erosion on the tops and backs of levees is widespread. Approximately 1,800 feet of levee is exposed to conditions that result in a high potential for failure and breaching requiring extensive repairs and cleanup to restore pre-event conditions and flood protection throughout the Study Area.

The entire rail prism is overtopped along the Bay Shoreline but the volume is reduced from 4,700 acre-feet to 10 acre-feet by the proposed rail prism elevation (Table 2). Myrtle Avenue/Old Arcata Road, as well as Highway 255 at Mad River Slough, experience up to 1 foot of flooding, eliminating alternate routes around the bay until water levels recede. Ingress and egress routes in Cell A are maintained.

Overtopping along the Interior Shoreline is widespread (Table 2 and Table 3). Levees protecting Cells A, B, C, E, F, G and on Ryan Slough upstream of Myrtle are subject to overtopping that exceeds 1 foot of depth and 2 hours in duration. These conditions pose a high potential for levee failure and breaching. In the event of a levee breach, the cell may be subject to inundation from daily tides and increase erosive forces along the interior shoreline, between the breach and Arcata Bay. Drainage of the cell occurs over multiple days, adding potential failure of levees due to seepage.

The developed areas adjacent to First, Second and Third Slough exhibit similar flood impacts, including the Shoreline RV Park at the end of 6th Street, the City of Eureka's Waterfront Trail and Hill Street sewer pump station off Tydd Street, as well as Y Street and 2nd Street. HCSD's sewer pump station and residences on Bay Street experience more than 2 feet of flooding. Flooding also propagates onto Edgewood Road and Myrtle Avenue. Low elevation lands within the other cells experience multiple feet of flooding and do not result in lasting impacts to pastures or utilities. However, The levees protecting cells A, B, C, E, F, G and on Ryan Slough upstream of Myrtle are subject to overtopping depth and duration that poses a high potential for failure and breaching. In the event of a breach, the cell is subject to daily tidal flooding and significant changes to the level of access and land management capabilities.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 6A

Table 2. Overtopping Summary for Bay Shoreline

<table>
<tr><th colspan="9">Bay Shoreline</th></tr>
<tr><th>Cell A</th><th>Location</th><th>Structure</th><th colspan="2">Overtopping (LF[1] | %)</th><th>Significant Overtopping (LF)</th><th>Volume Overtopping (ac-ft)</th><th>Typical Flood Depth (ft)</th><th>Max Interior Water Level (ft)</th></tr>
<tr><td rowspan="4">Bay</td><td rowspan="2">Eureka Slough to Brainard</td><td>Hwy 101</td><td>-</td><td>0%</td><td>-</td><td rowspan="4">10</td><td rowspan="6">Jacobs Ave 0.25 ft,

Fay Slough Wildlife Area 1 to 2 ft</td><td rowspan="6">5.1</td></tr>
<tr><td>Rail Prism</td><td>6,454</td><td>99%</td><td>-</td></tr>
<tr><td>Brainard Levee</td><td>Levee</td><td>693</td><td>13%</td><td>-</td></tr>
<tr><td>Brainard to Indianola Cutoff</td><td>Rail Prism</td><td>6,923</td><td>100%</td><td>-</td></tr>
<tr><td rowspan="2">Slough</td><td>Fay Slough</td><td>Levee</td><td>8,880</td><td>57%</td><td>136</td><td>216</td></tr>
<tr><td>Eureka Slough</td><td>Levee</td><td>2,987</td><td>45%</td><td>-</td><td>84</td></tr>
</table>

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

<table>
<tr><th colspan="7">Interior Shoreline & Protected Lands</th></tr>
<tr><th>Cell</th><th>Location</th><th colspan="2">Overtopping (LF | %)</th><th>Significant Overtopping (LF)</th><th>Approx. Flood Depth (ft)</th><th>Max Interior Water Level (feet NAVD)</th></tr>
<tr><td>B</td><td>Fay Slough</td><td>270</td><td>97%</td><td>135</td><td>3.5 to 4.5</td><td>10.0</td></tr>
<tr><td>C1</td><td>Fay Slough</td><td>6,008</td><td>54%</td><td>313</td><td>1.8 to 3.8</td><td>8.2</td></tr>
<tr><td></td><td>Freshwater Slough</td><td>5,513</td><td>54%</td><td>308</td><td></td><td></td></tr>
<tr><td>C2</td><td>Freshwater Slough</td><td>2,396</td><td>41%</td><td>-</td><td>0 to 1.8</td><td>8.2</td></tr>
<tr><td>D[2]</td><td>Freshwater Slough</td><td>3,431</td><td>75%</td><td>407</td><td>1.1 to 3.1</td><td>10.6</td></tr>
<tr><td>E</td><td>Freshwater Slough</td><td>2,024</td><td>78%</td><td>146</td><td>3.7 to 4.7</td><td>10.7</td></tr>
<tr><td>F</td><td>Ryan Slough</td><td>1,316</td><td>39%</td><td>-</td><td>4.3 to 5.3</td><td>10.3</td></tr>
<tr><td></td><td>Freshwater Slough</td><td>181</td><td>18%</td><td>6</td><td></td><td></td></tr>
<tr><td>G</td><td>Freshwater Slough</td><td>2,483</td><td>42%</td><td>35</td><td>4.9 to 5.4</td><td>10.8</td></tr>
<tr><td></td><td>Park Street</td><td>530</td><td>86%</td><td>289</td><td></td><td></td></tr>
<tr><td></td><td>Ryan Slough</td><td>1,721</td><td>73%</td><td>48</td><td></td><td></td></tr>
<tr><td>H</td><td>Freshwater Slough</td><td>289</td><td>13%</td><td>-</td><td>0 to 0.6</td><td>6.1</td></tr>
<tr><td></td><td>Eureka Slough</td><td>294</td><td>7%</td><td>-</td><td></td><td></td></tr>
<tr><td>I[2]</td><td>Eureka Slough</td><td>-</td><td></td><td>-</td><td>0 to 2.6</td><td>11.6</td></tr>
<tr><td>Myrtle</td><td>Ryan Slough</td><td>1,476</td><td>36%</td><td>75</td><td>2.7 to 4.7</td><td>10.7</td></tr>
</table>

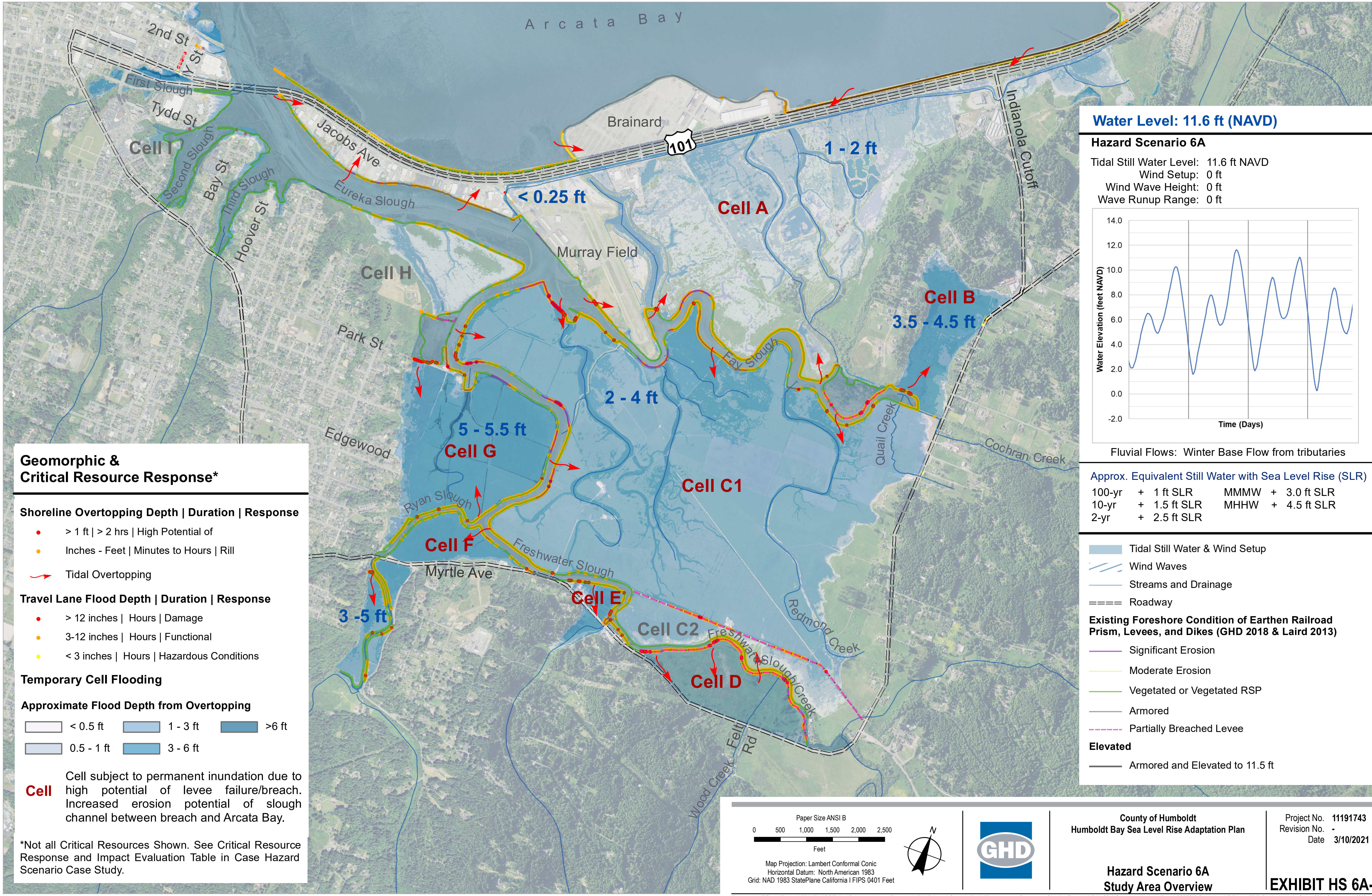
HAZARD SCENARIO 6A

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	Potential Failure
			Cell B	>1ft and >2 hrs	Potential Failure
			Cell C	>1ft and >2 hrs	Potential Failure
			Cell E	>1ft and >2 hrs	Potential Failure
			Cell F	>1ft and >2 hrs	Potential Failure
			Cell G	>1ft and >2 hrs	Potential Failure
			Cell H	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	shallow (<1ft) and/or short (< 2hrs)	Top and Land-facing Slope Rill Erosion
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	-	none
	Hwy 101 Northbound		Cell A - Arcata Bay	-	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	0.3	Closure
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G	3.6	Closure & Damage
	Hoover Street		Cell I	2.0	Closure & Damage
	2nd and Y Streets		Cell I	1.7	Closure & Damage
	4th, 5th, 6th, V St		Cell I	0.0	none
	Myrtle Ave		Cells B, C, F, D	0.3	Closure
	Hwy 255 (Alternate Route)		Arcata Bay	1.2	Closure & Damage
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	0.64	Limited Access
			City of Eureka Hill Street (Tydd Street)	1.66	Limited Access
			Humboldt CSD Hoover Street	1.66	Limited Access
			Humboldt CSD Edgewood	0.62	Limited Access
	Water Booster Station		City of Eureka Myrtle Ave	1.37	Limited Access
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	-	none

HAZARD SCENARIO 6A

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
			Cell I Hoover St - HCSD	19	Limited Access < 1 Day
	Sewer Gravity Main		Cell I Hoover St - HCSD	19	Limited Access < 1 Day
	Gas Main		Cell G	96	Limited Access Multiple Days
			Cell C	113	Limited Access Multiple Days
			Cell A	12	Limited Access < 1 Day
	Communications (Underground)		Cell A	12	Limited Access < 1 Day
	Communication Towers/Poles		Cell H	9	Limited Access < 1 Day
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	0.3	Shallow Flooding
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	0.3	Shallow Flooding
			Rainbow Storage Indianola Cutoff	0.0	none
			2nd and Y Street	1.7	**Damage/Stranding**
			6th and Tydd Street	0.0	none
			Hoover Street	2.0	**Damage/Stranding**
			Park Street	3.6	**Damage/Stranding**
			Edgewood	0.6	Shallow Flooding
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	12	Limited Access < 1 Day
			Cell B	80	**Limited Access Multiple Days**
			Cell C	113	**Limited Access Multiple Days**
			Cell E	90	**Limited Access Multiple Days**
			Cell F	53	**Limited Access Multiple Days**
			Cell G	96	**Limited Access Multiple Days**
			Cell H	9	Limited Access < 1 Day
			Ryan Slough Upstream of Myrtle	57	**Limited Access Multiple Days**



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Print date: 10 Mar 2021 - 21:05

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 7

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
12.6 feet NAVD	**Existing (2012 baseline)** Extremely Unlikely	**2 feet** 100-year 1% chance per year	**2.5 feet** 10-year 10% chance per year	**3.5 feet** 2-year 50% chance per year

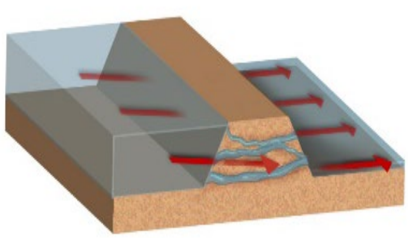
Introduction (See Exhibit HS 7-1):

This case study describes a scenario characterized by an extreme high tide, elevated low tides, and no significant wind or fluvial flood effects. An extreme tide of this magnitude is not known to have occurred in recent history. Based on historical accounts, the extent of flooding described in this scenario likely exceeds the descriptions of the November 24, 1885 water levels that were likely a result of a tsunami. This scenario is intended to describe potential future extreme conditions that affect the entire Study Area and alternate transportation routes around Humboldt Bay. This extreme tide overtops nearly the entire shoreline of the Study Area. Overtopping volumes flood all cells resulting in multiple feet of tidal flooding. All landforms under elevation 12.3 to 12.5 feet (NAVD) are submerged, with little difference in water levels between tidal sloughs, the bay and protected lands. Overtopping occurs on consecutive days, some days multiple times. Developed areas near the shoreline and in protected areas are typically flooded with four to eight feet of tidal water. Overtopping of levees and the rail prism result in rapid flooding of interior cells, creating life-safety hazards and flooding ingress and egress routes. Flooding results in multiple days of closure to Highway 101, alternate routes around the bay including Myrtle Avenue and Highway 255, as well as multiple smaller roadways, such as Tydd Street, Hoover Street, Y Street, 2nd, 4th, 5th and 6th Streets. Post event cleanup and reconstruction of multiple roadways is required. Flooding takes multiple days to drain, increasing the potential for levee failure due to saturation/seepage. Damage to the rail prism and levees requires extensive repairs to restore existing flood protection levels. Approximately 4.3 miles of rail prism and interior slough levees are overtopped with enough depth and for a long enough duration to meet criteria for a high probability of failure and breaching.

Highlighted shoreline processes in this scenario include slope failure/erosion of bay/slough facing slopes, overtopping and landward slope erosion, and channel adjustment due to high breach potential. Conceptual examples shown below.

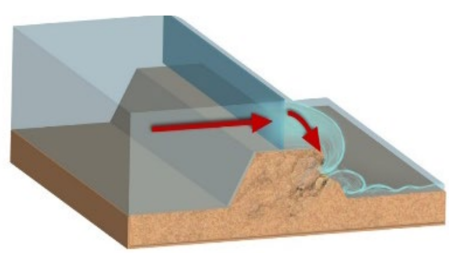
Internal Erosion/Seepage

Arcata Bay Shoreline
Interior Shoreline



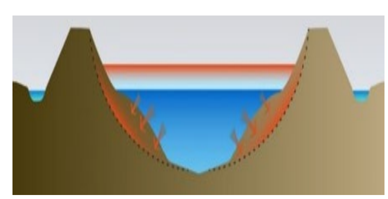
Overtopping/Erosion

83% of Arcata Bay Shoreline
94% of Interior Slough Levees



Channel Adjustment with Breach

4.3 miles of Significant Overtopping resulting in High Potential for Breach and downstream channel adjustment



Example Shoreline Structure Responses (National Science Foundation, 2020)

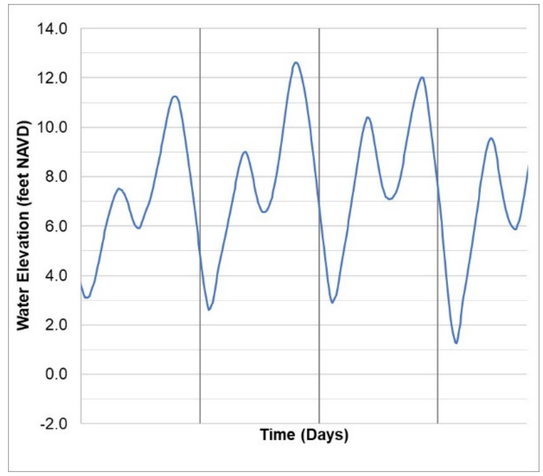
Hydraulics and Sea Level Rise:

This scenario includes potential future extreme spring tides that typically occur in the months from November through January, where extreme high and low tides occur over multiple days in combination with a low-pressure system (storm surge) that increases predicted tidal water levels entering Humboldt Bay. Low tide elevations are elevated due to sea level rise. In the days preceding the storm, extreme tidal water levels are observable. Based on predicted tides by NHE 2019 leading up to the still water event, high tide reaches 11 feet (NAVD) the day prior to the peak of 12.6 feet (NAVD) and 12 feet (NAVD) the following day.[1]. Water levels are referenced to 2012

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 12.6 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

Table 1: Scenario 7 Hydraulics

Tidal Still Water Level	12.6 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	Height: 0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	12.6 ft NAVD	
Fluvial Flows	Winter Base Flow from tributaries	

Antecedent Shoreline Conditions:
This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018.

Response:
The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, these hydraulic conditions are considered to be rare, exceeding the highest observed tide affecting the Study Area. Photos and observations of similar, but smaller events and engineering judgement were used to support the hydraulic assumptions and modeling results shown on the scenario Exhibit HS 7-1 and described in this case study. Exhibit HS 7-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

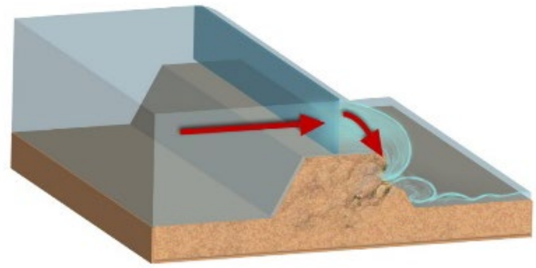
HAZARD SCENARIO 7

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101.

Hydraulic Conditions:

In the days leading up to the peak tidal water level, overtopping and flooding occur, similar to Scenario 5 and 6. The peak tidal still water level reaches 12.6 feet (NAVD) and is followed by a tide of 12 feet (NAVD). The entire railroad prism from Eureka Slough north and a large section of the southern Brainard levee. The capacity of the drainage channel between the southbound travel lanes of Highway 101 and the rail prism is exceeded. Highway 101 southbound lanes throughout the study area are flooded during the peak tides. Tidal flooding flows into the median ditch, where it is conveyed east to the ditch east of the highway and combines with overtopping flow from Fay Slough and Eureka Slough, eventually reaching a water level of 12.5 feet (NAVD) and flooding the northbound lanes as well. Overtopping of the railroad prism exceeds 1 foot depth and lasts for more than 2 hours resulting in a high potential for failure. Exhibit HS 7-1 shows the locations, depth and duration of shoreline overtopping associated with peak water levels for this scenario.



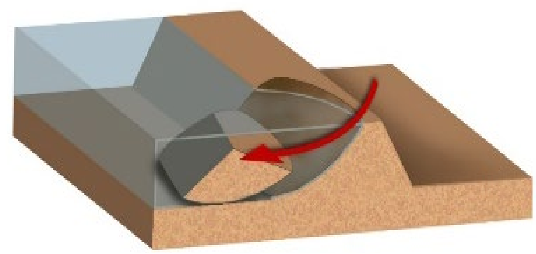
Example Overtopping and Erosion (National Science Foundation, 2020)

Resource Response and Impacts:

The physical response of the Bay Shoreline under this scenario will vary based on the existing shoreline condition. Anticipated responses are described below. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

Rail Prism: The extensive overtopping of the rail prism and observed composition, results in expected slope failures and significant rill erosion. The lack of cohesion within the ballast material would likely cause sloughing of the bank and movement of material down the slope. Overtopping of the rail prism by continuous flow will result in rill erosion across the top and land-facing slope. Damages that go unrepaired are subject to the following:

- Increased potential of saturation/seepage due to reduced levee width.
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.



Example Slope Failure from Sloughing (National Science Foundation, 2020)

Rill Erosion of Railroad Prism Top and Backslope Due to Overtopping

Highway 101: Overtopping results in flooding of the all lanes of Highway 101 with more than 1 foot depth of tidal waters. Dangerous conditions and eventually closure result for multiple days. Erosion along the landward slope of the southbound Highway prism is likely, requiring repairs. Significant clean up is required following the event. Drainage channels require inspection and removal of debris and sediment at drainage structures such as culverts and tide gates.

HAZARD SCENARIO 7

Interior Shoreline

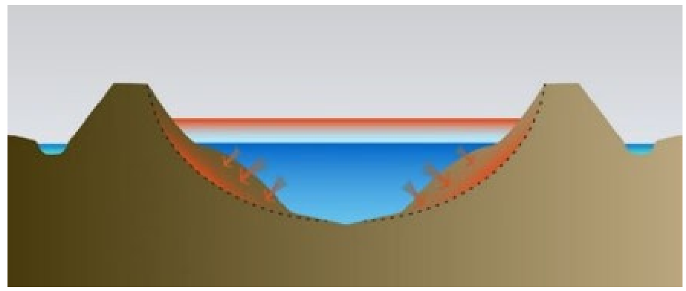
This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

<u>Hydraulic Conditions:</u>

Overtopping of tidal waters occurs along all slough channels and all cells, typically totaling hundreds to thousands of feet protecting each cell. Exhibit HS 6-1 shows the locations, depth and duration of shoreline overtopping. Levees protecting Cells A, B, C, E, F, G and the area upstream of Myrtle are all subject to significant overtopping, exceeding 1 foot of depth and 2 hours in duration. The extent of significant overtopping is typically hundreds of feet.

<u>Resource Response and Impacts:</u>

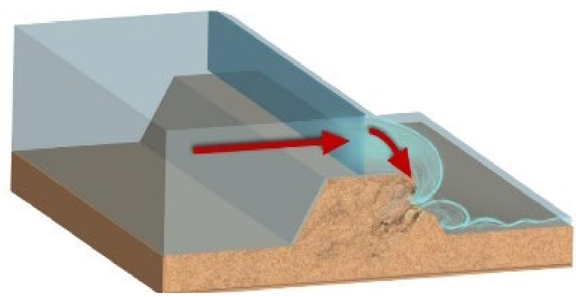
Overtopping of greater than 1 foot for greater than 2 hours results in conditions categorized as a high potential for failure that also change the hydraulics of the Study Area. As the failure (breach) allows tidal waters to exchange between the slough channel and Protected Lands, an increased volume of tide water travels through the slough channel(s) at increased speed, which increases the erosion potential along the interior shoreline between the breach and Arcata Bay. However, based on historical knowledge of the similar event providing the basis of this scenario, no failures are known to have occurred.



Conceptual Channel Adjustment with Breach Event

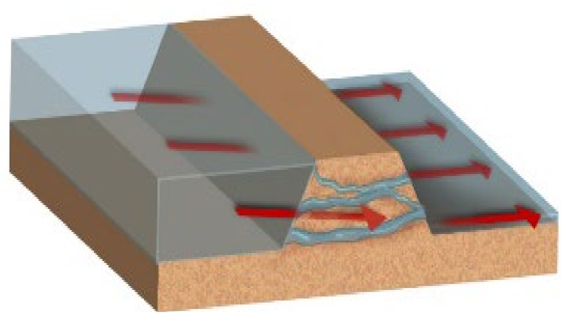
Overtopping of unarmored earthen levees induce shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion and at locations where penetrations, such as tide gates, are present. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.



Overtopping creates erosion on top and backside (above) (National Science Foundation, 2020)

The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.



Sustained erosion, differentials in water levels, and levee material can contribute to internal erosion and piping

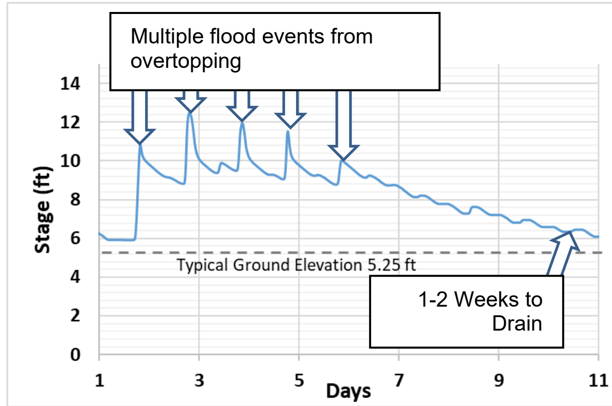
(National Science Foundation, 2020)

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions:

Exhibit HS 7-1 depicts the approximate maximum flood depth, based on volume of overtopping, for each cell. Overtopping of levees occurs in all cells, exceeding the capacity of existing interior drainage channels, flooding each cell with multiple feet of tidal waters, with additional overtopping and inundation occur before the cell has drained. The depth and duration of flooding for each cell are summarized in Table 3, at the end of this case study. Multiple high tides overtop levees, requiring one to two weeks to drain tidal flooding. In Cell A, tidal waters flowing over the rail prism and highway combine with overtopping from Fay and Eureka Sloughs resulting in an interior water level 12.5 feet (NAVD), with most levee crests submerged.



Multiple Overtopping Events, Followed by Multiple Days to Drain the Protected Lands

In other cells similar repetitive tidal inundation occurs during the peak tide and high tides overtopping lower elevation levees in the days leading up to the event and days following. Flooding is typically between three and six feet deep and takes one to two weeks to drain and retreat to within existing drainage channels.

Developed areas adjacent to First, Second and Third Slough, protected by a natural elevation gradient, also experience tidal flooding up to elevation 12.6 NAVD. Residential and commercial development, as well as public utility infrastructure such as sewer pump stations, roadways, and underground utilities are located within the elevation range 9 to 11 feet (NAVD), resulting in approximately 1.5 to nearly 3.5 feet of tidal flooding. Tidal flooding migrates onto Y Street, 2nd, 4th, 5th, and 6th Streets, as well as Tydd Street Hoover Street Edgewood, Myrtle Avenue and Indianola Cutoff.

Resource Response and Impacts:

Due to the magnitude, frequency and duration of overtopping and high tides, combined with lower land elevation protected by levee, nearly the entire Study Area experiences significant flooding. The magnitude and repetitive flooding and hydraulic conditions are not favorable for drainage of flood waters with increased low tides due to sea level rise and the repetitive high tides. Overtopping to Cell A results in flooding of three to eight feet of flooding in the developed areas, causing widespread damage. Overtopping rapidly floods all roadways providing ingress and egress in Cell A, resulting in extremely dangerous conditions for motorists on Highway 101 and residences and business within the cell. In other cells, while largely agricultural, all ingress and egress routes are flooded. Similarly, the rapidly rising tide floods the lower elevation, developed areas along First, Second and Third Slough. Tidal flooding migrates onto Myrtle Avenue, near Indianola Cutoff, eliminating alternate travel ways around the bay. Access is limited or prevented to repair levees, tend to utilities, or access developed areas for one to two weeks or more. Drainage of interior areas may be further delayed by accumulation of debris carried and deposited in drainage ditches by flooding. The depth and duration of overtopping and flooding likely results in partial or full levee failures, reducing future flood protection and resulting in lasting impacts to pastures and utilities as daily tidal inundation may occur.

The City of Eureka sewer pump stations along Jacobs Avenue and near Tydd Street experience two to six feet of flooding. The City of Eureka's Y Street sewer pump station is exposed to 1.5 feet of flooding.The City of Eureka Water Booster Station experiences nearly three feet of tidal flooding. The HCSD sewer pump stations on Edgewood Road and off Hoover Street experience 2.5 feet of flooding.

HAZARD SCENARIO 7

Scenario Summary:

The extreme tides result in widespread shoreline overtopping and flooding throughout the Study Area. Multiple roadways, including Highway 101, Myrtle Avenue and smaller local roadways including Jacobs Avenue, Airport Road, Park Street, Tydd Street, the Waterfront Trail, Hoover Street, Edgewood Road, Y Street, 2nd Street and 4th Street. Dangerous, life safety conditions exist throughout the lowlands protected by levees with flooding reaching more than five feet deep. The rail prism and levees show signs of partial failure and erosion including sloughing. Rill erosion on the tops and backs of levees is widespread. Approximately 4.3 miles of levee and rail prism is exposed to a high potential for failure and breaching requiring extensive repairs and cleanup to restore pre-event conditions and flood protection throughout the Study Area.

The entire rail prism is overtopped and exhibits a high potential for failure along the Bay Shoreline (Table 2). Highway 101 is flooded with multiple feet of tidal water. All lanes of Highway 101 are flooded within an hours of overtopping and lasts for nearly one week. Myrtle Avenue/Old Arcata Road, as well as Highway 255 at Mad River Slough, experiences up to 2 feet of flooding, eliminating alternate routes around the bay until water levels recede. Ingress and egress routes are flooded throughout the Study Area.

Flooding in the developed areas along Jacobs Avenue, Murray Field and Brainard is typically three to eight feet, resulting in wide spread damage to all development and residences. Interior levees and Park Street are overtopped, flooding large areas of agricultural pastures with tidal waters (Table 3). Overtopping depth and duration vary, with numerous locations exhibiting a high potential for failure from overtopping erosion, followed by potential of structural failure due to seepage/internal erosion as the levees area saturated and flood waters are stored within the cell. Access to levees and utilities throughout the Study Area is limited and extremely dangerous conditions are present.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 7

Table 2. Overtopping Summary for Bay Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	5,170	86%	-	240	Jacobs Ave 4.5 to 7 ft, Fay Slough Wildlife Area 7.5 to 8.5 ft	12.5
		Rail Prism	6,493	100 %	4,946			
	Brainard Levee	Levee	2,289	41%	240	507		
	Brainard to Indianola Cutoff	Rail Prism	6,923	100 %	6,495	5,589		
Slough	Fay Slough	Levee	13,916	90%	4,238	1,679		
	Eureka Slough	Levee	5,399	81%	153	657		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	279	100%	215	5.9 to 6.9	12.3
C1	Fay Slough	9,669	88%	2,069	5.9 to 7.9	12.3
	Freshwater Slough	9,419	92%	2,445		
C2	Freshwater Slough	5,375	92%	-	2.9 to 5.9	12.3
D[2]	Freshwater Slough	4,520	99%	1,069	2.9 to 4.9	12.3
E	Freshwater Slough	2,472	95%	81	5.4 to 6.4	12.3
F	Ryan Slough	2,998	89%	-	6.4 to 7.4	12.3
	Freshwater Slough	889	91%	-		
G	Freshwater Slough	4,215	72%	252	6.4 to 6.9	12.3
	Park Street	553	90%	340		
	Ryan Slough	2,129	90%	54		
H	Freshwater Slough	1,352	60%	-	5.9 to 6.9	12.3
	Eureka Slough	3,320	77%	26		
I[2]	Eureka Slough	-		-	0 to 3.6	12.6
Myrtle	Ryan Slough	4,136	100%	267	4.4 to 6.4	12.3

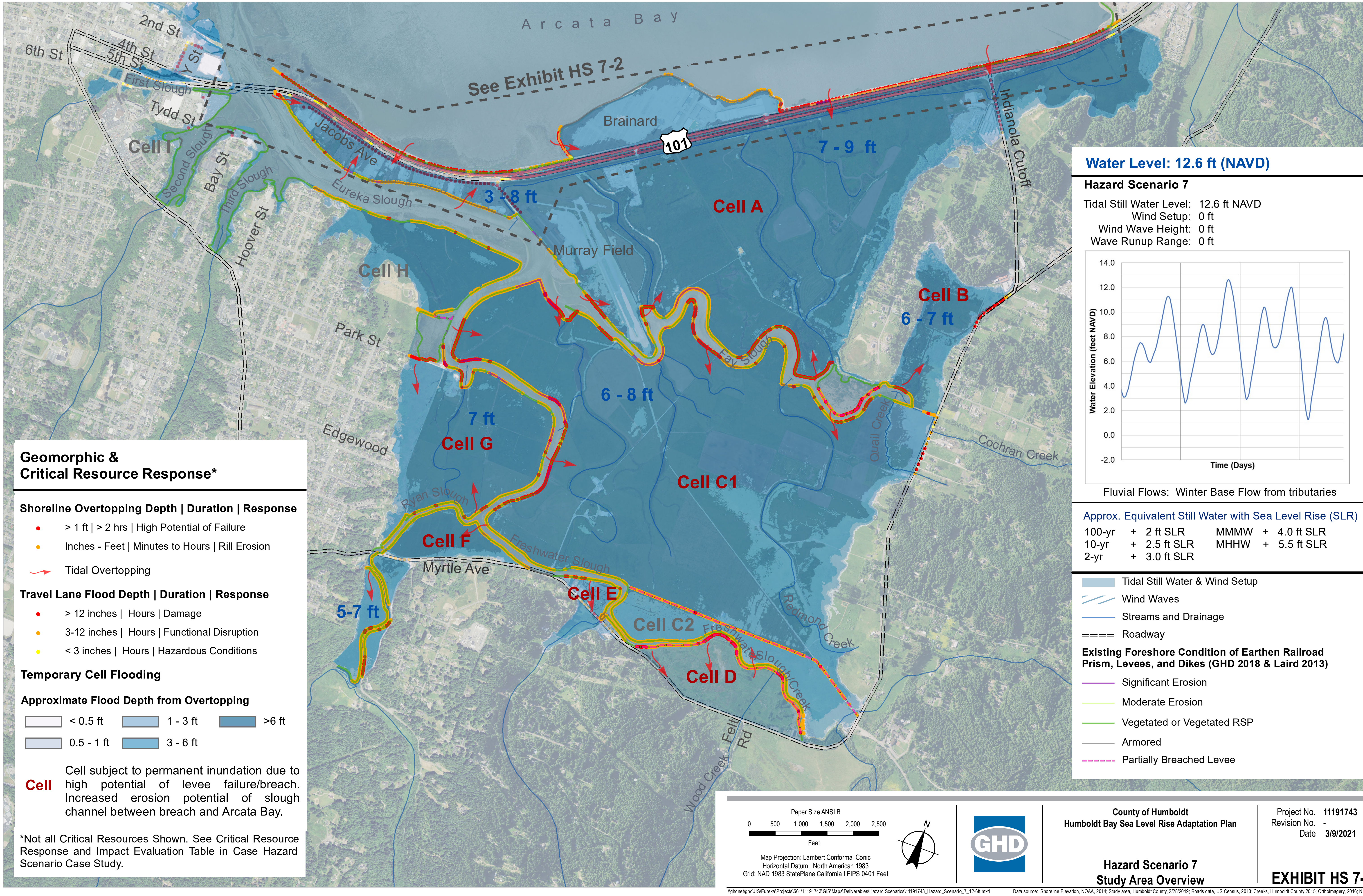
HAZARD SCENARIO 7

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	**Earthen Levees/ Dikes**	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	**Potential Failure**
			Cell B	>1ft and >2 hrs	**Potential Failure**
			Cell C	>1ft and >2 hrs	**Potential Failure**
			Cell E	>1ft and >2 hrs	**Potential Failure**
			Cell F	>1ft and >2 hrs	**Potential Failure**
			Cell G	>1ft and >2 hrs	**Potential Failure**
			Cell H	>1ft and >2 hrs	**Potential Failure**
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	>1ft and >2 hrs	**Potential Failure**
Transportation	**Hwy 101 Southbound**	Surface Flooding (ft)	Cell A - Arcata Bay	4.4	**Closure & Damage**
	Hwy 101 Northbound		Cell A - Arcata Bay	3.9	**Closure & Damage**
	Jacobs Ave		Cell A (ft)	6.9	**Closure & Damage**
	Airport Road		Cell A	8.7	**Closure & Damage**
	Indianola Cutoff		Cell A	4.5	**Closure & Damage**
	Park Street		Cell G	4.6	**Closure & Damage**
	Hoover Street		Cell I	3.0	**Closure & Damage**
	2nd and Y Streets		Cell I	2.7	**Closure & Damage**
	4th, 5th, 6th, V St		Cell I	1.3	**Closure & Damage**
	Myrtle Ave		Cells B, C, F, D	2.6	**Closure & Damage**
	Hwy 255 (Alternate Route)		Arcata Bay	2.2	**Closure & Damage**
Utilities	**Sewer Lift Stations**	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	5.8	**Potential Inflow/Overflow/Damage**
			City of Eureka Jacobs Ave #2	5.9	**Potential Inflow/Overflow/Damage**
			City of Eureka Y Street	1.6	**Limited Access**
			City of Eureka Hill Street (Tydd Street)	2.7	**Potential Inflow/Overflow/Damage**
			Humboldt CSD Hoover Street	2.7	**Potential Inflow/Overflow/Damage**
			Humboldt CSD Edgewood	2.1	**Potential Inflow/Overflow/Damage**

HAZARD SCENARIO 7

	Critical Resource	Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
	Water Booster Station		City of Eureka Myrtle Ave	2.9	**Potential Inflow/Overflow/Damage**
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	674	**Limited Access > 1 week**
			Cell I Hoover St - HCSD	30	**Limited Access Multiple Days**
	Sewer Gravity Main		Cell I Hoover St - HCSD	30	**Limited Access Multiple Days**
	Gas Main		Cell G	105	**Limited Access Multiple Days**
			Cell C	95	**Limited Access Multiple Days**
			Cell A	674	**Limited Access > 1 week**
	Communications (Underground)		Cell A	674	**Limited Access > 1 week**
	Communication Towers/Poles		Cell H	45	**Limited Access Multiple Days**
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	6.9	**Potential Loss of Property/Life**
			Murray Field	5.3	**Potential Loss of Property/Life**
			Harper Motors	5.3	**Potential Loss of Property/Life**
			Brainard	4.4	**Damage/Stranding**
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	2.7	**Damage/Stranding**
			6th and Tydd Street	1.3	**Damage/Stranding**
			Hoover Street	3.0	**Damage/Stranding**
			Park Street	4.6	**Damage/Stranding**
			Edgewood	2.1	**Damage/Stranding**
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	674	**Potential Changes to Land Management**
			Cell B	96	**Limited Access Multiple Days**
			Cell C	95	**Limited Access Multiple Days**
			Cell E	96	**Limited Access Multiple Days**
			Cell F	79	**Limited Access Multiple Days**
			Cell G	105	**Limited Access Multiple Days**
			Cell H	45	**Limited Access Multiple Days**
			Ryan Slough Upstream of Myrtle	86	**Limited Access Multiple Days**



Arcata Bay
See Exhibit HS 7-2
2nd St
4th St
5th St
6th St
Y St
First Slough
Tydd St
Cell I
Second Slough
Bay St
Third Slough
Hoover St
Jacobs Ave
Eureka Slough
Brainard
101
7 - 9 ft
3 - 8 ft
Cell A
Murray Field
Indianola Cutoff
Cell H
Cell B
6 - 7 ft
Park St
Fay Slough
6 - 8 ft
7 ft
Cell G
Edgewood
Quail Creek
Cochran Creek
Cell C1
Ryan Slough
Cell F
Freshwater Slough
Myrtle Ave
Cell E
5-7 ft
Cell C2
Redmond Creek
Freshwater Slough/Creek
Cell D
Felt Rd
Wood Creek
Water Level: 12.6 ft (NAVD)
Hazard Scenario 7
Tidal Still Water Level: 12.6 ft NAVD
Wind Setup: 0 ft
Wind Wave Height: 0 ft
Wave Runup Range: 0 ft
Water Elevation (feet NAVD)
Time (Days)
Fluvial Flows: Winter Base Flow from tributaries
Approx. Equivalent Still Water with Sea Level Rise (SLR)
100-yr + 2 ft SLR
10-yr + 2.5 ft SLR
2-yr + 3.0 ft SLR
MMMW + 4.0 ft SLR
MHHW + 5.5 ft SLR
Tidal Still Water & Wind Setup
Wind Waves
Streams and Drainage
Roadway
Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)
Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee
Geomorphic & Critical Resource Response*
Shoreline Overtopping Depth | Duration | Response
> 1 ft | > 2 hrs | High Potential of Failure
Inches - Feet | Minutes to Hours | Rill Erosion
Tidal Overtopping
Travel Lane Flood Depth | Duration | Response
> 12 inches | Hours | Damage
3-12 inches | Hours | Functional Disruption
< 3 inches | Hours | Hazardous Conditions
Temporary Cell Flooding
Approximate Flood Depth from Overtopping
< 0.5 ft
1 - 3 ft
>6 ft
0.5 - 1 ft
3 - 6 ft
Cell — Cell subject to permanent inundation due to high potential of levee failure/breach. Increased erosion potential of slough channel between breach and Arcata Bay.
*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.
Paper Size ANSI B
0 500 1,000 1,500 2,000 2,500
Feet
Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet
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GHD
County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan
Hazard Scenario 7
Study Area Overview
Project No. 11191743
Revision No. -
Date 3/9/2021
EXHIBIT HS 7-1

Water Level: 12.6 ft (NAVD)

Hazard Scenario 7
See Exhibit HS 7-1 for Water Level Detail

- Tidal Still Water
  (Wind Setup and Wind Waves Not Present)
- Streams and Drainage
- Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

- Significant Erosion
- Moderate Erosion
- Vegetated or Vegetated RSP
- Armored
- Partially Breached Levee

Drainage

- Drainage Swale/Ditch
- Culvert
- Culvert with Flash Board Riser
- Drop Inlet
- Culvert with Flap Gate or Tide Gate

Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion

Travel Lane Flood Depth | Duration | Response

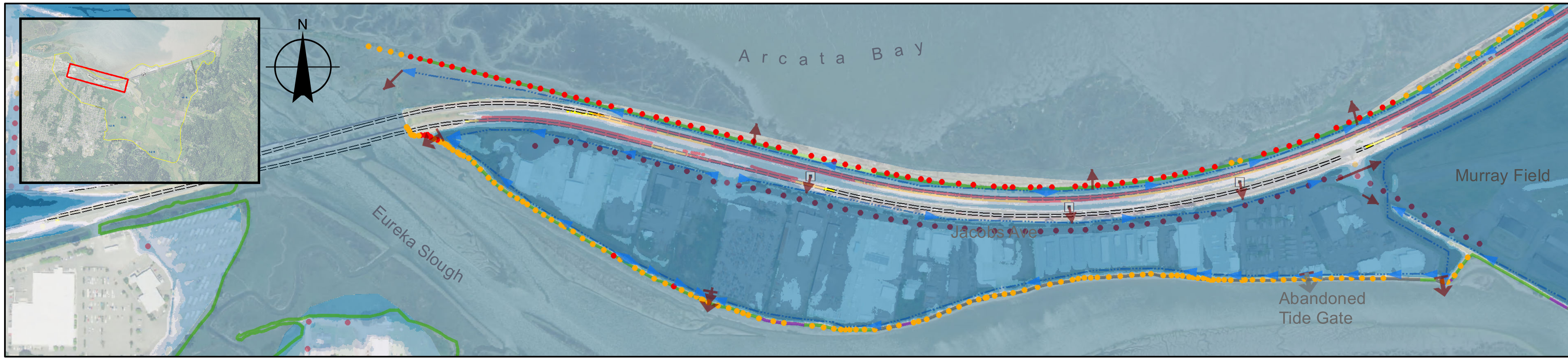
- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

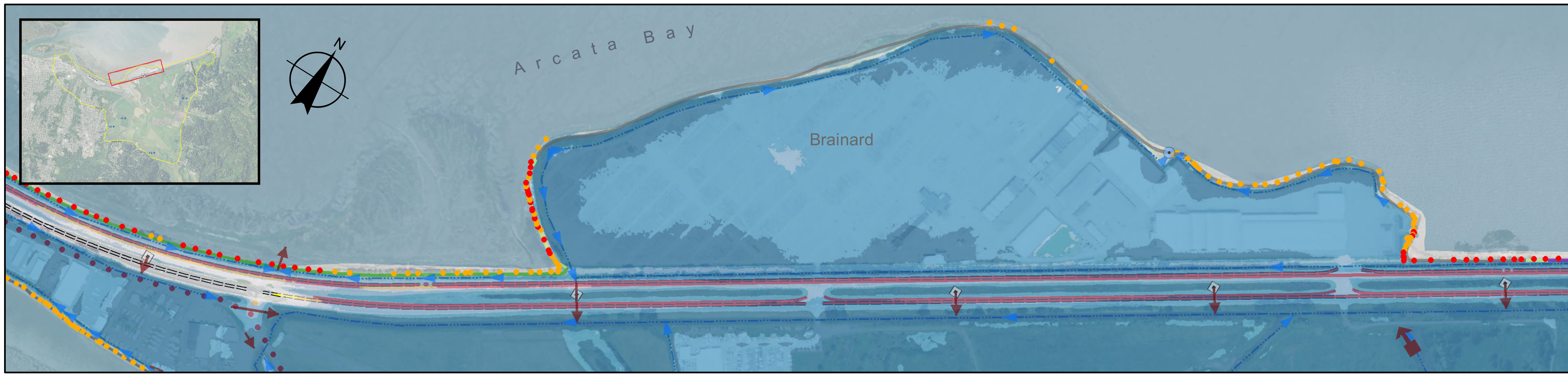
Temporary Cell Flooding

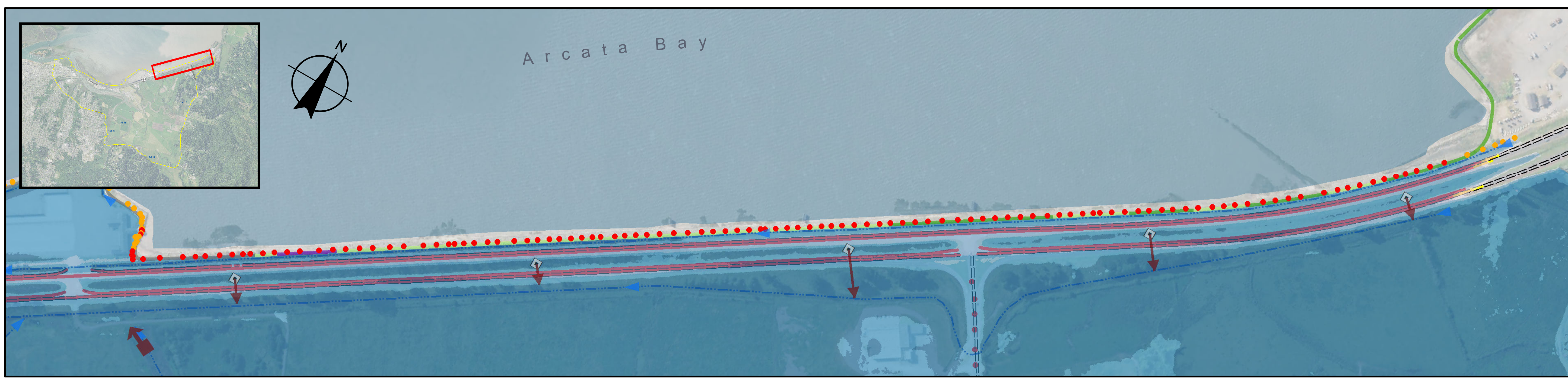
Approximate Flood Depth from Overtopping

- < 0.5 ft
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 6 ft
- >6 ft

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.







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Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 7
Bay Shoreline

Project No. **11191743**
Revision No. **-**
Date **3/9/2021**

EXHIBIT HS 7-2

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Print date: 09 Mar 2021 - 15:04

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 8

Tidal Still Water Level		Approximate Equivalent Still Water Event with Sea Level Rise		
13.6 feet NAVD	**Existing (2012 baseline)** Extremely Unlikely	**3 feet** 100-year 1% chance per year	**3.5 feet** 10-year 10% chance per year	**4.5 feet** 2-year 50% chance per year

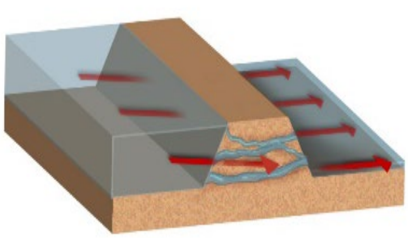
Introduction (See Exhibit HS 8-1):

This case study describes a scenario characterized by an extreme high tide, elevated low tides, and no significant wind or fluvial flood effects. Similar to Scenario 7, an extreme tide of this magnitude is not known to have occurred in recent history. Based on historical accounts, the extent of flooding described in this scenario likely exceeds the descriptions of the November 24, 1885 water levels that were likely a result of a tsunami. This scenario is intended to describe potential future extreme conditions that affect the entire Study Area and alternate transportation routes around Humboldt Bay. This extreme tide overtops the entire shoreline of the Study Area. Overtopping volumes flood all cells resulting in multiple feet of tidal flooding. All landforms under elevation 13.6 feet (NAVD) are submerged, with no difference in water levels between tidal sloughs, the bay and protected lands. Overtopping occurs on consecutive days, some days multiple times. Developed areas near the shoreline and in protected areas are typically flooded with four to nine feet of tidal water. Overtopping of levees and the rail prism result in rapid flooding of interior cells, creating life-safety hazards and flooding ingress and egress routes. Flooding results in multiple days of closure to Highway 101, alternate routes around the bay including Myrtle Avenue and Highway 255, as well as multiple smaller roadways, such as Tydd Street, Hoover Street, Y Street, 2nd, 4th, 5th and 6th Streets. Post event cleanup and reconstruction of multiple roadways is required. Flooding takes multiple days to drain, increasing the potential for levee failure due to saturation/seepage. Damage to the rail prism and levees requires extensive repairs to restore existing flood protection levels. Approximately 5.4 miles of rail prism and interior slough levees are overtopped with enough depth and for a long enough duration to meet criteria for a high probability of failure and breaching.

Highlighted shoreline processes in this scenario include slope failure/erosion of bay/slough facing slopes, overtopping and landward slope erosion, and channel adjustment due to high breach potential. Conceptual examples shown below.

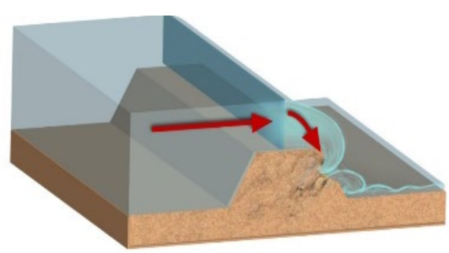
Internal Erosion/Seepage

Arcata Bay Shoreline
Interior Shoreline



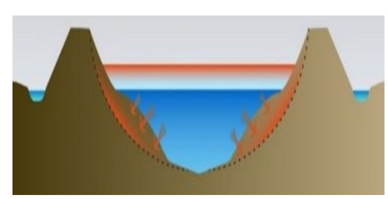
Overtopping/Erosion

93% of Arcata Bay Shoreline
96% of Interior Slough Levees



Channel Adjustment with Breach

5.3 miles of Significant Overtopping resulting in High Potential for Breach and downstream channel adjustment



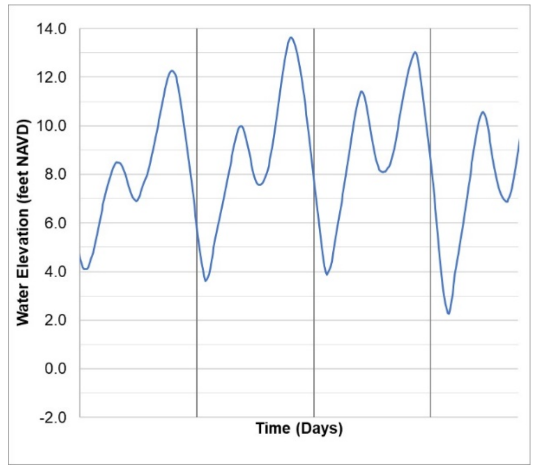
Example Shoreline Structure Responses (National Science Foundation, 2020)

Hydraulics and Sea Level Rise:

This scenario includes potential future extreme spring tides that typically occur in the months from November through January, where extreme high and low tides occur over multiple days in combination with a low-pressure system (storm surge) that increases predicted tidal water levels entering Humboldt Bay. Low tide elevations are elevated due to sea level rise. In the days preceding the storm, extreme tidal water levels are observable. Based on predicted tides by NHE 2019 leading up to the still water event, high tide reaches 12 feet (NAVD) the day prior to the peak of 13.6 feet (NAVD) and 13 feet (NAVD) the following day.[1]. Water levels are referenced to 2012

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. Approximate equivalent recurrences for this still water level scenario of 13.6 feet (NAVD), with variable amounts of sea level rise, are presented on the previous page. Sea level rise will increase the frequency and time of year that similar peak water levels occur, while also increasing the elevation of low tides, reducing and eventually eliminating the duration of favorable drainage conditions for low-lying lands. In this scenario, interior lands are assumed to be drained and dry prior to the onset of this event. Table 1 presents the hydraulic conditions for this scenario.

<table>
<tr><th colspan="3">Table 1: Scenario 8 Hydraulics</th></tr>
<tr><td>Tidal Still Water Level</td><td>13.6 ft NAVD</td><td rowspan="6">
</td></tr>
<tr><td>Wind Set-up</td><td>0 ft</td></tr>
<tr><td>Wind Wave Height</td><td>Height: 0 ft</td></tr>
<tr><td>Wave Runup Range</td><td>0 ft</td></tr>
<tr><td>Total Water Level (TWL)</td><td>13.6 ft NAVD</td></tr>
<tr><td>Fluvial Flows</td><td>Winter Base Flow from tributaries</td></tr>
</table>

Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018. Tidal marsh along the eastern bay shoreline is assumed to be match the extent shown in **Exhibit G-1** geomorphic trends.

Response:

A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 1 through 3 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model and then compared to established resource thresholds. The following section provides a landscape-scale discussion of Tables 1 through 3 describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. As described above, predicted water levels associated with the event were used throughout the study area. Modeling results are shown on the scenario Exhibit HS 8-1. Exhibit HS 8-1 shows the modeled overtopping depth and duration of the interior and bay shoreline, as well as, the maximum inundation depth associated with predicted tidal still water overtopping on protected lands. Inundation depths are approximate; the volume of overtopping is assumed to fill areas with the lowest elevations first; hydraulic routing across the landscape is not presented in detail.

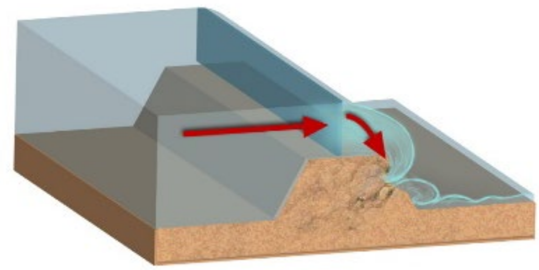
HAZARD SCENARIO 8

Bay Shoreline

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101.

Hydraulic Conditions:

In the days leading up to and following the peak tidal water level, overtopping of the railroad prism is extensive. At the peak and other high tidal still water levels, overtopping occurs along the entirety of the railroad prism, and most of Brainard levee. The capacity of the drainage channel between the southbound travel lanes of Highway 101 and the rail prism is quickly exceeded and the Highway 101 southbound travel lanes are flooded. Highway elevations throughout the study area are below the water level. Tidal waters flow into the median ditch, where it is conveyed east to the ditch east of the highway. Tidal flooding from overtopping of the rail prism combines with tidal flooding from overtopping of the interior slough levees and eventually floods all lanes of the highway as the cell fills to the bay and slough water level. Overtopping of the railroad prism is typically more than 1 foot and occurs for multiple hours at each highest tide. Exhibit HS 8-1 shows the locations, depth and duration of shoreline overtopping associated with peak water levels for this scenario.

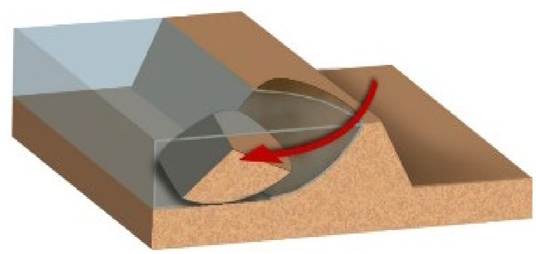


Example Overtopping and Erosion (National Science Foundation, 2020)

Resource Response and Impacts:

The physical response of the bay shoreline under this scenario will vary based on the existing shoreline condition. The anticipated responses are described below. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.

Rail Prism: Due to the extensive overtopping and composition of the railroad prism, wide spread slope failures and rill erosion is expected. The lack of cohesion within the ballast material would likely cause sloughing of the bank and movement down the slope. Overtopping of the rail prism by continuous flow will result in rill erosion across the top and landward slope of the rail prism, reducing the elevation of the rail prism and providing a pathway for future flooding. Future overtopping at these locations are subject to increased failure potential as rills can deepen and widen. If unrepaired following the event, the protection to future events is effectively reduced. The entire railroad prism is exposed to overtopping conditions resulting in a high potential for failure.



Example Slope Failure from Sloughing (National Science Foundation, 2020)

Rill Erosion of Railroad Prism Top and Backslope Due to Overtopping

Brainard Levee: Nearly three quarters of the Brainard Levee is overtopped, with 1,175 feet of levee exposed to overtopping conditions resulting in a high potential for failure.

Highway 101: Flooding of the all lanes of Highway 101 occurs within hours of overtopping during the peak event, resulting dangerous conditions and rapidly requiring closure. Flooding of the roadway occurs on multiple days, requiring extended closure. Debris and sediment is deposited across the roadway, requiring cleanup prior to the roadway opening. Erosion along the Highway prism slopes is likely, requiring repairs and reconstruction. Drainage channels require inspection and removal of debris and sediment at drainage structures such as culverts and tide gates.

HAZARD SCENARIO 8

Interior Shoreline

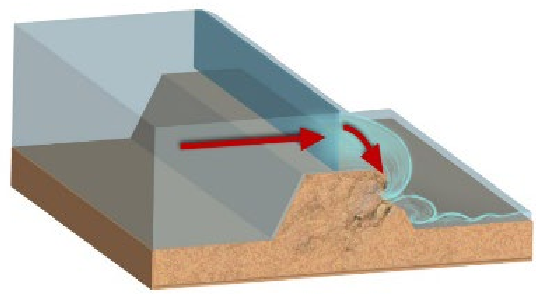
This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Exhibit HS 8-1 shows the locations, depth and duration of shoreline overtopping associated with tidal still water elevations for interior slough channels. Overtopping occurs along all slough channels and all cells, typically overtopping 95 to 100 percent of the leveed shoreline protecting the low-lying lands. Many levees are overtopped multiple times during the days leading up to and following the peak tide. Significant overtopping of greater than 1 foot for more than 2 hours is widespread in nearly all cells.

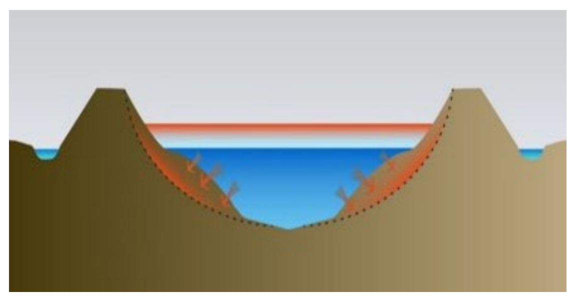
Resource Response and Impacts:

Overtopping of unarmored earthen levees induce significant rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion. Significant overtopping of greater than 1 foot for greater than 2 hours occurs over approximately 13,800 feet of levees protecting low lying lands. Levees subject to this threshold have a high probability of structural failure and breaching. A levee failure, likely unrepaired due to extent of failures, increases erosional forces within the slough channel between the breach location and Humboldt Bay with increased tidal volume exchanged and inundation of existing protected lands. Levees damaged to a lesser extent, that go unrepaired following the event are susceptible to the following:



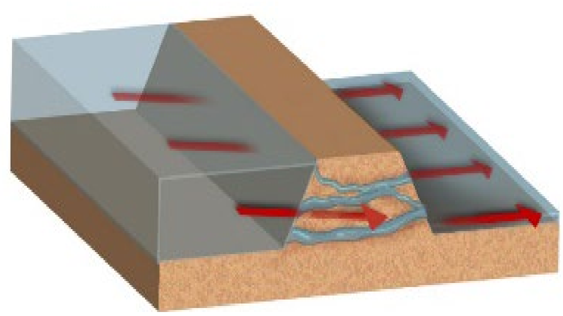
Example Overtopping of Levees
(National Science Foundation, 2020)

- Increased potential of saturation/seepage due to reduced levee width.
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.



Conceptual Channel Adjustment with Breach Event

The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.



Example Internal Erosion/Seepage of Levees
(National Science Foundation, 2020)

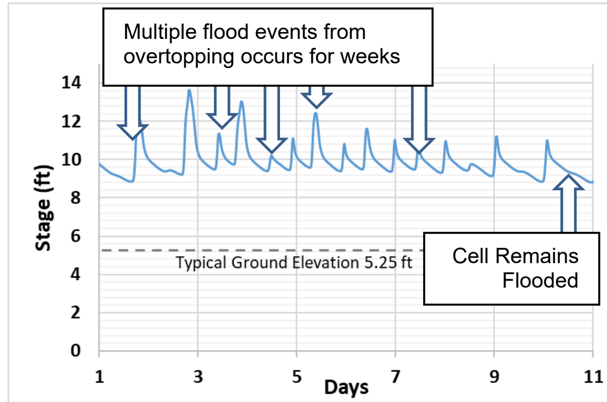
HAZARD SCENARIO 8

Protected Lands

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

<u>Hydraulic Conditions:</u>

Exhibit HS 8-1 depicts the approximate maximum flood depth, based on volume of overtopping, for each cell. Overtopping of levees occurs in all cells, exceeding the capacity of existing interior drainage channels, flooding each cell with multiple feet of tidal waters, with additional overtopping and inundation occurring before the cell has drained. This daily flooding occurs for one to two weeks. The depth and duration of flooding for each cell are summarized in Table 3, at the end of this case study. Tidal waters flowing over the shoreline levees, rail prism, and roadways fill the interior water levels to 13.6 feet (NAVD), with nearly all levee crests submerged.



Multiple Overtopping Events, Followed by Multiple Days to Drain the Protected Lands

Developed areas adjacent to First, Second and Third Slough, protected by a natural elevation gradient, also experience tidal flooding up to elevation 13.6 NAVD. Residential and commercial development, as well as public utility infrastructure such as sewer pump stations, roadways, and underground utilities are located within the elevation range 9 to 11 feet (NAVD), resulting in approximately 2.5 to nearly 4.5 feet of tidal flooding. Tidal flooding migrates onto Y Street, 2nd, 4th, 5th, and 6th Streets, as well as Tydd Street Hoover Street Edgewood, Myrtle Avenue and Indianola Cutoff.

<u>Resource Response and Impacts:</u>

Due to the magnitude, frequency and duration of overtopping and high tides, combined with lower land elevation protected by levee, nearly the entire Study Area experiences significant flooding. The magnitude and repetitive flooding and hydraulic conditions are not favorable for drainage of flood waters with increased low tides due to sea level rise and the repetitive high tides. Overtopping to Cell A results in flooding of three to eight feet of flooding in the developed areas, causing widespread damage. Overtopping rapidly floods all roadways providing ingress and egress in Cell A, resulting in extremely dangerous conditions for motorists on Highway 101 and residences and business within the cell. In other cells, while largely agricultural, all ingress and egress routes are flooded. Similarly, the rapidly rising tide floods the lower elevation, developed areas along First, Second and Third Slough. Tidal flooding migrates onto Myrtle Avenue, near Indianola Cutoff, eliminating alternate travel ways around the bay. Access is limited or prevented to repair levees, tend to utilities, or access developed areas for one to two weeks or more. Drainage of interior areas may be further delayed by accumulation of debris carried and deposited in drainage ditches by flooding. The depth and duration of overtopping and flooding likely results in partial or full levee failures, reducing future flood protection and resulting in lasting impacts to pastures and utilities as daily tidal inundation may occur.

The City of Eureka sewer pump stations along Jacobs Avenue and near Tydd Street experience two to six feet of flooding. The City of Eureka's Y Street sewer pump station is exposed to 2.5 feet of flooding.The City of Eureka Water Booster Station experiences nearly three feet of tidal flooding. The HCSD sewer pump stations on Edgewood Road and off Hoover Street experience 3.5 feet of flooding.

HAZARD SCENARIO 8

Scenario Summary:

The extreme tides result in widespread shoreline overtopping and flooding throughout the Study Area. Multiple roadways, including Highway 101, Myrtle Avenue and smaller local roadways including Jacobs Avenue, Airport Road, Park Street, Tydd Street, the Waterfront Trail, Hoover Street, Edgewood Road, Y Street, 2nd Street and 4th Street. Dangerous, life safety conditions exist throughout the lowlands protected by levees with flooding reaching more than five feet deep. The rail prism and levees show signs of partial failure and erosion including sloughing. Rill erosion on the tops and backs of levees is widespread. Approximately 5.3 miles of levee and rail prism is exposed to a high potential for failure and breaching requiring extensive repairs and cleanup to restore pre-event conditions and flood protection throughout the Study Area.

The entire rail prism is overtopped and exhibits a high potential for failure along the Bay Shoreline (Table 2). Highway 101 is flooded with multiple feet of tidal water. All lanes of Highway 101 are flooded within an hours of overtopping and lasts for nearly one week. Myrtle Avenue/Old Arcata Road, as well as Highway 255 at Mad River Slough, experiences up to 3 feet of flooding, eliminating alternate routes around the bay until water levels recede. Ingress and egress routes are flooded throughout the Study Area.

Flooding in the developed areas along Jacobs Avenue, Murray Field and Brainard is typically three to eight feet, resulting in wide spread damage to all development and residences. Interior levees and Park Street are overtopped, flooding large areas of agricultural pastures with tidal waters (Table 3). Overtopping depth and duration vary, with numerous locations exhibiting a high potential for failure from overtopping erosion, followed by potential of structural failure due to seepage/internal erosion as the levees area saturated and flood waters are stored within the cell. Access to levees and utilities throughout the Study Area is limited and extremely dangerous conditions are present.

A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 8

Table 2. Overtopping Summary for Bay Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	5,490	91%	-	407	Jacobs Ave 5.7 to 8.2 ft, Fay Slough Wildlife Area 8.7 to 9.7 ft	13.6
		Rail Prism	6,493	100%	6,472			
	Brainard Levee	Levee	4,150	75%	1,175	668		
	Brainard to Indianola Cutoff	Rail Prism	6,923	100%	6,923	5,602		
Slough	Fay Slough	Levee	15,376	99%	4,115	3,259		
	Eureka Slough	Levee	6,540	98%	3,280	1,603		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	279	100%	231	7.2 to 8.2	13.6
C1	Fay Slough	10,706	97%	2,444	7.2 to 9.2	13.6
	Freshwater Slough	9,986	97%	713		
C2	Freshwater Slough	5,816	99%	-	4.2 to 7.2	13.6
D[2]	Freshwater Slough	4,551	100%	1,311	4.2 to 6.2	13.6
E	Freshwater Slough	2,482	95%	182	6.7 to 7.7	13.6
F	Ryan Slough	3,261	97%	13	7.7 to 8.7	13.6
	Freshwater Slough	981	100%	9		
G	Freshwater Slough	5,244	89%	348	7.7 to 8.2	13.6
	Park Street	566	92%	547		
	Ryan Slough	2,183	92%	-		
H	Freshwater Slough	1,754	77%	-	7.2 to 8.2	13.6
	Eureka Slough	3,666	85%	113		
I[2]	Eureka Slough	-		-	0 to 4.7	13.6
Myrtle	Ryan Slough	4,007	97%	468	5.7 to 7.7	13.6

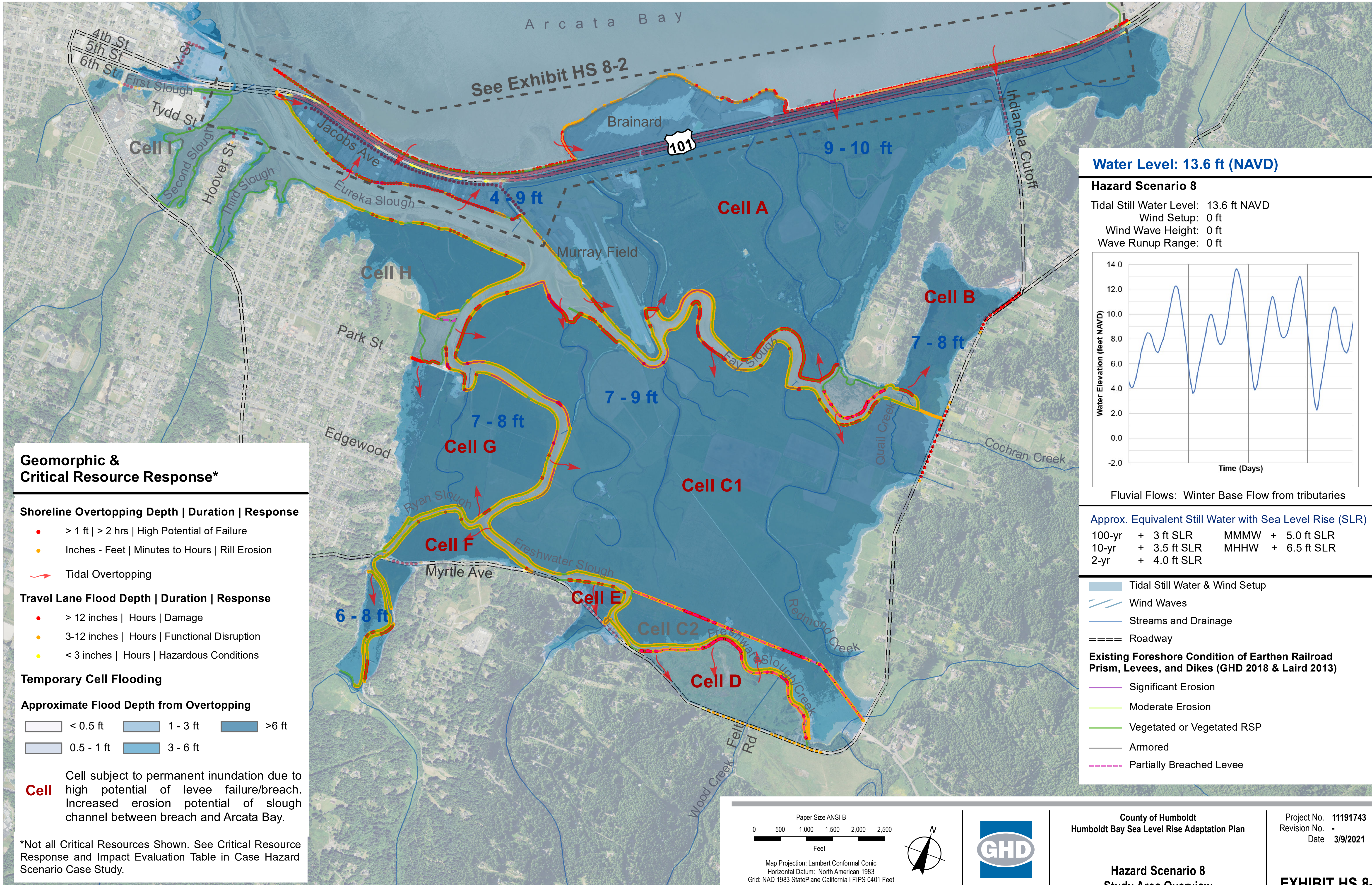
HAZARD SCENARIO 8

Table 4. Critical Resource Response and Impact Evaluation

	Critical Resource	Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees/ Dikes	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	Potential Failure
			Cell B	>1ft and >2 hrs	Potential Failure
			Cell C	>1ft and >2 hrs	Potential Failure
			Cell E	>1ft and >2 hrs	Potential Failure
			Cell F	>1ft and >2 hrs	Potential Failure
			Cell G	>1ft and >2 hrs	Potential Failure
			Cell H	>1ft and >2 hrs	Potential Failure
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	>1ft and >2 hrs	Potential Failure
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	5.4	Closure & Damage
	Hwy 101 Northbound		Cell A - Arcata Bay	5.0	Closure & Damage
	Jacobs Ave		Cell A (ft)	8.1	Closure & Damage
	Airport Road		Cell A	9.9	Closure & Damage
	Indianola Cutoff		Cell A	5.7	Closure & Damage
	Park Street		Cell G	5.6	Closure & Damage
	Hoover Street		Cell I	4.1	Closure & Damage
	2nd and Y Streets		Cell I	3.8	Closure & Damage
	4th, 5th, 6th, V St		Cell I	2.4	Closure & Damage
	Myrtle Ave		Cells B, C, F, D	3.9	Closure & Damage
	Hwy 255 (Alternate Route)		Arcata Bay	3.2	Closure & Damage
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	6.9	Potential Inflow/Overflow/Damage
			City of Eureka Jacobs Ave #2	7.0	Potential Inflow/Overflow/Damage
			City of Eureka Y Street	2.7	Potential Inflow/Overflow/Damage
			City of Eureka Hill Street (Tydd Street)	3.7	Potential Inflow/Overflow/Damage
			Humboldt CSD Hoover Street	3.7	Potential Inflow/Overflow/Damage
			Humboldt CSD Edgewood	3.4	Potential Inflow/Overflow/Damage
	Water Booster Station		City of Eureka Myrtle Ave	4.2	Potential Inflow/Overflow/Damage
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	690	Limited Access > 1 week
			Cell I Hoover St - HCSD	47	Limited Access Multiple Days

HAZARD SCENARIO 8

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
	Sewer Gravity Main		Cell I Hoover St - HCSD	47	Limited Access Multiple Days
	Gas Main		Cell G	106	Limited Access Multiple Days
			Cell C	104	Limited Access Multiple Days
			Cell A	690	Limited Access > 1 week
	Communications (Underground)		Cell A	690	Limited Access > 1 week
	Communication Towers/Poles		Cell H	94	Limited Access Multiple Days
Protected Lands	Residential/ Commercial/ Industrial	Surface Flooding (ft)	Jacobs Ave	8.1	Potential Loss of Property/Life
			Murray Field	6.5	Potential Loss of Property/Life
			Harper Motors	6.5	Potential Loss of Property/Life
			Brainard	5.4	Potential Loss of Property/Life
			Rainbow Storage Indianola Cutoff	0.5	Shallow Flooding
			2nd and Y Street	3.8	Damage/Stranding
			6th and Tydd Street	2.4	Damage/Stranding
			Hoover Street	4.1	Damage/Stranding
			Park Street	5.6	Potential Loss of Property/Life
			Edgewood	3.4	Damage/Stranding
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	690	Potential Changes to Land Management
			Cell B	106	Limited Access Multiple Days
			Cell C	104	Limited Access Multiple Days
			Cell E	106	Limited Access Multiple Days
			Cell F	96	Limited Access Multiple Days
			Cell G	106	Limited Access Multiple Days
			Cell H	94	Limited Access Multiple Days
			Ryan Slough Upstream of Myrtle	107	Limited Access Multiple Days



County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 8
Study Area Overview

Project No. 11191743
Revision No. -
Date 3/9/2021

EXHIBIT HS 8-1

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Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

Water Level: 13.6 ft (NAVD)

Hazard Scenario 8
See Exhibit HS 8-1 for Water Level Detail

Tidal Still Water
(Wind Setup and Wind Waves Not Present)
Streams and Drainage
Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee

Drainage

Drainage Swale/Ditch
Culvert
Culvert with Flash Board Riser
Drop Inlet
Culvert with Flap Gate or Tide Gate

Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion

Travel Lane Flood Depth | Duration | Response

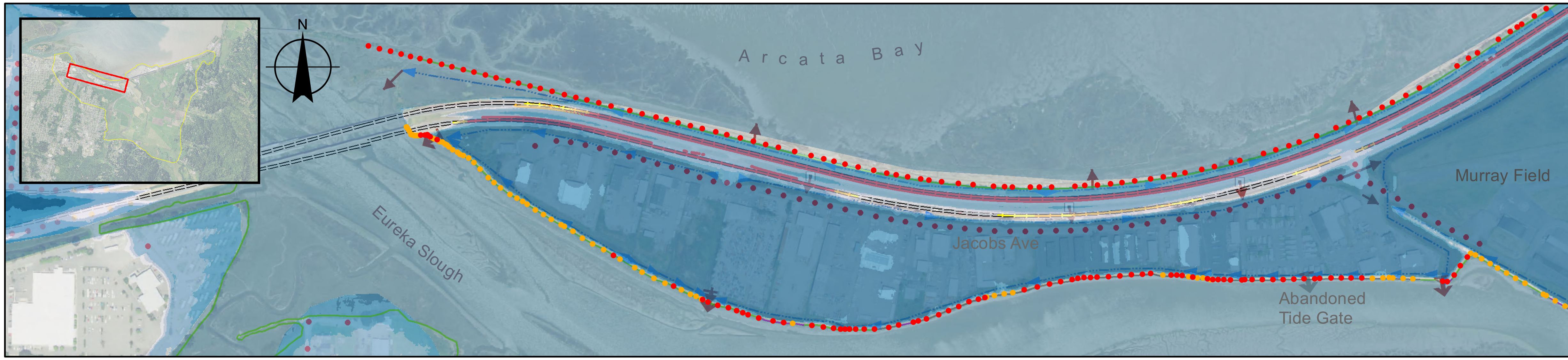
- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

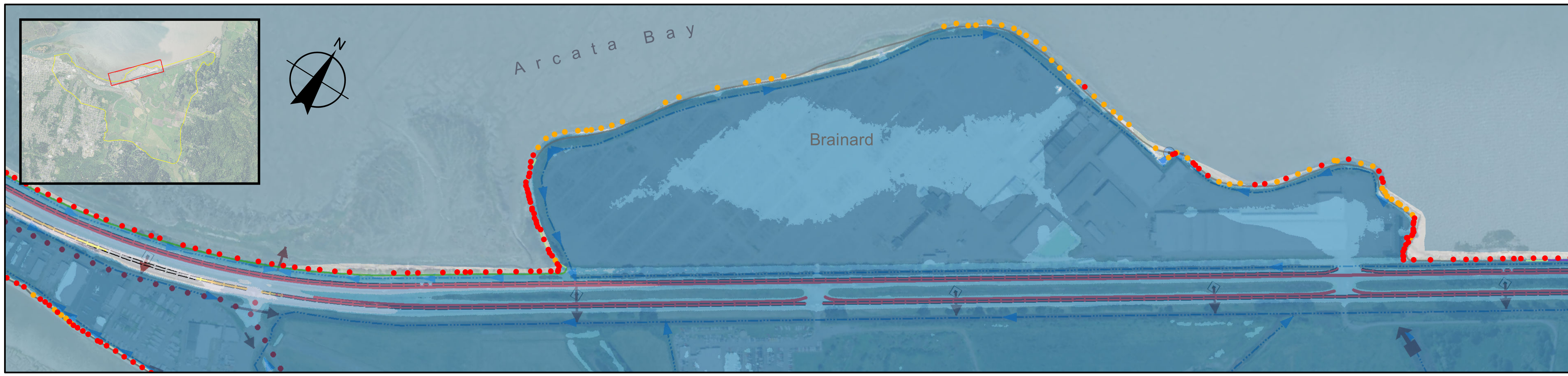
Temporary Cell Flooding

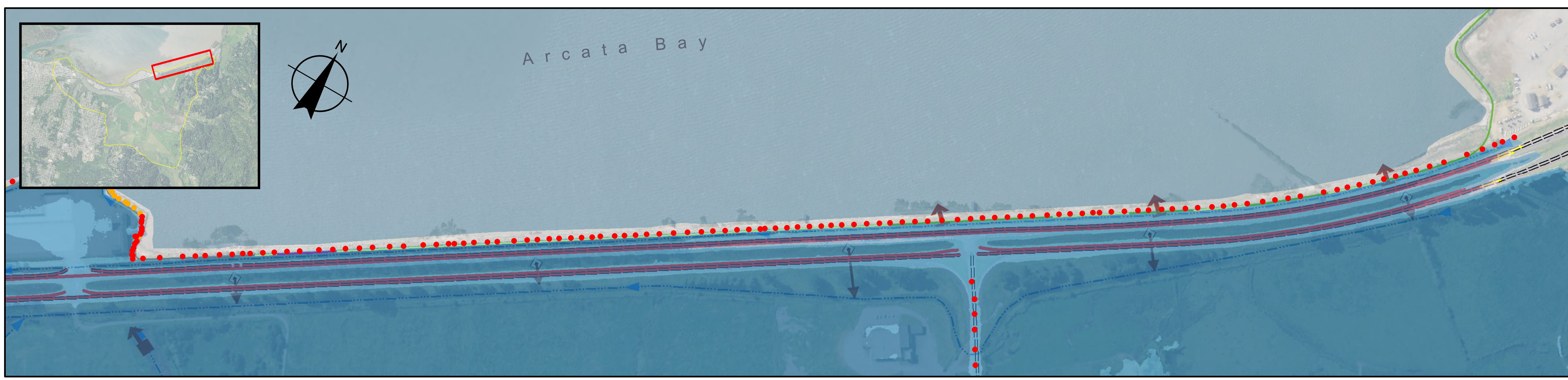
Approximate Flood Depth from Overtopping

< 0.5 ft
0.5 - 1 ft
1 - 3 ft
3 - 6 ft
>6 ft

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.







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County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 8
Bay Shoreline

Project No. **11191743**
Revision No. **-**
Date **3/9/2021**

EXHIBIT HS 8-2

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Print date: 09 Mar 2021 - 15:39

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan

HAZARD SCENARIO 9

Tidal Still Water Level		Fluvial Flow
8.3 feet NAVD	**Existing (2012 baseline)** MMMW 5 -6 times per year	**Existing (2012 baseline)** 2-yr 50% chance per year

Introduction (See Exhibit HS 9-1):

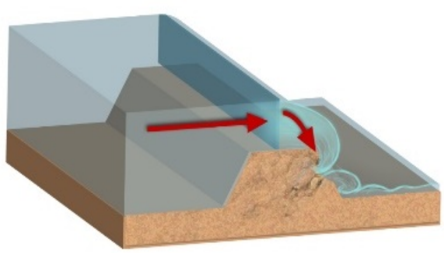
This case study describes a scenario characterized by a fluvial 2-year recurrence flow on freshwater tributaries and typical high tide without local wind effects that further increase water levels. Overtopping of fluvial, fresh occurs at levees along Freshwater and Ryan Slough. Minor tidal overtopping occurs in limited locations along the interior slough channels and is typically shallow and for short duration. Fluvial flow from tributaries connected to sloughs through tide gates are impounded until tidal water levels drop below interior water levels. Fluvial flooding affects Cells C, E, G and the area upstream of Myrtle Avenue on Ryan Slough, with flood depths typically between one and three feet. Similar flooding within the study area was observed on January 2, 1997.

Example Inundation, Similar to Modeled 2-yr Storm, from January 2, 1997

Highlighted shoreline processes and responses in this scenario include overtopping and landward slope erosion, fluvial flooding of protected lands due to overtopping and impoundment of drainage, and typical roadway flooding. Examples shown below.

Overtopping and Erosion

0% Arcata Bay Shoreline
10% of Interior Slough Levees



Example Shoreline Overtopping (National Science Foundation, 2020)

Fluvial Flooding of Agricultural Lands

Cells C, E, G, and Ryan Slough

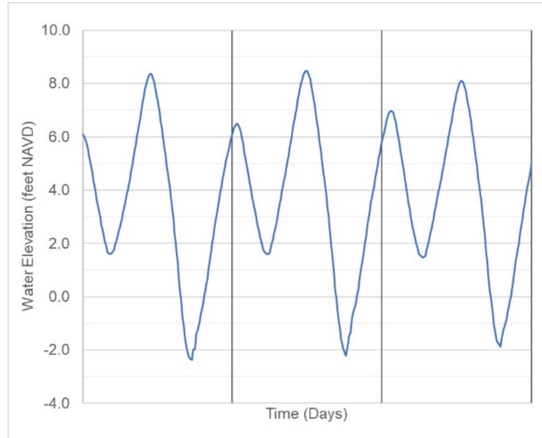
Typical Roadway Flooding

Park Street

Hydraulics and Sea Level Rise:

This scenario combines the 2-year storm event on fluvial tributaries and the highest spring tides that occur during the year, from November through January, during average meteorological conditions and any combination of astronomical conditions. High spring tides occur over multiple days and multiple times during this time of year and are not considered to be extreme. Sea level rise will increase the frequency of similar peak water levels to occur throughout the year, while also increasing the elevation of the lowest tides. The duration of peak tides occur during calm conditions, without wind effects inducing increased water levels or producing waves. Water levels and fluvial flows are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. The interior lands are assumed to be dry with the onset of this event. Hydraulic conditions for this scenarios are presented in Table 1.

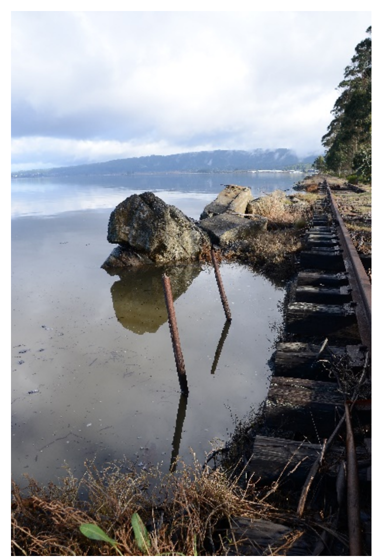
HAZARD SCENARIO 9

Table 1: Scenario 9 Hydraulics and Sea Level Rise		
Fluvial Flows	2-year recurrence on tributaries	
Tidal Still Water Level	8.3 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	8.3 ft NAVD	

Antecedent Shoreline Conditions:
This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018. Tidal marsh along the eastern bay shoreline is assumed to match the extent shown in **Exhibit G-1** geomorphic trends.

Response:
The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. This scenario is based on predicted fluvial flows, tidal elevations and modeled overtopping by NHE. Exhibit HS 9-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

Bay Shoreline Response
This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.



Hydraulic Conditions:
High tides occur for multiple days, with the peak reaching 8.3 feet. As the tide rises, water levels approach the crest move into low elevation areas of the rail prism created by previous high tide and storm events. Active erosion of the rail prism and levee is not observable as still water levels increase. Fluvial flows do not affect water levels along the Bay Shoreline. With sea level rise, high tide water levels will increase and become more frequent. See Scenarios 1 through 8 for additional tidal water levels and recurrences.

HAZARD SCENARIO 9

Interior Shoreline Response

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Exhibit HS 9-1 shows the locations, depth and duration of shoreline overtopping associated with fluvial flows and the limited tidal still water overtopping for interior slough channels. Fluvial flows on Freshwater and Ryan Sloughs overtop adjacent levees protecting Cells C, D, E, G and the area upstream of Myrtle Avenue on Ryan Slough. Tidal waters are largely contained within the sloughs, with freeboard between the levee crests and tidal water, throughout a majority of the study area.

Resource Response and Impacts:

Although somewhat limited in extent, overtopping of unarmored earthen levees induces shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion. Damaged levees that go unrepaired following the event are susceptible to the following:

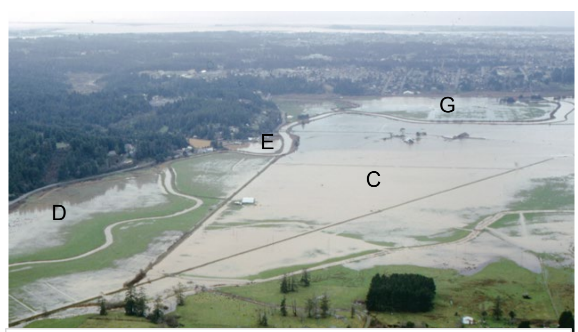
- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

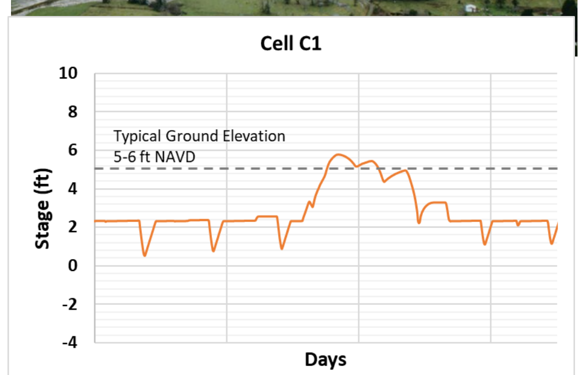
Example Levee Crest Erosion from Overtopping (Laird, 2013)

Significant overtopping of greater than one foot for more than two hours occurs at along two small three to six foot sections of levee protecting Cell C and Cell E. Most of the Cell D levee is overtopped, however this cell is open to tidal flooding and a levee failure would not significantly increase downstream flow. The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.





Hydraulic Conditions: Exhibit HS 9-1 depicts the approximate maximum flood depth, based on volume of overtopping, for each cell. The largest effect noted is the flooding of Cells C, E, G and the area upstream of Myrtle Avenue on Ryan Slough. Overtopping of Park Street and other minor overtopping of levees protecting pathways for tidal flooding to Cell C and G, but contributions to flooding are minor.

Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient and fluvial flows to not increase water levels significantly in these areas.

Resource Response and Impacts:

HAZARD SCENARIO 9

Fluvial flooding occurs in Cells C, E, G and the area upstream of Myrtle Avenue on Ryan Slough. Flooding occurs over the course of approximately 24 hours, overwhelms the drainage system and then begins to recede as flows decrease and tides drop allowing drainage. Flooding in the lowest elevations typically lasts one to two days. In all other cells the existing capacity of drainage channels are sufficient to store and convey overtopping tidal water and fluvial contributions to Protected Lands. However, hydrauli **Example Flood Hydrograph** e drainage of fresh water from fluvial, groundwater and precipita n tide gates. The duration of favorable drainage conditions are further reduced with increases to low tide elevations with sea level rise.

Impoundment of fluvial, groundwater and precipitation is common during this time of year, with favorable conditions for drainage from the Protected Lands to the slough channels limited to a few hours per day.

The low lying area at the end of Park Street is flooded during each high tide event and ponding likely persists for days. This occurrence is typical and observed multiple time each year.

Inundation Due to Impoundment of Fresh Water

Scenario Summary:

The fluvial flows and spring tides result in limited, shallow, short duration overtopping in the study area. The appearance of the landscape is generally similar to wet winter conditions around Humboldt Bay, with large swings from high tide to low tides and standing water filling low-lying, saturated lands.

Fluvial flows do not affect water levels along the Bay Shoreline.The Interior Shoreline is largely in the reach of Freshwater Slough adjacent to Cells C, D and E, and on Ryan Slough adjacent to Cell G (Table 3). Overtopping volume typically results in shallow, less than one foot of flooding, but up to three feet on Protected Lands. The high tides and typical saturated conditions in the winter result in reduced conditions favorable to drain fluvial, groundwater and precipitation. A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 9

Table 2. Overtopping Summary for Cell A Bay and Slough Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	0%	-	-	-	-
		Rail Prism	-	0%	-			
	Brainard Levee	Levee	-	0%	-	-		
	Brainard to Indianola Cutoff	Rail Prism	-	0%	-	-		
Slough	Fay Slough	Levee	-	0%	-	-		
	Eureka Slough	Levee	-	0%	-	-		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	20	7%	-	-	0.0
C1	Fay Slough	13	-	-	0 to 1.3	5.8
	Freshwater Slough	47	-	-		
C2	Freshwater Slough	2,408	41%	3	0 to 1.1	7.6
D[2]	Freshwater Slough	3,676	81%	1,439	1 to 3	10.5
E	Freshwater Slough	657	25%	6	2.7 to 3.7	9.6
F	Ryan Slough	-	-	-	-	0.0
	Freshwater Slough	-	-	-		
G	Freshwater Slough	16	-	-	0 to 0.4	5.8
	Park Street	162	26%	-		
	Ryan Slough	38	2%	-		
H	Freshwater Slough	-	-	-	-	0.0
	Eureka Slough	-	-	-		
I[2]	Eureka Slough	-		-	-	0.0
Myrtle	Ryan Slough	685	17%	101	1.8 to 3.8	9.8

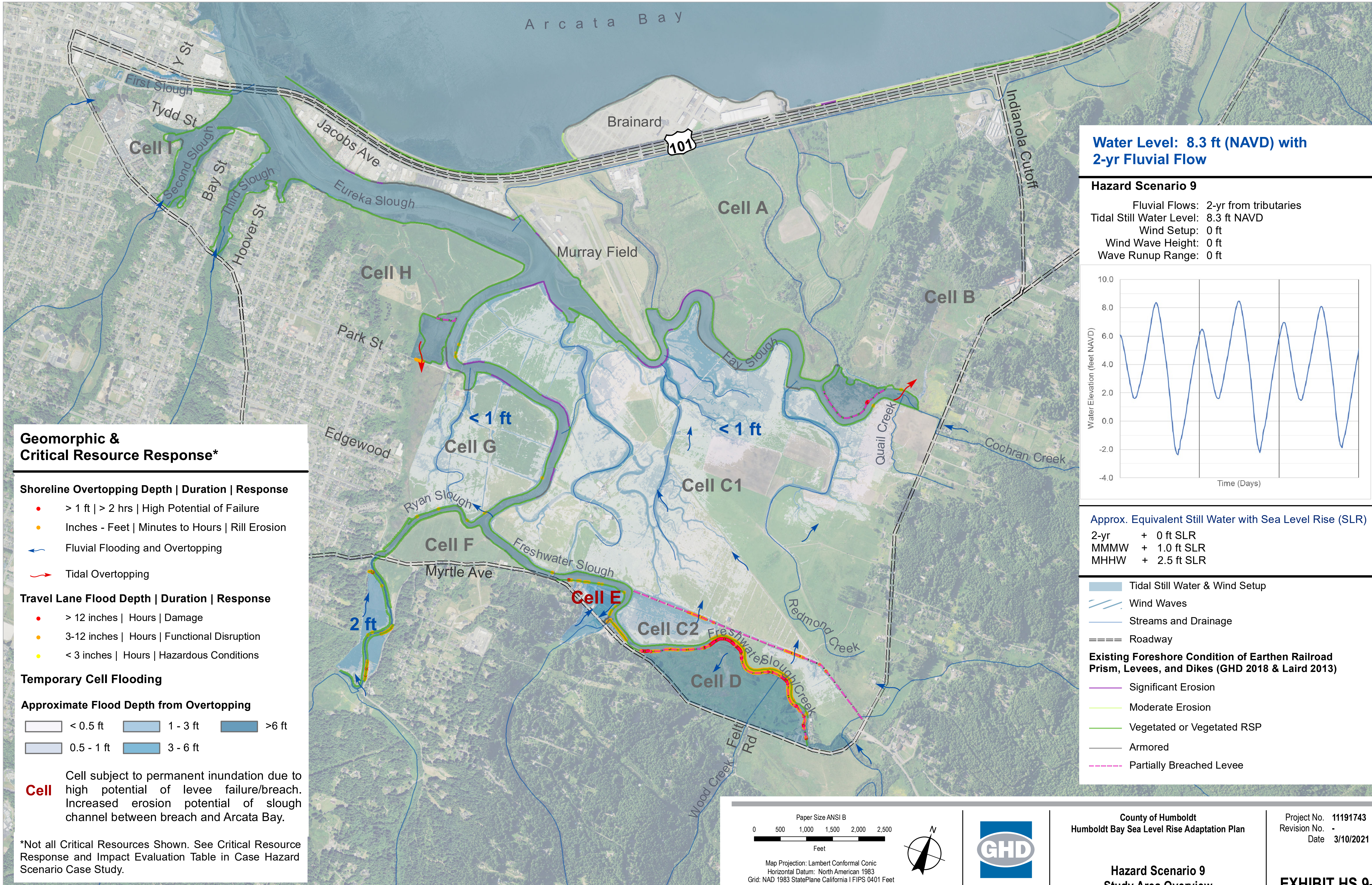
HAZARD SCENARIO 9

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees	Overtopping (depth and time)	Cell A	-	None Observed
			Cell B	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell C	>1ft and >2 hrs	**Potential Failure**
			Cell E	>1ft and >2 hrs	**Potential Failure**
			Cell F	-	None Observed
			Cell G	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell H	-	None Observed
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay	-	N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	-	None Observed
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	-	none
	Hwy 101 Northbound		Cell A - Arcata Bay	-	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	-	none
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G		none
	Hoover Street		Cell I	-	none
	2nd and Y Streets		Cell I	-	none
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alternate Route)		Arcata Bay		none
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	-	none
			Humboldt CSD Hoover Street	-	none
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	-	none
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	-	none
			Cell I Hoover St - HCSD	-	none
	Sewer Gravity Main		Cell I Hoover St - HCSD	-	none
	Gas Main		Cell G	26	**Limited Access Multiple Days**
			Cell C	29	**Limited Access Multiple Days**
			Cell A	-	none
	Communications (Underground)		Cell A	-	none
	Communication Towers/Poles		Cell H	-	none
Protect ed		Surface Flooding (ft)	Jacobs Ave	-	none
			Murray Field	-	none

HAZARD SCENARIO 9

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
	Residential/ Commercial/ Industrial		Harper Motors	-	none
			Brainard	-	none
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	-	none
			6th and Tydd Street	-	none
			Hoover Street	-	none
			Park Street	-	none
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	-	none
			Cell B	-	none
			Cell C	29	**Limited Access Multiple Days**
			Cell E	45	**Limited Access Multiple Days**
			Cell F	-	none
			Cell G	26	**Limited Access Multiple Days**
			Cell H	-	none
			Ryan Slough Upstream of Myrtle	38	**Limited Access Multiple Days**



County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 9
Study Area Overview

Project No. 11191743
Revision No. -
Date 3/10/2021

EXHIBIT HS 9-1

\\ghdnet\ghd\US\Eureka\Projects\561\11191743\GIS\Maps\Deliverables\Hazard Scenarios\11191743_Hazard_Scenario_9_2yrFluvial_8-3ft.mxd Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Print date: 10 Mar 2021 - 21:08
Created by: bvivyan

HAZARD SCENARIO 10

Tidal Still Water Level		Fluvial Flow
8.3 feet NAVD	**Existing (2012 baseline)** MMMW 5 -6 times per year	**Existing (2012 baseline)** 10-yr 10% chance per year

Introduction (See Exhibit HS 10-1):

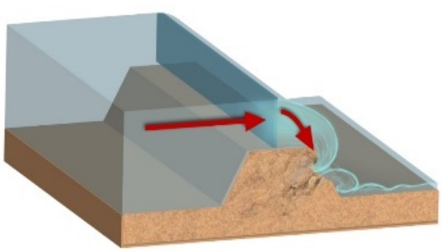
This case study describes a scenario characterized by a fluvial 10-year recurrence flow on freshwater tributaries and typical high tide without local wind effects that further increase water levels. Overtopping of fluvial, fresh occurs at levees along Freshwater and Ryan Slough. Minor tidal overtopping occurs in limited locations along the interior slough channels and is typically shallow and for short duration. Fluvial flow from tributaries connected to sloughs through tide gates are impounded until tidal water levels drop below interior water levels. Fluvial flooding affects Cells C, E, F, G and the area upstream of Myrtle Avenue on Ryan Slough, with flood depths typically between three and six feet. Similar flooding within the study area was observed on March 18, 1975.

Example Inundation, Similar to Modeled 10-yr Storm, from March 18, 1975.

Highlighted shoreline processes and responses in this scenario include overtopping and landward slope erosion, fluvial flooding of protected lands due to overtopping and impoundment of drainage, and typical roadway flooding. Examples shown below.

Overtopping and Erosion

0% Arcata Bay Shoreline
16% of Interior Slough Levees



Example Shoreline Overtopping (National Science Foundation, 2020)

Tidal Flooding of Agricultural Lands

Cells C, E, G, and Ryan Slough

Typical Roadway Flooding

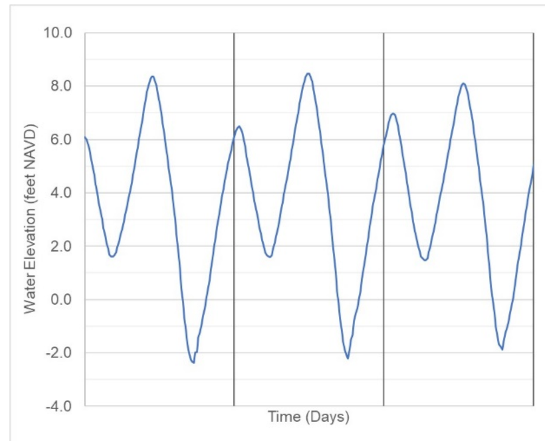
Park Street

Hydraulics and Sea Level Rise:

This scenario combines the 2-year storm event on fluvial tributaries and the highest spring tides that occur during the year, from November through January, during average meteorological conditions and any combination of astronomical conditions. High spring tides occur over multiple days and multiple times during this time of year and are not consider to be extreme. Sea level rise will increase the frequency of similar peak water levels to occur throughout the year, while also increasing the elevation of the lowest tides. Based on predicted tides leading up to the event, high tides exceed 9 feet the day prior to the peak and the day following[1]. The duration of peak tides occur during calm conditions, without wind effects inducing increased water levels or producing waves. Water levels and fluvial flows are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

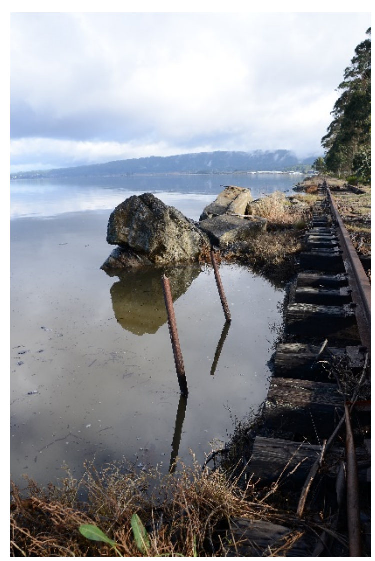
supplemental topographic surveys previously described. The interior lands are assumed to be dry with the onset of this event. Hydraulic conditions for this scenarios are presented in Table 1.

<table>
<tr><th colspan="3">Table 1: Scenario 9 Hydraulics and Sea Level Rise</th></tr>
<tr><td>Fluvial Flows</td><td>2-year recurrence on tributaries</td><td rowspan="6">
</td></tr>
<tr><td>Tidal Still Water Level</td><td>8.3 ft NAVD</td></tr>
<tr><td>Wind Set-up</td><td>0 ft</td></tr>
<tr><td>Wind Wave Height</td><td>0 ft</td></tr>
<tr><td>Wave Runup Range</td><td>0 ft</td></tr>
<tr><td>Total Water Level (TWL)</td><td>8.3 ft NAVD</td></tr>
</table>

Antecedent Shoreline Conditions:
This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018. Tidal marsh along the eastern bay shoreline is assumed to match the extent shown in **Exhibit G-1** geomorphic trends.

Response:
The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. This scenario is based on predicted tidal elevations and modeled overtopping by NHE. Exhibit HS 9-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

Bay Shoreline Response
This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.



Hydraulic Conditions:
High tides occur for multiple days, with the peak reaching 8.3 feet. As the tide rises, water levels approach the crest move into low elevation areas of the rail prism created by previous high tide and storm events. Active erosion of the rail prism and levee is not observable as still water levels increase. Fluvial flows do not affect water levels along the Bay Shoreline. With sea level rise, high tide water levels will increase and become more frequent. See Scenarios 1 through 8 for additional tidal water levels and recurrences.

HAZARD SCENARIO 10

Interior Shoreline Response

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Exhibit HS 9-1 shows the locations, depth and duration of shoreline overtopping associated with fluvial flows and the limited tidal still water overtopping for interior slough channels. Fluvial flows on Freshwater and Ryan Sloughs overtop adjacent levees protecting Cells C, D, E G and the area upstream of Myrtle Avenue on Ryan Slough. Tidal waters are largely contained within the sloughs, with freeboard between the levee crests and tidal water, throughout a majority of the study area.

Resource Response and Impacts:

Although somewhat limited in extent, overtopping of unarmored earthen levees induces shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion. Damaged levees that go unrepaired following the event are susceptible to the following:

Example Levee Crest Erosion from Overtopping (Laird, 2013)

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

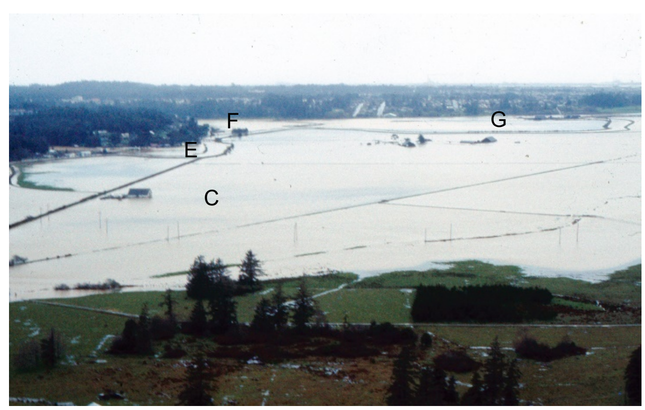
Significant overtopping of greater than one foot for more than two hours occurs at along two small three to six foot sections of levee protecting Cell C and Cell E. Most of the Cell D levee is overtopped, however this cell is open to tidal flooding and a levee failure would not significantly increase downstream flow. The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions: Exhibit HS 10-1 depicts the approximate maximum flood depth, based on volume of overtopping, for each cell. The largest effect noted is the flooding of Cells C, E, F, G and the area upstream of Myrtle Avenue on Ryan Slough. Tidal overtopping occurs on Park Street and select other locations, but contributions to flooding are minor.

Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient and fluvial flows to not increase water levels significantly in these areas.

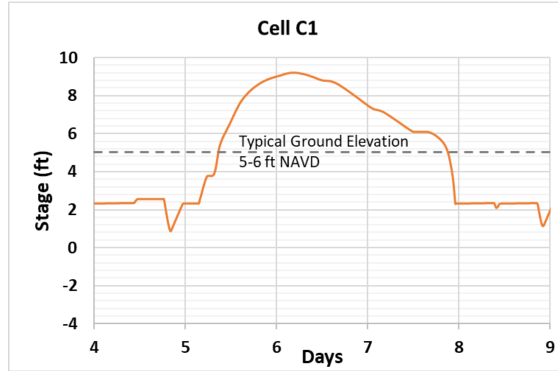


Example Flooding of Cell C, E, F and G Similar to the Modeled 10-year Fluvial Event

HAZARD SCENARIO 10

<u>Resource Response and Impacts:</u>

Fluvial flooding occurs in Cells C, E, F, G and the area upstream of Myrtle Avenue on Ryan Slough. Flooding occurs over the course of approximately 24 hours, overwhelming the drainage system and impounding within the cells. Due to the large volume of flooding, 24 to 36 hours are required to drain the flood waters. In all other cells the existing capacity of drainage channels are sufficient to store and convey overtopping tidal water and fluvial contributions to Protected Lands. However, hydraulic conditions are not continuously favorable for the drainage of fresh water from fluvial, groundwater and precipitation sources with high tides preventing flow from tide gates. The duration of favorable drainage conditions are further reduced with increases to low tide elevations with sea level rise.



Example Flood Hydrograph

Impoundment of fluvial, groundwater and precipitation is common during this time of year, with favorable conditions for drainage from the Protected Lands to the slough channels limited to a few hours per day.

Inundation Due to Impoundment of Fresh Water

Scenario Summary:

The fluvial flows and spring tides result in multiple feet of flooding to cells located along Freshwater and Ryan Sloughs. Protected lands are flooded for 24 to 60 hours.

Fluvial flows do not affect water levels along the Bay Shoreline. Overtopping of the Interior Shoreline is largely in the reach of Freshwater Slough adjacent to Cells C, D and E, and on Ryan Slough adjacent to Cells F and G (Table 3). Overtopping volume typically results in three to six feet of flooding. The large volume of fluvial flooding, high tides and typical saturated conditions in the winter result in reduced conditions favorable to drain fluvial, groundwater and precipitation. A summary of impacts to critical resources is presented in Table 4.

HAZARD SCENARIO 10

Table 2. Overtopping Summary for Cell A Bay and Slough Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	0%	-	-	-	-
		Rail Prism	-	0%	-			
	Brainard Levee	Levee	-	0%	-	-		
	Brainard to Indianola Cutoff	Rail Prism	-	0%	-	-		
Slough	Fay Slough	Levee	-	0%	-	-		
	Eureka Slough	Levee	-	0%	-	-		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	20	7%	-	-	0.0
C1	Fay Slough	67	1%	-	2.7 to 4.7	9.2
	Freshwater Slough	232	2%	3		
C2	Freshwater Slough	2,703	46%	283	0 to 2.7	9.2
D[2]	Freshwater Slough	4,270	94%	2,469	1.5 to 3.5	10.9
E	Freshwater Slough	1,521	58%	96	3.4 to 4.4	10.4
F	Ryan Slough	1,215	36%	3	4.6 to 5.6	10.6
	Freshwater Slough	136	14%	9		
G	Freshwater Slough	116	2%	-	1.1 to 1.6	7.1
	Park Street	169	27%	-		
	Ryan Slough	291	12%	26		
H	Freshwater Slough	-	0%	-	-	0.0
	Eureka Slough	-	0%	-		
I[2]	Eureka Slough	-		-	-	0.0
Myrtle	Ryan Slough	2,019	49%	770	3.1 to 5.1	11.0

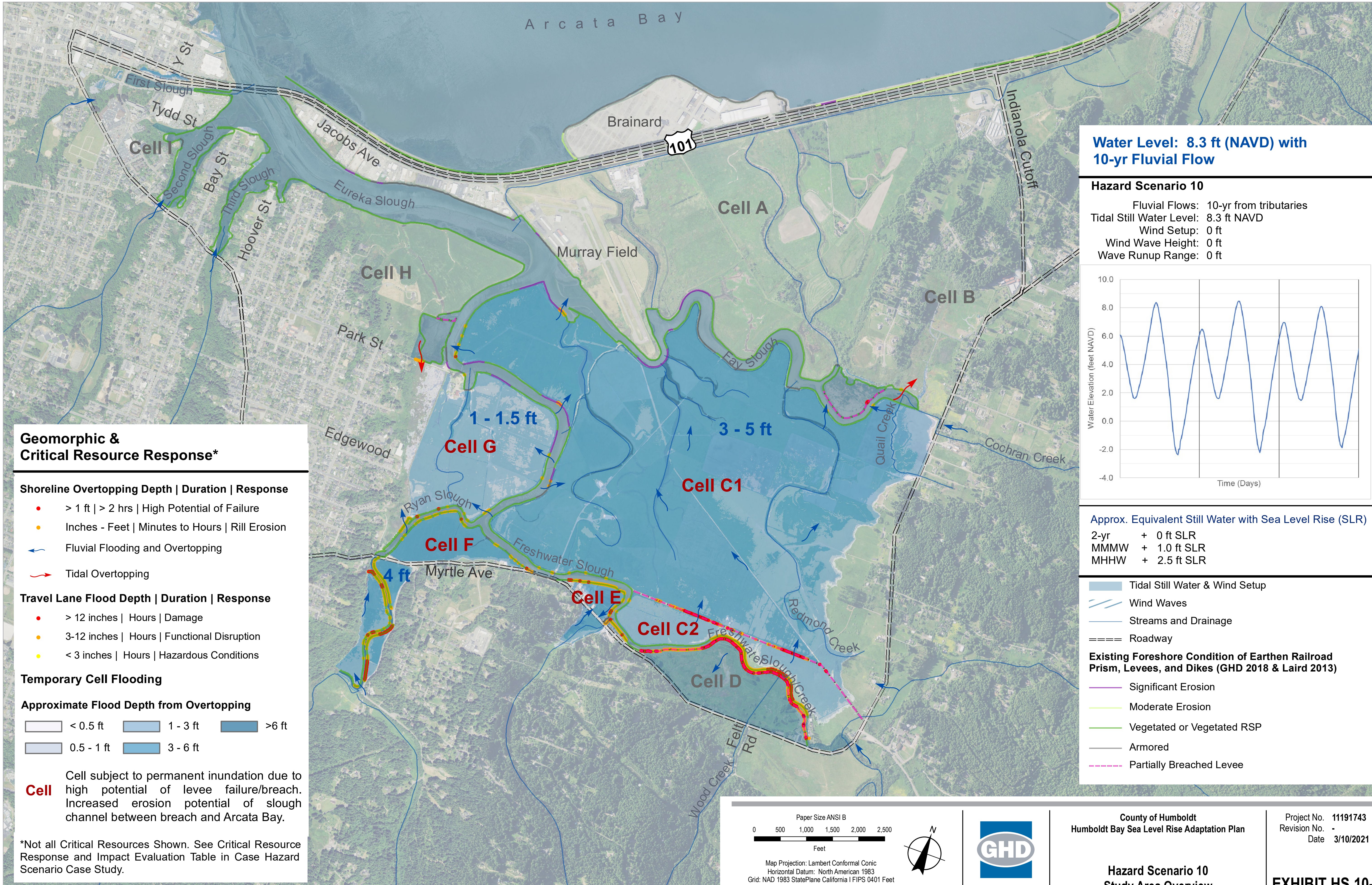
HAZARD SCENARIO 10

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	**Earthen Levees/ Dikes**	Overtopping (depth and time)	Cell A	none	None Observed
			Cell B	shallow (<1ft) and/or short (< 2hrs)	**Top and Land-facing Slope Rill Erosion**
			Cell C	>1ft and >2 hrs	**Potential Failure**
			Cell E	>1ft and >2 hrs	**Potential Failure**
			Cell F	>1ft and >2 hrs	**Potential Failure**
			Cell G	>1ft and >2 hrs	**Potential Failure**
			Cell H	none	None Observed
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay		N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	none	None Observed
Transportation	**Hwy 101 Southbound**	Surface Flooding (ft)	Cell A - Arcata Bay	-	none
	Hwy 101 Northbound		Cell A - Arcata Bay	-	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	-	none
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G		none
	Hoover Street		Cell I	-	none
	2nd and Y Streets		Cell I	-	none
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	-	none
	Hwy 255 (Alternate Route)		Arcata Bay		none
Utilities	**Sewer Lift Stations**	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	-	none
			Humboldt CSD Hoover Street	-	none
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	-	none
	Sewer or Water Pressure Main		Cell A Jacobs Ave - COE	-	none

HAZARD SCENARIO 10

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
		Surface Flooding (Hours)	Cell I Hoover St - HCSD	-	none
	Sewer Gravity Main		Cell I Hoover St - HCSD	-	none
	Gas Main		Cell G	53	**Limited Access Multiple Days**
			Cell C	61	**Limited Access Multiple Days**
			Cell A	-	none
	Communications (Underground)		Cell A	-	none
	Communication Towers/Poles		Cell H	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	-	none
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	-	none
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	-	none
			6th and Tydd Street	-	none
			Hoover Street	-	none
			Park Street	-	none
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	-	none
			Cell B	-	none
			Cell C	61	**Limited Access Multiple Days**
			Cell E	60	**Limited Access Multiple Days**
			Cell F	45	**Limited Access Multiple Days**
			Cell G	53	**Limited Access Multiple Days**
			Cell H	-	none
			Ryan Slough Upstream of Myrtle	52	**Limited Access Multiple Days**



Arcata Bay
Y St
First Slough
Tydd St
Cell I
Second Slough
Bay St
Third Slough
Hoover St
Jacobs Ave
Eureka Slough
Brainard
101
Indianola Cutoff
Cell A
Murray Field
Cell H
Cell B
Park St
Fay Slough
1 - 1.5 ft
3 - 5 ft
Cell G
Edgewood
Quail Creek
Cochran Creek
Cell C1
Ryan Slough
Cell F
Freshwater Slough
4 ft
Myrtle Ave
Cell E
Cell C2
Redmond Creek
Freshwater Slough/Creek
Cell D
Felt Rd
Wood Creek
Water Level: 8.3 ft (NAVD) with 10-yr Fluvial Flow
Hazard Scenario 10
Fluvial Flows: 10-yr from tributaries
Tidal Still Water Level: 8.3 ft NAVD
Wind Setup: 0 ft
Wind Wave Height: 0 ft
Wave Runup Range: 0 ft
Water Elevation (feet NAVD)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
Time (Days)
Approx. Equivalent Still Water with Sea Level Rise (SLR)
2-yr + 0 ft SLR
MMMW + 1.0 ft SLR
MHHW + 2.5 ft SLR
Tidal Still Water & Wind Setup
Wind Waves
Streams and Drainage
Roadway
Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)
Significant Erosion
Moderate Erosion
Vegetated or Vegetated RSP
Armored
Partially Breached Levee
Geomorphic & Critical Resource Response*
Shoreline Overtopping Depth | Duration | Response
> 1 ft | > 2 hrs | High Potential of Failure
Inches - Feet | Minutes to Hours | Rill Erosion
Fluvial Flooding and Overtopping
Tidal Overtopping
Travel Lane Flood Depth | Duration | Response
> 12 inches | Hours | Damage
3-12 inches | Hours | Functional Disruption
< 3 inches | Hours | Hazardous Conditions
Temporary Cell Flooding
Approximate Flood Depth from Overtopping
< 0.5 ft
1 - 3 ft
>6 ft
0.5 - 1 ft
3 - 6 ft
Cell
Cell subject to permanent inundation due to high potential of levee failure/breach. Increased erosion potential of slough channel between breach and Arcata Bay.
*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.
Paper Size ANSI B
0 500 1,000 1,500 2,000 2,500
Feet
Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet
N
GHD
County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan
Hazard Scenario 10
Study Area Overview
Project No. 11191743
Revision No. -
Date 3/10/2021
EXHIBIT HS 10-1

HAZARD SCENARIO 11

Tidal Still Water Level		Fluvial Flow
8.3 feet NAVD	**Existing (2012 baseline)** MMMW 5 -6 times per year	**Existing (2012 baseline)** 100-yr 1% chance per year

Introduction (See Exhibit HS 11-1):

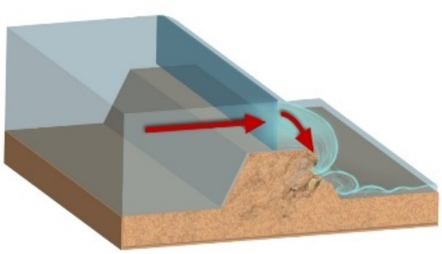
This case study describes a scenario characterized by a fluvial 100-year recurrence flow on freshwater tributaries and typical high tide without local wind effects that further increase water levels. Overtopping of fluvial, fresh water occurs at levees along Freshwater, Ryan and Fay Sloughs. Minor tidal overtopping occurs in limited locations along the interior slough channels and is typically shallow and for short duration. Fluvial flow from tributaries connected to sloughs through tide gates are impounded until tidal water levels drop below interior water levels. Fluvial flooding affects Cells C, E, F, G and the area upstream of Myrtle Avenue on Ryan Slough, with flood depths typically between four and six feet. Myrtle Avenue experiences less than one foot of flooding, resulting in temporary closure. Similar flooding extent within the study area was observed on March 18, 1975, but with what appears to be shallower flooding.

Example Inundation, Similar to Modeled 100-yr Storm Flooding Extent, from March 18, 1975.

Highlighted shoreline processes and responses in this scenario include overtopping and landward slope erosion, fluvial flooding of protected lands due to overtopping and impoundment of drainage, and typical roadway flooding. Examples shown below.

Overtopping and Erosion

0% Arcata Bay Shoreline
38% of Interior Slough Levees



Example Shoreline Overtopping (National Science Foundation, 2020)

Fluvial Flooding of Agricultural Lands

Cells A, B, C, E, F, G, and Ryan Slough

Roadway Flooding

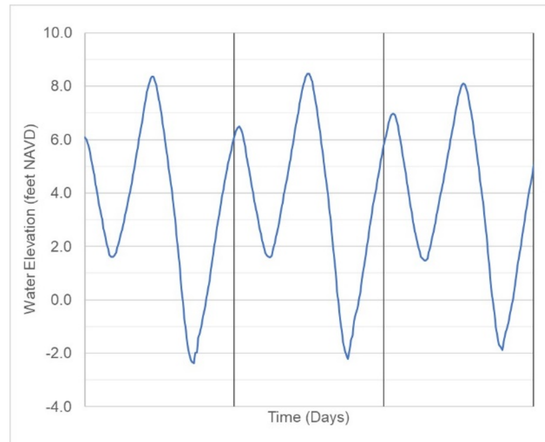
Myrtle Avenue
Park Street

Hydraulics and Sea Level Rise:

This scenario combines the 100-year storm event on fluvial tributaries and high spring tides that occur during the year, from November through January, during average meteorological conditions and any combination of astronomical conditions. High spring tides occur over multiple days and multiple times during this time of year and are not consider to be extreme. Sea level rise will increase the frequency of similar peak water levels to occur throughout the year, while also increasing the elevation of the lowest tides. Based on predicted tides leading up to the event, high tides exceed 9 feet the day prior to the peak and the day following[1]. The duration of peak tides occur during calm conditions, without wind effects inducing increased water levels or producing waves. Water

[1] NHE 2019, Draft -Hydraulic Modeling to Support the Sea Level Rise Adaptation Plan for Humboldt Bay Transportation Infrastructure (Phase 1) Project, Humboldt County, CA December 2019

levels and fluvial flows are referenced to 2012 baseline and ground elevations referenced to the 2010 DEM and supplemental topographic surveys previously described. The interior lands are assumed to be dry with the onset of this event. Hydraulic conditions for this scenarios are presented in Table 1.

Table 1: Scenario 11 Hydraulics and Sea Level Rise		
Fluvial Flows	100-year recurrence on tributaries	
Tidal Still Water Level	8.3 ft NAVD	
Wind Set-up	0 ft	
Wind Wave Height	0 ft	
Wave Runup Range	0 ft	
Total Water Level (TWL)	8.3 ft NAVD	

Antecedent Shoreline Conditions:

This scenario assumes the existing shoreline elevations and conditions are consistent with the observations made in Laird 2013 and GHD 2018. Tidal marsh along the eastern bay shoreline is assumed to match the extent shown in **Exhibit G-1** geomorphic trends.

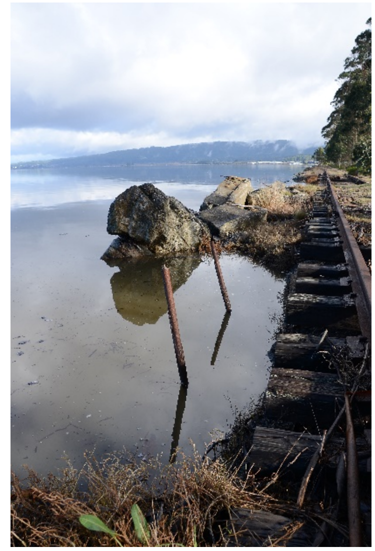
Response:

The following section provides a landscape-scale discussion of this event, describing the hydraulic conditions and associated resource response/impacts for three geographical areas comprising the total Study Area, referred to as the ***Bay Shoreline, Interior Shoreline***, and ***Protected Lands***. This scenario is based on predicted tidal elevations and modeled overtopping by NHE. Exhibit HS 11-1 shows the modeled overtopping depth and duration of the interior and bay shoreline. A summary of overtopping characteristics and specific critical resource impacts associated with this scenario are presented in Tables 2 through 4 at the end of this case study and are based on the hydraulic modeling results, resulting physical processes described by the geomorphic response conceptual model, and then compared to established resource thresholds.

HAZARD SCENARIO 11

Bay Shoreline Response

This area refers to the eastern shoreline of Arcata Bay within the Study Area including the rail prism, Brainard levee and Highway 101. The extent of overtopping for the rail prism is summarized in Table 2, at the end of this case study.



Hydraulic Conditions:

High tides occur for multiple days, with the peak reaching 8.3 feet. As the tide rises, water levels approach the crest move into low elevation areas of the rail prism created by previous high tide and storm events. Active erosion of the rail prism and levee is not observable as still water levels increase. Fluvial flows do not affect water levels along the Bay Shoreline. With sea level rise, high tide water levels will increase and become more frequent. See Scenarios 1 through 8 for additional tidal water levels and recurrences.

Interior Shoreline Response

This area refers to the interior sloughs and adjacent shoreline of the Study Area including Eureka, Freshwater, Fay and Ryan Sloughs.

Hydraulic Conditions:

Exhibit HS 11-1 shows the locations, depth and duration of shoreline overtopping associated with fluvial flows and the limited tidal still water overtopping for interior slough channels. Fluvial flows on Freshwater, Ryan and Fay Sloughs overtop adjacent levees protecting the adjacent cells, which include Cells A through G and the area upstream of Myrtle Avenue on Ryan Slough. Tidal waters are largely contained within the sloughs, with freeboard between the levee crests and tidal water, throughout a majority of the study area.

Resource Response and Impacts:

Overtopping is extensive of unarmored earthen levees induces shallow rill erosion across the top and land-facing slope of earthen levees. Erosion is exacerbated in areas where there is existing foreshore erosion. Damaged levees that go unrepaired following the event are susceptible to the following:

- Increased overtopping potential due to eroded levee crest elevation and width.
- Reduced potential for natural recruitment of vegetation due to active/vertical erosion scarps.
- Increased potential of saturation/seepage due to reduced levee width.

Example Levee Crest Erosion from Overtopping (Laird, 2013)

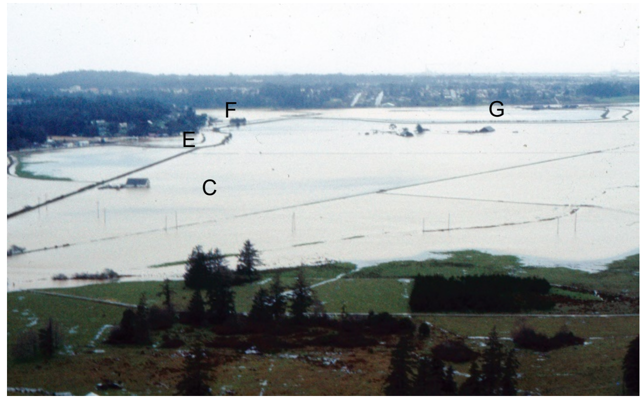
Significant overtopping of greater than one foot for more than two hours occurs at levee locations along Cells A through G and the area upstream of Myrtle Avenue on Ryan Slough. The extent of overtopping for each cell is summarized in Table 3, at the end of this case study. The response of the resources landward of the shoreline are described in the **Protected Lands Response** section.

Protected Lands Response

This area refers to the protected lands and critical resources within the Study Area that are landward of the shorelines previously described. This includes Jacobs Avenue, Murray Field Airport, Fay Slough Wildlife Area, Agricultural Lands, Communities along First, Second and Third Slough, and Myrtle Avenue/Old Arcata Road.

Hydraulic Conditions: Exhibit HS 11-1 depicts the approximate maximum flood depth, based on volume of overtopping, for each cell. The largest effect noted is the flooding of Cells C, E, F, G and the area upstream of Myrtle Avenue on Ryan Slough. Tidal overtopping occurs on Park Street and select other locations, but contributions to flooding are minor.

Developed areas adjacent to First, Second and Third Slough are protected by a natural elevation gradient and fluvial flows to not increase water levels significantly in these areas.

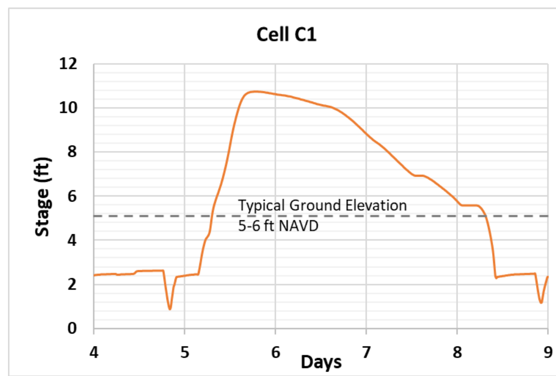


Example Flooding of Cell C, E, F and G Similar to the Modeled 10-year Fluvial Event

Resource Response and Impacts:

Fluvial flooding occurs in Cells C, E, F, G and the area upstream of Myrtle Avenue on Ryan Slough. Flooding occurs over the course of approximately 24 hours, overwhelming the drainage system and impounding within the cells. Due to the large volume of flooding, 36 to 48 hours are required to drain the flood waters. In all other cells the existing capacity of drainage channels are sufficient to store and convey overtopping tidal water and fluvial contributions to Protected Lands. However, hydraulic conditions are not continuously favorable for the drainage of fresh water from fluvial, groundwater and precipitation sources with high tides preventing flow from tide gates. The duration of favorable drainage conditions are further reduced with increases to low tide elevations with sea level rise.

Impoundment of fluvial, groundwater and precipitation is common during this time of year, with favorable conditions for drainage from the Protected Lands to the slough channels limited to a few hours per day.



Example Flood Hydrograph

Inundation Due to Impoundment of Fresh Water

HAZARD SCENARIO 11

Scenario Summary:

The fluvial flows and spring tides result in multiple feet of flooding to cells located along Freshwater and Ryan Sloughs. Protected lands are flooded for 48 to 72 hours.

Fluvial flows do not affect water levels along the Bay Shoreline. Overtopping of the Interior Shoreline is widespread along Freshwater, Ryan, and Fay Sloughs (Table 3). Overtopping volume typically results in four to six feet of flooding, exceeding cell storage capacity and overtopping from the cell to the slough channels. The large volume of fluvial flooding, high tides and typical saturated conditions in the winter result in reduced conditions favorable to drain fluvial, groundwater and precipitation. A summary of impacts to critical resources are presented in Table 4.

Table 2. Overtopping Summary for Cell A Bay and Slough Shoreline

Bay Shoreline								
Cell A	Location	Structure	Overtopping (LF[1] | %)		Significant Overtopping (LF)	Volume Overtopping (ac-ft)	Typical Flood Depth (ft)	Max Interior Water Level (ft)
Bay	Eureka Slough to Brainard	Hwy 101	-	0%	-	-	-	-
		Rail Prism	-	0%	-			
	Brainard Levee	Levee	-	0%	-	-		
	Brainard to Indianola Cutoff	Rail Prism	-	0%	-	-		
Slough	Fay Slough	Levee	1,586	10%	16	-		
	Eureka Slough	Levee	-	0%	-	-		

Table 3. Overtopping Summary for Interior Shoreline and Protected Lands

Interior Shoreline & Protected Lands						
Cell	Location	Overtopping (LF | %)		Significant Overtopping (LF)	Approx. Flood Depth (ft)	Max Interior Water Level (feet NAVD)
B	Fay Slough	177	63%	22	2.2 to 3.2	8.6
C1	Fay Slough	3,195	29%	316	4.3 to 6.3	10.7
	Freshwater Slough	5,211	51%	511		
C2	Freshwater Slough	3,405	58%	2,248	1.3 to 4.3	10.7
D[2]	Freshwater Slough	4,422	97%	3,206	1.9 to 3.9	11.4
E	Freshwater Slough	2,219	85%	876	4 to 5	10.9
F	Ryan Slough	2,095	62%	800	5.4 to 6.4	11.3
	Freshwater Slough	619	63%	76		
G	Freshwater Slough	1,304	22%	144	4.1 to 4.6	10.1
	Park Street	504	82%	185		
	Ryan Slough	1,708	72%	73		
H	Freshwater Slough	-	-	-	-	-
	Eureka Slough	-	-	-		
I[2]	Eureka Slough	-	-	-	-	-
Myrtle	Ryan Slough	3,940	95%	1,468	3.8 to 5.8	11.8

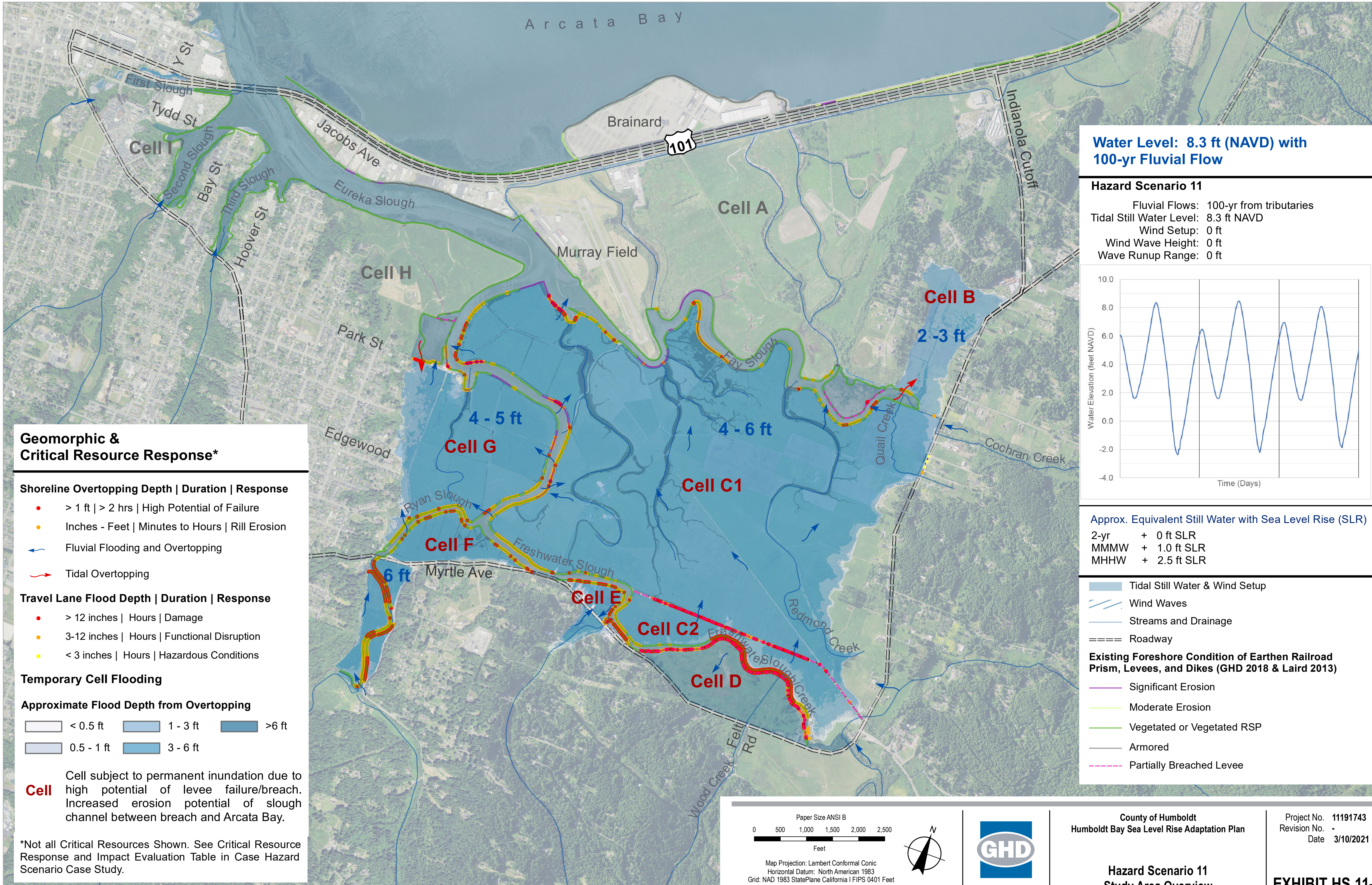
HAZARD SCENARIO 11

Table 4. Critical Resource Response and Impact Evaluation

Critical Resource		Physical Process	Location/Exposure	Flood Depth/Duration/ Extent	Impact to Resource
Shoreline Protection	Earthen Levees	Overtopping (depth and time)	Cell A	>1ft and >2 hrs	Potential Failure
			Cell B	>1ft and >2 hrs	Potential Failure
			Cell C	>1ft and >2 hrs	Potential Failure
			Cell E	>1ft and >2 hrs	Potential Failure
			Cell F	>1ft and >2 hrs	Potential Failure
			Cell G	>1ft and >2 hrs	Potential Failure
			Cell H	-	None Observed
	Rail Prism	Wind Waves (height)	Cell A- Arcata Bay	-	N/A
		Overtopping (depth and time)	Cell A- Arcata Bay	-	None Observed
Transportation	Hwy 101 Southbound	Surface Flooding (ft)	Cell A - Arcata Bay	-	none
	Hwy 101 Northbound		Cell A - Arcata Bay	-	none
	Jacobs Ave		Cell A (ft)	-	none
	Airport Road		Cell A	-	none
	Indianola Cutoff		Cell A	-	none
	Park Street		Cell G		none
	Hoover Street		Cell I	-	none
	2nd and Y Streets		Cell I	-	none
	4th, 5th, 6th, V St		Cell I	-	none
	Myrtle Ave		Cells B, C, F, D	0.3	Closure
	Hwy 255 (Alternate Route)		Arcata Bay		none
Utilities	Sewer Lift Stations	Surface Flooding (ft)	City of Eureka Jacobs Ave #1	-	none
			City of Eureka Jacobs Ave #2	-	none
			City of Eureka Y Street	-	none
			City of Eureka Hill Street (Tydd Street)	-	none
			Humboldt CSD Hoover Street	-	none
			Humboldt CSD Edgewood	-	none
	Water Booster Station		City of Eureka Myrtle Ave	0.7	Limited Access
	Sewer or Water Pressure Main	Surface Flooding (Hours)	Cell A Jacobs Ave - COE	-	none
			Cell I Hoover St - HCSD	-	none
	Sewer Gravity Main		Cell I Hoover St - HCSD	-	none
	Gas Main		Cell G	60	Limited Access Multiple Days
			Cell C	73	Limited Access Multiple Days
			Cell A	-	none
	Communications (Underground)		Cell A	-	none

HAZARD SCENARIO 11

	Communication Towers/Poles		Cell H	-	none
Protected Lands	**Residential/ Commercial/ Industrial**	Surface Flooding (ft)	Jacobs Ave	-	none
			Murray Field	-	none
			Harper Motors	-	none
			Brainard	-	none
			Rainbow Storage Indianola Cutoff	-	none
			2nd and Y Street	-	none
			6th and Tydd Street	-	none
			Hoover Street	-	none
			Park Street	-	none
			Edgewood	-	none
	Agricultural Land and Wildlife Areas	Surface Flooding (hrs)	Cell A	-	none
			Cell B	64	**Limited Access Multiple Days**
			Cell C	73	**Limited Access Multiple Days**
			Cell E	64	**Limited Access Multiple Days**
			Cell F	49	**Limited Access Multiple Days**
			Cell G	60	**Limited Access Multiple Days**
			Cell H	-	none
			Ryan Slough Upstream of Myrtle	54	**Limited Access Multiple Days**



Water Level: 8.3 ft (NAVD) with 100-yr Fluvial Flow

Hazard Scenario 11

Fluvial Flows:	100-yr from tributaries
Tidal Still Water Level:	8.3 ft NAVD
Wind Setup:	0 ft
Wind Wave Height:	0 ft
Wave Runup Range:	0 ft

10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
Water Elevation (feet NAVD)
Time (Days)

Approx. Equivalent Still Water with Sea Level Rise (SLR)

2-yr	+	0 ft SLR
MMMW	+	1.0 ft SLR
MHHW	+	2.5 ft SLR

- Tidal Still Water & Wind Setup
- Wind Waves
- Streams and Drainage
- Roadway

Existing Foreshore Condition of Earthen Railroad Prism, Levees, and Dikes (GHD 2018 & Laird 2013)

- Significant Erosion
- Moderate Erosion
- Vegetated or Vegetated RSP
- Armored
- Partially Breached Levee

Geomorphic & Critical Resource Response*

Shoreline Overtopping Depth | Duration | Response

- > 1 ft | > 2 hrs | High Potential of Failure
- Inches - Feet | Minutes to Hours | Rill Erosion
- Fluvial Flooding and Overtopping
- Tidal Overtopping

Travel Lane Flood Depth | Duration | Response

- > 12 inches | Hours | Damage
- 3-12 inches | Hours | Functional Disruption
- < 3 inches | Hours | Hazardous Conditions

Temporary Cell Flooding

Approximate Flood Depth from Overtopping

- < 0.5 ft
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 6 ft
- >6 ft

Cell Cell subject to permanent inundation due to high potential of levee failure/breach. Increased erosion potential of slough channel between breach and Arcata Bay.

*Not all Critical Resources Shown. See Critical Resource Response and Impact Evaluation Table in Case Hazard Scenario Case Study.

Paper Size ANSI B

0 500 1,000 1,500 2,000 2,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

County of Humboldt
Humboldt Bay Sea Level Rise Adaptation Plan

Hazard Scenario 11
Study Area Overview

Project No. **11191743**
Revision No. **-**
Date **3/10/2021**

EXHIBIT HS 11-1

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Print date: 10 Mar 2021 - 21:18

Data source: Shoreline Elevation, NOAA, 2014; Study area, Humboldt County, 2/28/2019; Roads data, US Census, 2013; Creeks, Humboldt County 2015; Orthoimagery, 2016; NAIP; .
Created by: bvivyan