WORKSHOP

Sea Level Rise Adaptation Plan for Eureka Slough Hydrographic Area, Humboldt Bay

March 12, 2020 1:00 pm – 4:00 pm

Workshop Agenda

I. Planning Framework	1:00-1:45 pm
II. Vulnerability Assessment	1:45-3:15 pm
III. Adaptation	3:15-3:45 pm
IV. Key Conclusions and Next Steps	3:45-4:00 pm

Opportunities for feedback:

1. Verbal feedback today
2. Written feedback by March 27, 2020
3. Request follow-up meeting or conversation

Funding

- Caltrans Adaptation Planning Grant Program
- City of Eureka
- Humboldt County Association of Governments
- County of Humboldt

(Total Budget = $480,000)

Schedule

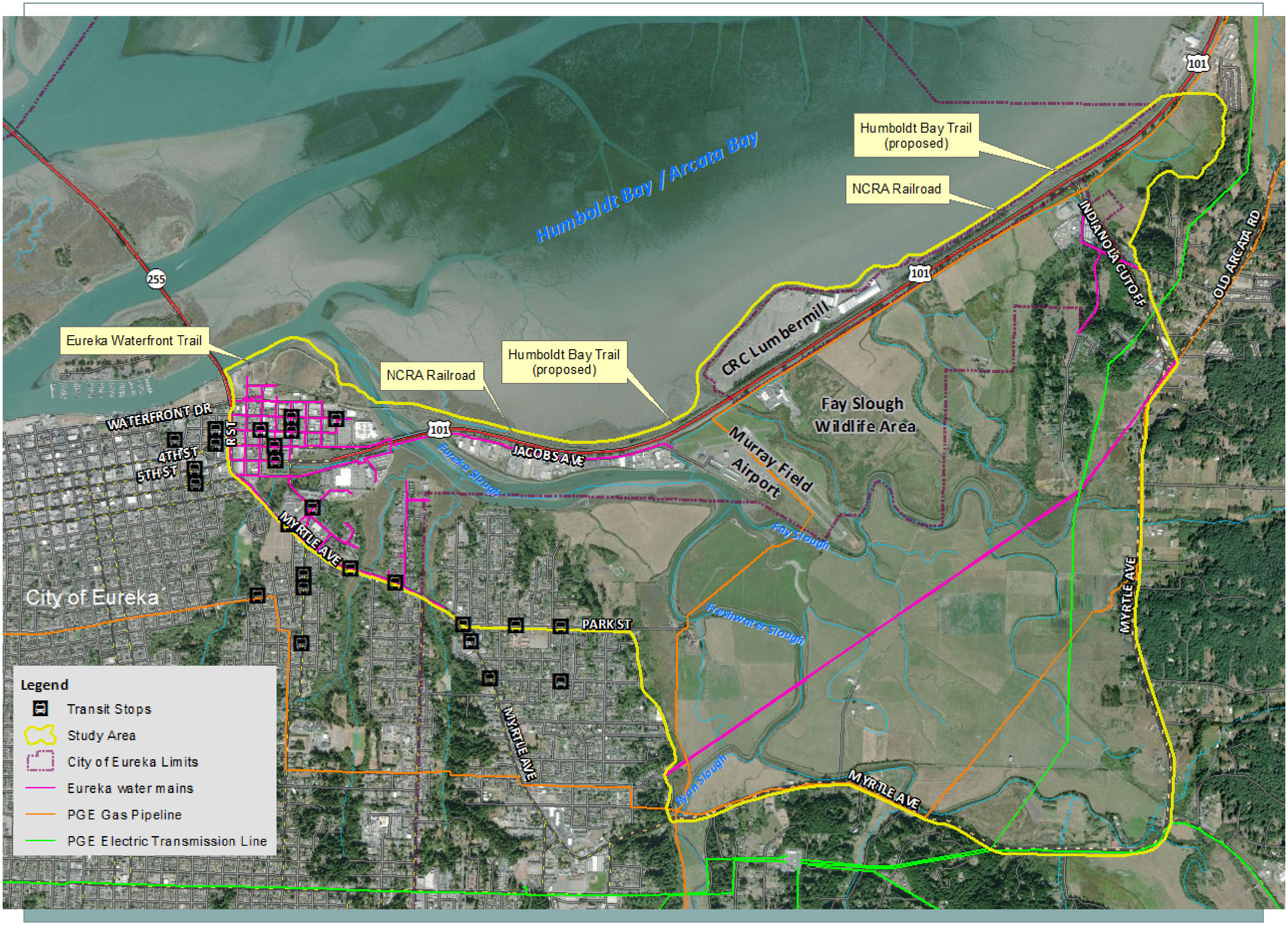
- February 2018: applied for funds
- February 2019: initiated work with consultant team
- December 2020: target date for project completion

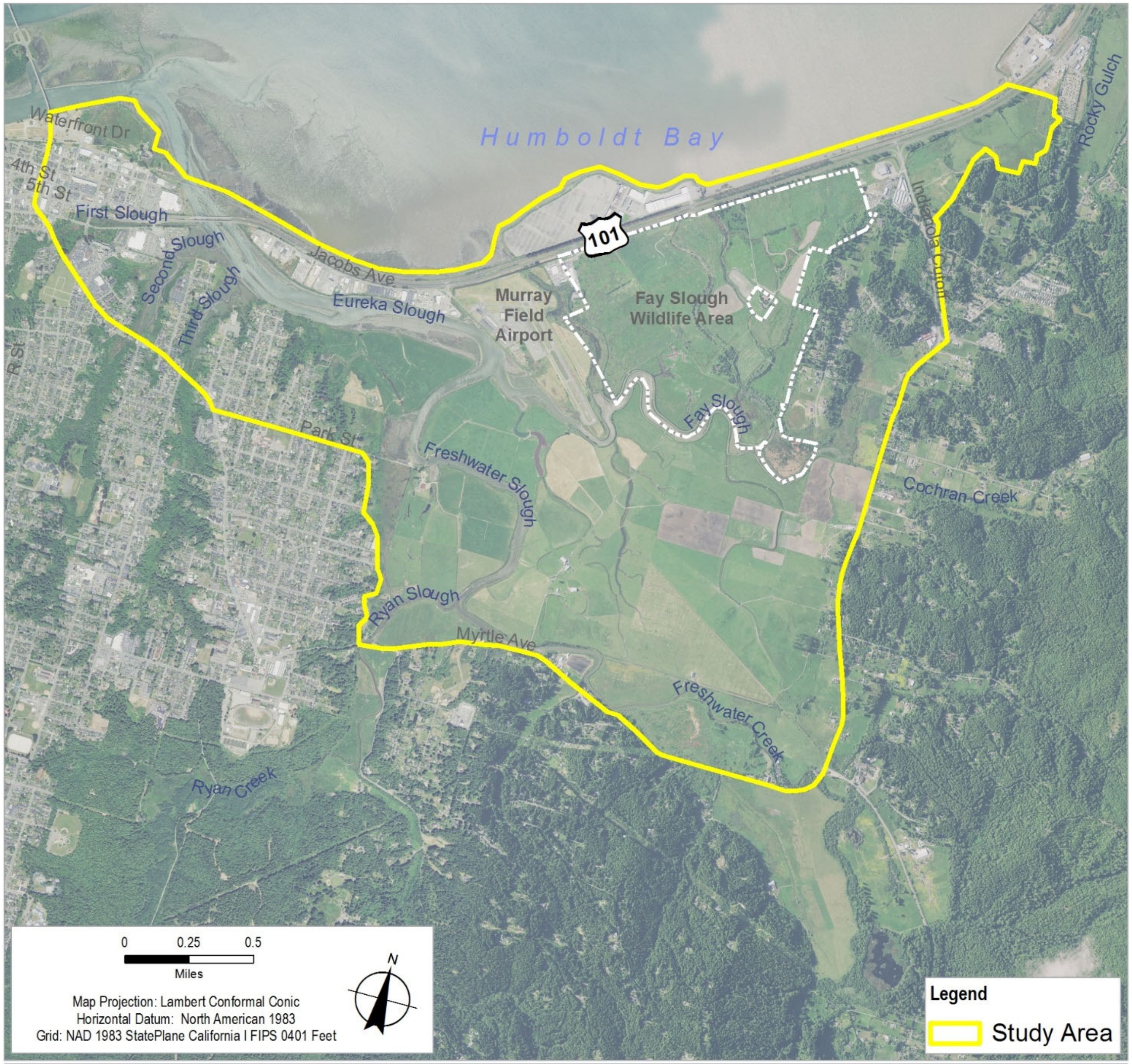
Project Team

- GHD Inc.
- Northern Hydrology & Engineering
- Environmental Science Associates
- GMA Hydrology, Inc.
- Trinity Associates (Aldaron Laird)
- Philip King, San Francisco State University
- Emily Sinkhorn, RCAA
- Ryan Rice
- Jerry Rohde

I. Planning Framework

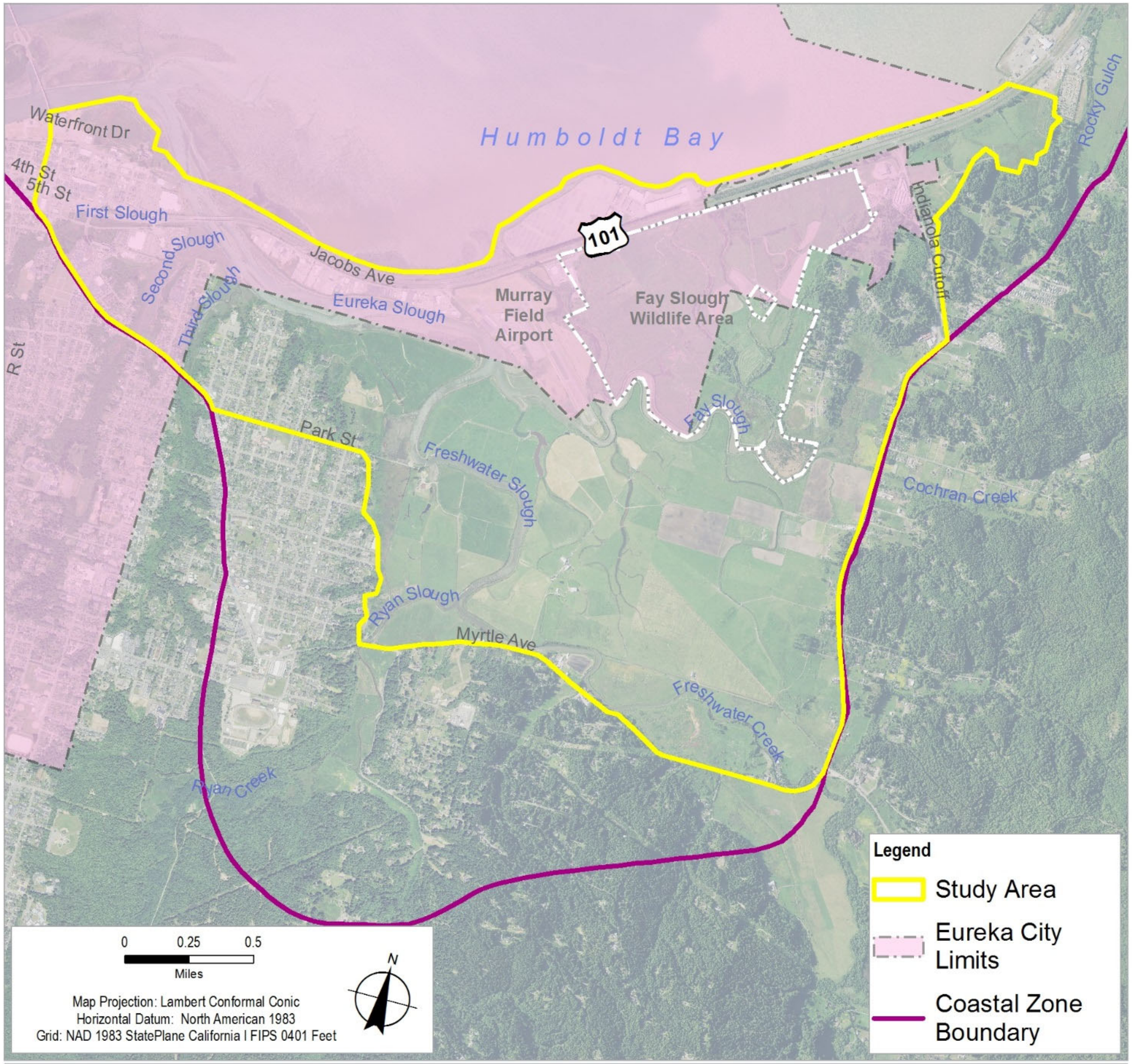

City of Arcata
101
255
101
101
Study Area
City of Eureka


Humboldt Bay / Arcata Bay
Humboldt Bay Trail (proposed)
NCRA Railroad
Eureka Waterfront Trail
NCRA Railroad
Humboldt Bay Trail (proposed)
CRC Lumbermill
Fay Slough Wildlife Area
Murray Field Airport
INDIANOLA CUTOFF
OLD ARCATA RD
WATERFRONT DR
R ST
4TH ST
5TH ST
JACOBS AVE
Eureka Slough
Fay Slough
MYRTLE AVE
PARK ST
Freshwater Slough
Ryan Slough
MYRTLE AVE
MYRTLE AVE
MYRTLE AVE
City of Eureka
101
255
Legend
Transit Stops
Study Area
City of Eureka Limits
Eureka water mains
PGE Gas Pipeline
PGE Electric Transmission Line



G:\561\11191743\GIS\Maps\Deliverables\EC_HumBaySymp\11191743_001_StudyArea_revA.mxd

Data source: Study area, Humboldt County; Roads data, TIGER; Orthoimagery, 2016; NAIP; . Created by: ashows



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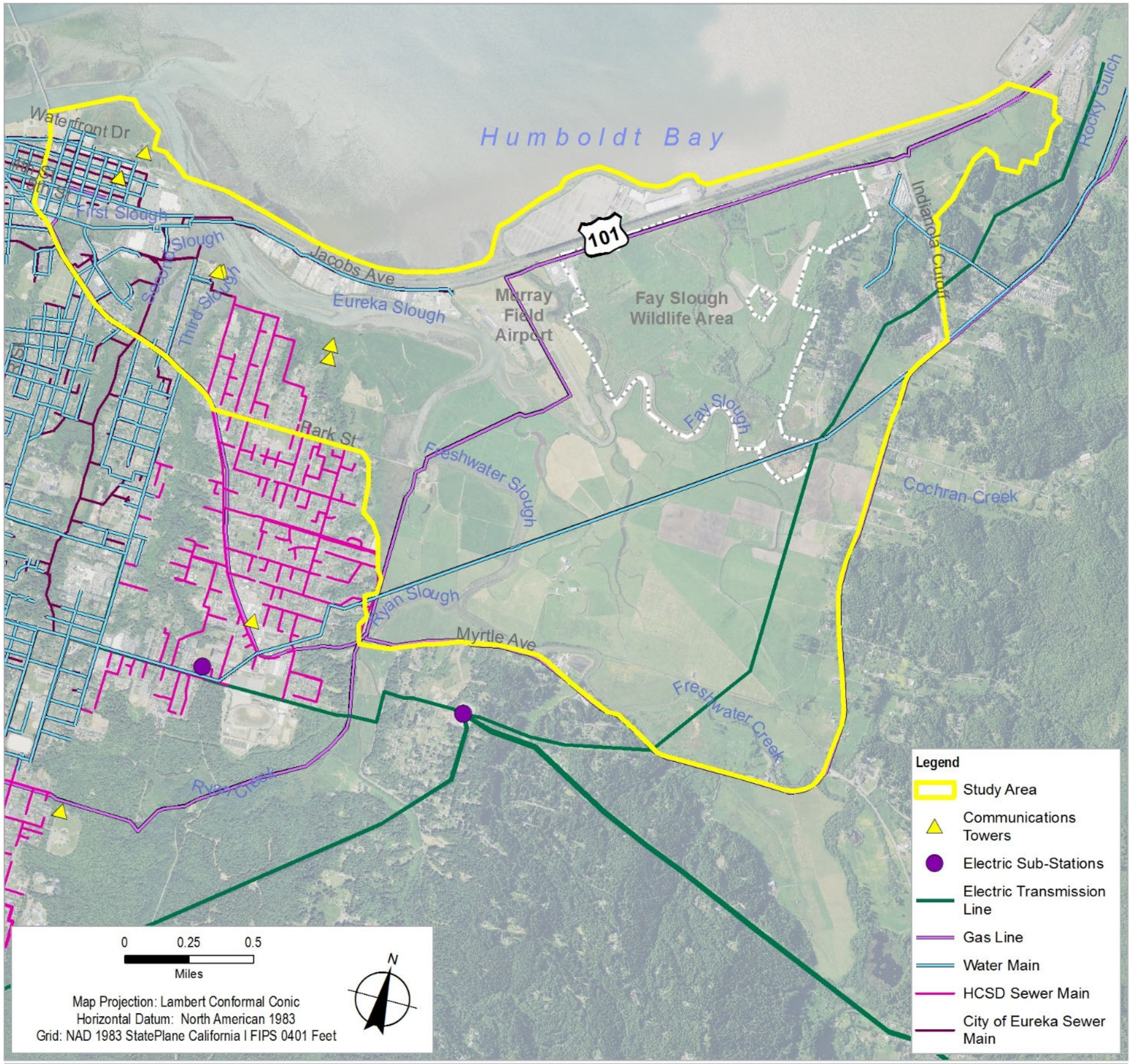
Data source: Study Area boundary, Humboldt County; City Boundary, City of Eureka, 4/3/2019; Coastal Zone boundary, Laird; Roads data, TIGER; Orthoimagery 2016, NAIP; . Created by: ashows



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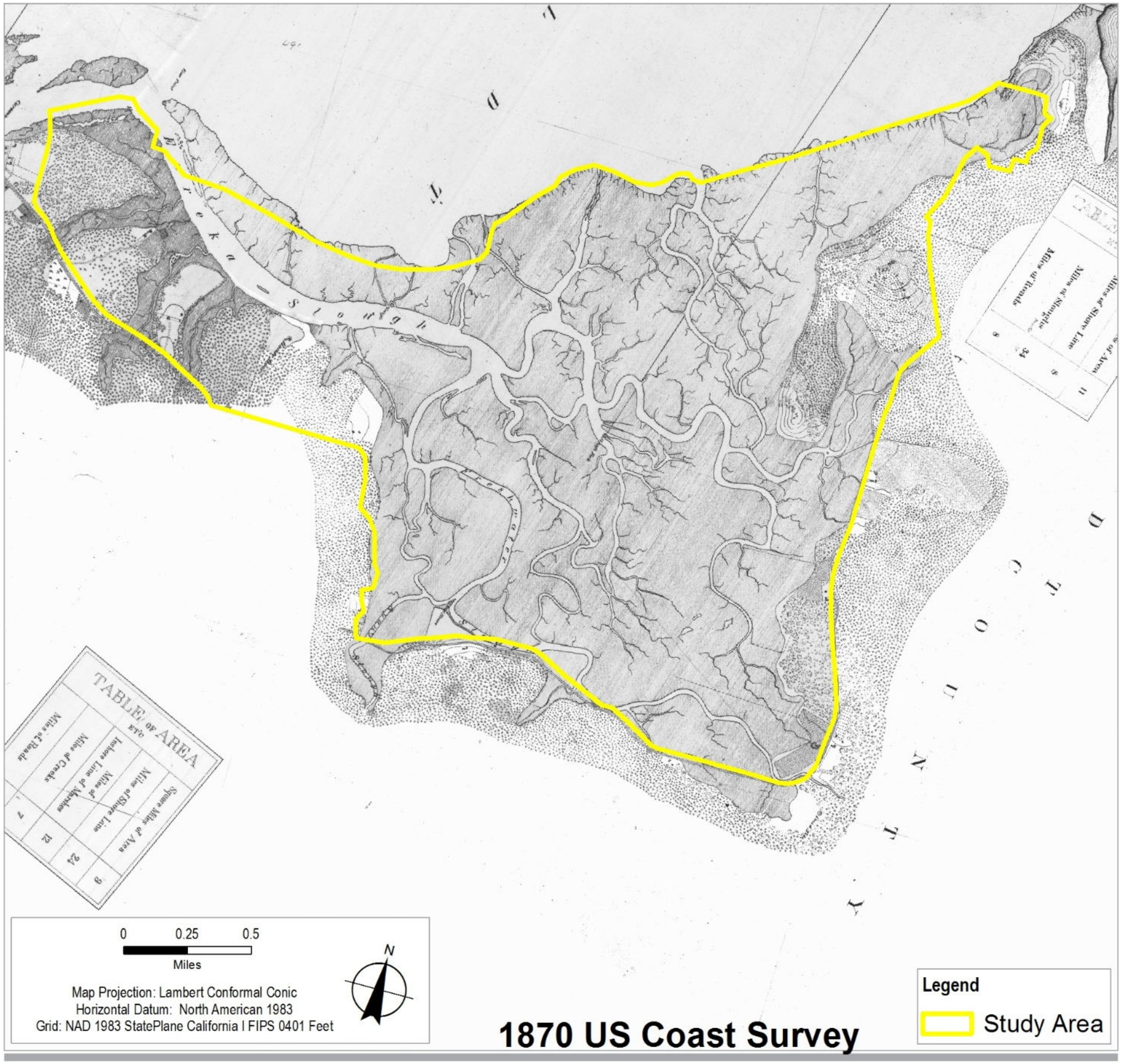
Data source: Study Area, County; Wastewater features, water features, City of Eureka; Wastewater Myrtletown, Electric lines and sub-stations, Gas lines, Comm towers, Greenway; Roads data, TIGER; Orthoimagery 2016, NAIP; . Created by: ashows



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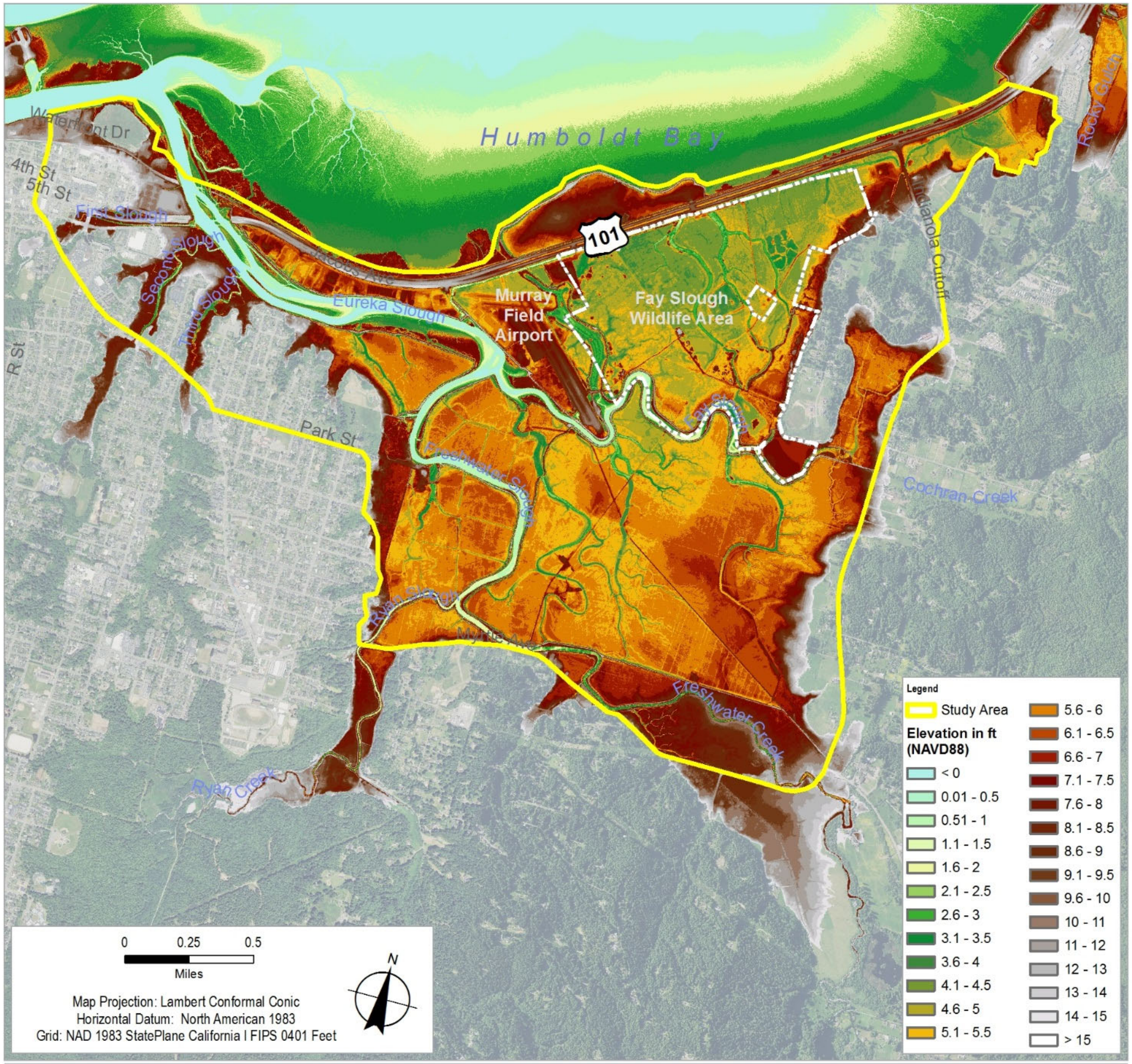
Data source: Study Area boundary, Humboldt County; City Boundary, City of Eureka, 4/3/2019; Coastal Zone boundary, Laird; Roads data, TIGER; Orthoimagery 2016, NAIP; . Created by: ashows



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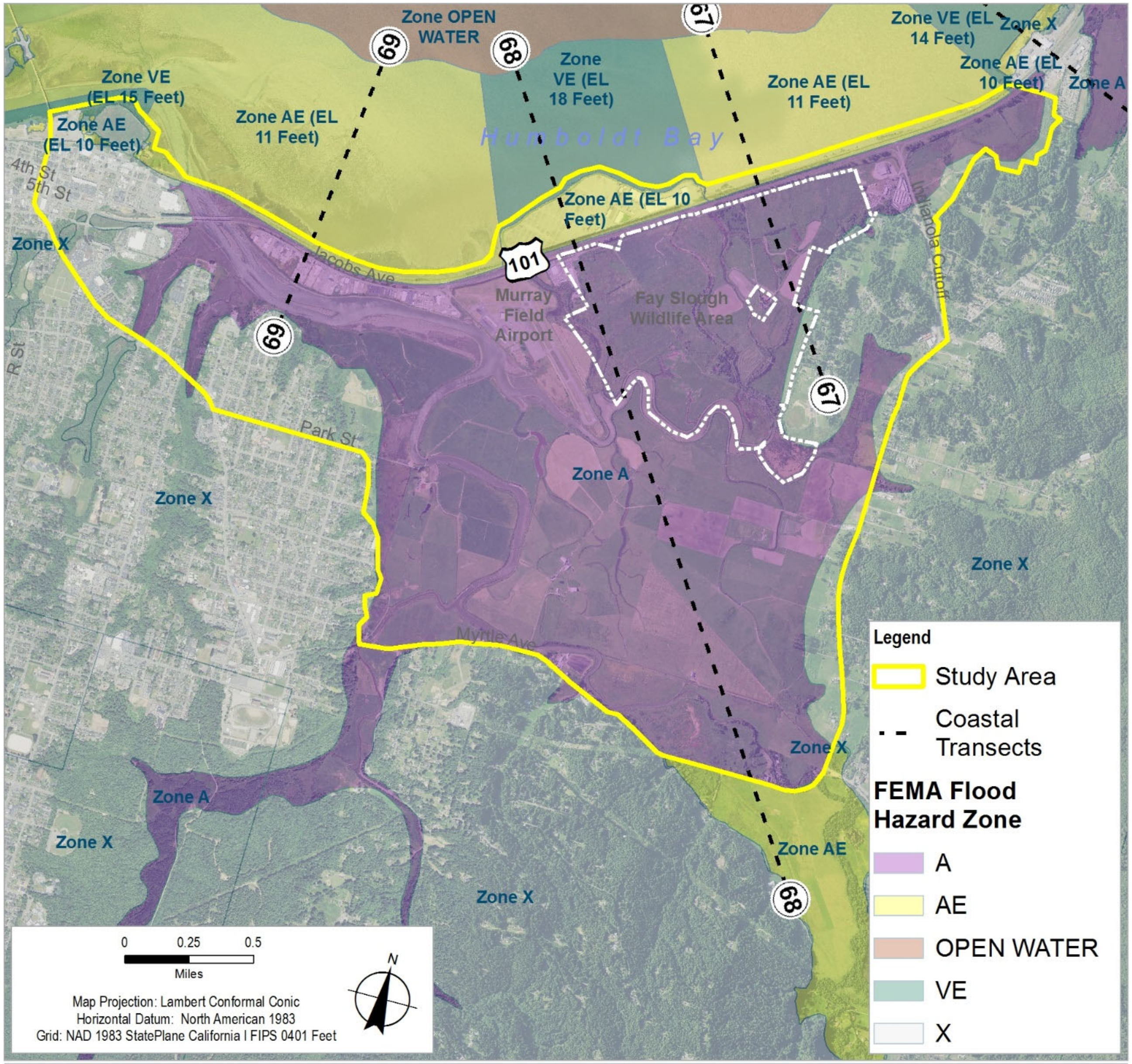

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Data source: Study Area boundary, Humboldt County; Flood hazard, FEMA; Roads data, TIGER; Orthoimagery 2016, NAIP; .
Created by: ashows

Guiding Questions

1. What are the most significant risks within the study area?

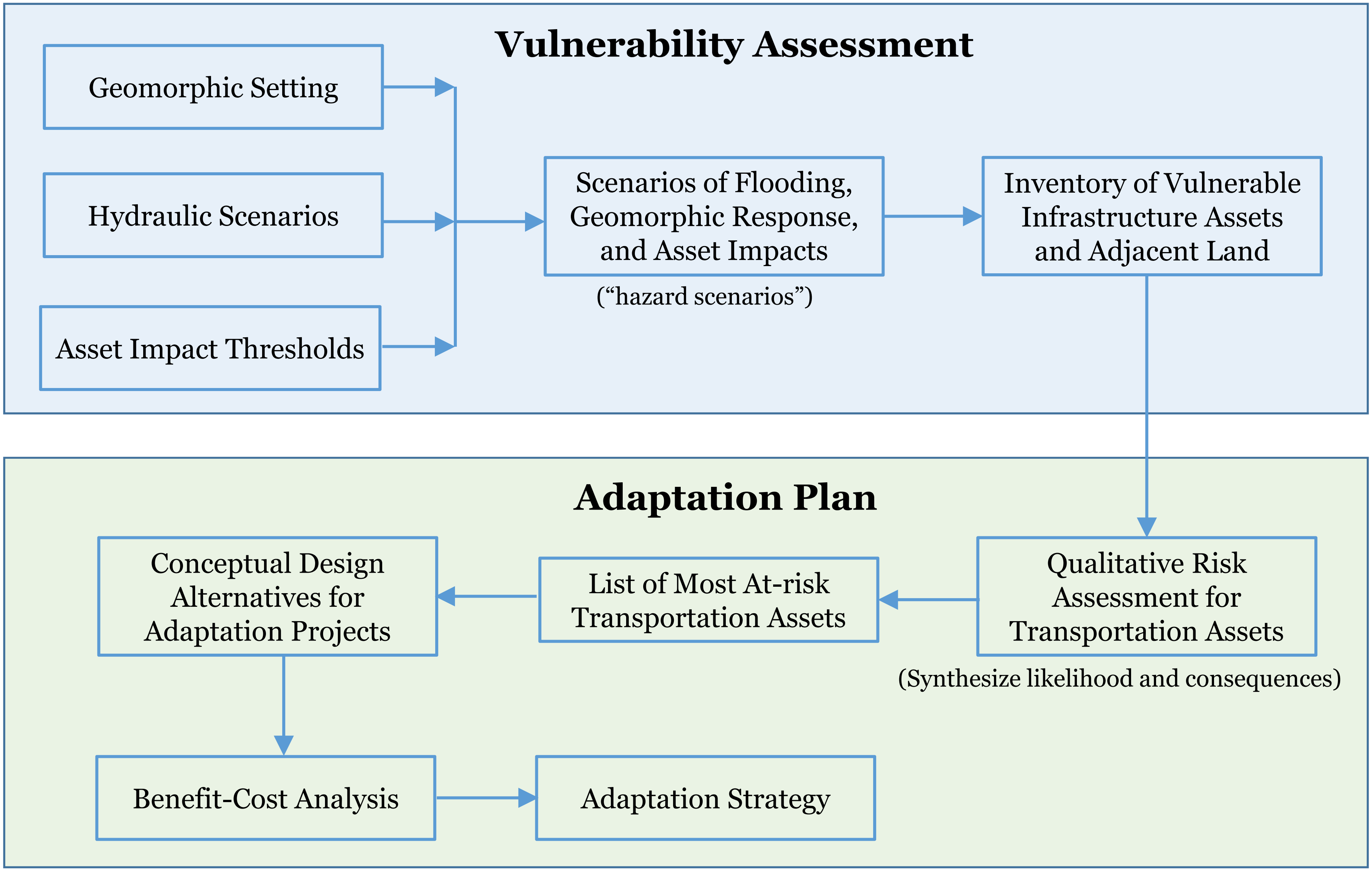
2. What designs for adaptation projects could be feasible and effective?

3. How can collaborative efforts be advanced?

Project Objectives

1. Build relationships and an organizing framework for advancing collaborative efforts among public and private landowners at a regional scale
2. Improve the collective understanding of risks to transportation infrastructure from flooding and inundation hazards associated with sea level rise in Humboldt Bay
3. Identify vulnerable populations and the interests of affected landowners and stakeholders, including non-transportation infrastructure (water, natural gas, electricity) and agriculture
4. Identify feasible conceptual designs that protect infrastructure and are compatible with adjacent land and develop an implementation strategy
5. Develop tools for evaluating the costs and benefits of investing in adaptation projects
6. Establish a methodology for developing adaptation plans that can be applied in other discrete watershed basins around the perimeter of Humboldt Bay

Sea Level Rise Adaptation Planning Flow Diagram



Vision Statement

1. Infrastructure, residences, businesses, agricultural operations, and natural areas are resilient to flooding under current and future sea level conditions.
2. The critical resources of the Eureka Slough hydrographic area are protected from flooding hazards by multiple lines of defense including natural features (mud flats and salt marsh) and built structures (such as levees and embankments).
3. Public officials, landowners, and residents are aware of flood hazards associated with Humboldt Bay and freshwater tributaries and incorporate the goal of reducing flood risk into all pertinent planning and management decisions.
4. Landowners and managers collaborate on implementing an integrated strategy of short-term and long-term actions to achieve and maintain an acceptable level of flood risk.
5. Diverse habitat types and healthy ecosystem functions are maintained.
6. Adaptation projects are led by local agencies and supported by federal and state funding.

Guiding Principles

1. Landscape-scale and process-based evaluation
2. Risk management approach
3. Apply best available science
4. Engage stakeholders
5. Aim to maximize multi-benefit projects and nature-based solutions
6. Multiple lines of defense
7. Adaptive management

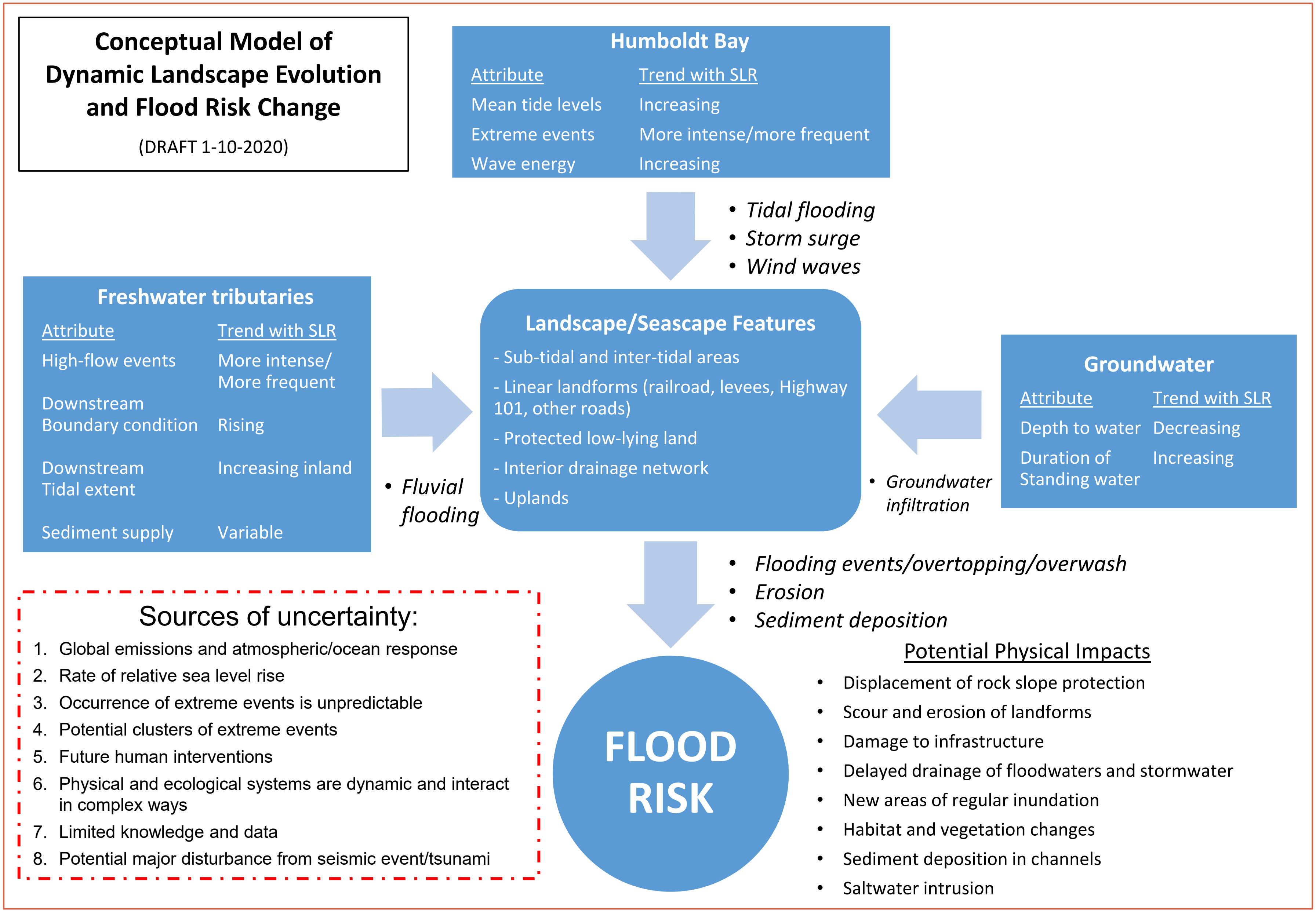
Key Assumptions

1. The Highway 101 transportation corridor between Eureka and Arcata will remain in its current location along the Humboldt Bay shoreline well into the 22nd century

2. Sea level rise adaptation will require an incremental approach utilizing a combination of short-term actions to reduce immediate risk and gain time along with long-term actions to address future conditions.

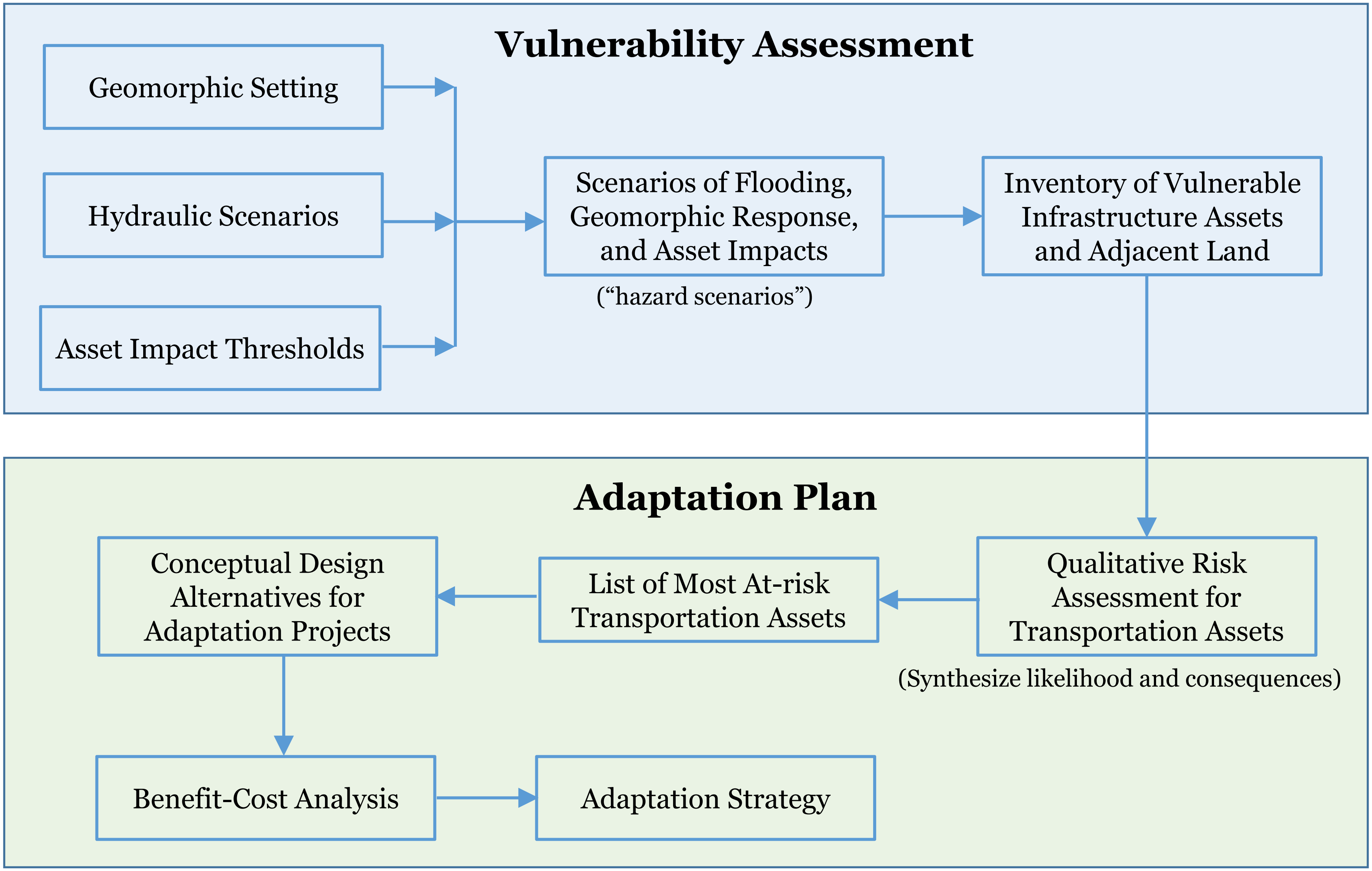
3. Adaptation projects will need to minimize impacts to the extent practicable and comply with applicable laws and regulations.

4. Many adaptation projects will depend on the availability of state or federal funding and the willingness to participate of affected landowners.

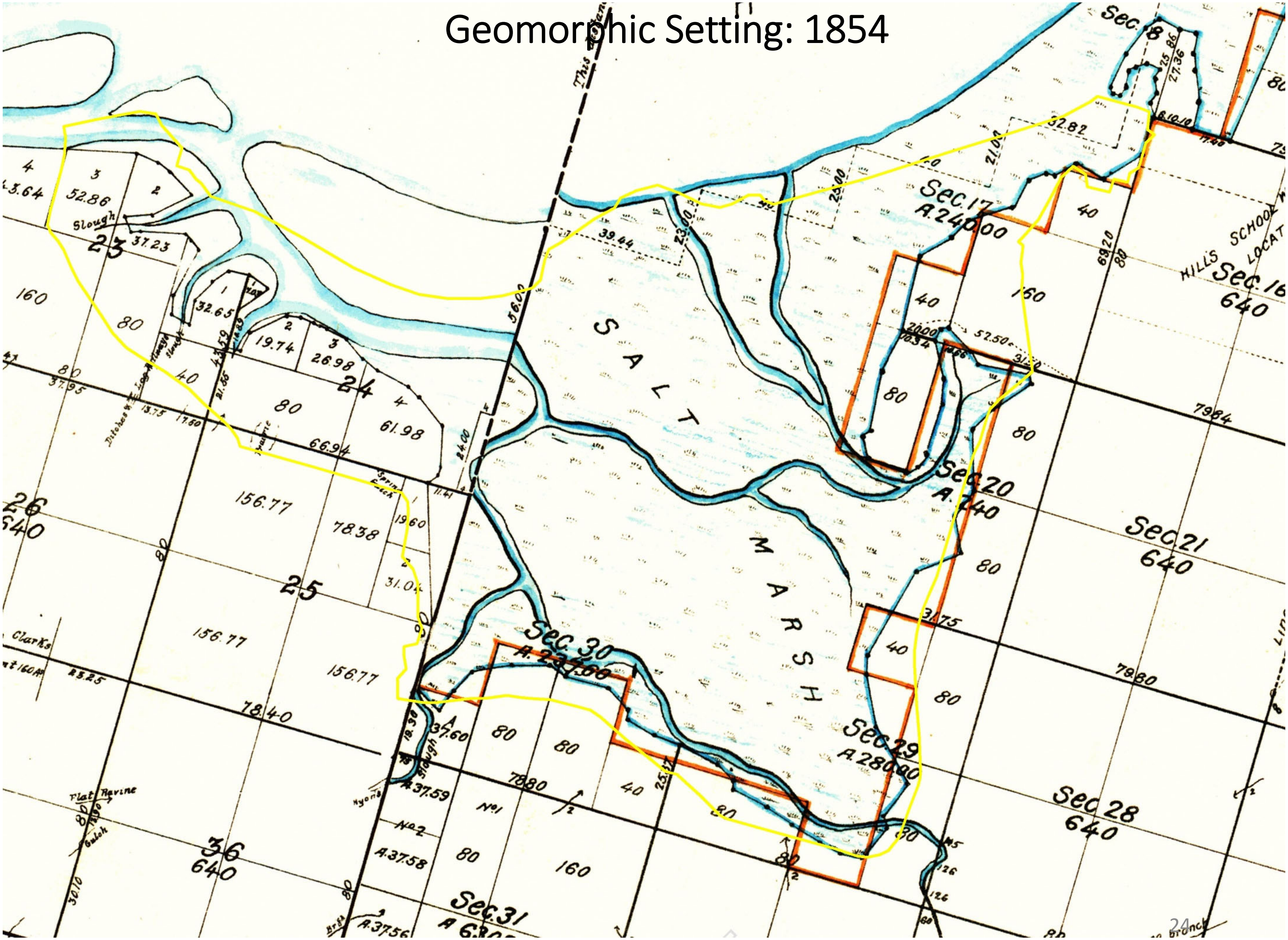

Conceptual Model of Dynamic Landscape Evolution and Flood Risk Change
(DRAFT 1-10-2020)
Humboldt Bay
Attribute | Trend with SLR
Mean tide levels | Increasing
Extreme events | More intense/more frequent
Wave energy | Increasing
• Tidal flooding
• Storm surge
• Wind waves
Freshwater tributaries
Attribute | Trend with SLR
High-flow events | More intense/ More frequent
Downstream Boundary condition | Rising
Downstream Tidal extent | Increasing inland
Sediment supply | Variable
• Fluvial flooding
Landscape/Seascape Features
- Sub-tidal and inter-tidal areas
- Linear landforms (railroad, levees, Highway 101, other roads)
- Protected low-lying land
- Interior drainage network
- Uplands
Groundwater
Attribute | Trend with SLR
Depth to water | Decreasing
Duration of Standing water | Increasing
• Groundwater infiltration
• Flooding events/overtopping/overwash
• Erosion
• Sediment deposition
FLOOD RISK
Potential Physical Impacts
• Displacement of rock slope protection
• Scour and erosion of landforms
• Damage to infrastructure
• Delayed drainage of floodwaters and stormwater
• New areas of regular inundation
• Habitat and vegetation changes
• Sediment deposition in channels
• Saltwater intrusion
Sources of uncertainty:
1. Global emissions and atmospheric/ocean response
2. Rate of relative sea level rise
3. Occurrence of extreme events is unpredictable
4. Potential clusters of extreme events
5. Future human interventions
6. Physical and ecological systems are dynamic and interact in complex ways
7. Limited knowledge and data
8. Potential major disturbance from seismic event/tsunami

II. Vulnerability Assessment

Sea Level Rise Adaptation Planning Flow Diagram

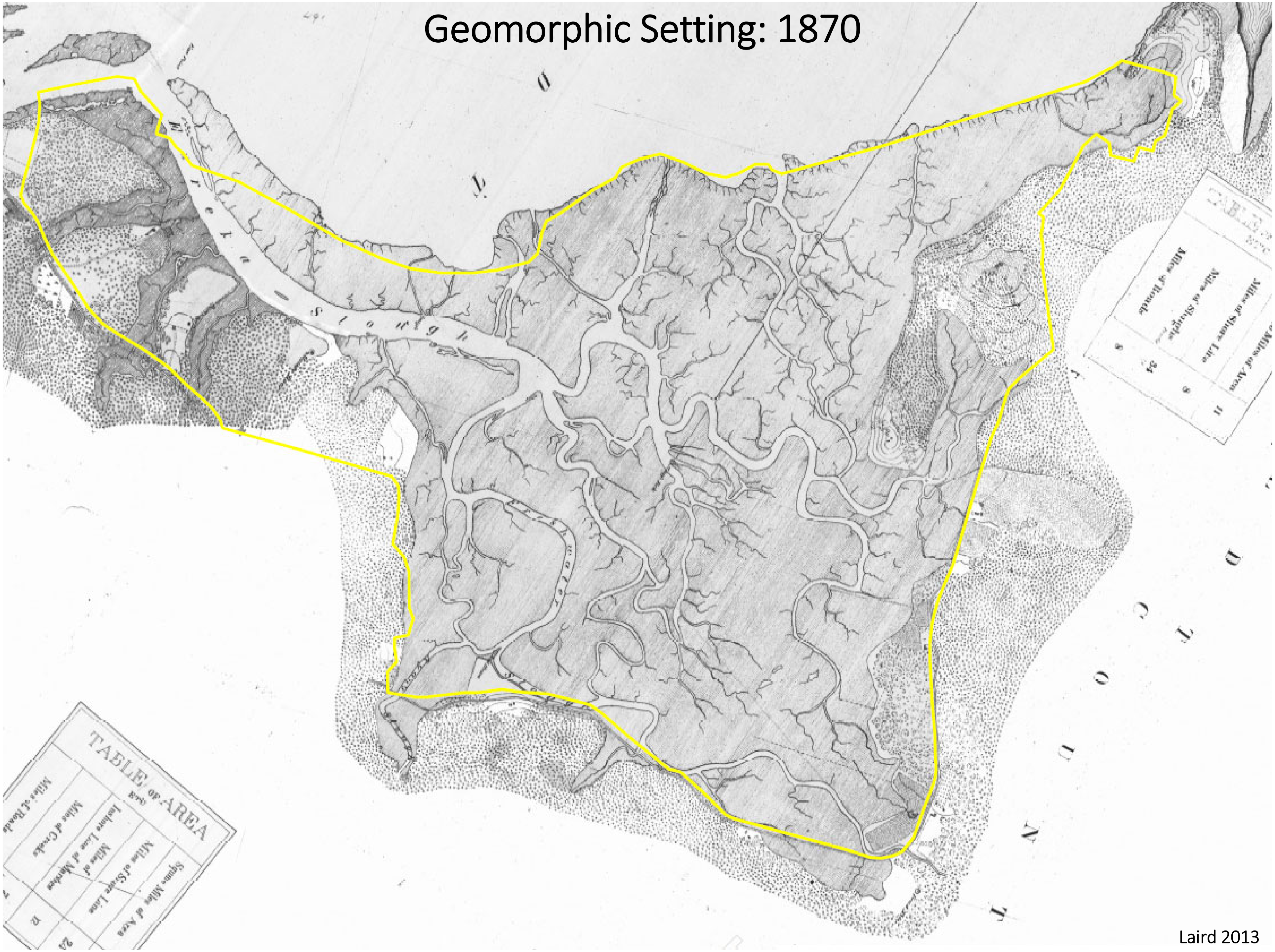


Geomorphic Setting: 1854



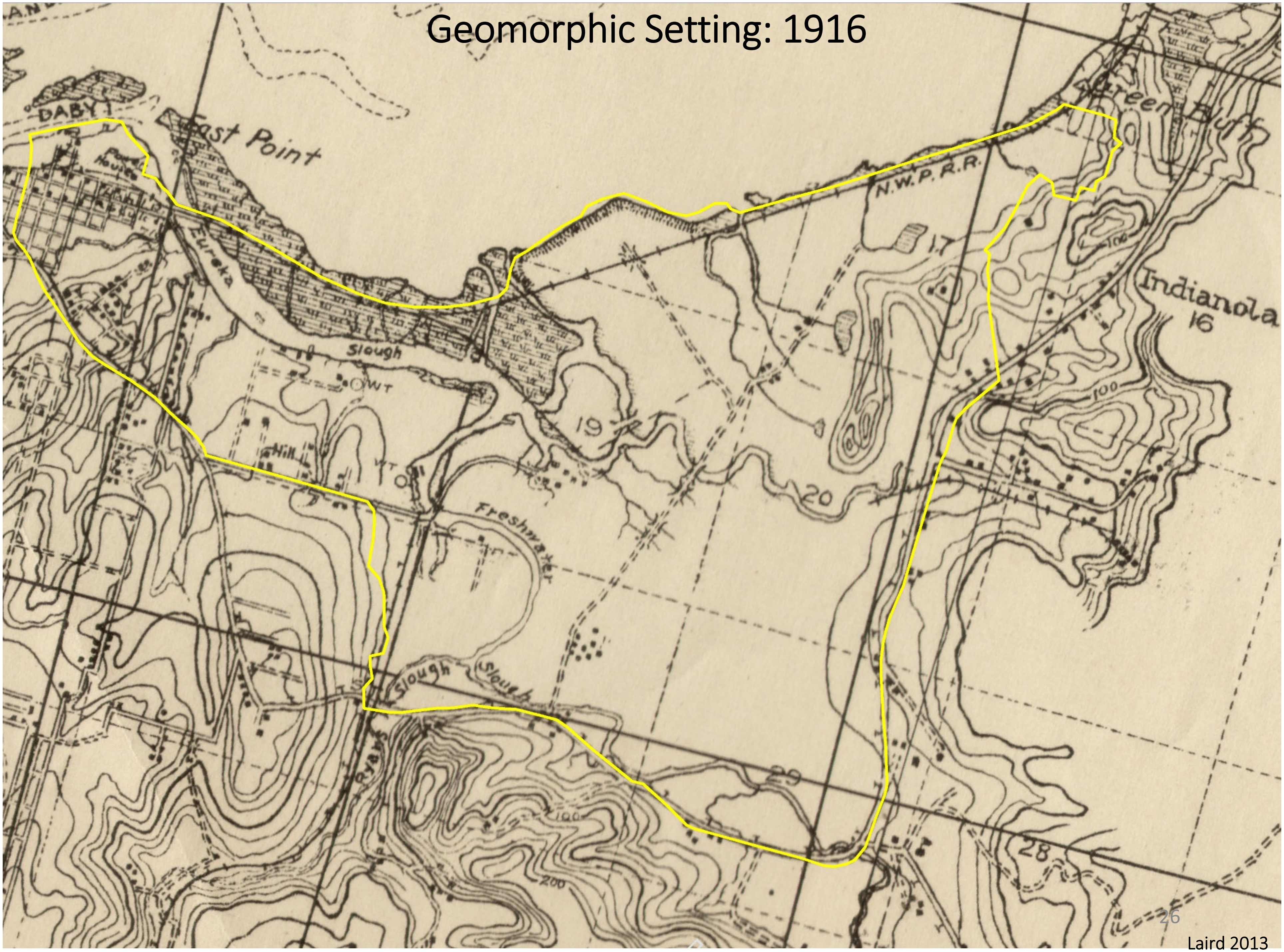
Laird 2013

Geomorphic Setting: 1870



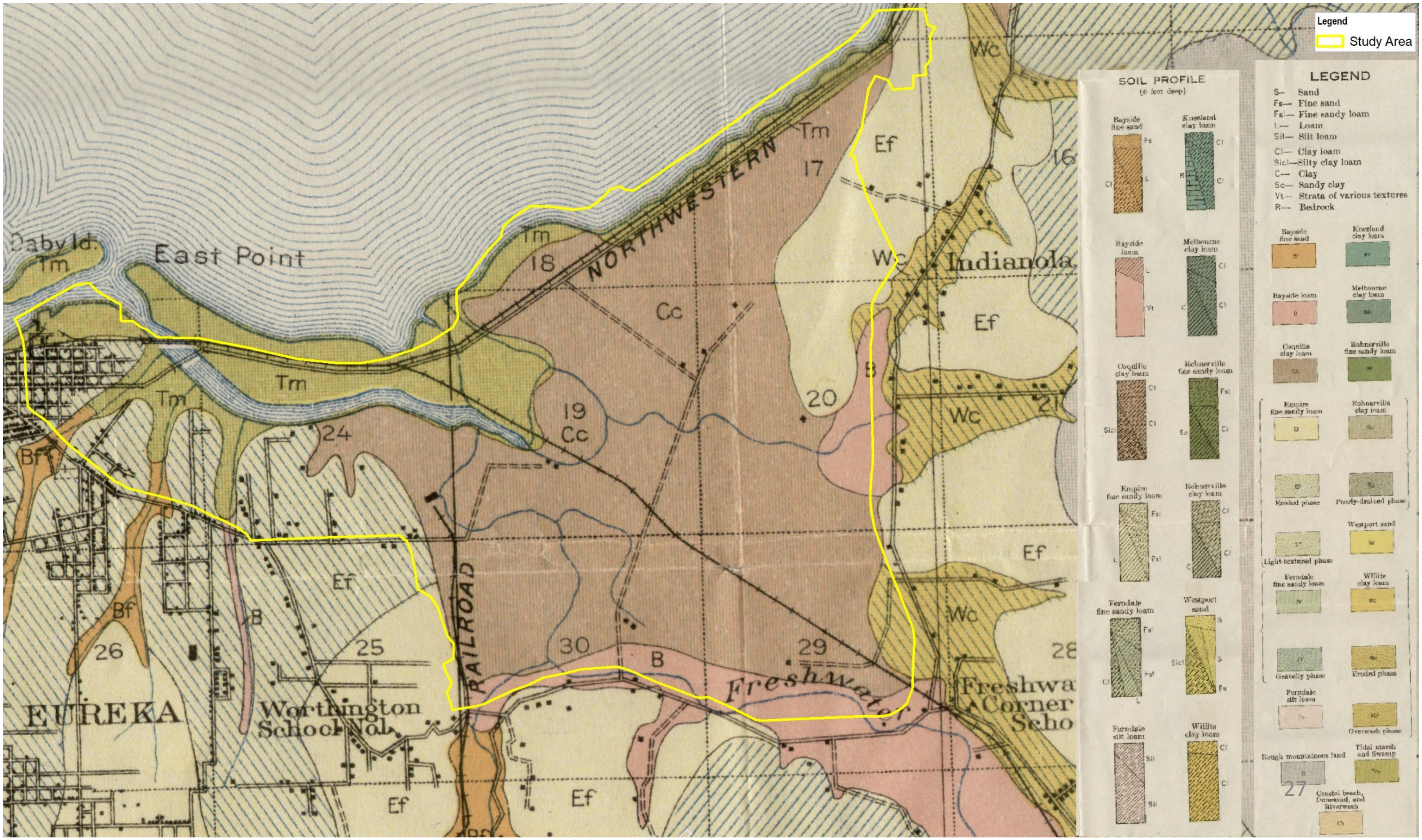
Laird 2013

Geomorphic Setting: 1916

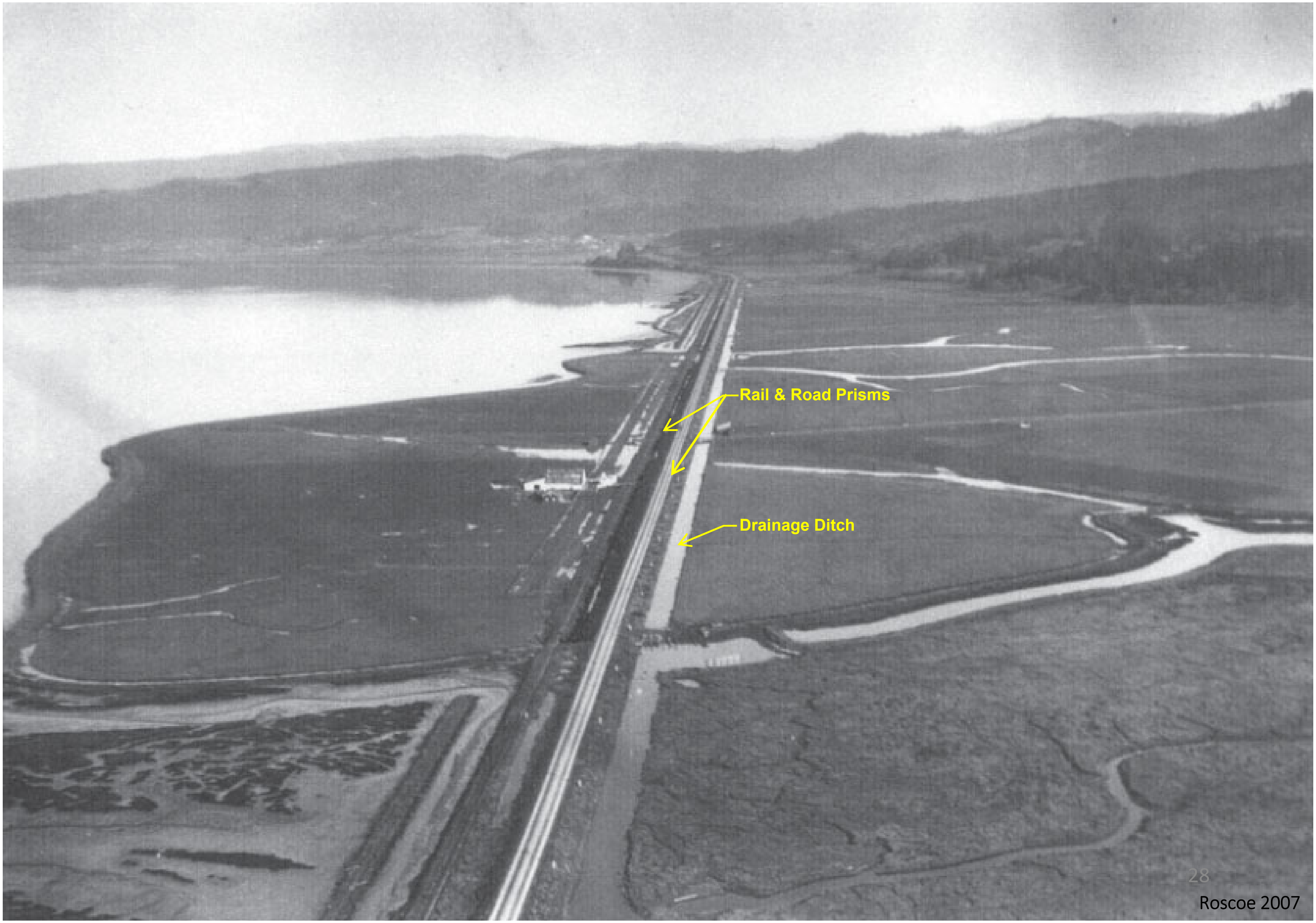


Laird 2013

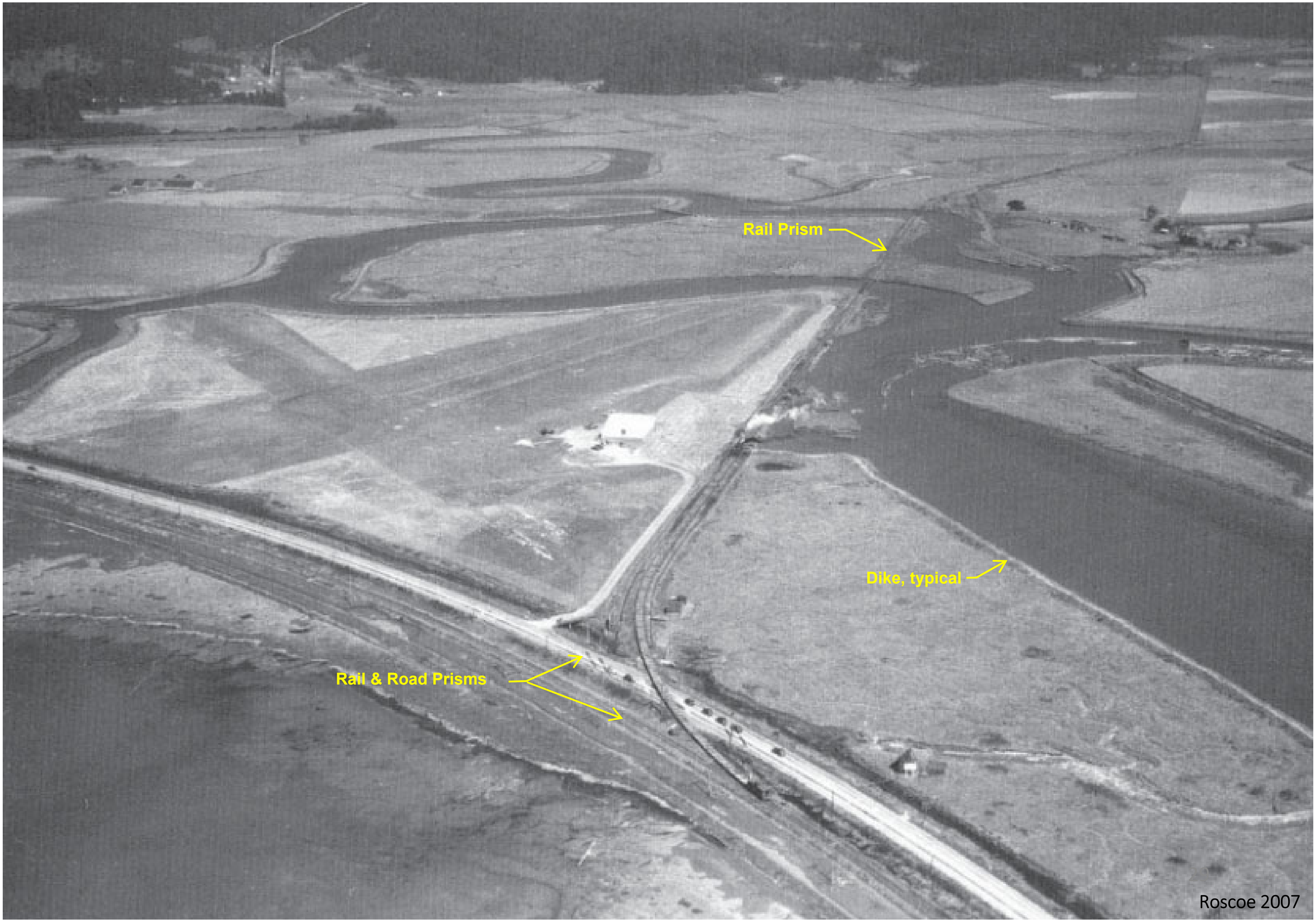
Geomorphic Setting: 1921 (Soils Mapping, USDA)



Geomorphic Setting: Circa 1927

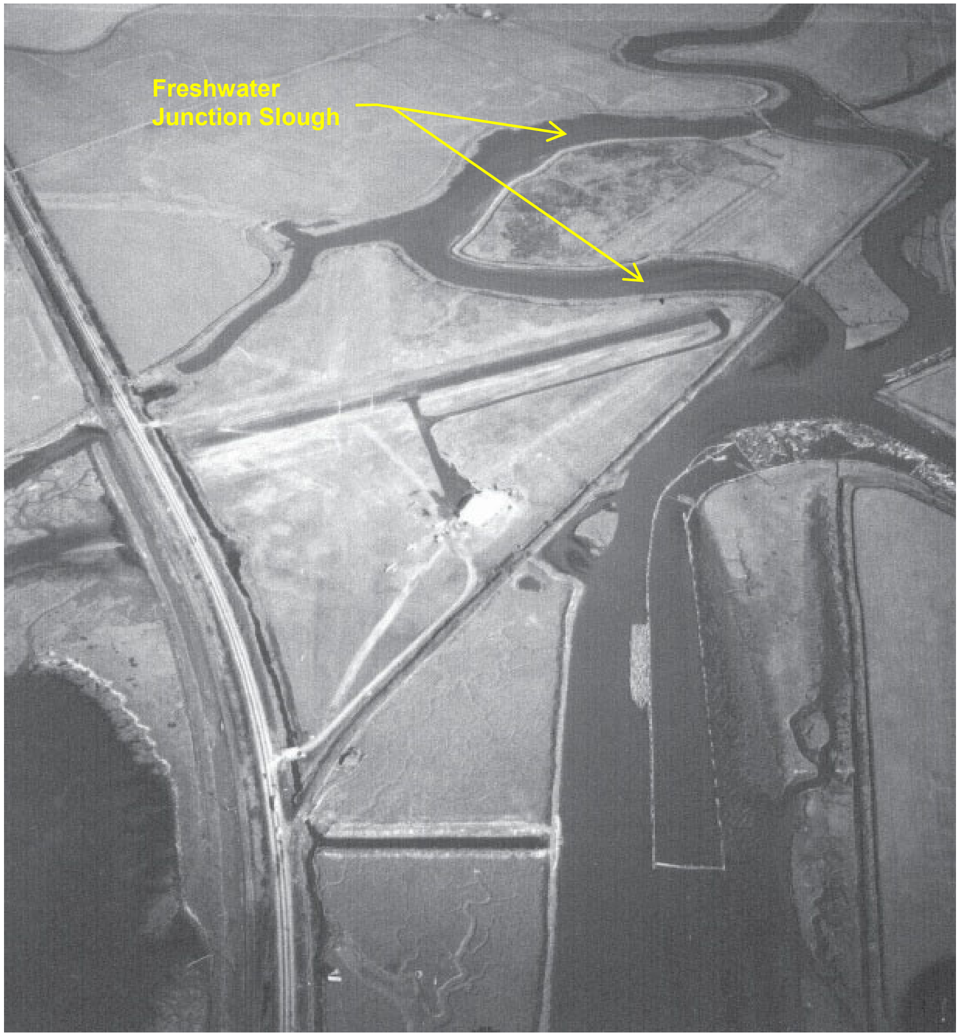


Geomorphic Setting: 1941

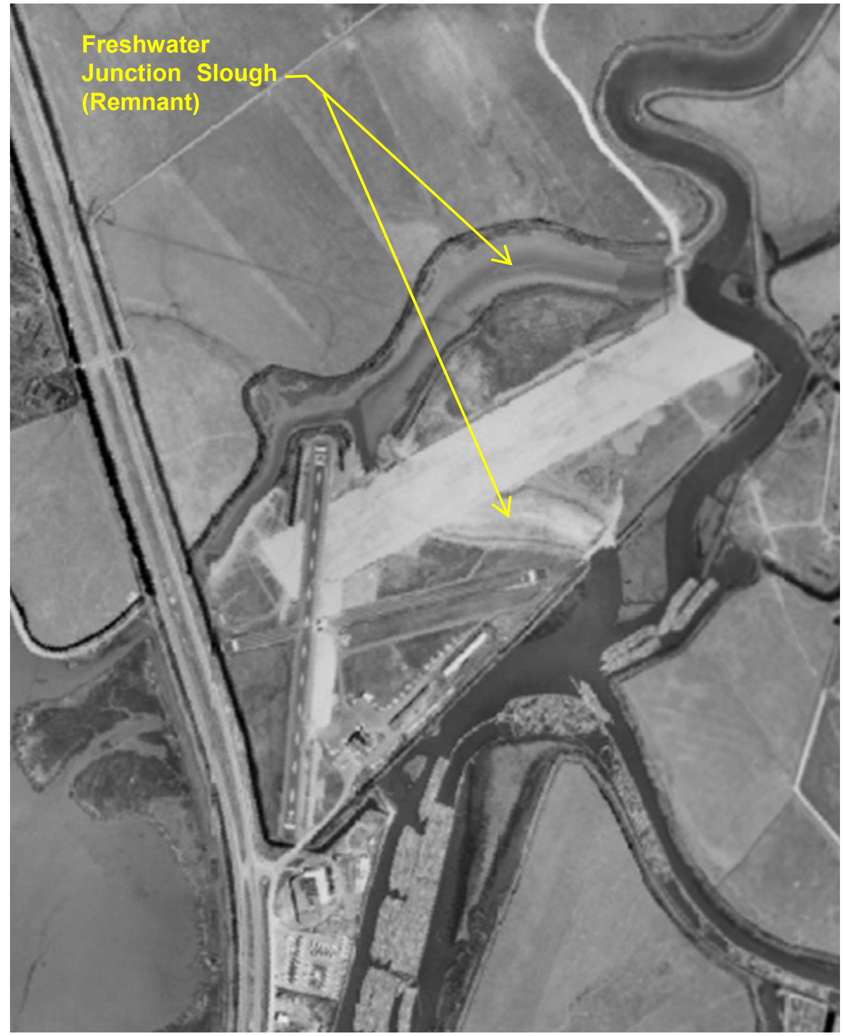


Geomorphic Setting

1946



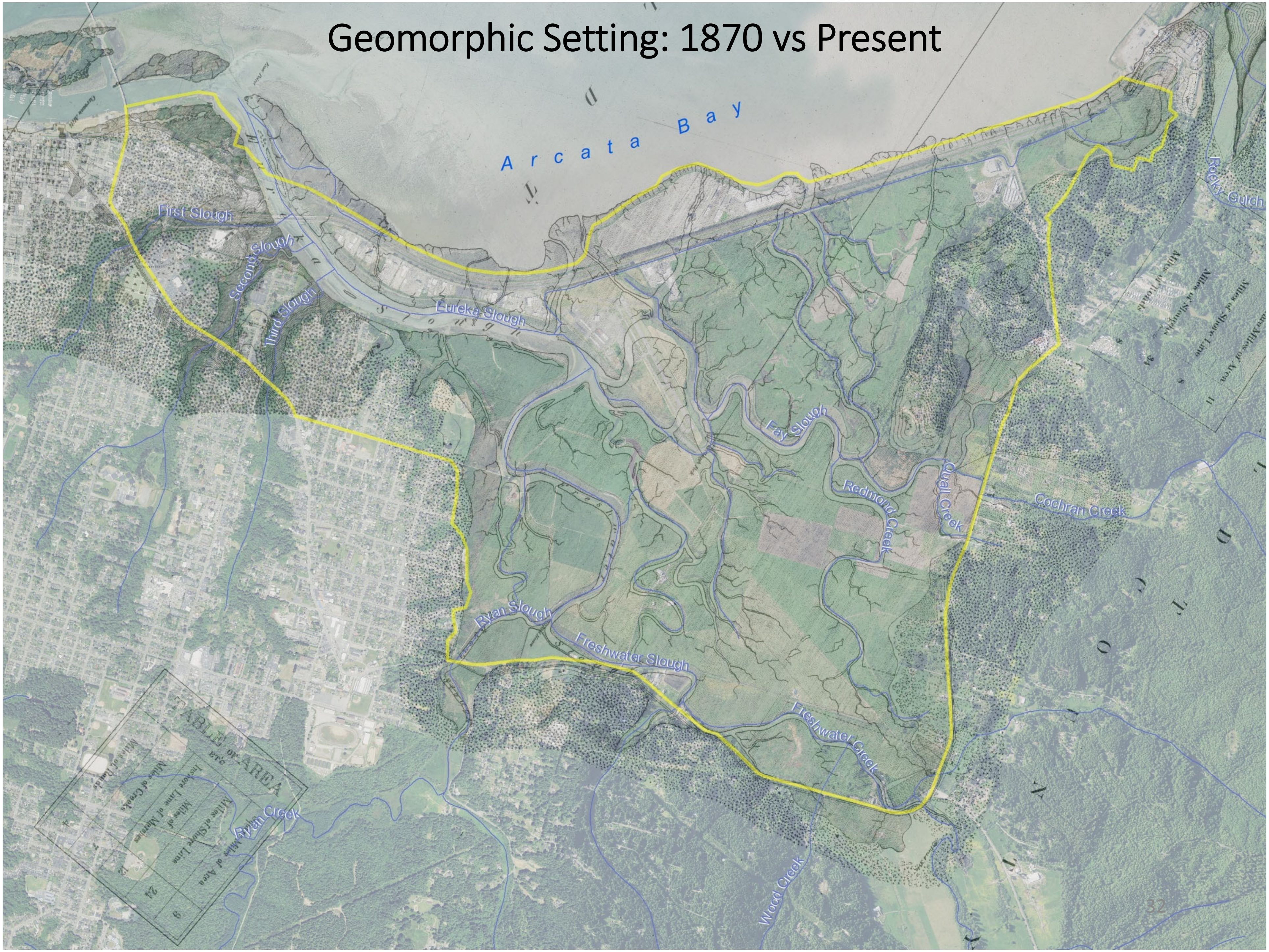
1958



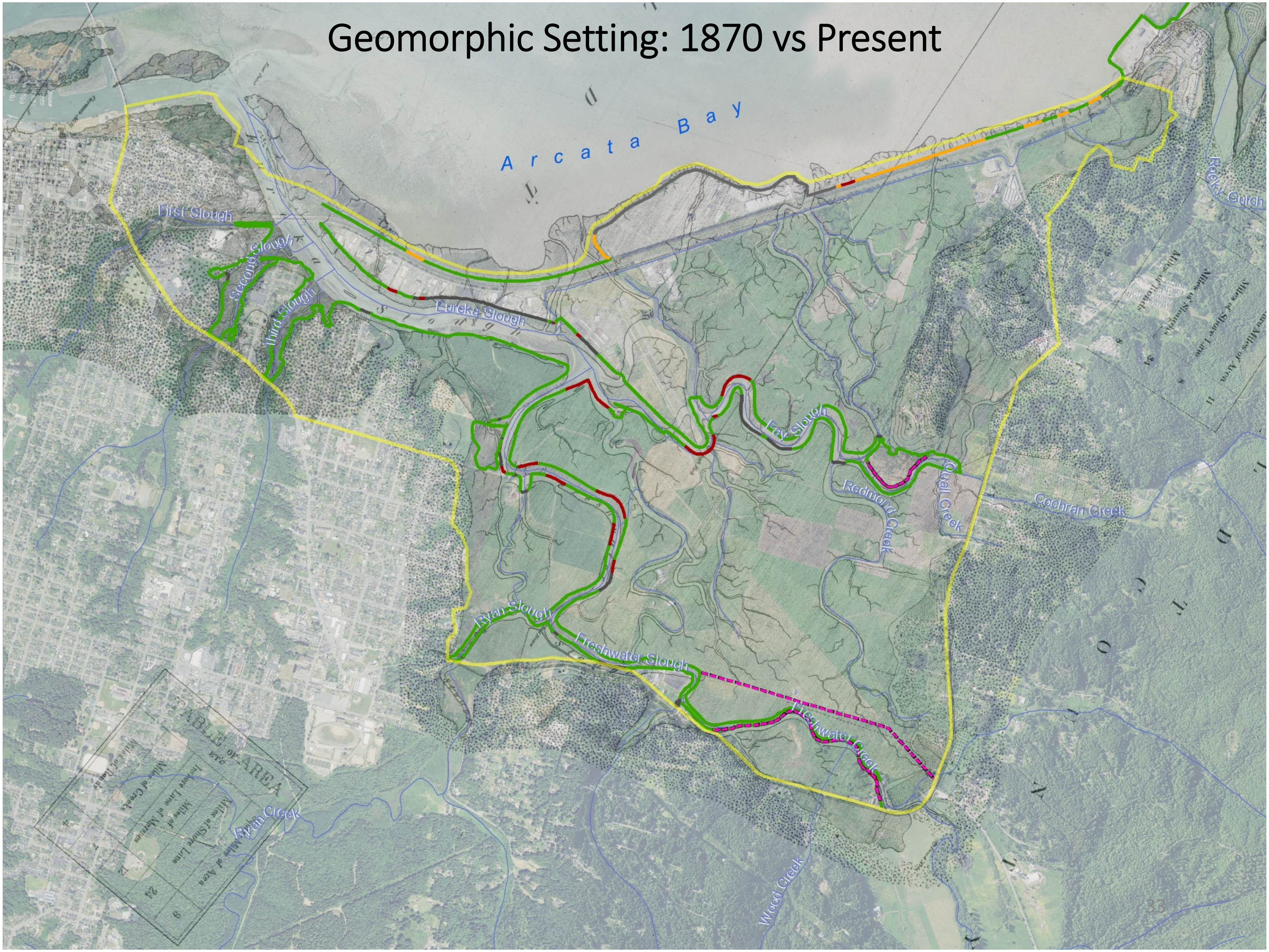
Roscoe 2007

Geomorphic Setting: 1958

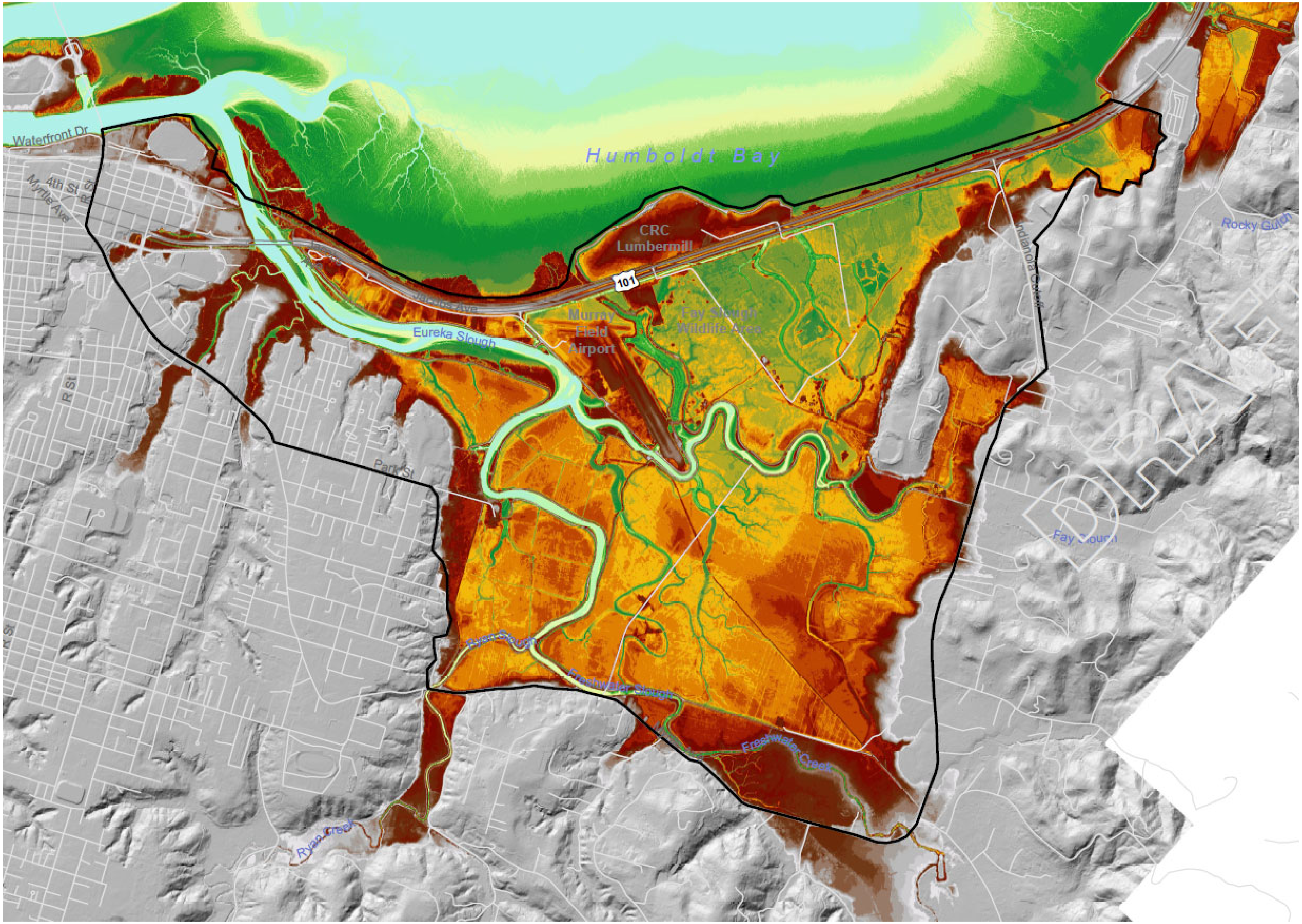
Geomorphic Setting: 1870 vs Present



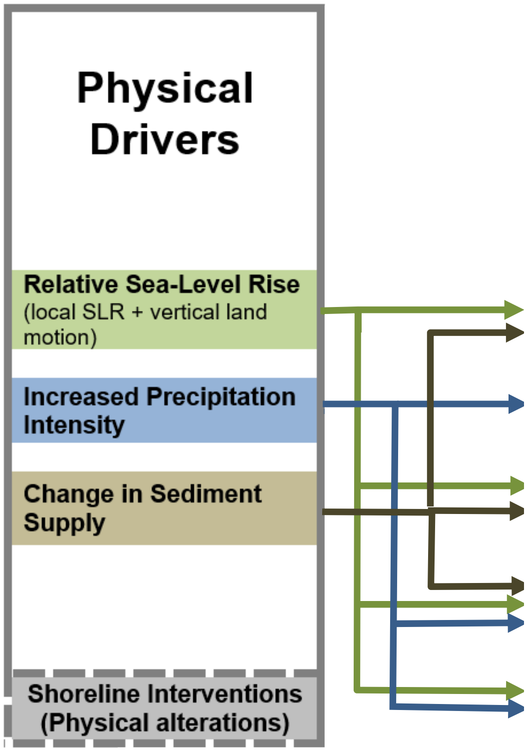
Geomorphic Setting: 1870 vs Present

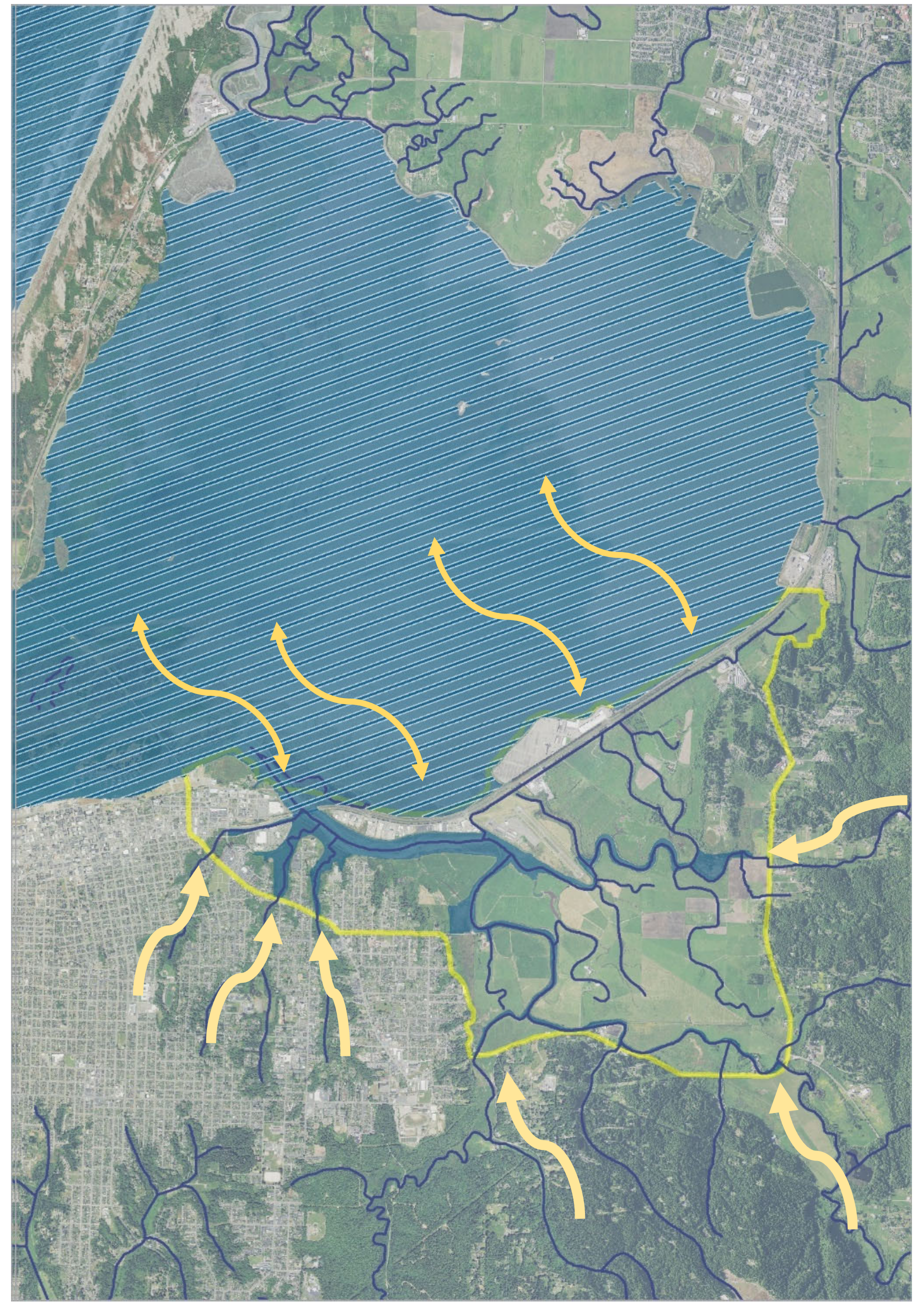


Geomorphic Setting: Current Elevations



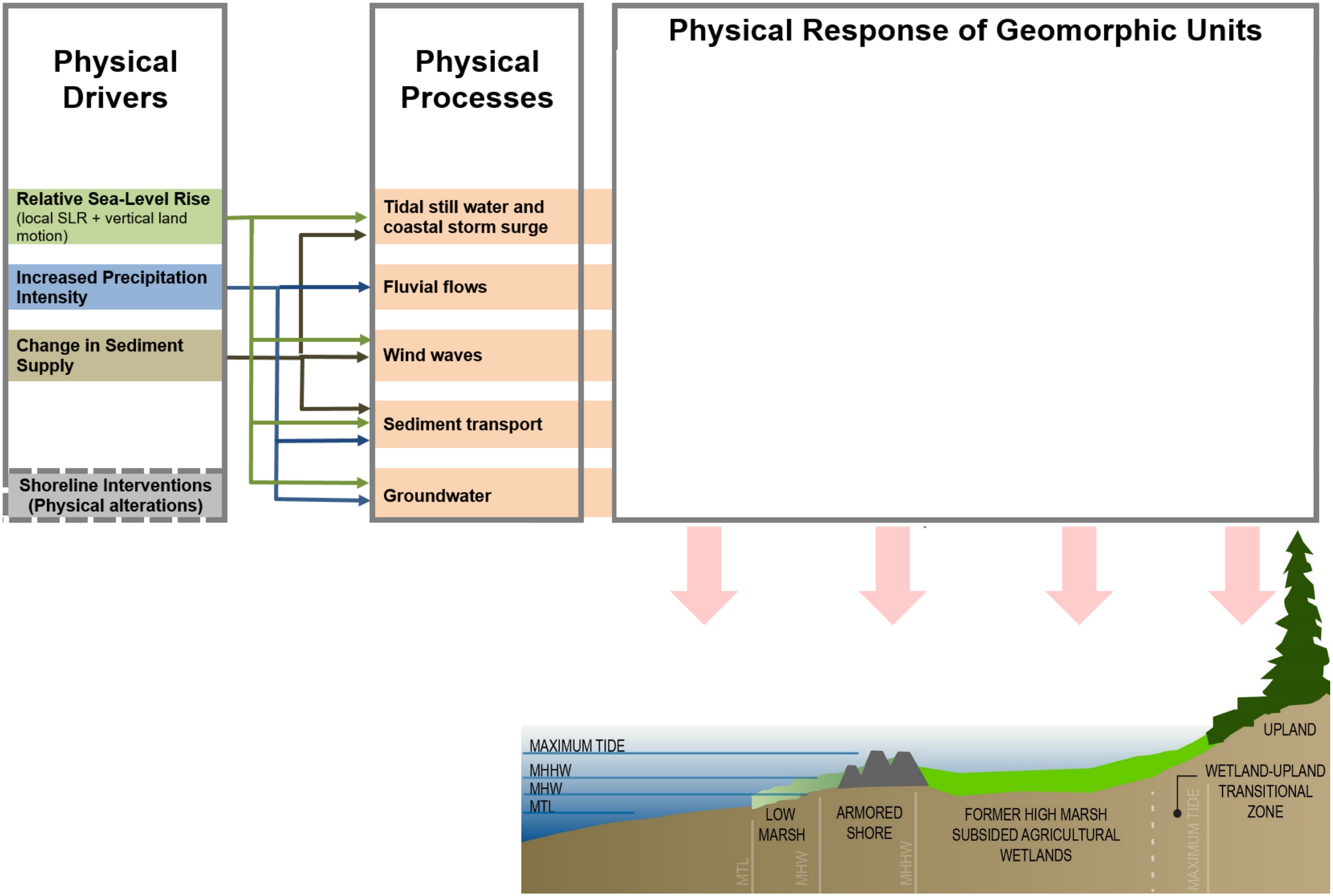
Vulnerability Assessment:
Characterization of Geomorphic Response Conceptual Model





Adapted from IPCC, 2019

Vulnerability Assessment:
Characterization of Geomorphic Response Conceptual Model



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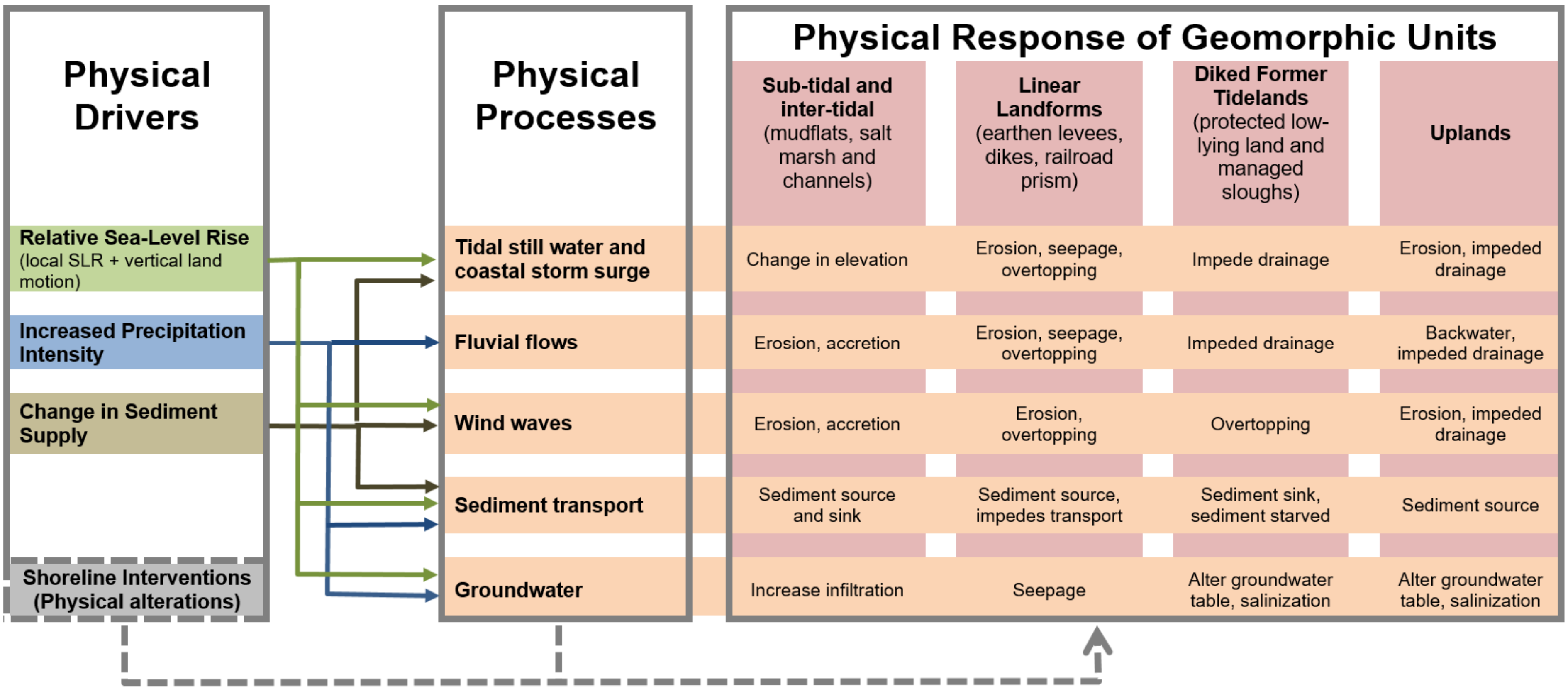
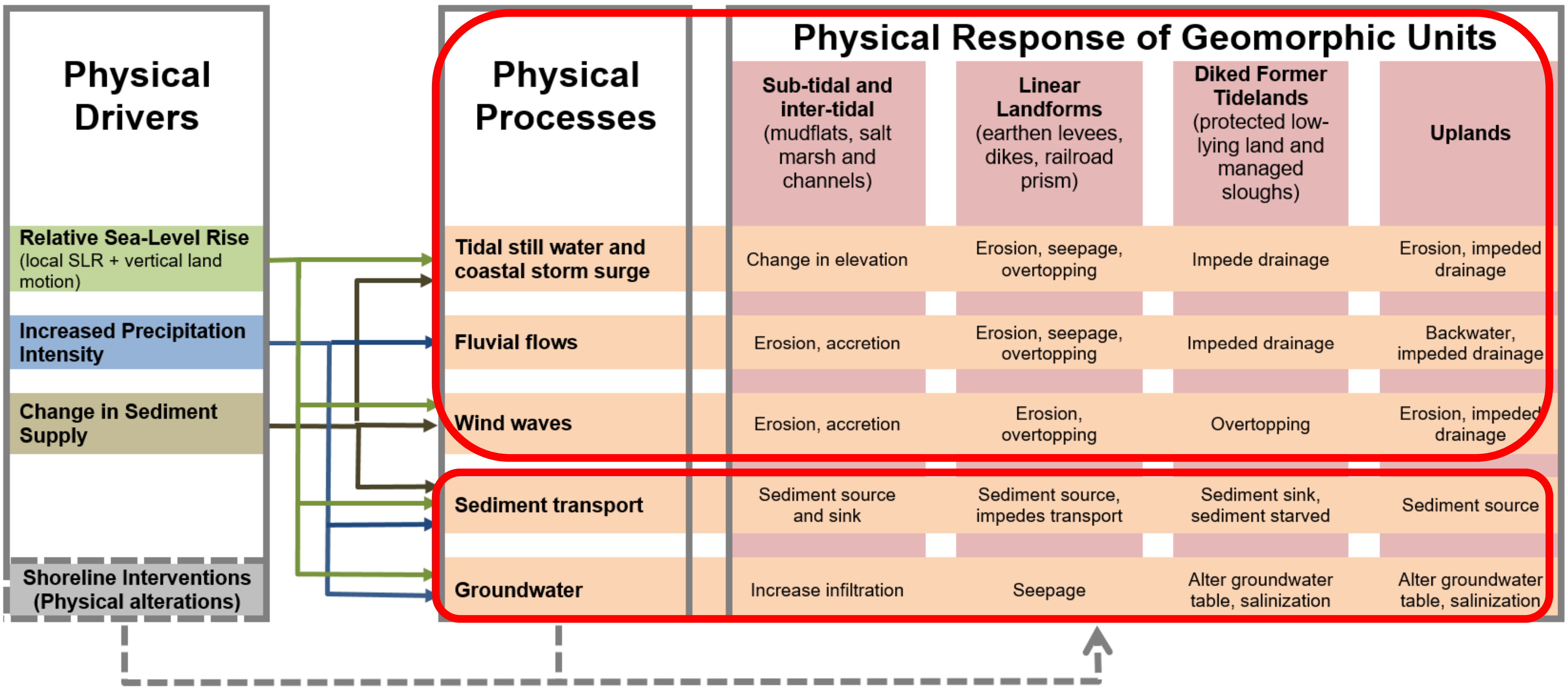
Characterization of Geomorphic Response Conceptual Model



Adapted from IPCC, 2019

Vulnerability Assessment:
Characterization of Geomorphic Response Conceptual Model



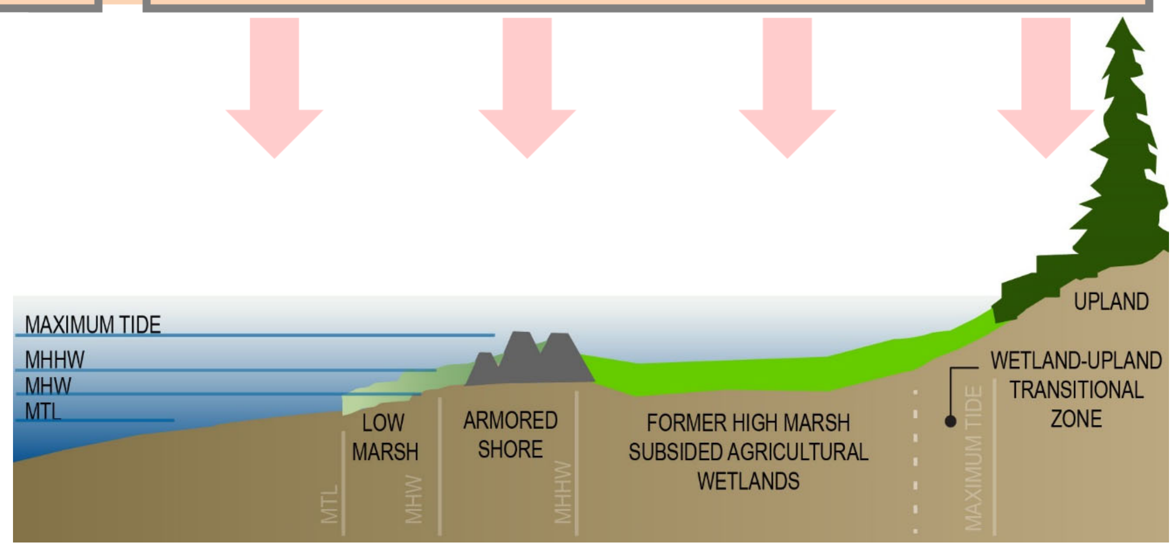
Vulnerability Assessment:
Characterization of Geomorphic Response Conceptual Model

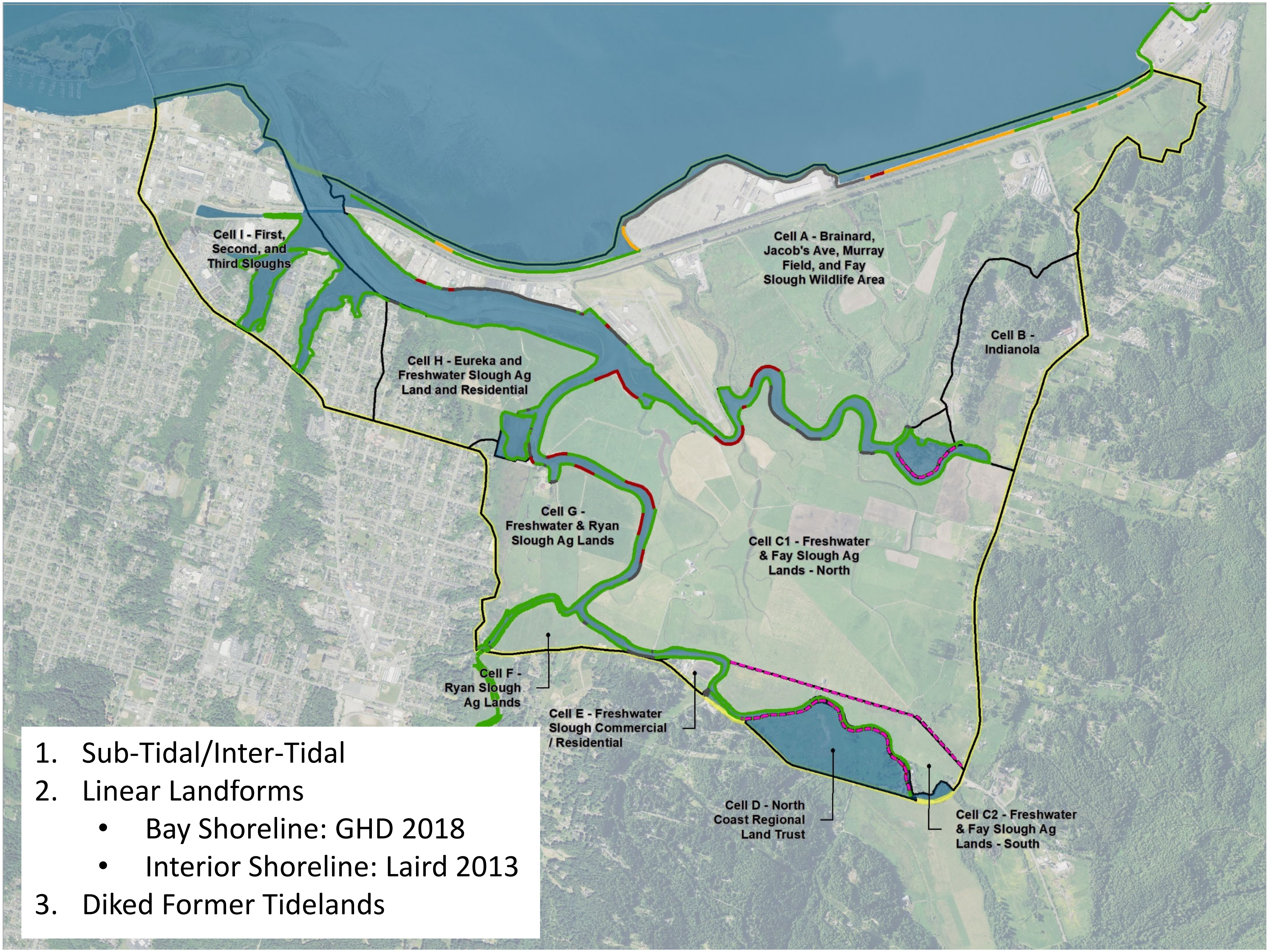
Physical Drivers

- **Relative Sea-Level Rise** (local SLR + vertical land motion)
- **Increased Precipitation Intensity**
- **Change in Sediment Supply**
- **Shoreline Interventions (Physical alterations)**

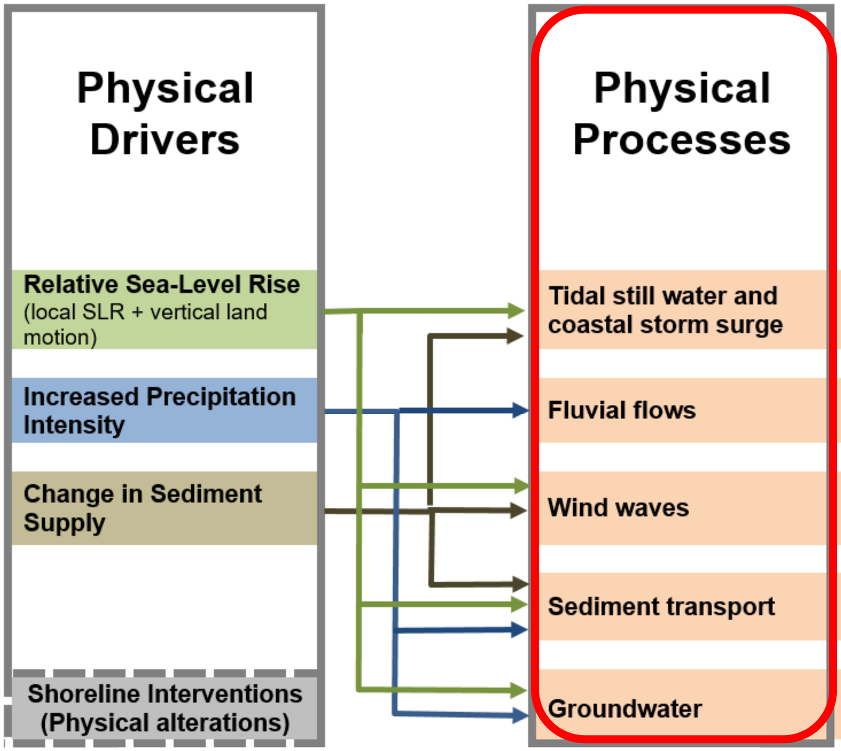
Physical Response of Geomorphic Units

Physical Processes	Sub-tidal and inter-tidal (mudflats, salt marsh and channels)	Linear Landforms (earthen levees, dikes, railroad prism)	Diked Former Tidelands (protected low-lying land and managed sloughs)	Uplands
Tidal still water and coastal storm surge	Change in elevation	Erosion, seepage, overtopping	Impede drainage	Erosion, impeded drainage
Fluvial flows	Erosion, accretion	Erosion, seepage, overtopping	Impeded drainage	Backwater, impeded drainage
Wind waves	Erosion, accretion	Erosion, overtopping	Overtopping	Erosion, impeded drainage
Sediment transport	Sediment source and sink	Sediment source, impedes transport	Sediment sink, sediment starved	Sediment source
Groundwater	Increase infiltration	Seepage	Alter groundwater table, salinization	Alter groundwater table, salinization




Cell I - First, Second, and Third Sloughs
Cell A - Brainard, Jacob's Ave, Murray Field, and Fay Slough Wildlife Area
Cell B - Indianola
Cell H - Eureka and Freshwater Slough Ag Land and Residential
Cell G - Freshwater & Ryan Slough Ag Lands
Cell C1 - Freshwater & Fay Slough Ag Lands - North
Cell F - Ryan Slough Ag Lands
Cell E - Freshwater Slough Commercial / Residential
Cell D - North Coast Regional Land Trust
Cell C2 - Freshwater & Fay Slough Ag Lands - South
1. Sub-Tidal/Inter-Tidal
2. Linear Landforms
• Bay Shoreline: GHD 2018
• Interior Shoreline: Laird 2013
3. Diked Former Tidelands

Geomorphic Response Conceptual Model: Physical Processes



Physical Response of Geomorphic Units

Physical Processes	**Sub-tidal and inter-tidal** (mudflats, salt marsh and channels)	**Linear Landforms** (earthen levees, dikes, railroad prism)	**Diked Former Tidelands** (protected low-lying land and managed sloughs)	**Uplands**
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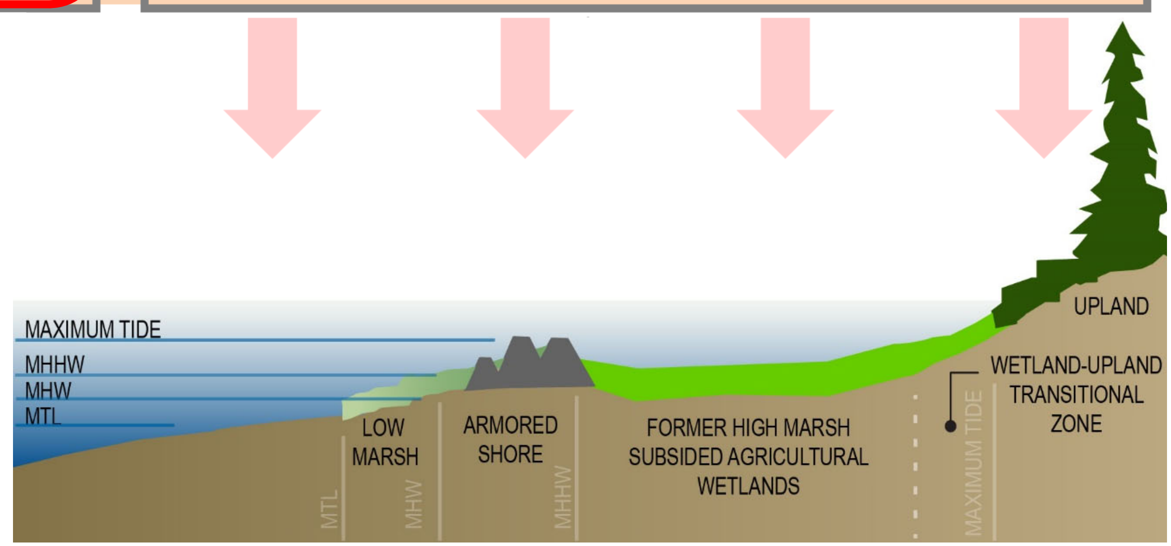
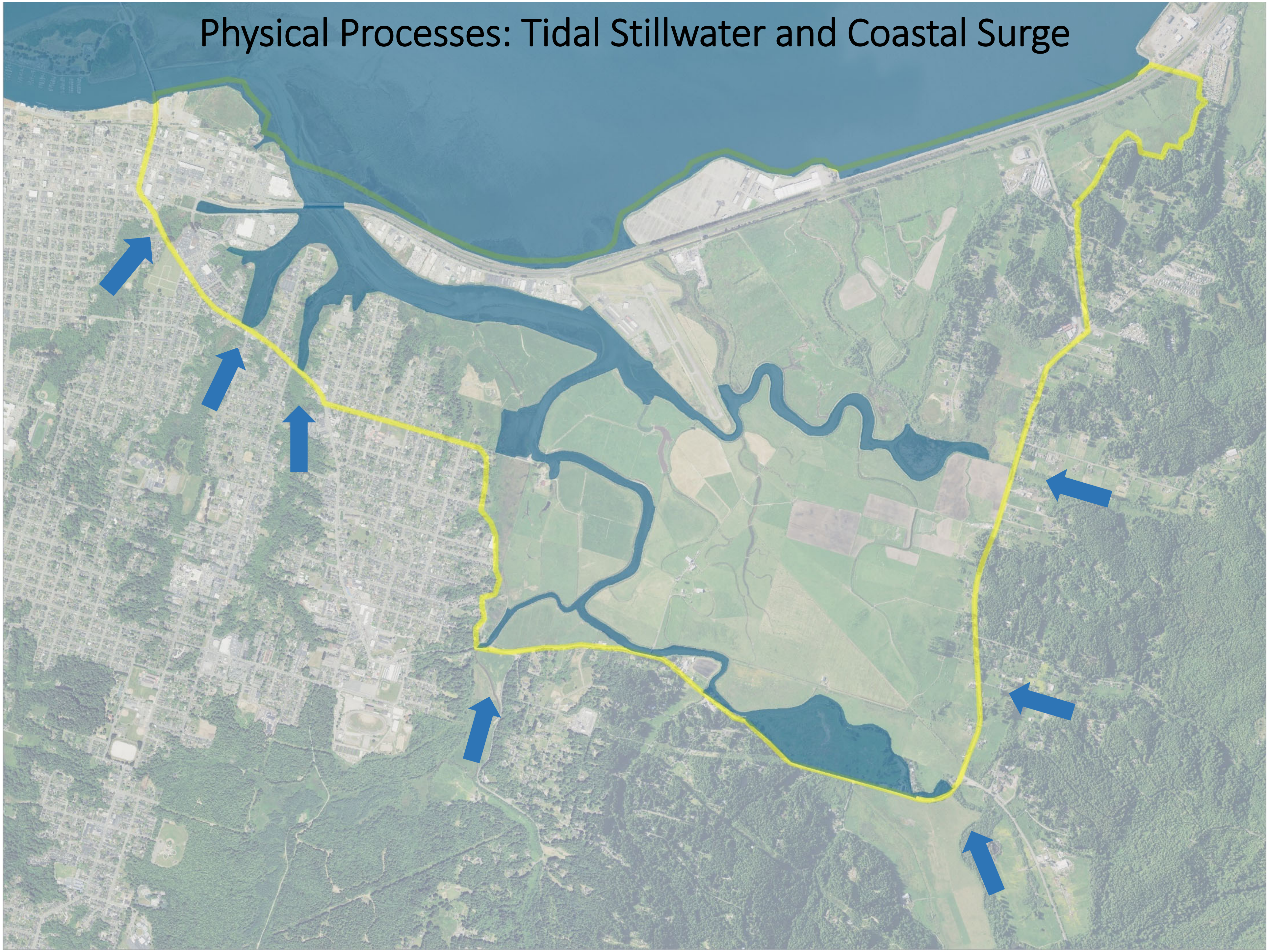
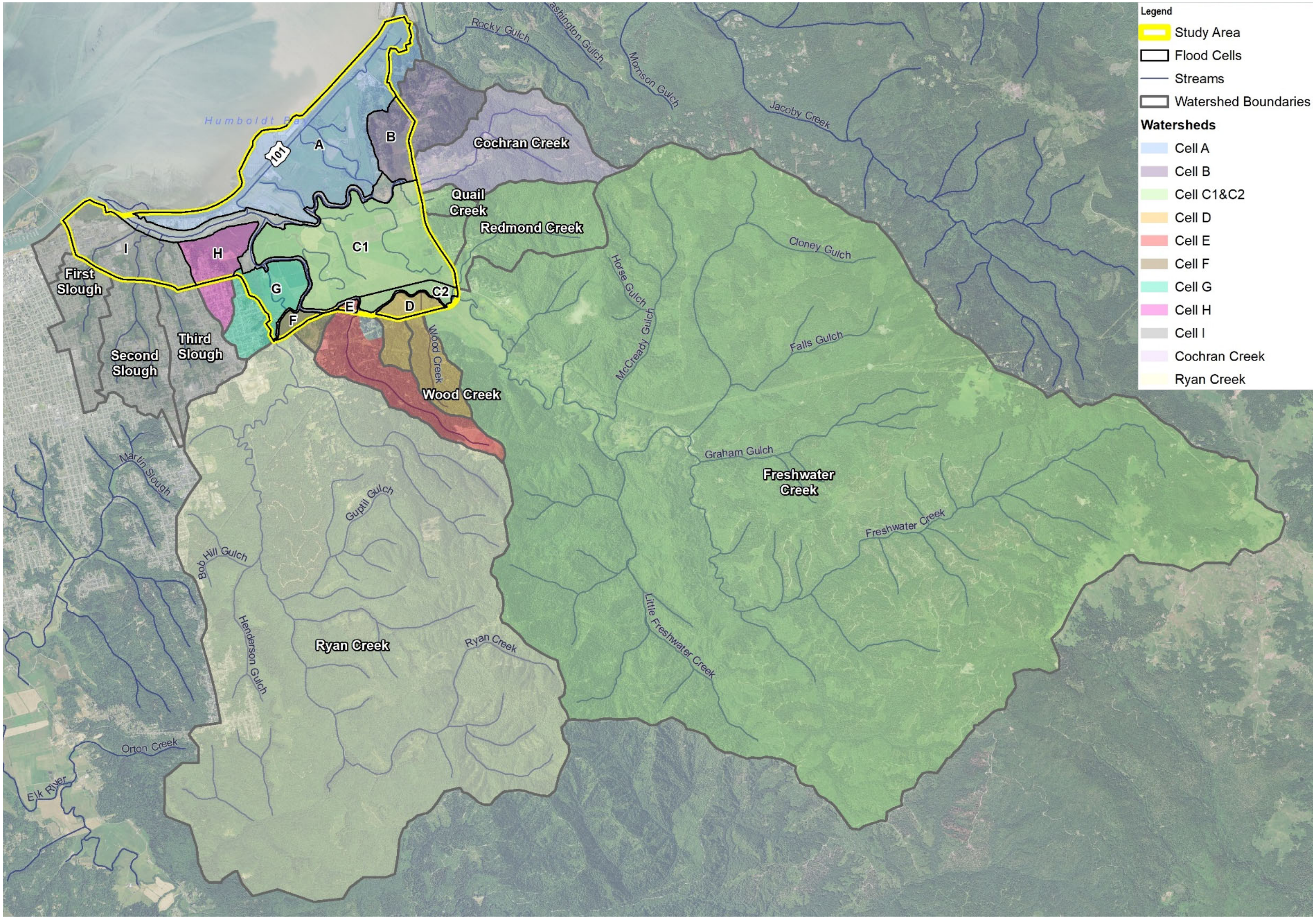


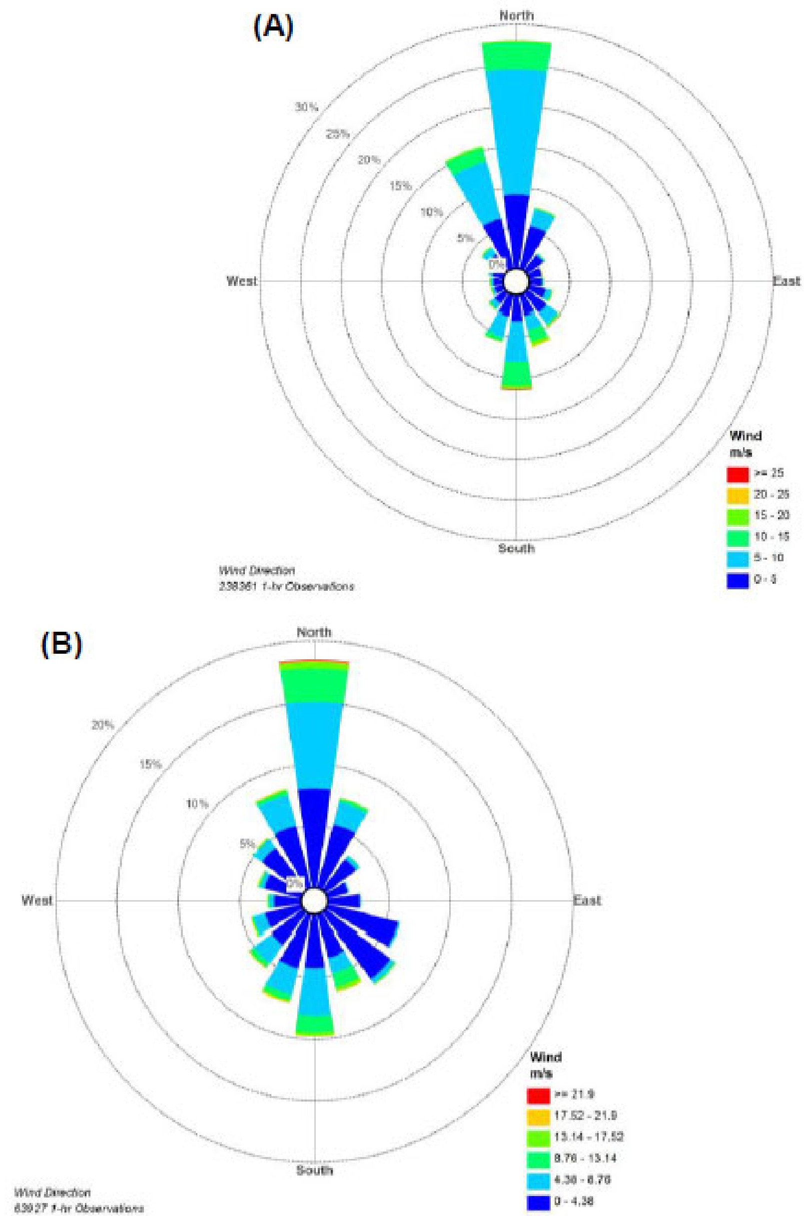
Physical Processes: Tidal Stillwater and Coastal Surge



Physical Processes: Fluvial Flows

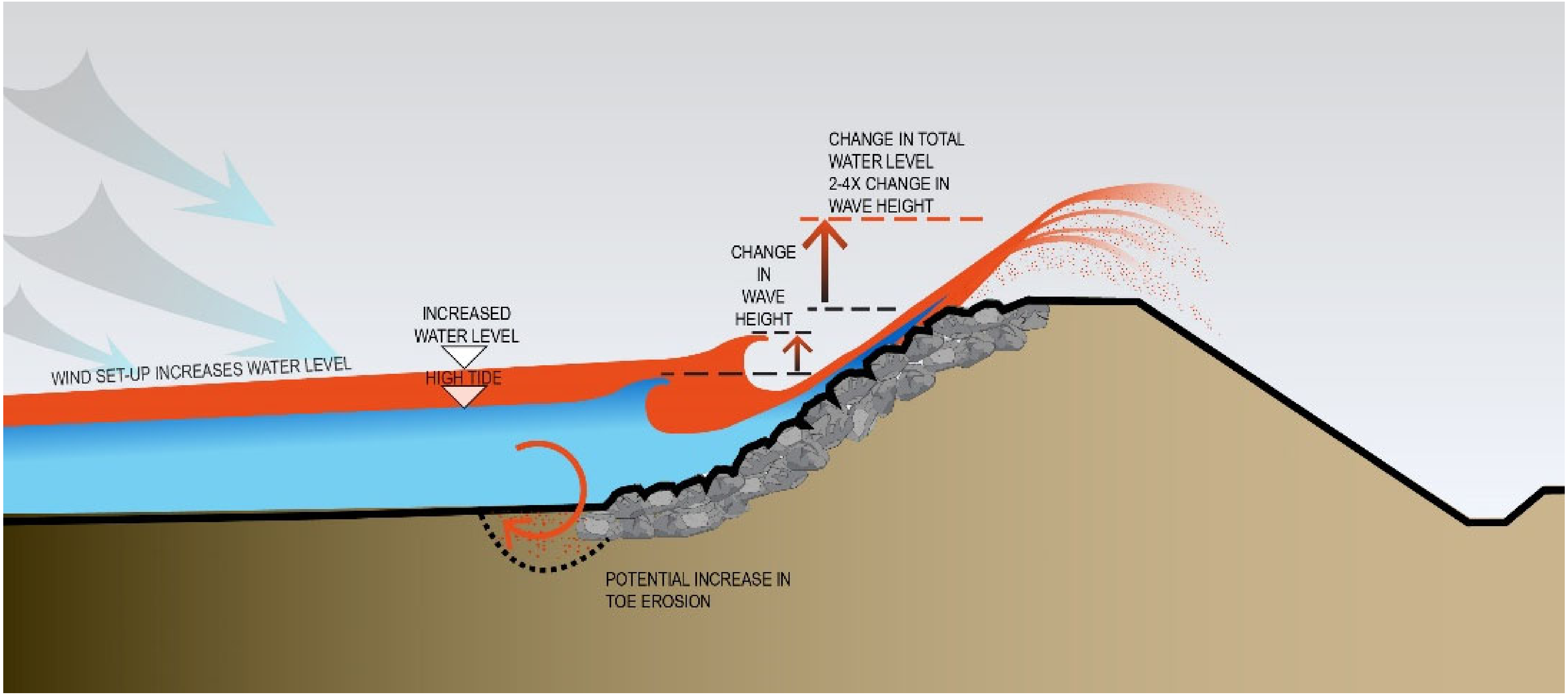


Physical Processes: Wind Waves



Wind Rose Plots for Buoy 22 (A) and North Spit (B), NHE 2016

Physical Processes: Wind Waves, Con't



Geomorphic Response Conceptual Model: Physical Response

Physical Drivers

- **Relative Sea-Level Rise** (local SLR + vertical land motion)
- **Increased Precipitation Intensity**
- **Change in Sediment Supply**
- **Shoreline Interventions (Physical alterations)**

Physical Response of Geomorphic Units

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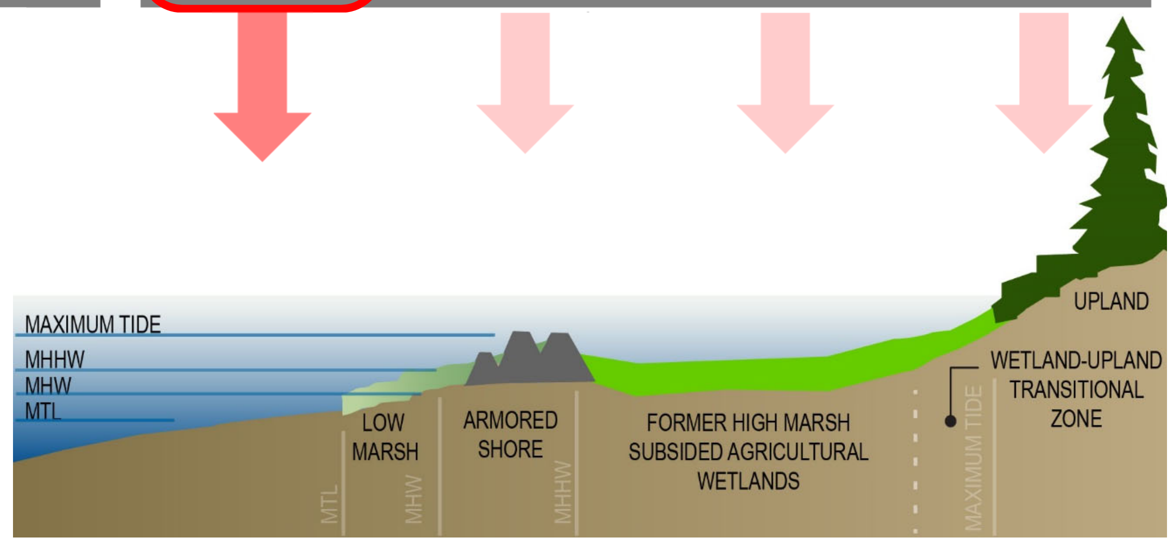
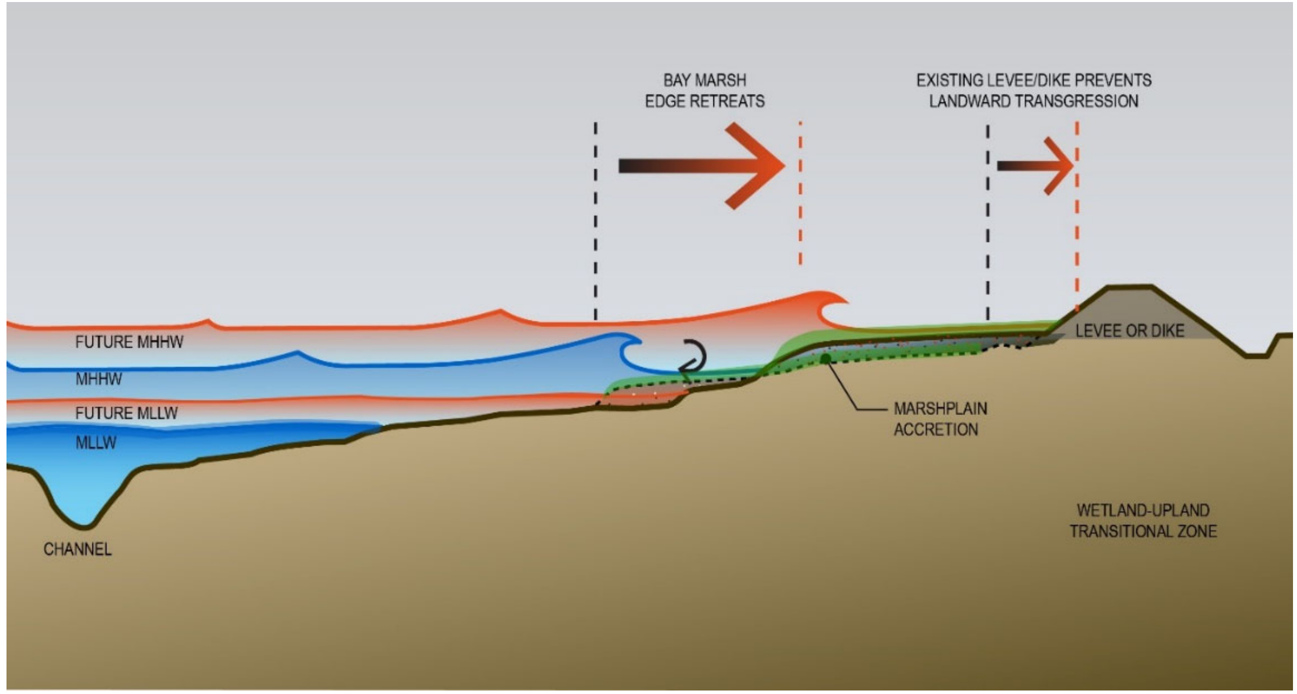
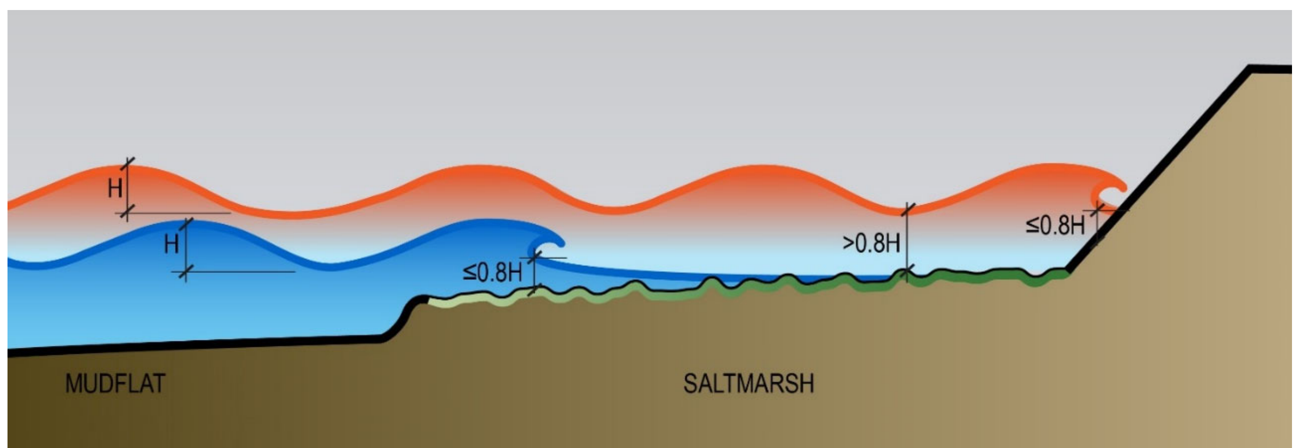


Physical Response: Sub-Tidal and Inter-Tidal (Bay Shoreline)

Physical Processes	Sub-tidal and inter-tidal (mudflats, salt marsh and channels)
Tidal still water and coastal storm surge	Change in elevation
Fluvial flows	Erosion, accretion
Wind waves	Erosion, accretion
Sediment transport	Sediment source and sink
Groundwater	Increase infiltration





Geomorphic Response Conceptual Model: Physical Response

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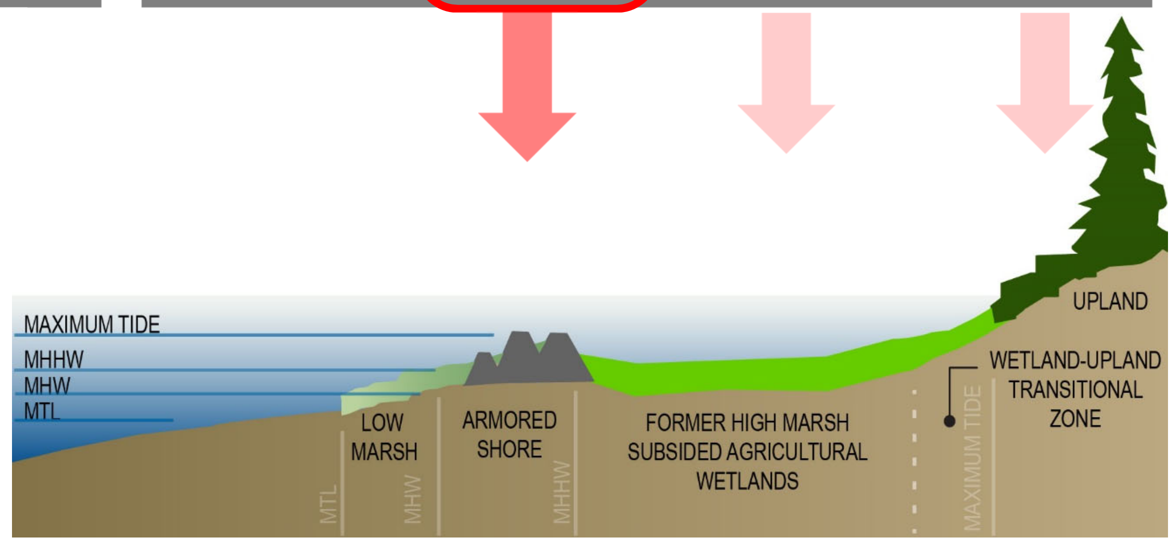
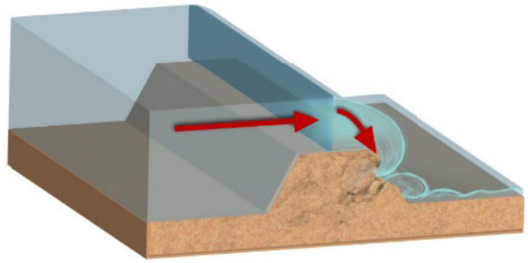
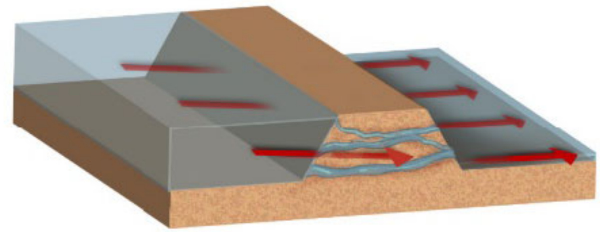


Physical Response: Linear Landforms (Bay and Interior Shoreline)

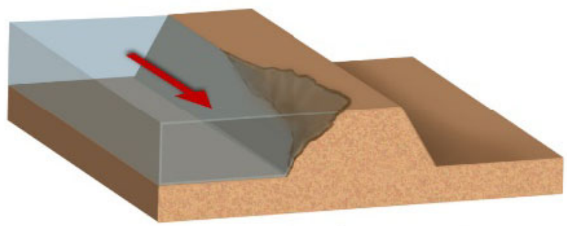
Physical Processes	**Linear Landforms** (earthen levees, dikes, railroad prism)
Tidal still water and coastal storm surge	Erosion, seepage, overtopping
Fluvial flows	Erosion, seepage, overtopping
Wind waves	Erosion, overtopping
Sediment transport	Sediment source, impedes transport
Groundwater	Seepage



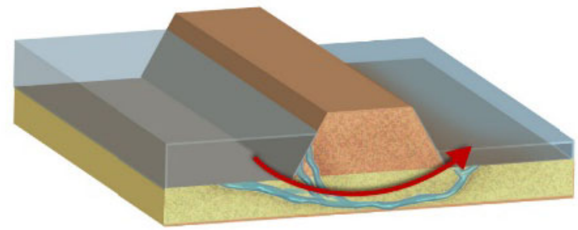
1b. Overtopping/Jetting



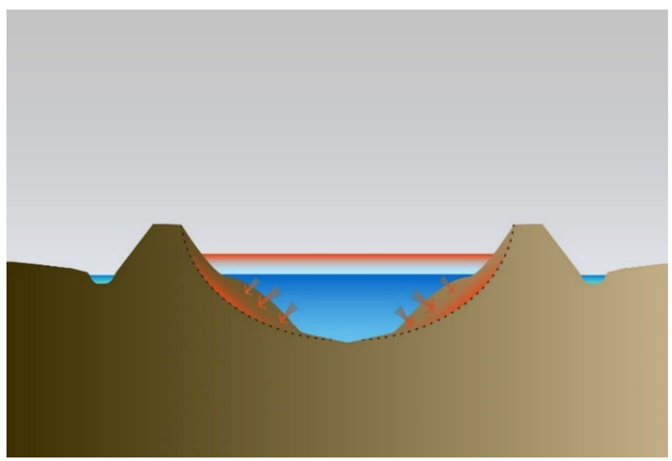
2. Internal Erosion/Piping

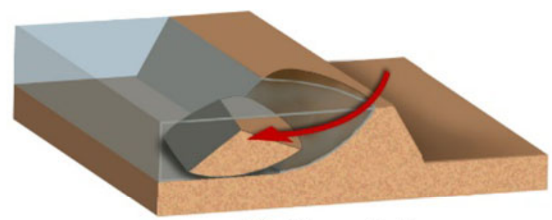


3. Surface Erosion



8. Piping of substratum





10. Slope failure

National Science Foundation, 2016

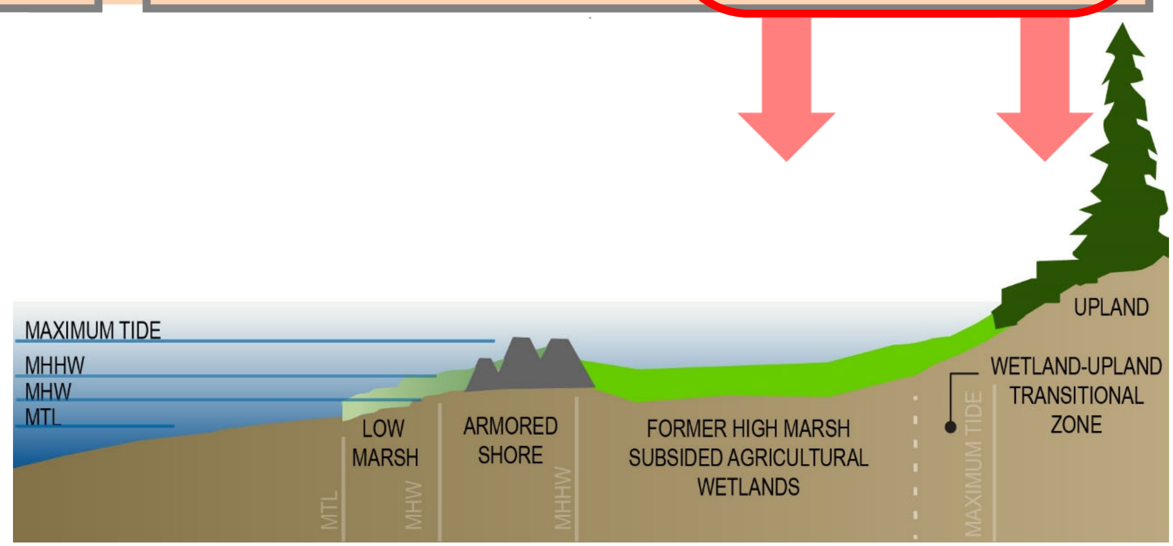
Geomorphic Response Conceptual Model: Physical Response

Physical Drivers

- **Relative Sea-Level Rise** (local SLR + vertical land motion)
- **Increased Precipitation Intensity**
- **Change in Sediment Supply**
- **Shoreline Interventions (Physical alterations)**

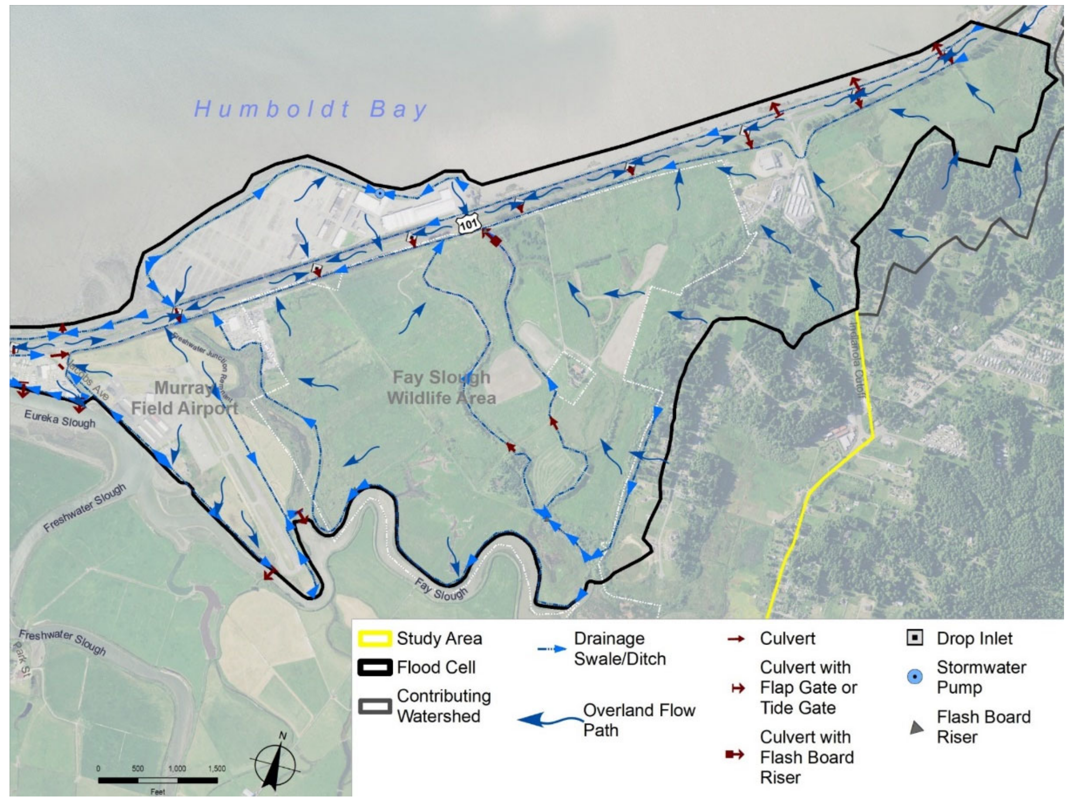
Physical Response of Geomorphic Units

Physical Processes	**Sub-tidal and inter-tidal** (mudflats, salt marsh and channels)	**Linear Landforms** (earthen levees, dikes, railroad prism)	**Diked Former Tidelands** (protected low-lying land and managed sloughs)	**Uplands**
Tidal still water and coastal storm surge	Change in elevation	Erosion, seepage, overtopping	Impede drainage	Erosion, impeded drainage
Fluvial flows	Erosion, accretion	Erosion, seepage, overtopping	Impeded drainage	Backwater, impeded drainage
Wind waves	Erosion, accretion	Erosion, overtopping	Overtopping	Erosion, impeded drainage
Sediment transport	Sediment source and sink	Sediment source, impedes transport	Sediment sink, sediment starved	Sediment source
Groundwater	Increase infiltration	Seepage	Alter groundwater table, salinization	Alter groundwater table, salinization

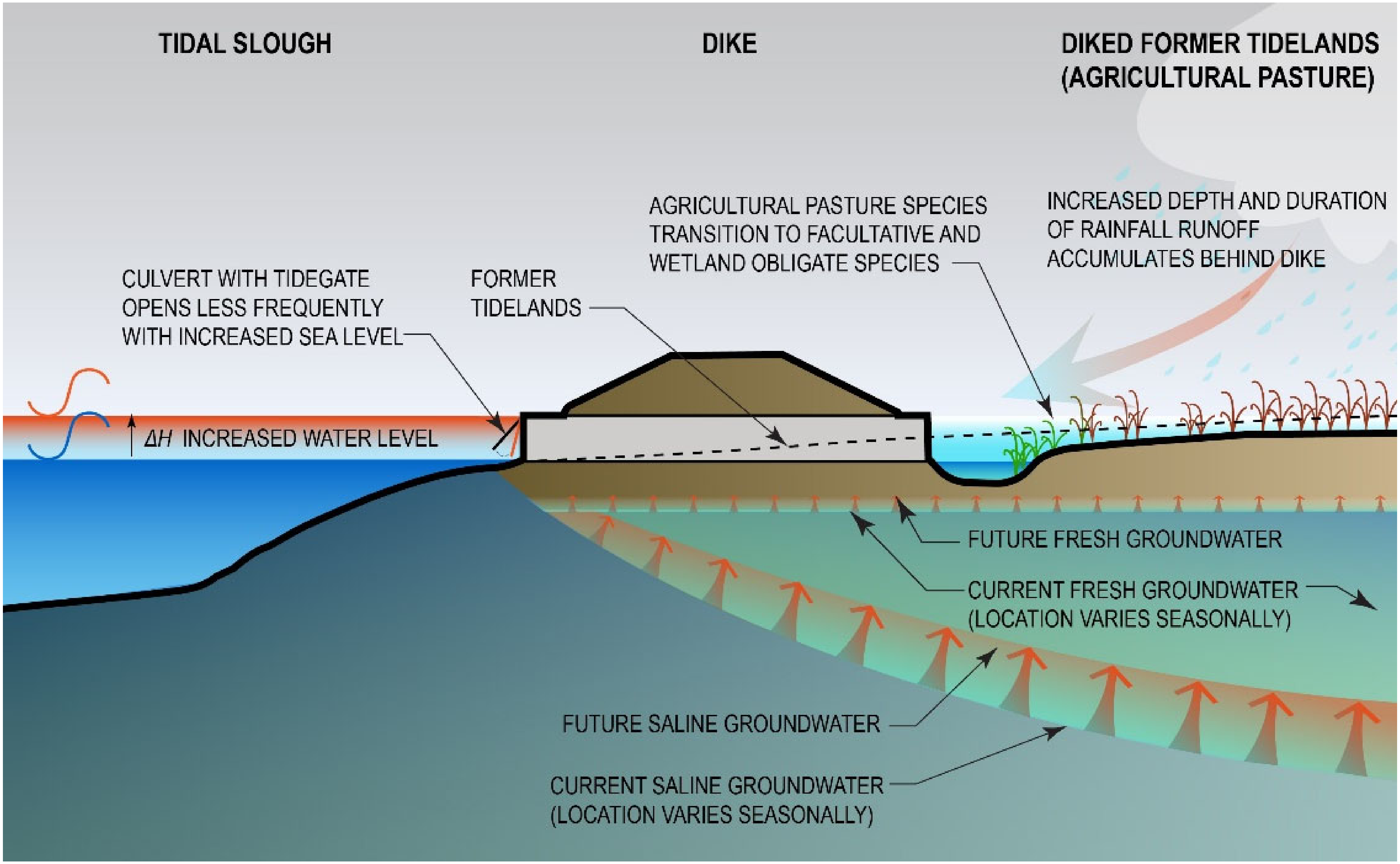


Physical Response: Diked Former Tidelands and Uplands

Physical Processes	Diked Former Tidelands (protected low-lying land and managed sloughs)	Uplands
Tidal still water and coastal storm surge	Impede drainage	Erosion, impeded drainage
Fluvial flows	Impeded drainage	Backwater, impeded drainage
Wind waves	Overtopping	Erosion, impeded drainage
Sediment transport	Sediment sink, sediment starved	Sediment source
Groundwater	Alter groundwater table, salinization	Alter groundwater table, salinization



Physical Response: Diked Former Tidelands and Uplands



Geomorphic Response Conceptual Model: Summary

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- **Relative Sea-Level Rise** (local SLR + vertical land motion)
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- **Change in Sediment Supply**
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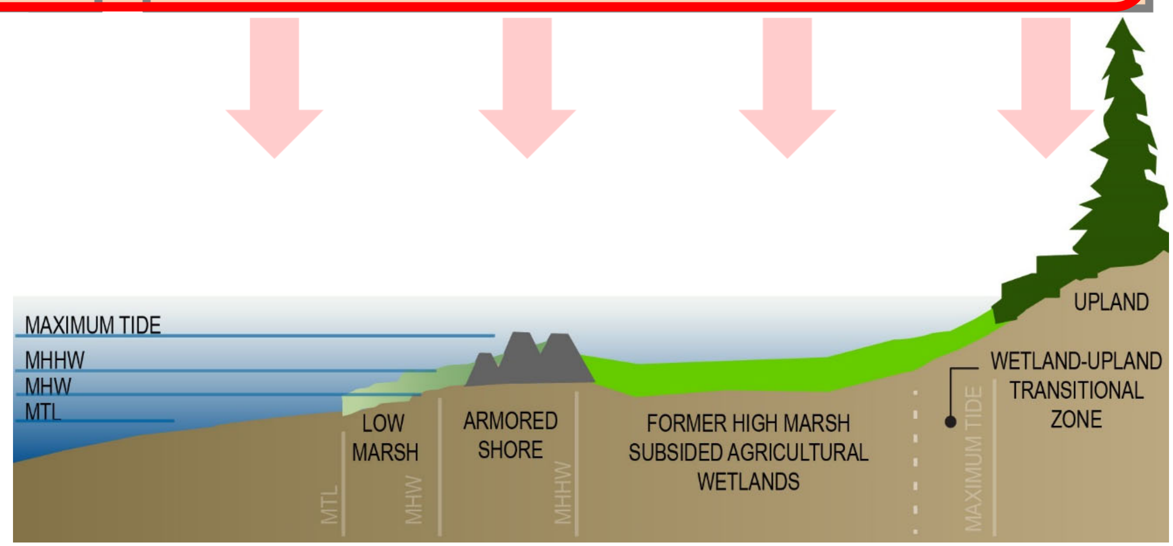
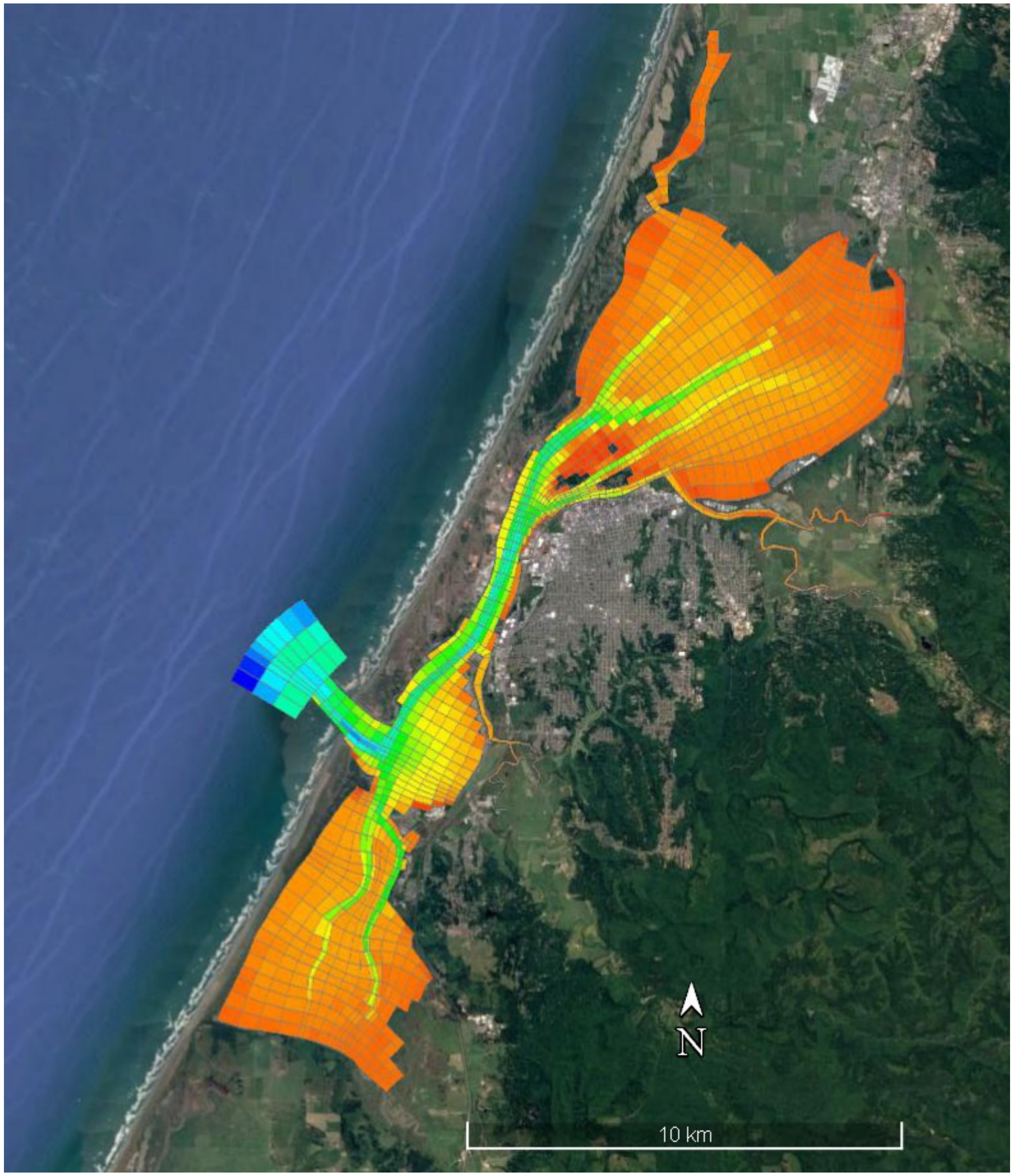


Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling and Inundation Vulnerability Mapping



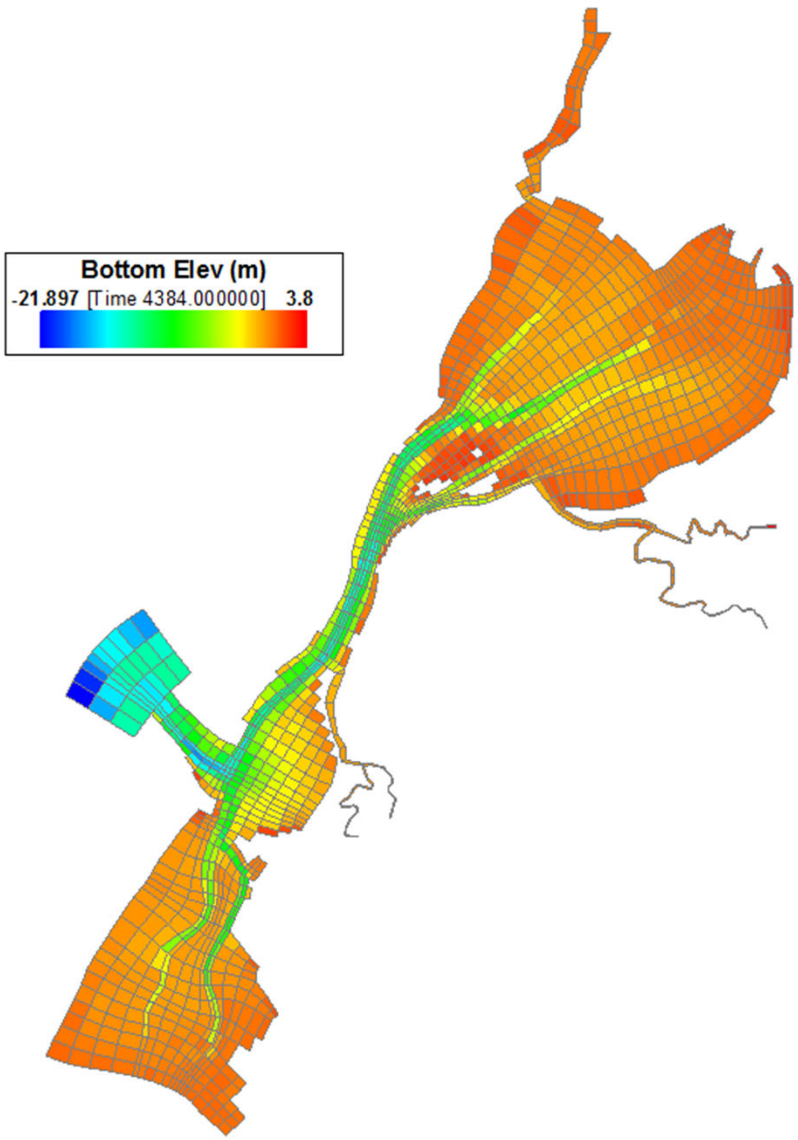
Project:

- Work conducted in 2015
- Funded by the California State Coastal Conservancy

Study Goals:

- Conduct sea level rise (SLR) hydrodynamic modeling in Humboldt Bay
- Identify areas surrounding Humboldt Bay vulnerable to existing and future sea levels
- Create Humboldt Bay Project Digital Elevation Model (DEM)
- Develop a conceptual groundwater model to analyze projected SLR in the Eureka–Arcata coastal plain

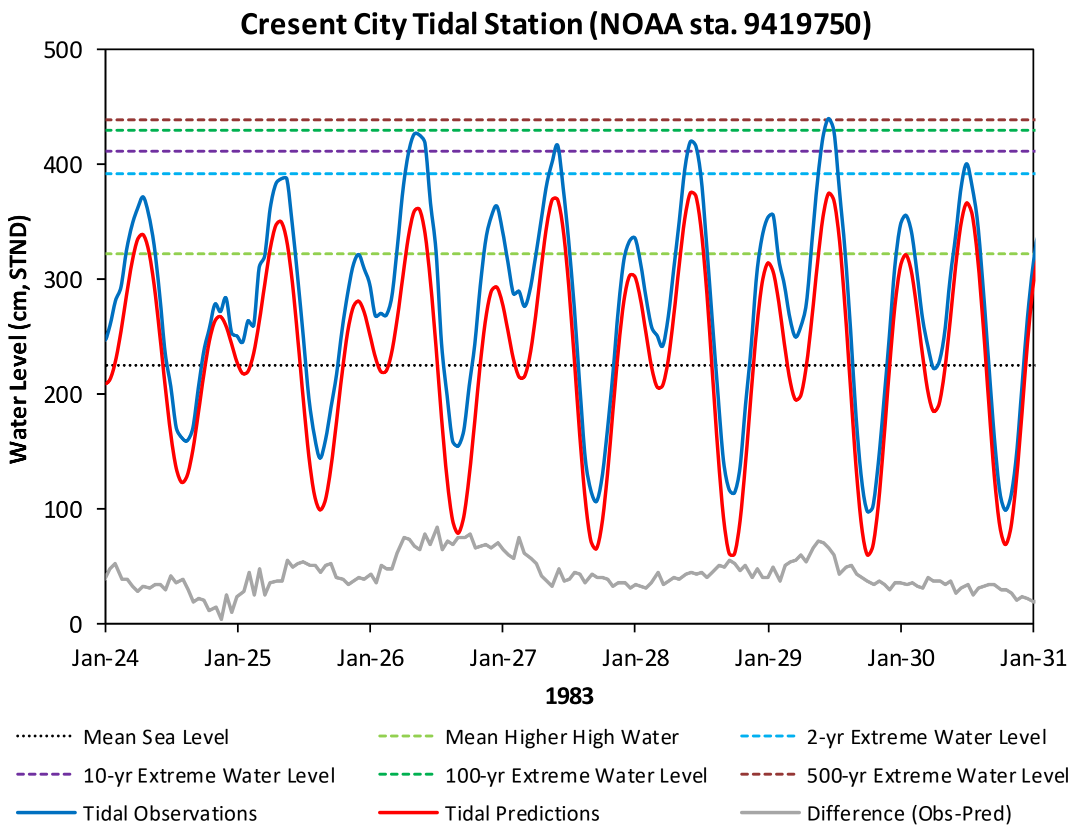
Humboldt Bay SLR Hydrodynamic Model



Hydrodynamic Model:

- Configured as 2D model using EFDC Modeling System (EPA, Public Domain)
- Grid cell elevations based on Project DEM
- Model forcing: Ocean sea-levels only using Crescent City tide data
- Wind waves and tributary creek flows were not modeled
- Extreme water levels developed in this study are still water elevations, not the FEMA 1% annual base flood elevation, which includes wave effects

Sea Level Height Variability

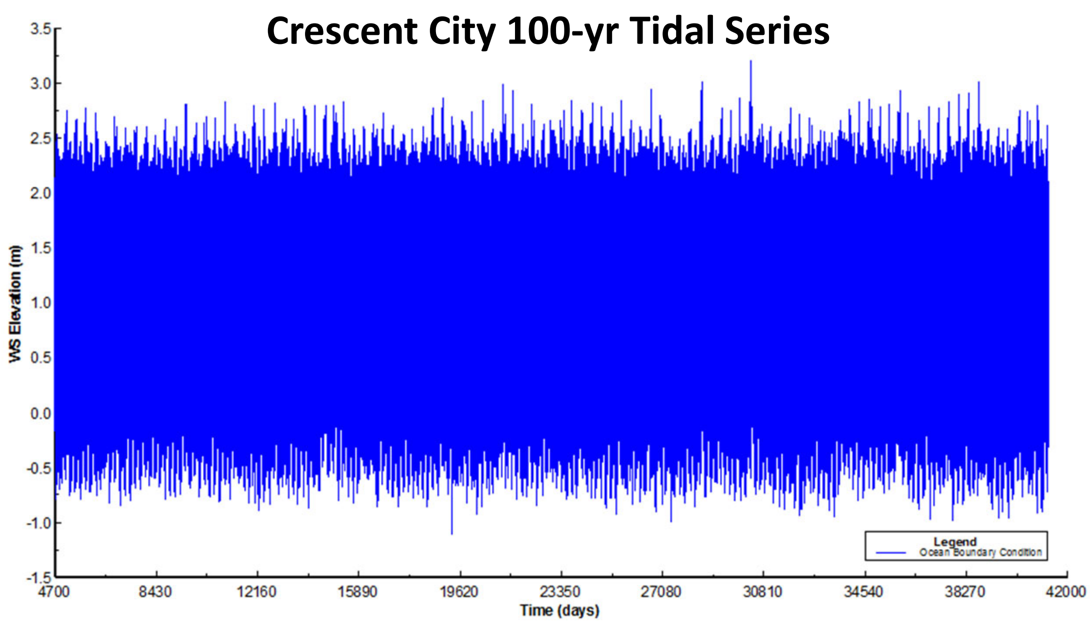


Sea Level Height Variability:

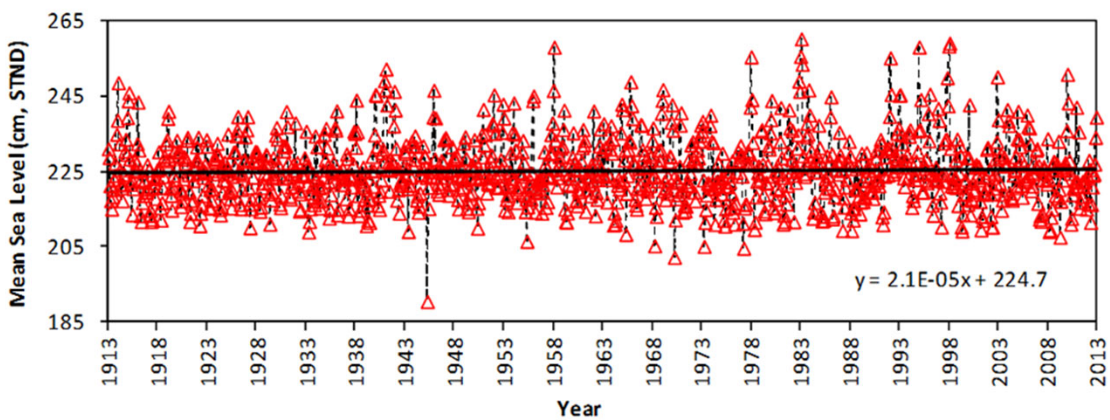
- Sea level height varies around mean sea level from the influence of
  - Astronomical tides
  - Non-tidal sea levels
    - El Niño and PDO cycles
    - Storm surge (wind stress and barometric pressure changes)

- Extreme sea level heights occur when forces coincide, for example
  - Jan 1983 large El Niño driven storm event occurred in Crescent City
  - 6-days water levels > 2-yr event
  - 4-days water levels > 10-yr event
  - 2-days water levels > 100-yr event
  - 1-day water level > 500-yr event

Humboldt Bay SLR Hydrodynamic Modeling



Crescent City 100-yr Tidal Series Detrended Monthly Max

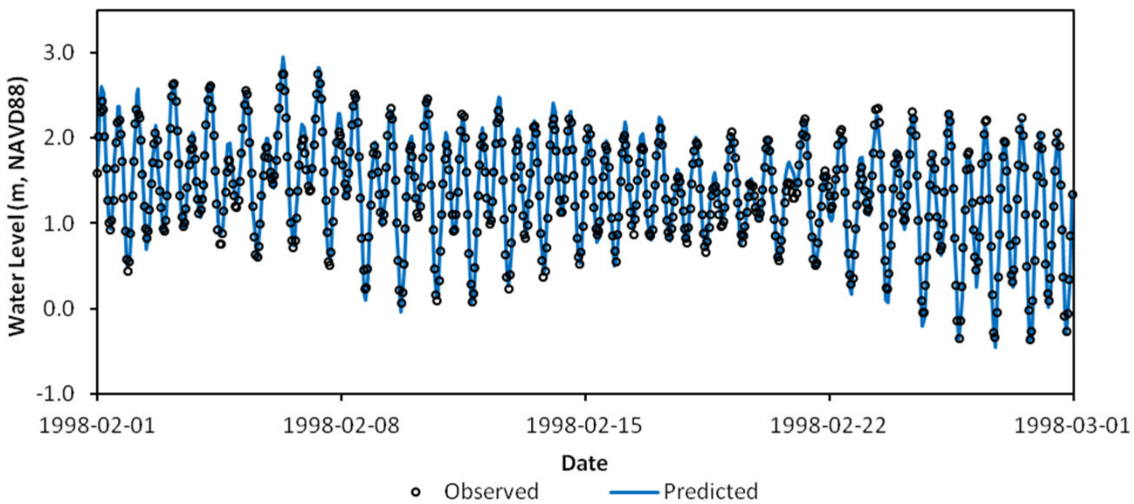


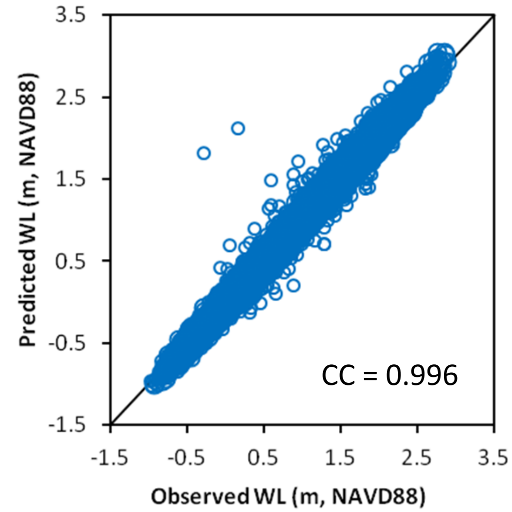
Ocean Boundary Condition:

- 100-yr hourly sea level height series was developed for the Crescent City tide station
- Period: 1913-2012
- 639,011 hourly observations and 246,373 hourly predictions
- Predictions based on astronomical tides and non-tide sea level model that accounts for wind, sea level pressure and El Niño variability
- 100-yr series was detrended to remove the effects of SLR and VLM (stationary series)
- 100-yr series accounts for the sea level height variability in the Crescent City tidal record
- See report for more detail

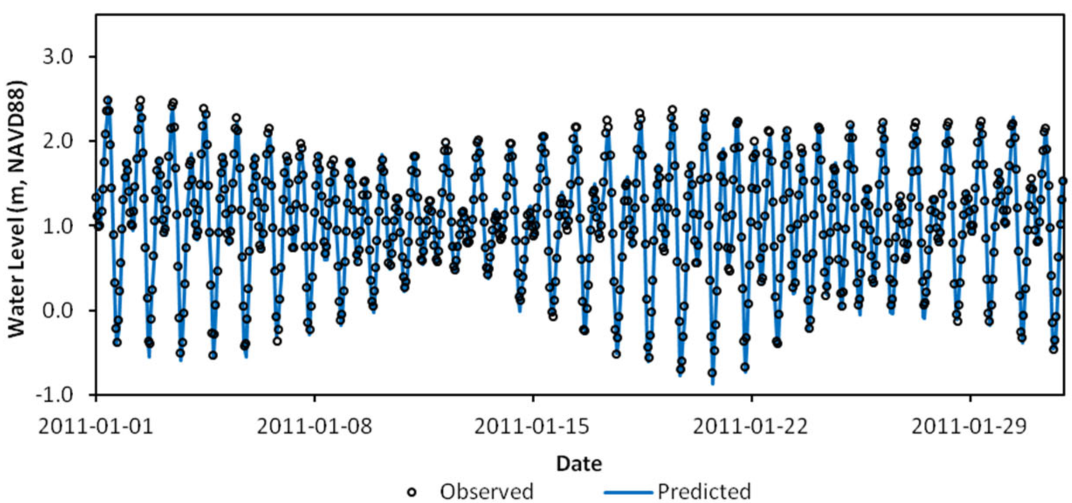
Observed and Predicted Humboldt Bay Water Levels

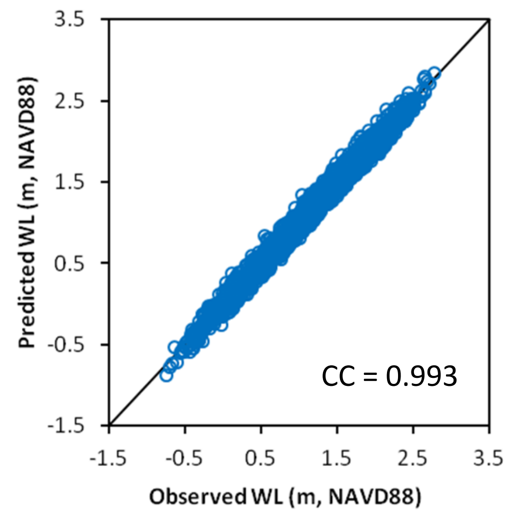
North Spit





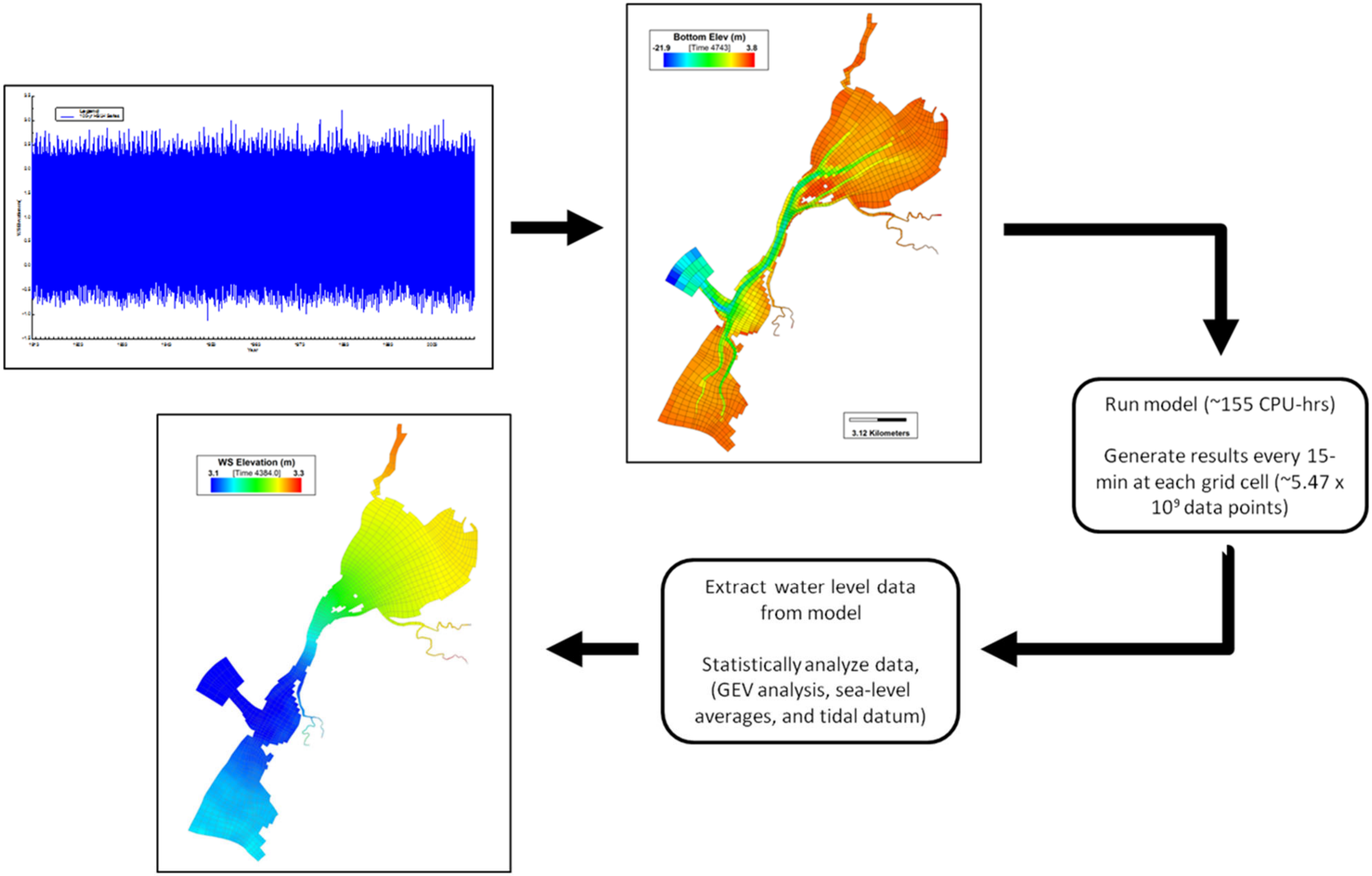
Samoa





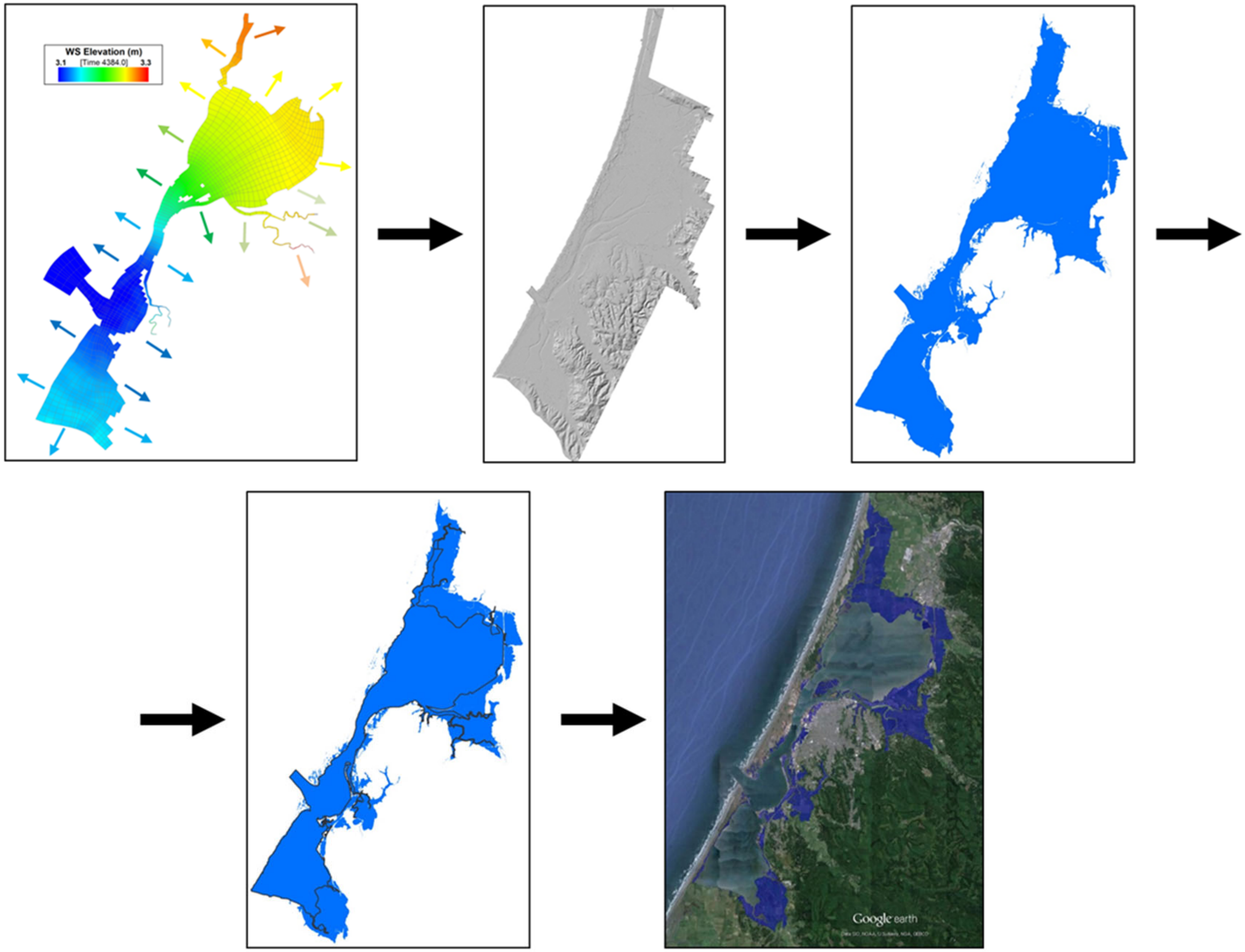
Humboldt Bay SLR Hydrodynamic Modeling

General Modeling Framework

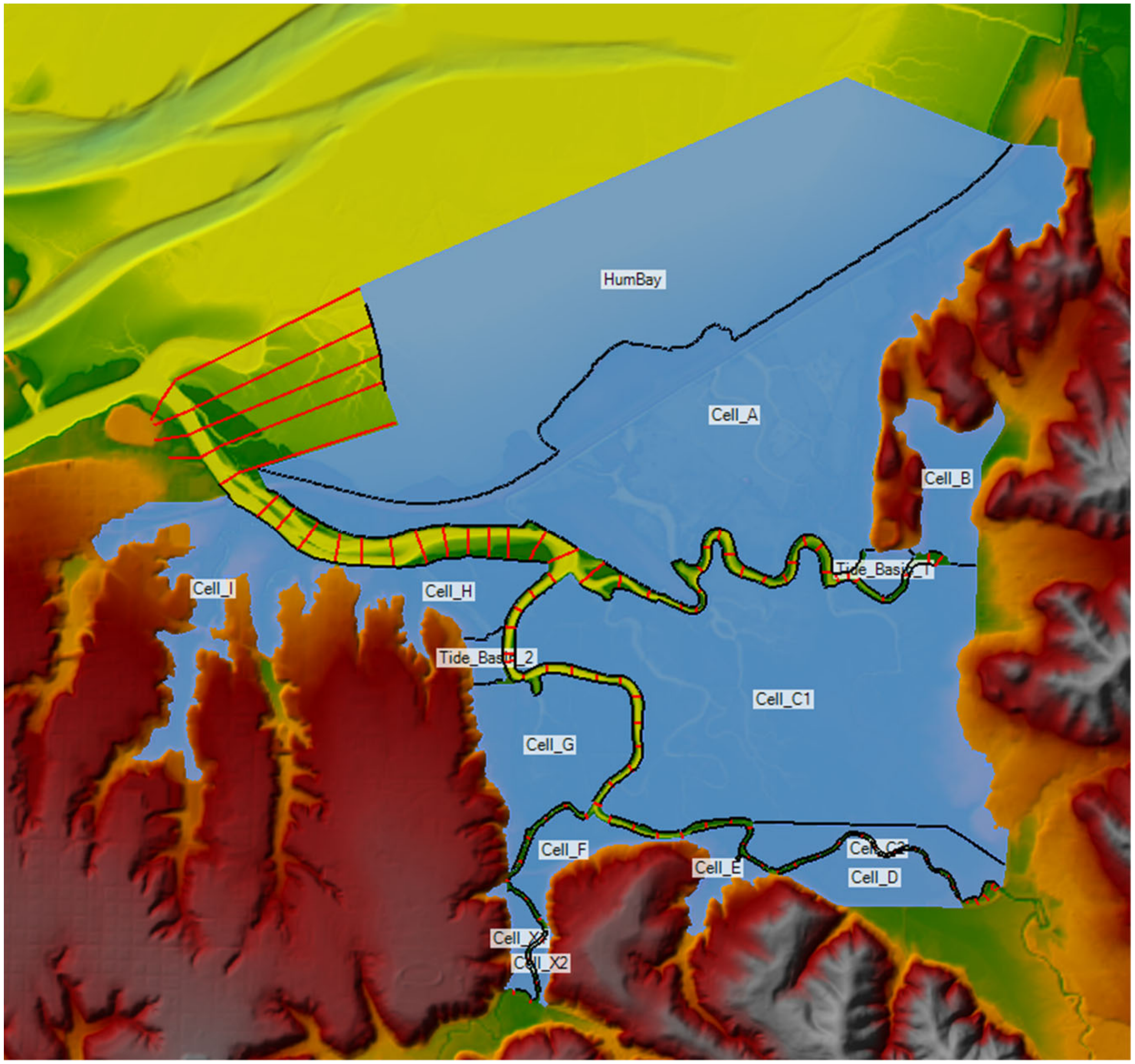


Humboldt Bay SLR
Inundation Vulnerability Mapping

General Inundation Mapping Framework



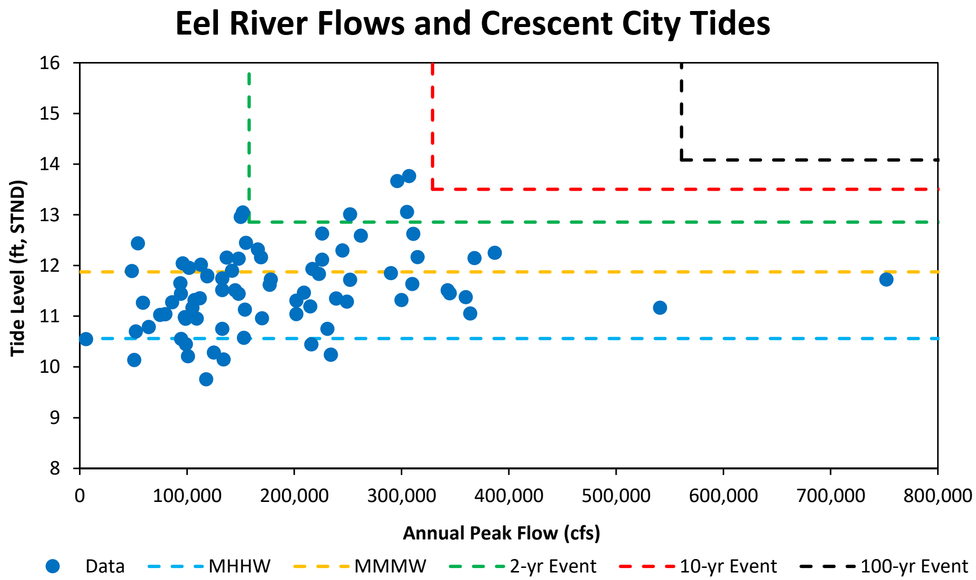
Eureka Slough SLR Project
Hydraulic Model

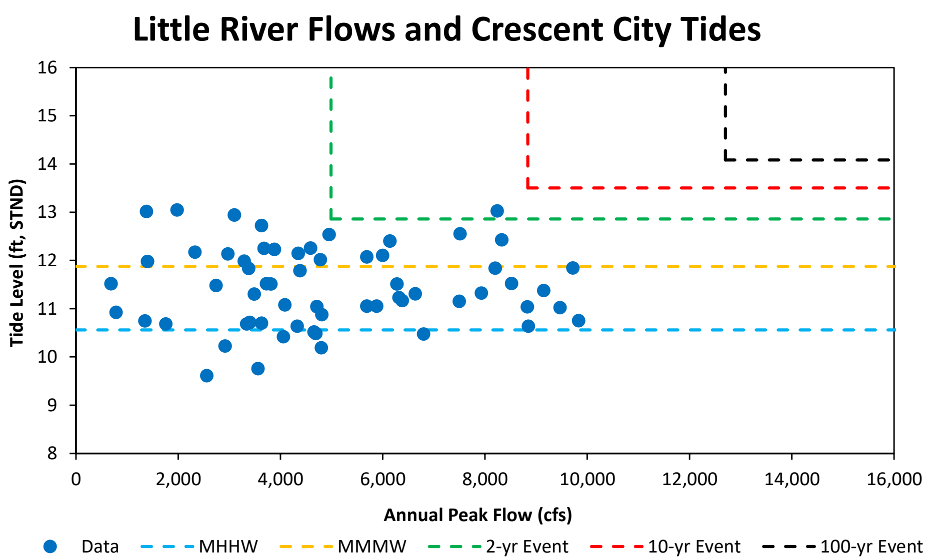


Hydraulic Model:

- Developed as Project specific model
- 1D Unsteady Model using HEC-RAS Modeling System
  - Channels represented as cross sections (red lines)
  - Levees represented as lateral structures (black lines)
  - Geomorphic units represented as storage areas (blue polys)
- Model elevations based on existing LiDAR and ground-based topographic surveys
- Model forcing: Humboldt Bay tide levels and tributary creek flows

Independence of Coastal Extreme Water Levels and Riverine Flood Events





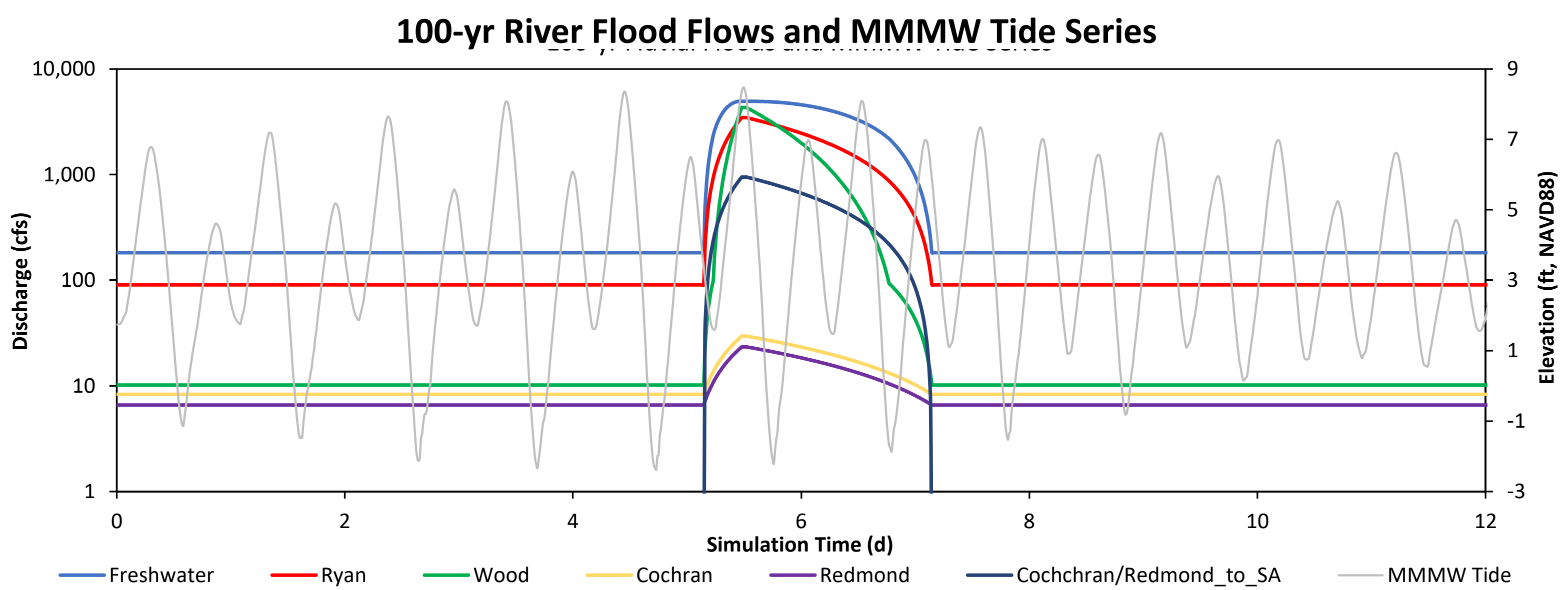
Independence of Events:

- On west coast weather (meteorological) events that produce extreme sea-levels are different than produce riverine floods
- Comparison of Eel River and Little River annual peak flows and Crescent City coincident maximum daily tide levels demonstrate that
  - Large riverine floods do not occur during extreme coastal floods
  - Coastal and riverine events exceeding 10-year probabilities have not occurred
  - Large riverine floods tend to occur during spring tides (MMMW), and not MHHW
- General result is that coastal and riverine extreme events appear independent, and can be modeled separately
- Design flood level (e.g. 100-yr level) is just maximum of coastal or riverine event

Boundary Conditions for Riverine Flood Modeling

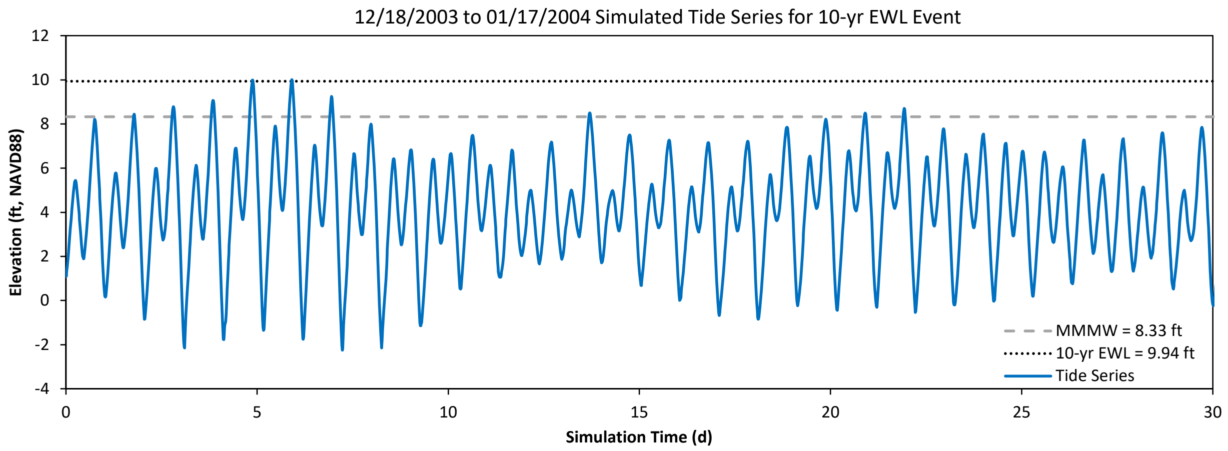
Riverine Flood Boundary Conditions:

- Downstream Model Boundary
  - Used typical mean monthly maximum water (MMMW) level (extracted from Humboldt Bay SLR model)
- Upstream Model Boundaries
  - Estimated flood hydrographs for all tributaries in Project area
  - Peak-flood flows determined from USGS regional regression equation
  - Assumed 48-hr triangle hydrograph
    - Rising limb in 16 hours
    - Falling limb in 32 hours

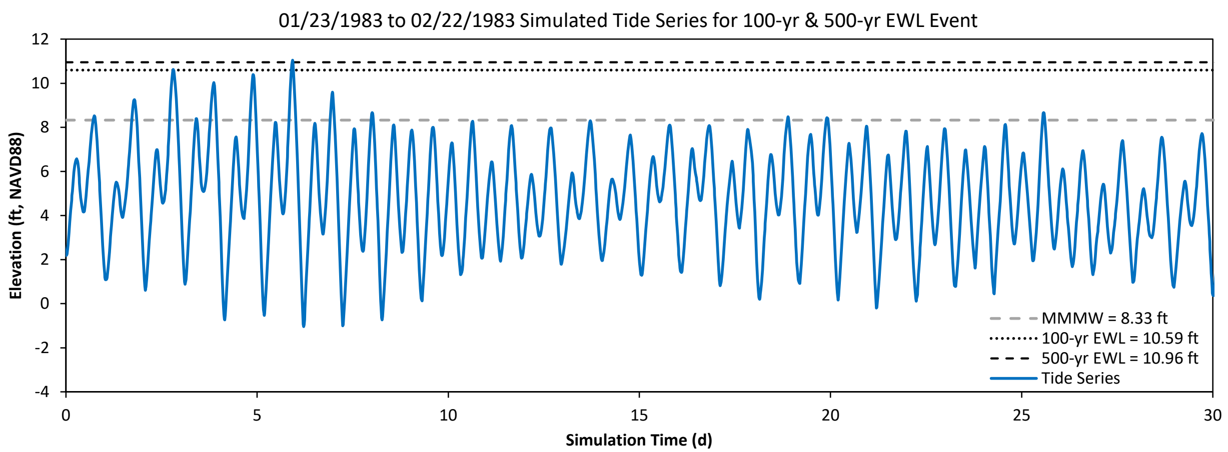


Boundary Conditions for Coastal Extreme Water Level Event Modeling

10-yr Coastal Extreme Water Level Tide Series



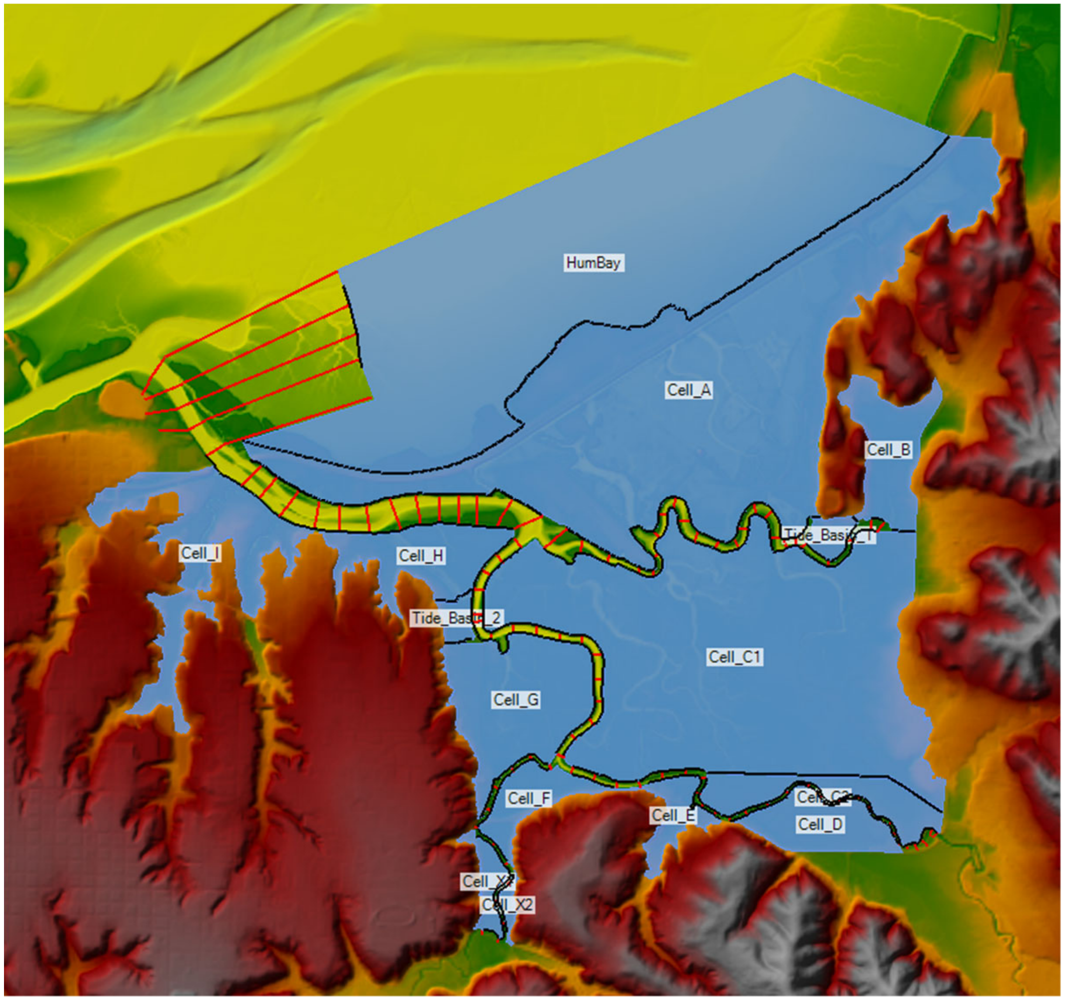
100-yr Coastal Extreme Water Level Tide Series



Coastal Event Boundary Conditions:

- Upstream Model Boundaries
  - Assumed all tributaries were at winter base flow (scaled from Little River)
- Downstream Model Boundary
  - Extracted typical representative tidal series from Humboldt Bay SLR Model
  - Most tidal series had multiple days that exceeded flood threshold

Eureka Slough SLR Project
Hydraulic Model Summary



Hydraulic Model:

- Developed Project specific model
- Predicted various results from coastal and riverine flood events
  - Water levels in channels and storage areas
  - Levee overtopping flow rates, volumes and depths
  - Storage area maximum and minimum inundation patterns
  - Storage area inundation and drainage time series
- Can use developed model to simulate sea-level rise scenarios

Scenario-based Planning: Overview

- A planning framework to inform decision-making by considering a range of plausible future scenarios
- Useful for contexts with “deep uncertainty”
- Can incorporate a variety of information and insight from multiple perspectives (and can be updated)
- The process makes assumptions explicit and improves awareness of uncertainty
- Common examples:
  1. Global emission scenarios
  2. Regional sea level rise scenarios
  3. Regional temperature and precipitation scenarios

Scenario-based Planning: Guidance

Scenario-based Planning: Context

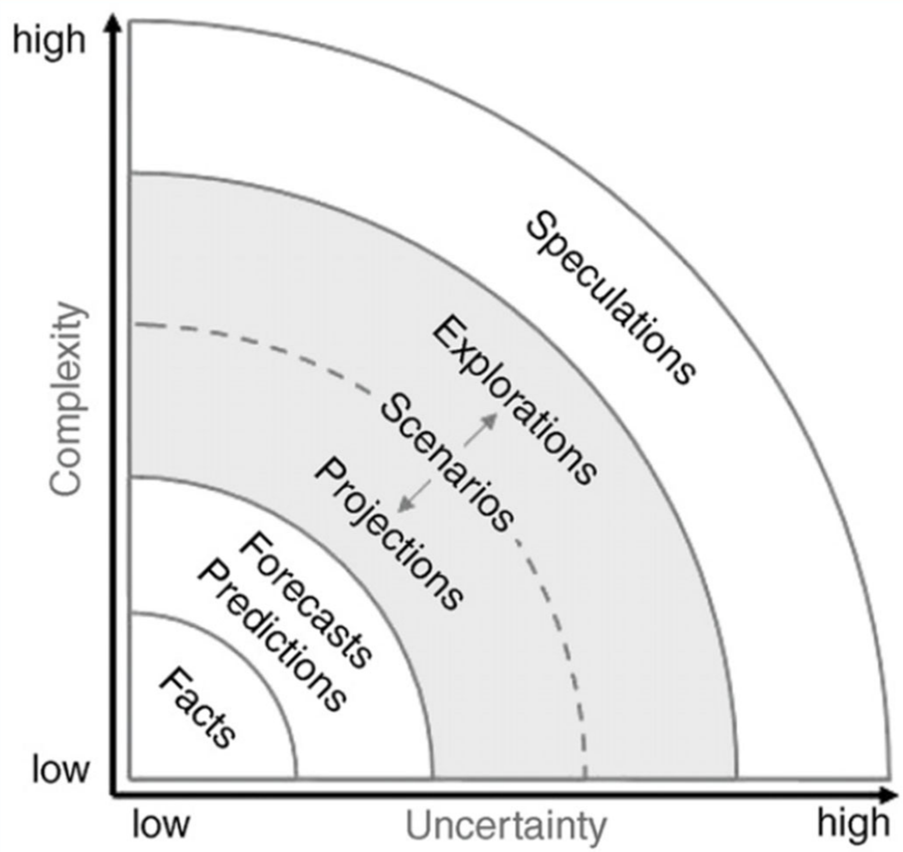
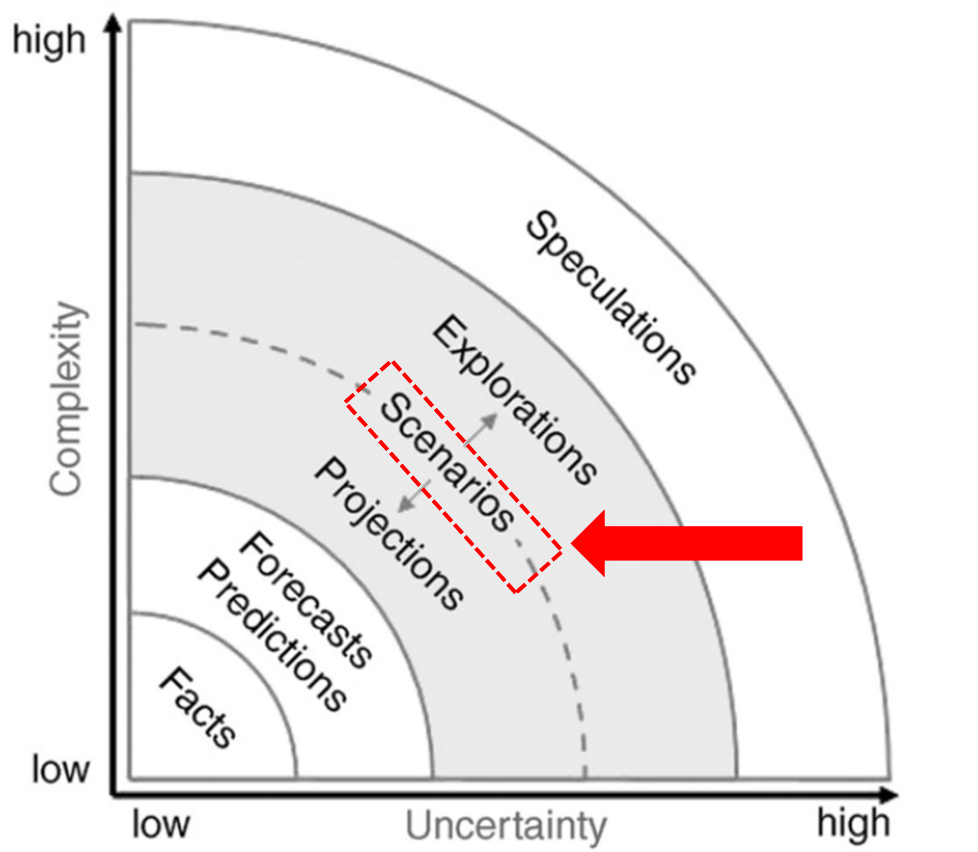


Figure 1.3. The levels of uncertainty and complexity in situations for which scenarios can be useful in comparison with other methods and tools for considering future possibilities (from Zurek and Henrichs 2007).

Source: Considering Multiple Futures: Scenario Planning To Address Uncertainty in Natural Resource Conservation (USFWS, 2014)

Scenario-based Planning: Context



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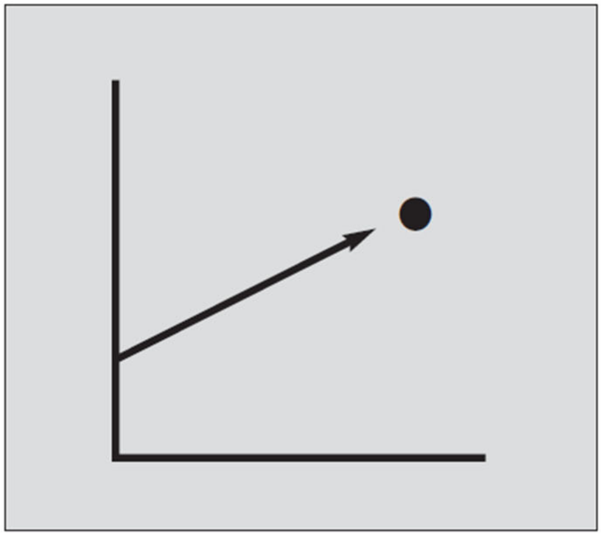
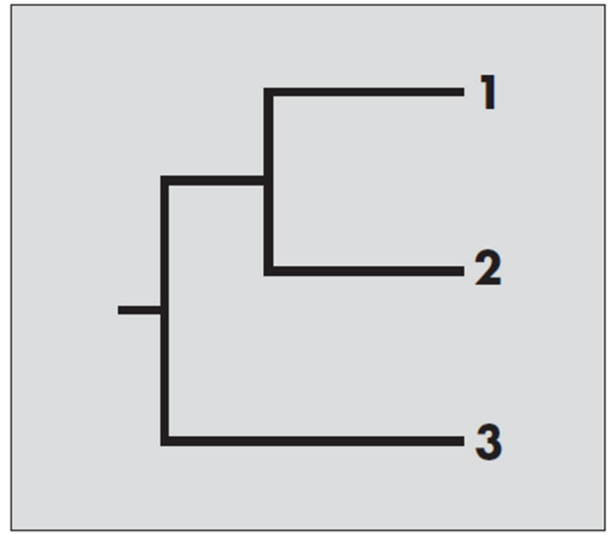
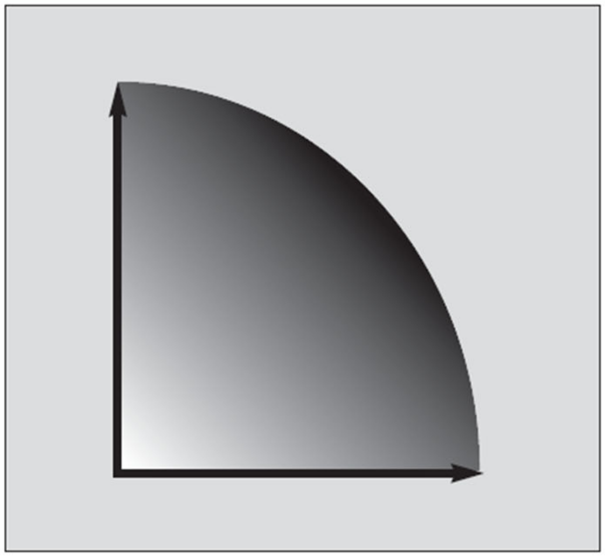
Scenario-based Planning: Context

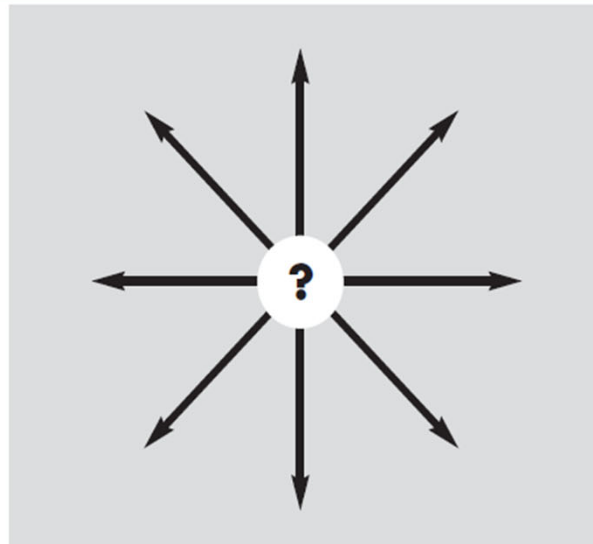
How to Use the Four Levels of Uncertainty

	A Clear-Enough Future	Alternate Futures
		
What Can Be Known?	• A single forecast precise enough for determining strategy	• A few discrete outcomes that define the future
Analytic Tools	• "Traditional" strategy tool kit	• Decision analysis • Option valuation models • Game theory

Source: Harvard Business Review, Strategies under Uncertainty, November-December 1997

Scenario-based Planning: Context

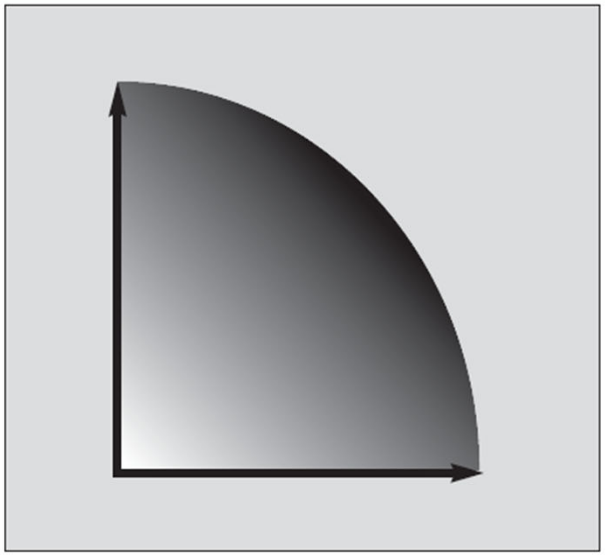


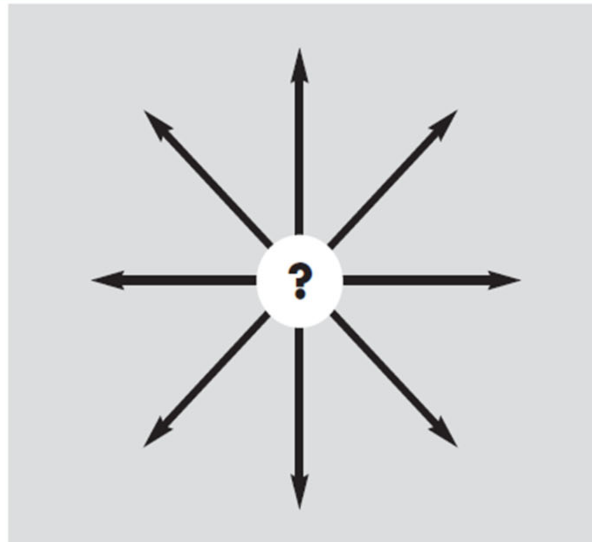


A Range of Futures	True Ambiguity	
• A range of possible outcomes, but no natural scenarios	• No basis to forecast the future	**What Can Be Known?**
• Latent-demand research • Technology forecasting • Scenario planning	• Analogies and pattern recognition • Nonlinear dynamic models	**Analytic Tools**

Source: Harvard Business Review, Strategies under Uncertainty, November-December 1997

Scenario-based Planning: Context





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• Latent-demand research • Technology forecasting • Scenario planning	• Analogies and pattern recognition • Nonlinear dynamic models	**Analytic Tools**

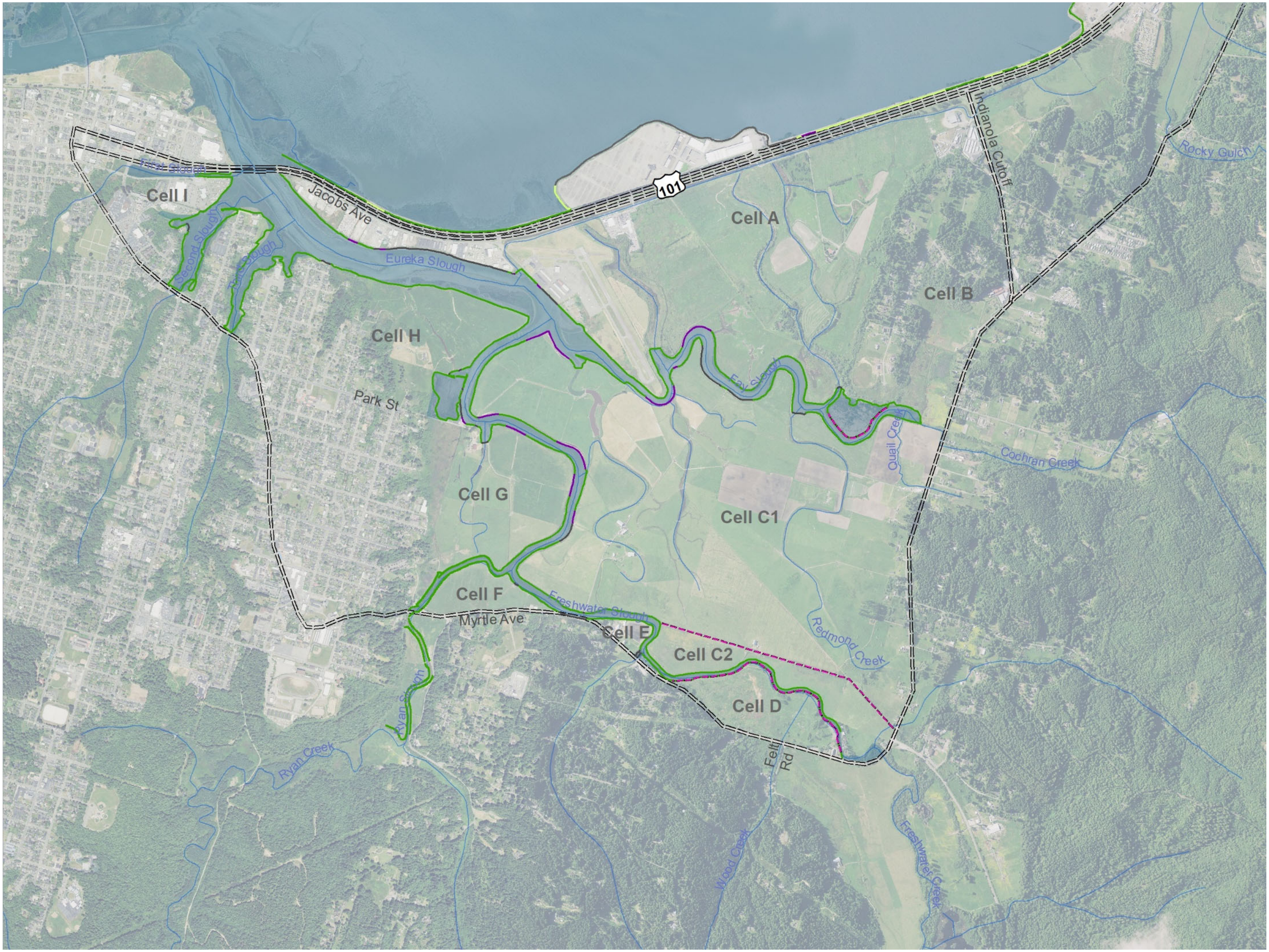
Source: Harvard Business Review, Strategies under Uncertainty, November-December 1997

Hazard Scenarios for Flooding Impacts

- We apply scenario-based planning at the scale of the hydrographic area
- Each scenario is a hypothesis about the potential cause-and-effect linkages between hydrologic and geomorphic processes and physical changes to the landscape and seascape
- 11 scenarios are being considered for this study
- Objectives:
  1. Gain a better understanding of dynamic physical processes
  2. Interpret technical information to make flooding risks more understandable
  3. Explore thresholds and tipping points to gain a better understanding of site-specific vulnerabilities
  4. Inform the design objectives for adaptation projects to maximize effectiveness
  5. Increase the robustness of decisions

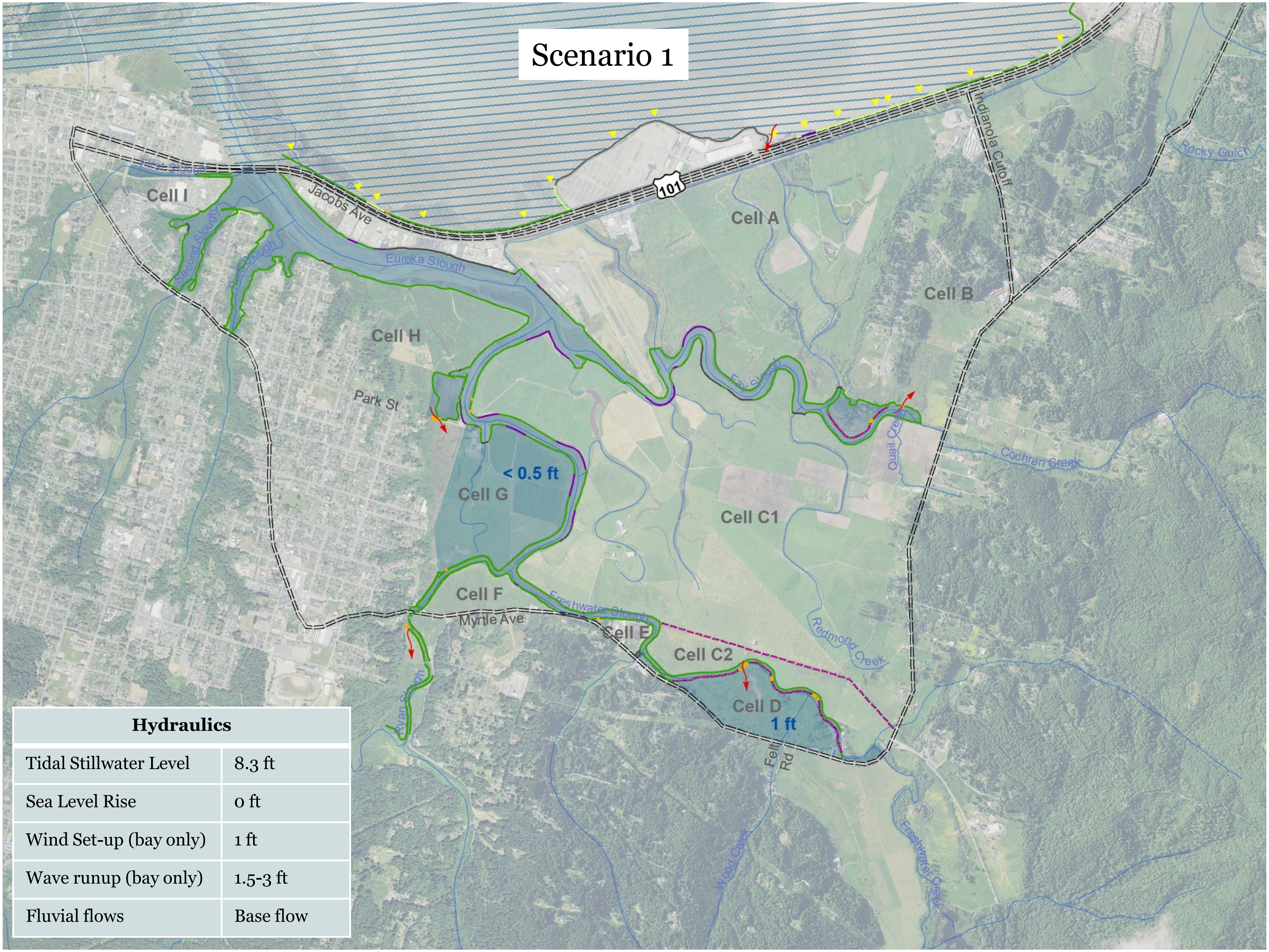
Hazard Scenarios for Flooding Impacts

- Let's walk through the Summary of Hazard Scenarios (work in progress)
- Primary elements:
  1. Hydraulics and sea level rise
  2. Shoreline conditions
  3. Geomorphic response
  4. Resource impact thresholds
- Work products:
  1. Case study narratives with supporting figures
  2. Summary table
  3. Inventory of vulnerable critical resources



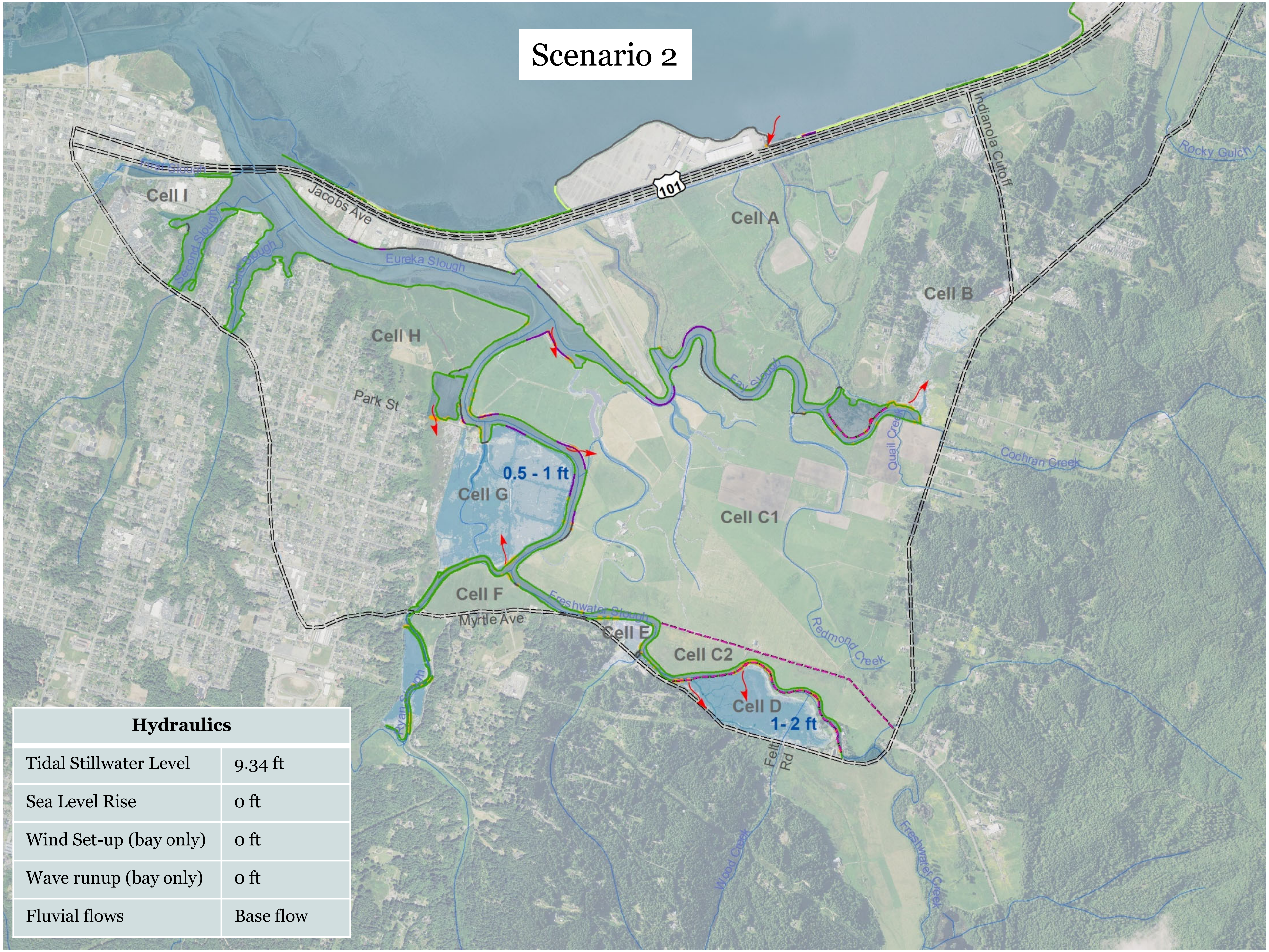
Cell A
Cell B
Cell C1
Cell C2
Cell D
Cell E
Cell F
Cell G
Cell H
Cell I
101
Jacobs Ave
Eureka Slough
Second Slough
Park St
Myrtle Ave
Freshwater Slough
Fay Slough
Indianola Cutoff
Rocky Gulch
Cochran Creek
Quail Creek
Redmond Creek
Felt Rd
Ryan Slough
Ryan Creek
Wood Creek
Freshwater Creek

Scenario 1



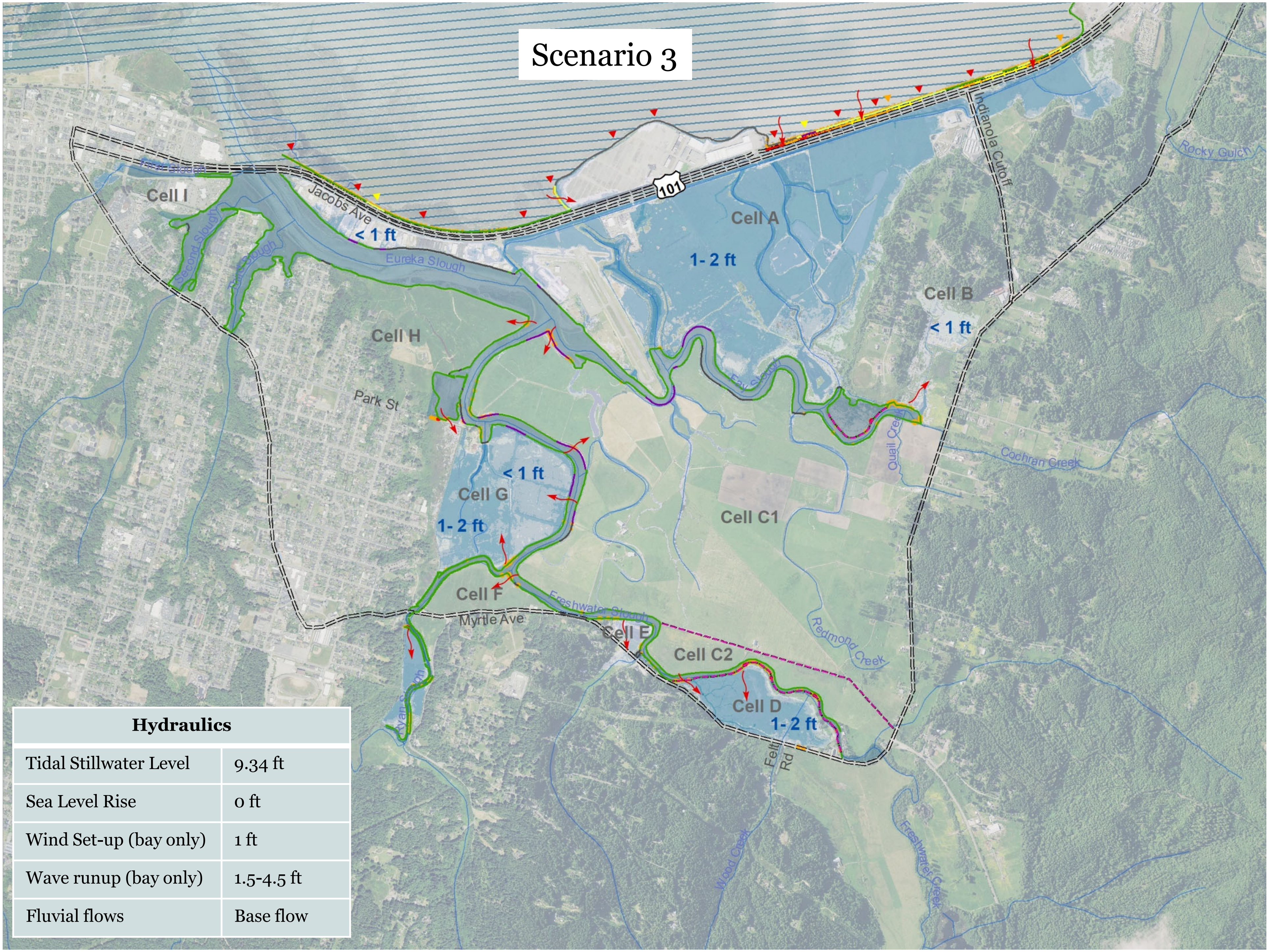
Hydraulics	
Tidal Stillwater Level	8.3 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	1 ft
Wave runup (bay only)	1.5-3 ft
Fluvial flows	Base flow

Scenario 2



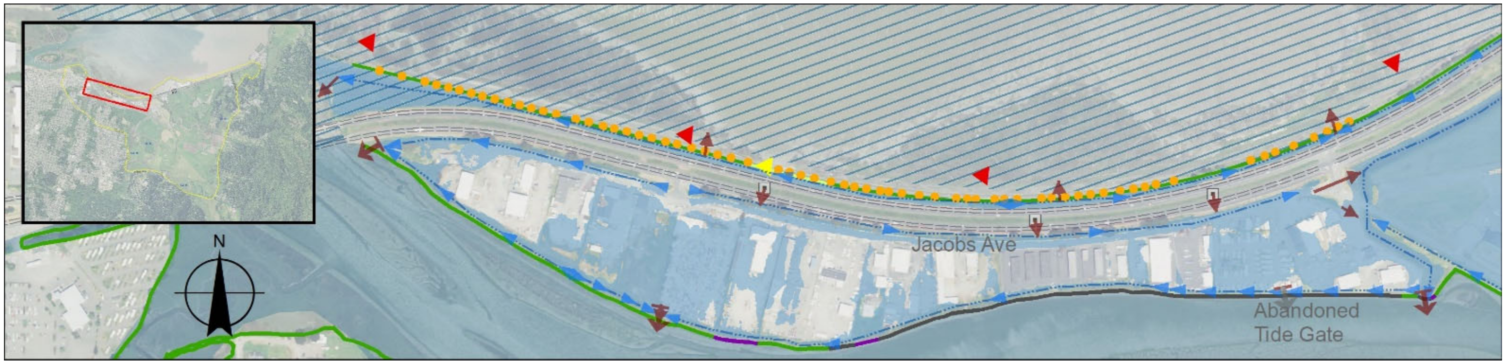
Hydraulics	
Tidal Stillwater Level	9.34 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	0 ft
Wave runup (bay only)	0 ft
Fluvial flows	Base flow

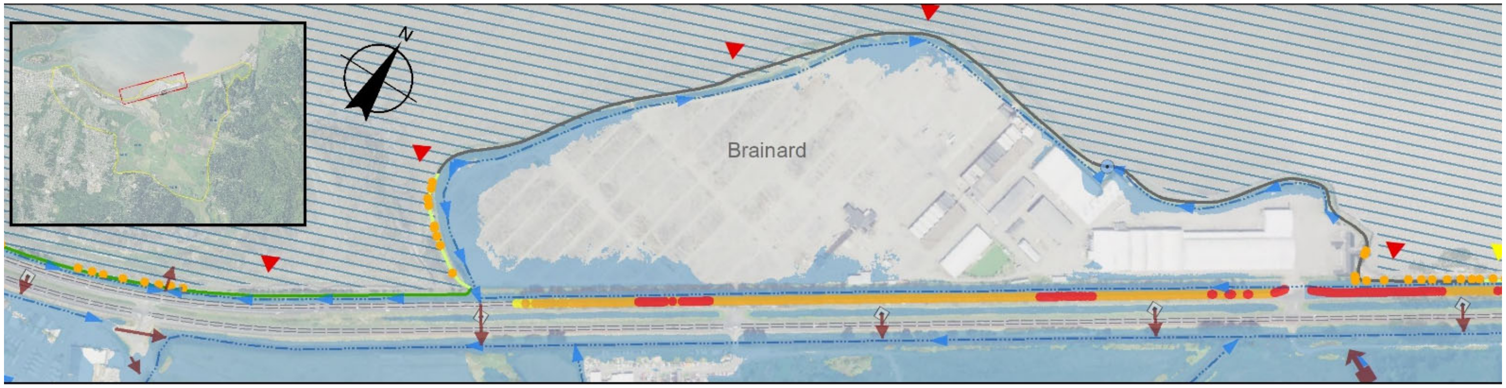
Scenario 3

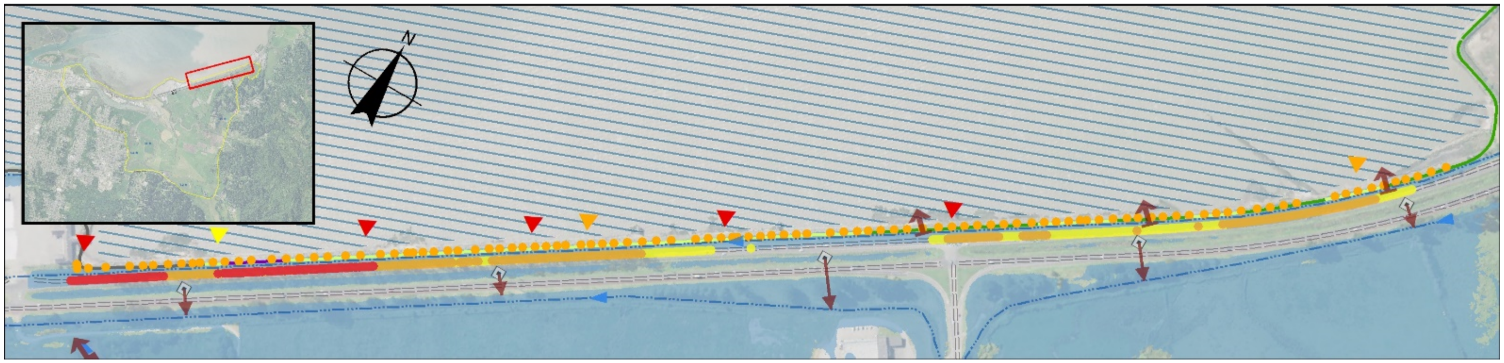


Hydraulics	
Tidal Stillwater Level	9.34 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	1 ft
Wave runup (bay only)	1.5-4.5 ft
Fluvial flows	Base flow

Scenario 3







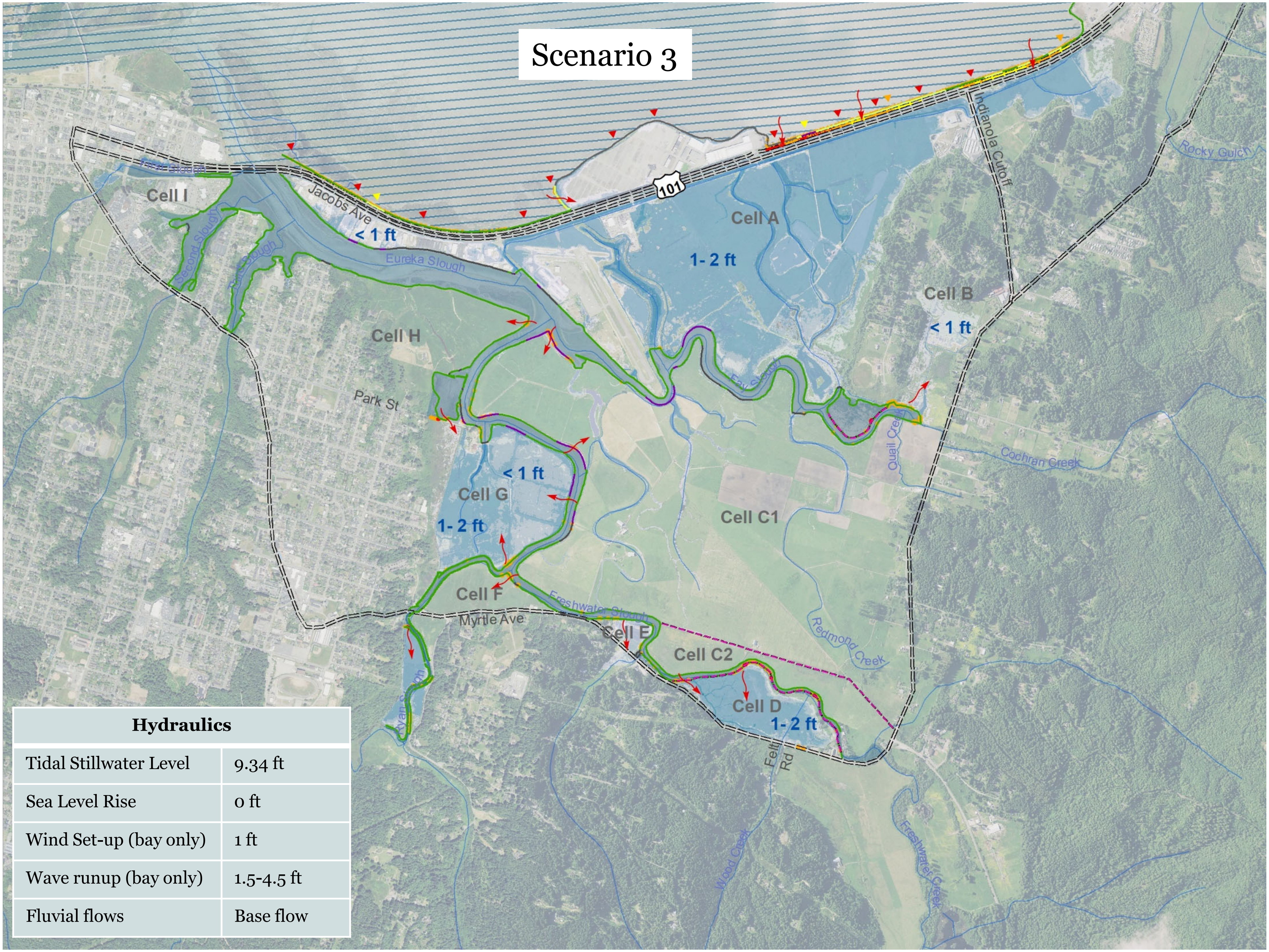
Eureka-Arcata Highway 101 Corridor: December 31, 2005

Eureka-Arcata Highway 101 Corridor: December 31, 2005


SPEED
LIMIT
50
30 YEARS

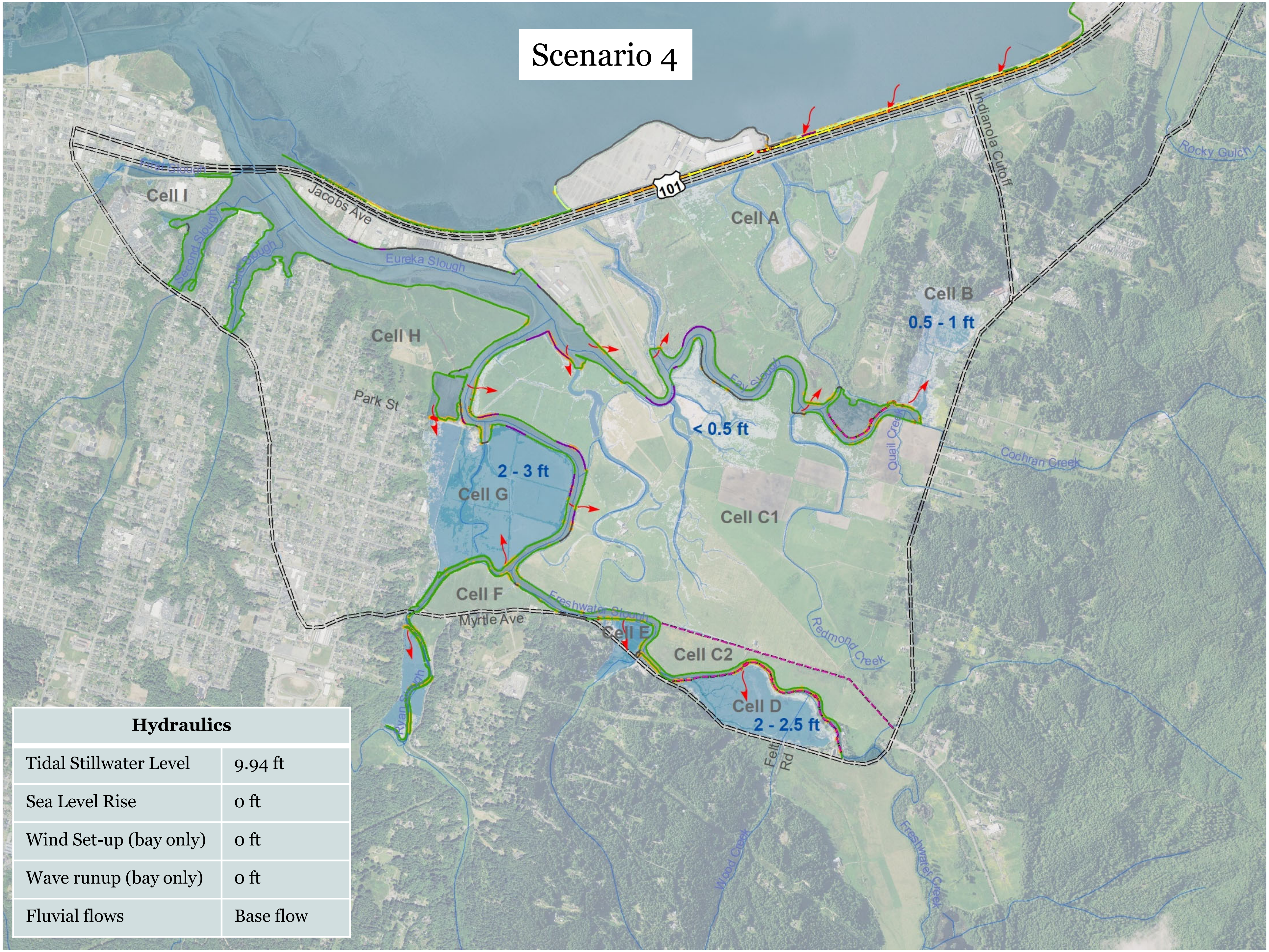



Scenario 3



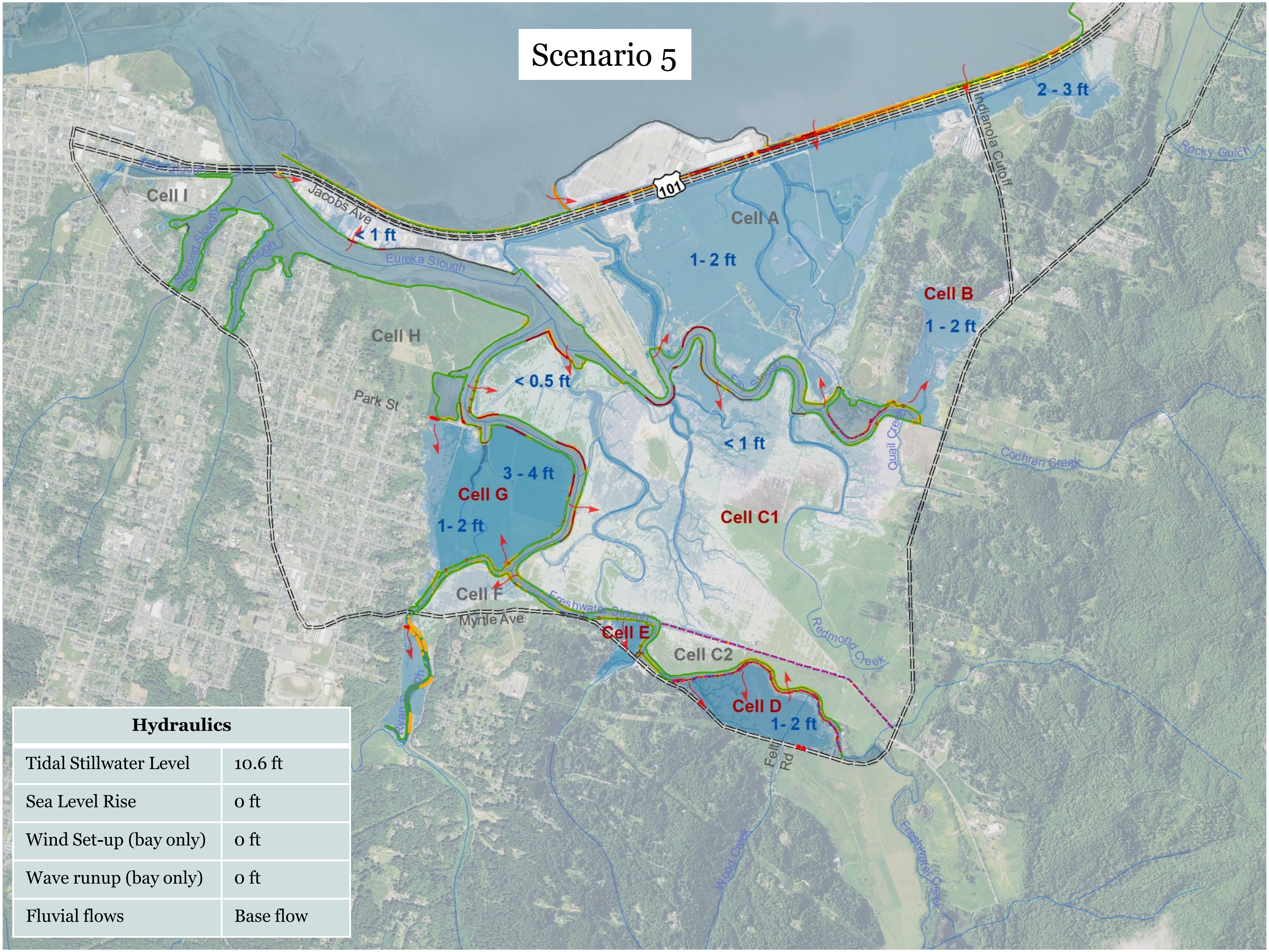
Hydraulics	
Tidal Stillwater Level	9.34 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	1 ft
Wave runup (bay only)	1.5-4.5 ft
Fluvial flows	Base flow

Scenario 4



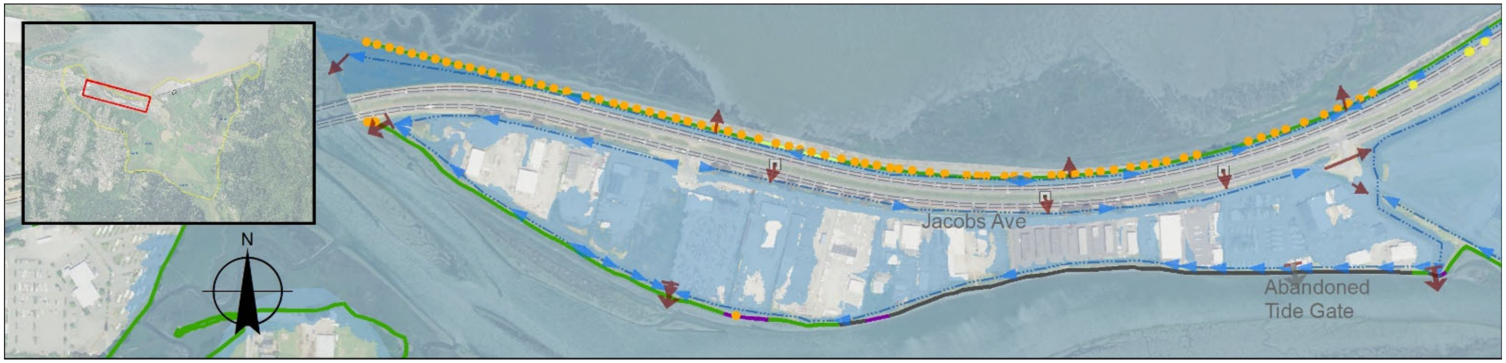
Hydraulics	
Tidal Stillwater Level	9.94 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	0 ft
Wave runup (bay only)	0 ft
Fluvial flows	Base flow

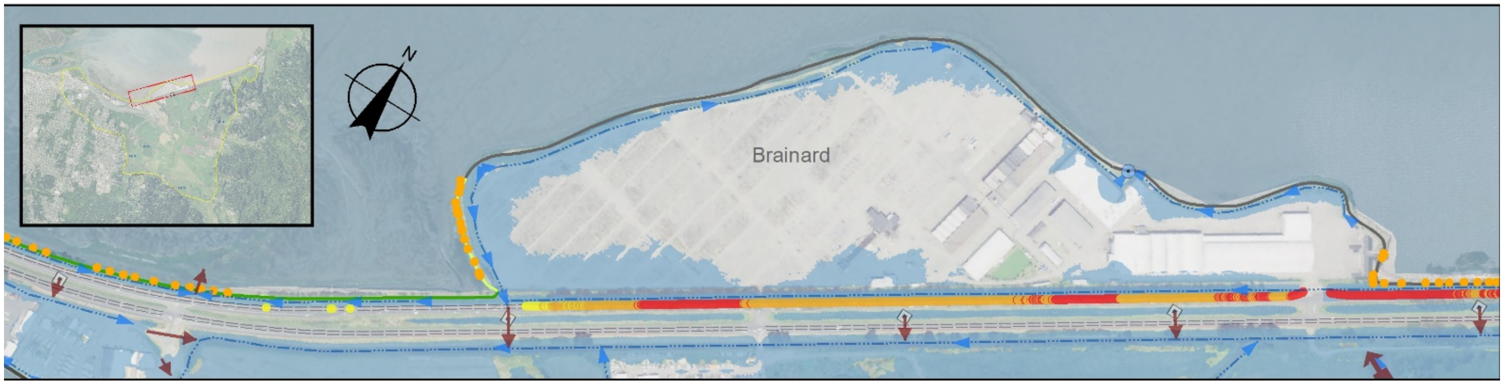
Scenario 5

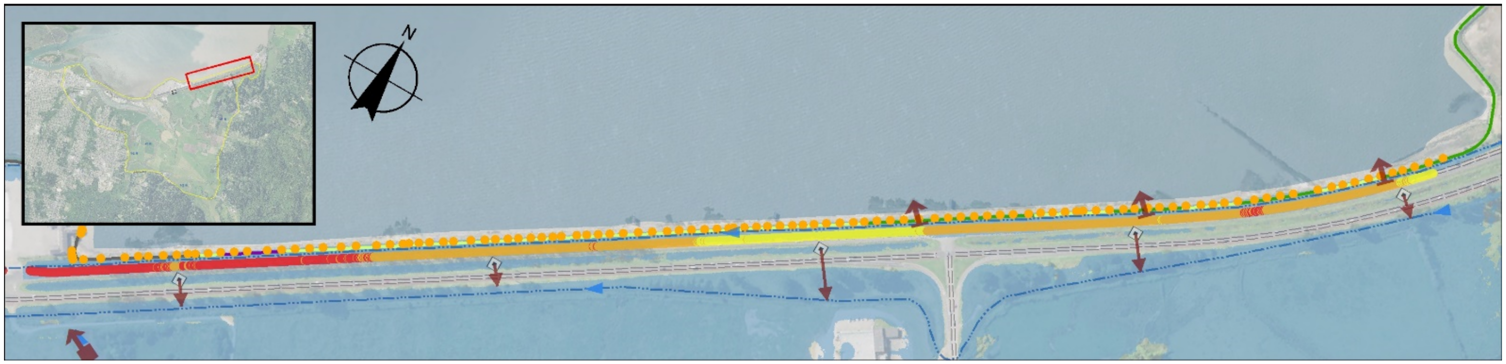


Hydraulics	
Tidal Stillwater Level	10.6 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	0 ft
Wave runup (bay only)	0 ft
Fluvial flows	Base flow

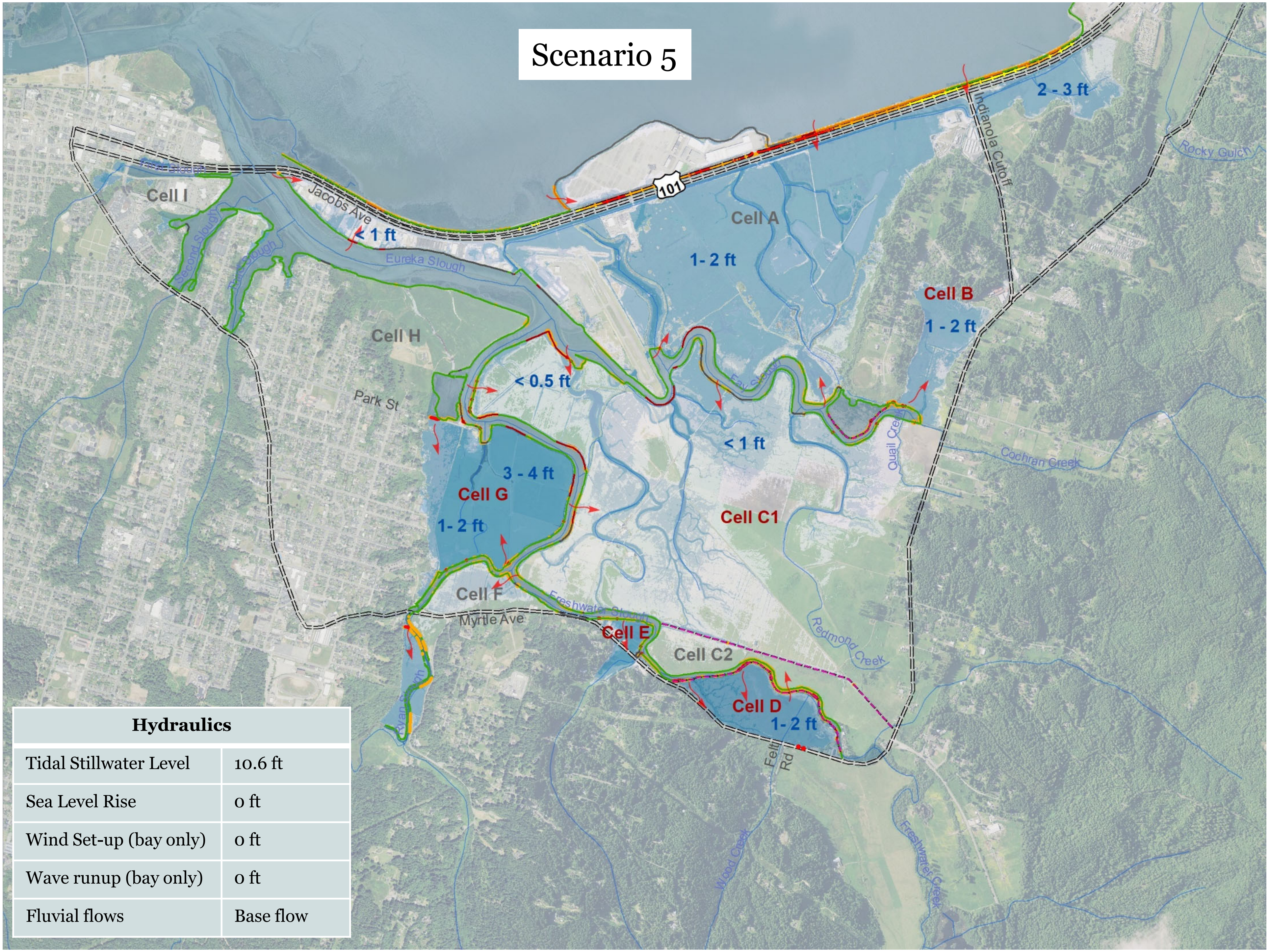
Scenario 5





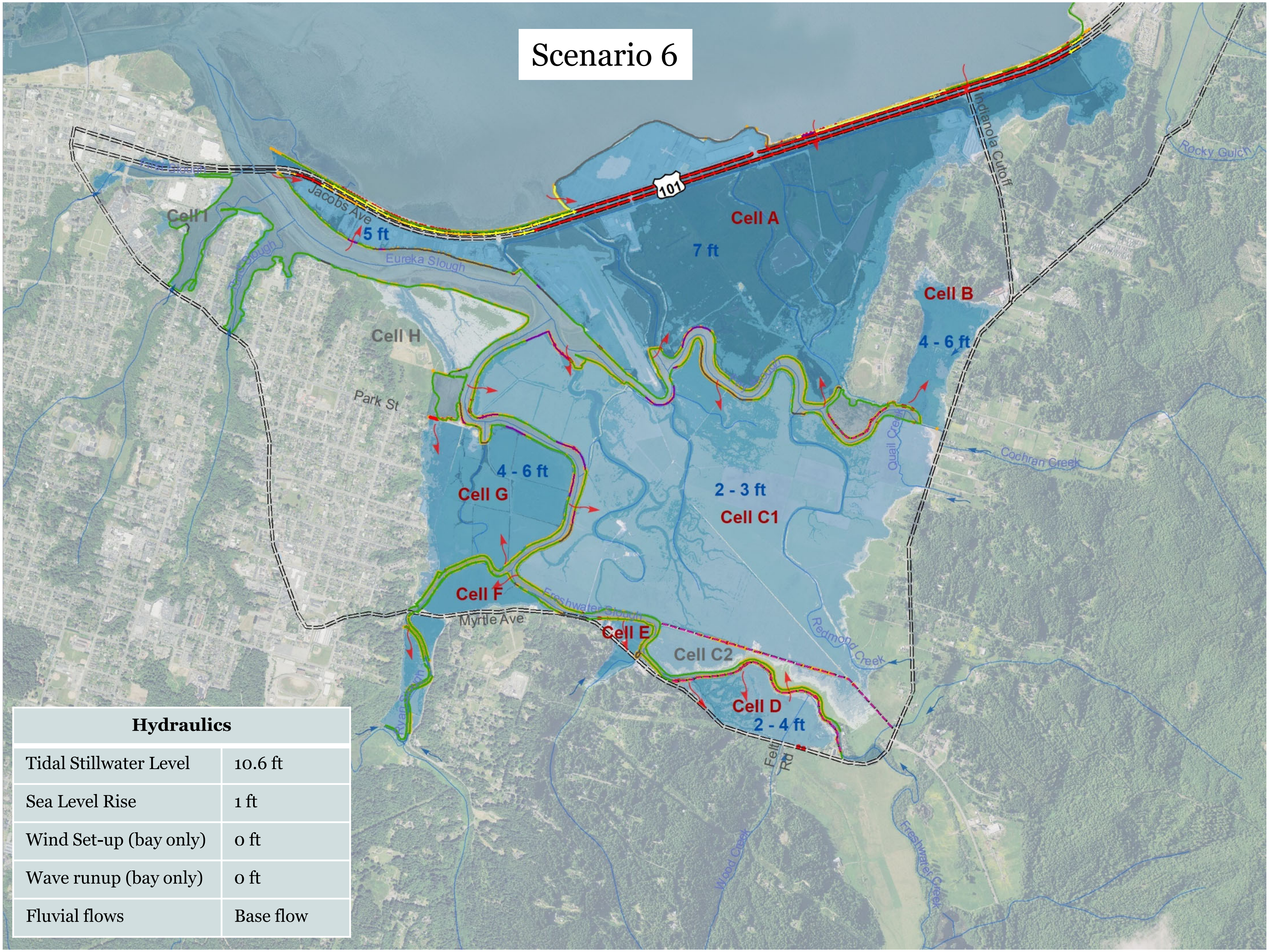


Scenario 5



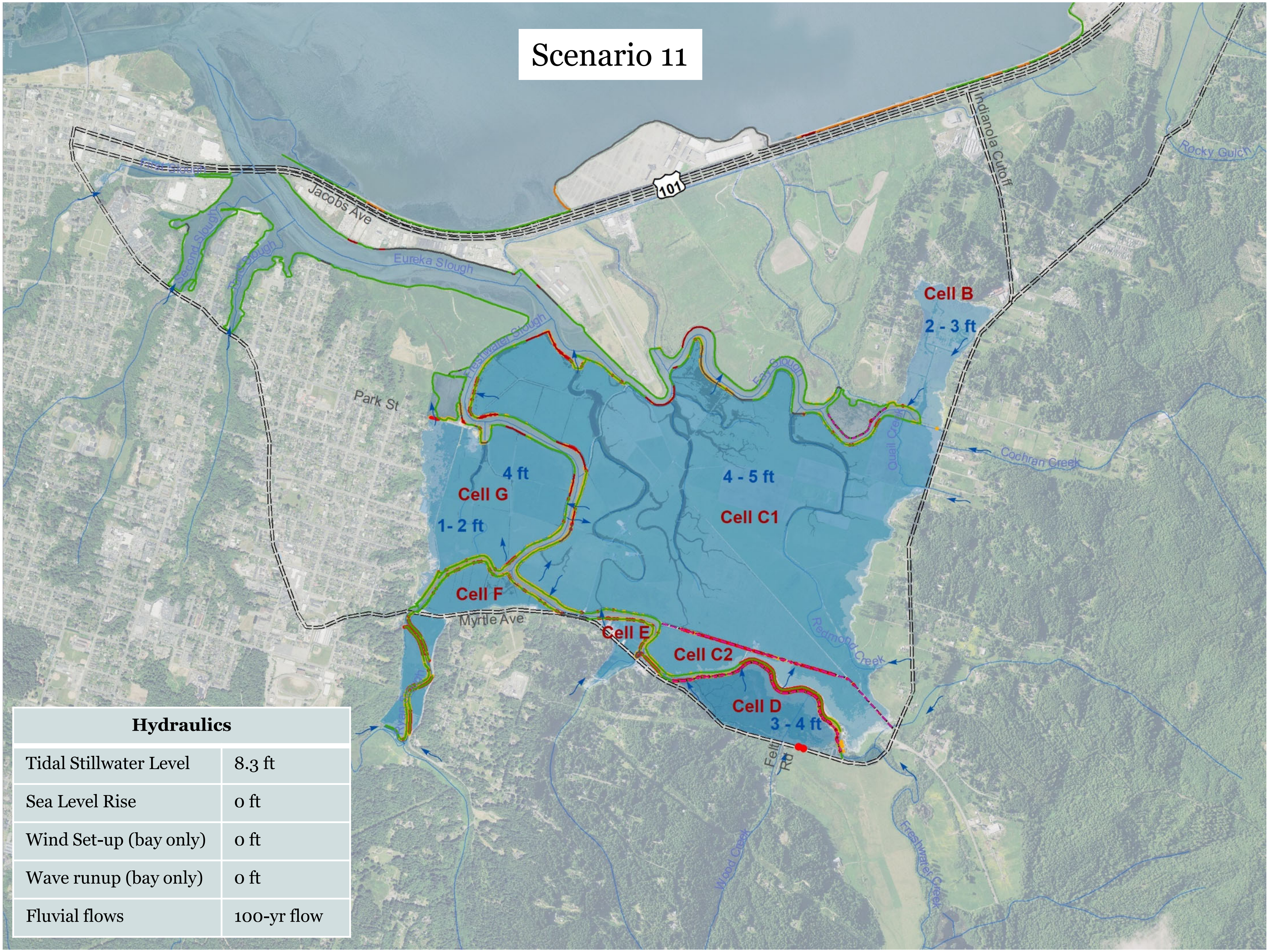
Hydraulics	
Tidal Stillwater Level	10.6 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	0 ft
Wave runup (bay only)	0 ft
Fluvial flows	Base flow

Scenario 6



Hydraulics	
Tidal Stillwater Level	10.6 ft
Sea Level Rise	1 ft
Wind Set-up (bay only)	0 ft
Wave runup (bay only)	0 ft
Fluvial flows	Base flow

Scenario 11



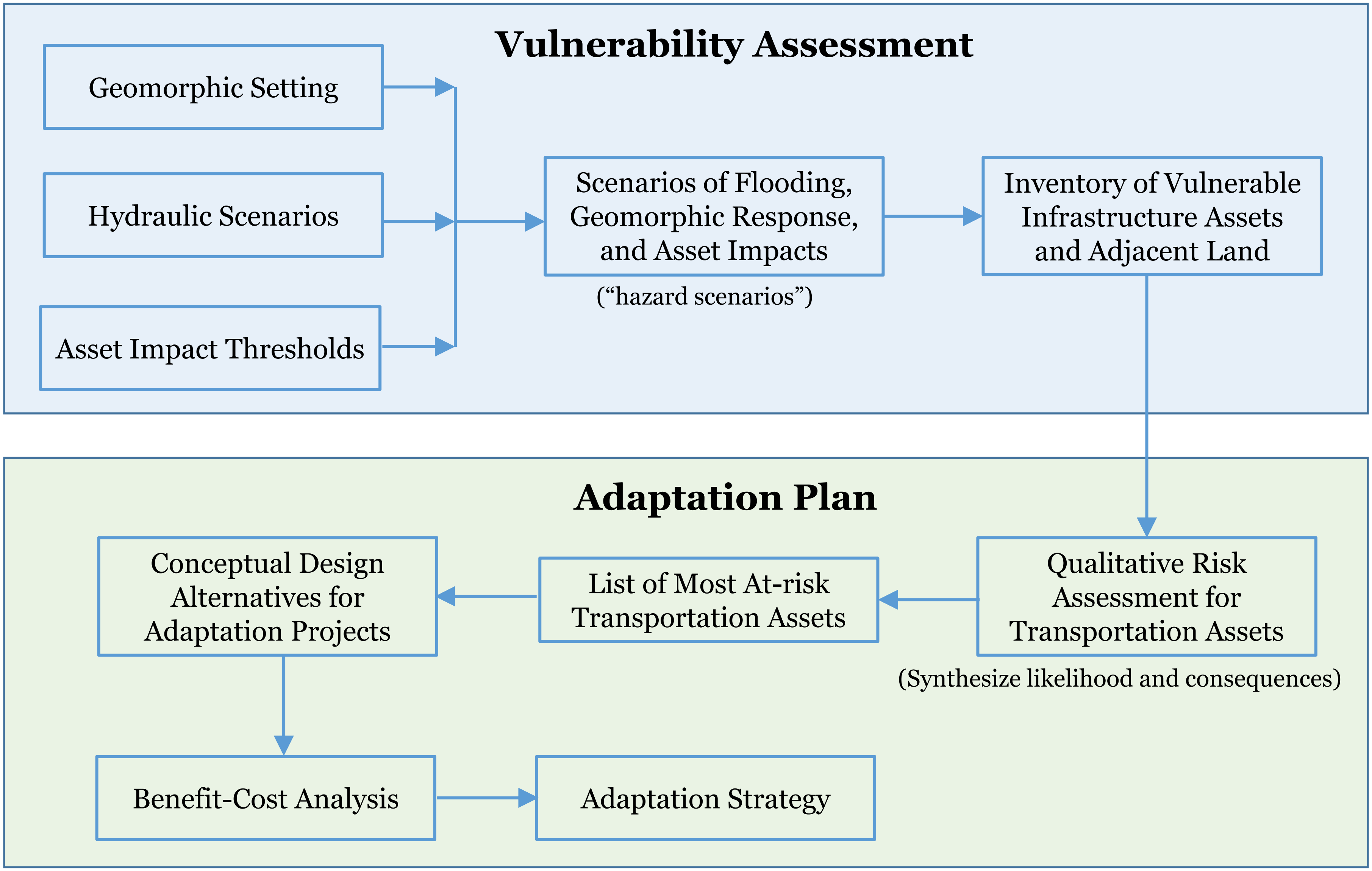
Hydraulics	
Tidal Stillwater Level	8.3 ft
Sea Level Rise	0 ft
Wind Set-up (bay only)	0 ft
Wave runup (bay only)	0 ft
Fluvial flows	100-yr flow

Scenario-based Planning: Discussion

- Is this framework understandable?
- Is this framework useful?
- What questions are prompted?
- What adaptation concepts come to mind?
- Would you support using this framework in the future?

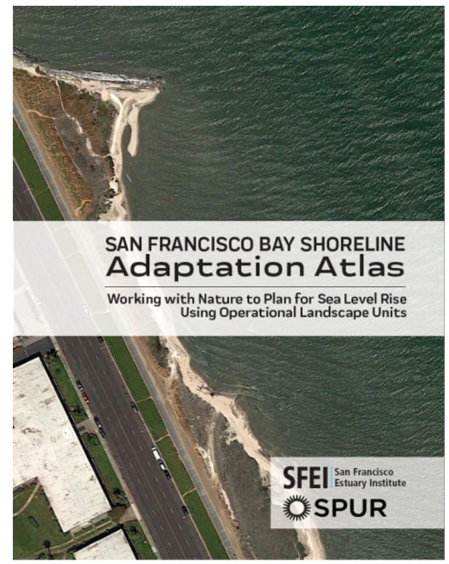
III. Adaptation

Sea Level Rise Adaptation Planning Flow Diagram



Overview of Adaptation Measures

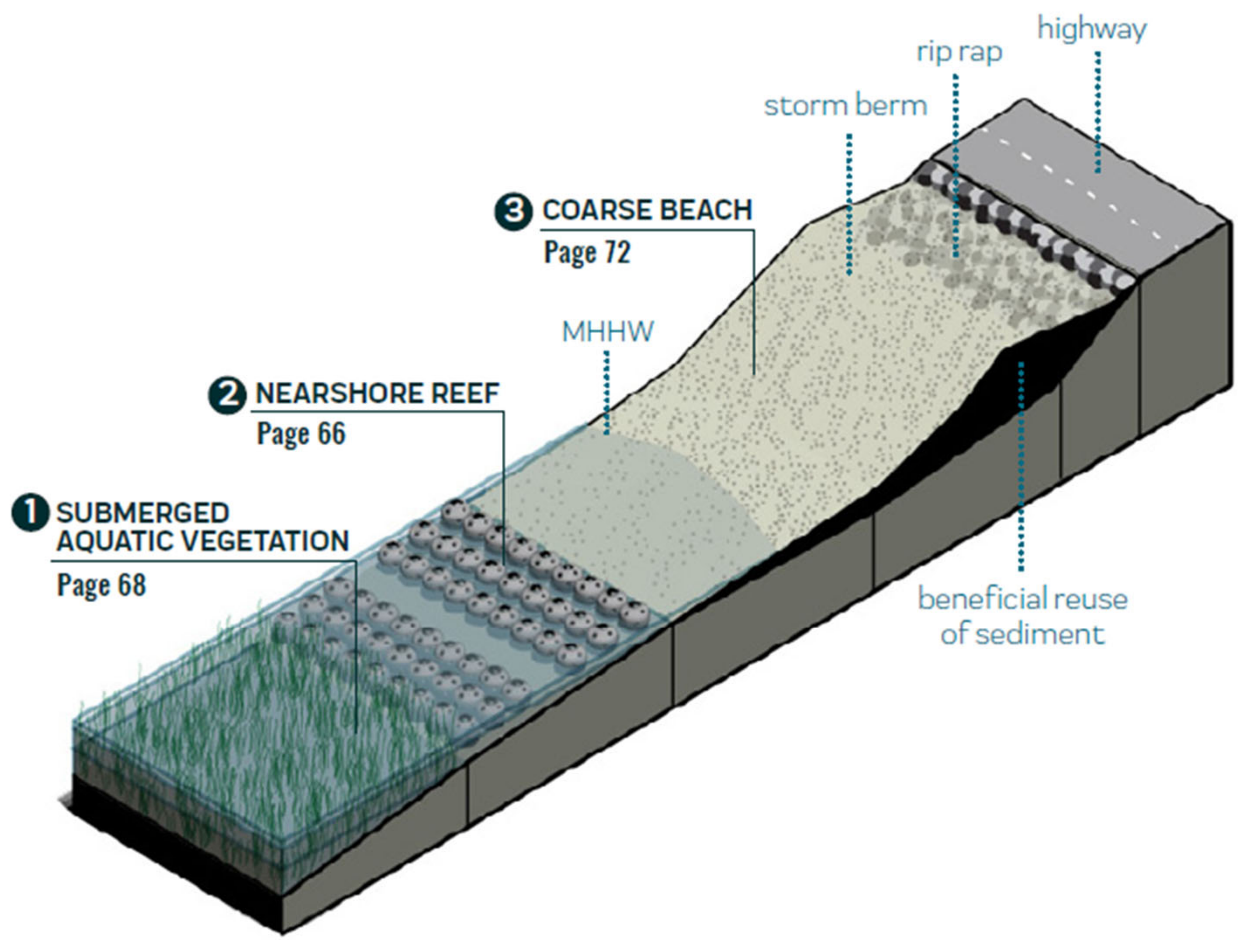
Class	Category	Adaptation measures
Structural	Natural and nature-based measures	Nearshore reefs Submerged aquatic vegetation Mudflat augmentation Beaches Tidal marshes Polder management Ecotone levees Migration space preparation Creek-to-baylands reconnection Green stormwater infrastructure
	Conventional physical (grey) infrastructure	Super levees Elevate land Flood walls and berms Elevate or realign transportation Seawalls Bulkheads Revetments and riprap Levees and dikes
Non-structural	Policy and regulatory measures	Zoning and overlay zones Setbacks, buffers, and clustering Building codes and building retrofits Rebuilding and redevelopment restrictions
	Financial measures	Conservation easements Tax incentives and special assessments Geologic Hazard Abatement Districts (GHAD) Transfer of Development Rights (TDR) Buyouts



Source: San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise (SFEI, 2019)

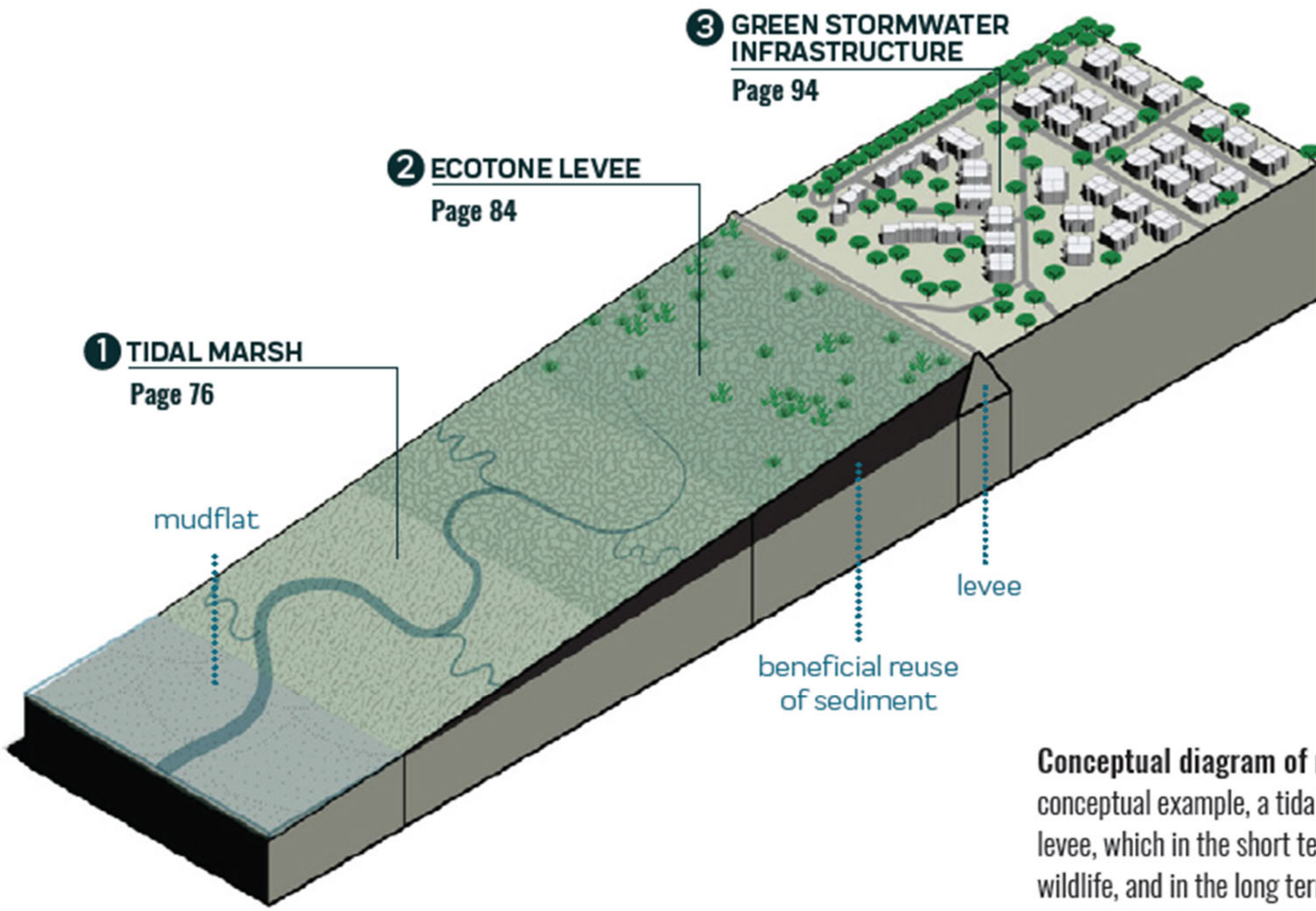
Adaptation Concepts

Combining multiple measures into a cohesive strategy. In this conceptual example, submerged aquatic vegetation, a nearshore reef, and coarse beach provide protection to each-other and a highway.



Source: San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise (SFEI, 2019)

Adaptation Concepts



Conceptual diagram of multiple adaptation measures. In this conceptual example, a tidal marsh fronts a gently sloping ecotone levee, which in the short term provides high-tide refuge for marsh wildlife, and in the long term provides space for marsh migration. Behind the flood risk levee at the back of the ecotone levee, green infrastructure is helpful for spreading, sinking runoff, and lowering peak flows.

Source: San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise (SFEI, 2019)

Natural Shoreline Infrastructure Preliminary Design:

Highway 101 Eureka-Arcata corridor between Brainard and Bracut

NFWF

Full Proposal Project Narrative

Project Title: Natural Shoreline Infrastructure in Humboldt Bay for Intertidal Coastal Marsh Restoration and Transportation Corridor Protection

1. **Coastal Community Context:**

<u>**Project Summary**</u>

The project will integrate the natural flood risk reduction properties of salt marsh into a shoreline management strategy to help protect a critical transportation corridor along Humboldt Bay from flood hazards. The project will perform site characterization and prepare preliminary design (50%) for a project utilizing tidal benches or similar natural infrastructure techniques. The project will lay the groundwork for implementation of an innovative approach to restore and perpetuate intertidal coastal marsh, increase community resilience to flooding, and demonstrate the use of natural ecological systems for sea level rise adaptation.

Budget: $250,000 (NFWF and OPC)

Schedule: July 2020 – December 2021

TOWARD NATURAL SHORELINE INFRASTRUCTURE TO MANAGE COASTAL CHANGE IN CALIFORNIA

A Report for:

California's Fourth Climate Change Assessment

Prepared By:
Sarah Newkirk[1], Sam Veloz[2], Maya Hayden[2], Bob Battalio[3], Tiffany Cheng[3], Jenna Judge[4], Walter Heady[1], Kelly Leo[1], Mary Small[5]

1 The Nature Conservancy
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3 Environmental Science Associates
4 National Oceanic and Atmospheric Administration
5 California State Coastal Conservancy

DISCLAIMER

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California natural resources Agency

Edmund G. Brown, Jr. *Governor*

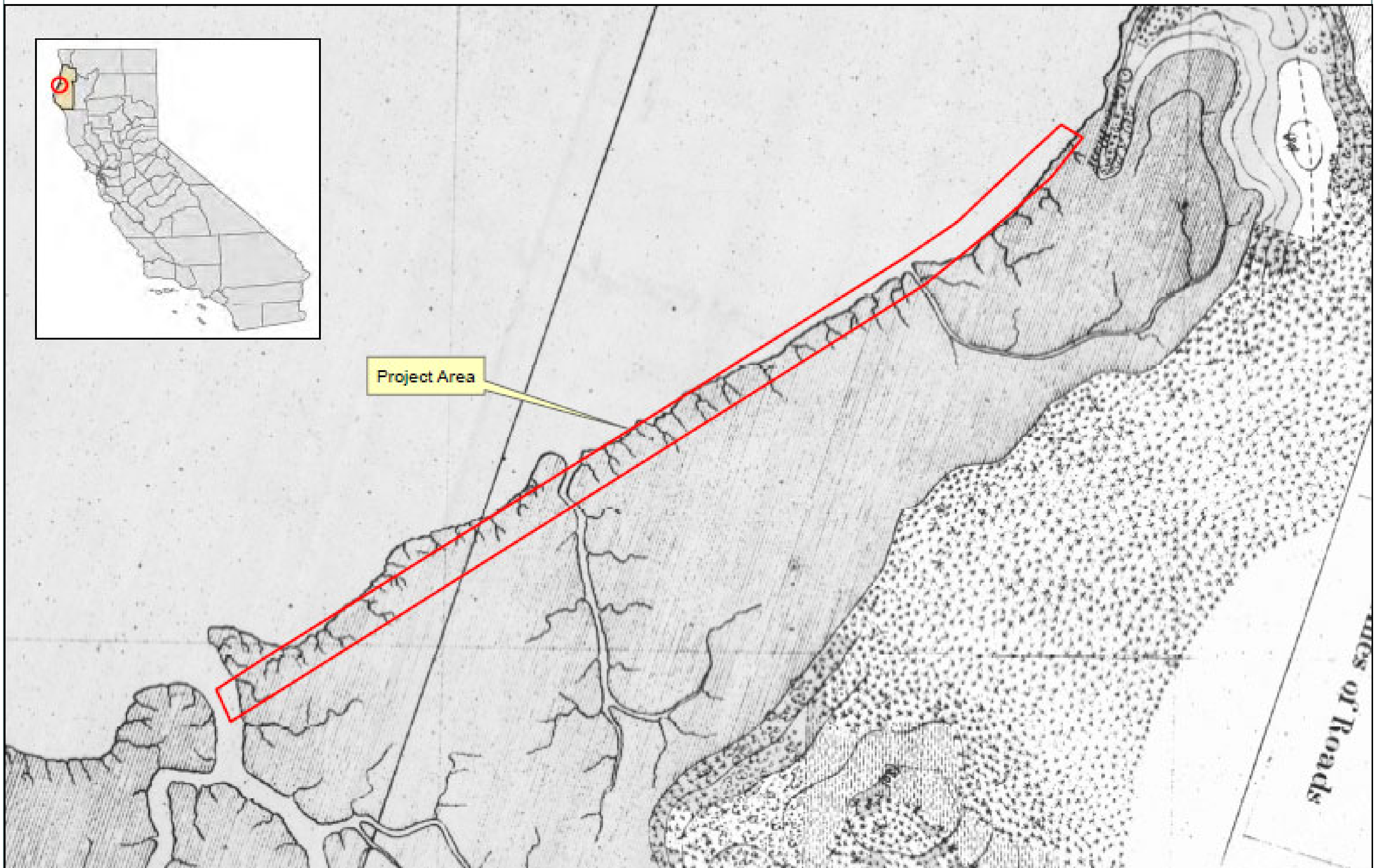
August 2018
CCCA4-CNRA-2018-011

Project Area
Eureka-Arcata Corridor

50


SPEED
LIMIT
50

Project Area
Eureka-Arcata Corridor


Project Area

Levee Example: Arcata Marsh & Wildlife Sanctuary

- Primary challenge is available footprint

Causeway Example: Highway 101 Willits Bypass

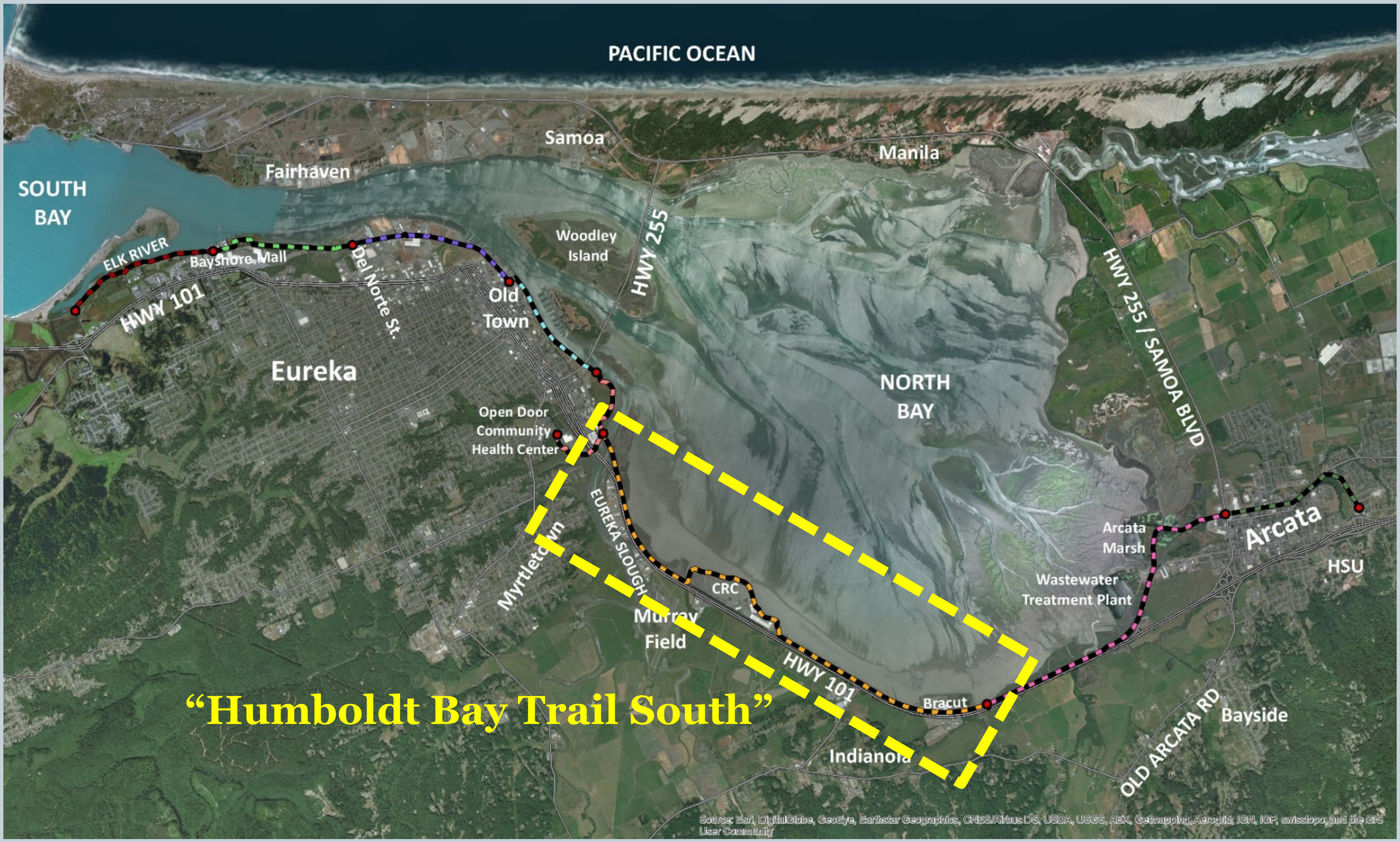
- 6 miles
- Planning started 1960s
- Constructed 2012-2016
- Purpose: congestion relief
- 40 acres permanent wetland impacts
- Built for expansion to four-lanes in future

Total cost to date:
$459 million

Incorporating Adaptation into Project Design

Humboldt Bay Trail South

Humboldt Bay Trail South Project



SLR Report for Humboldt Bay Trail South

Final

HUMBOLDT BAY TRAIL SOUTH

Sea-Level Rise Vulnerability and Adaptation Report

Prepared for
County of Humboldt, under contract with
GHD

June 2018

ESA

Photo by GHD, 2017

www.humboldtbaytrail.info

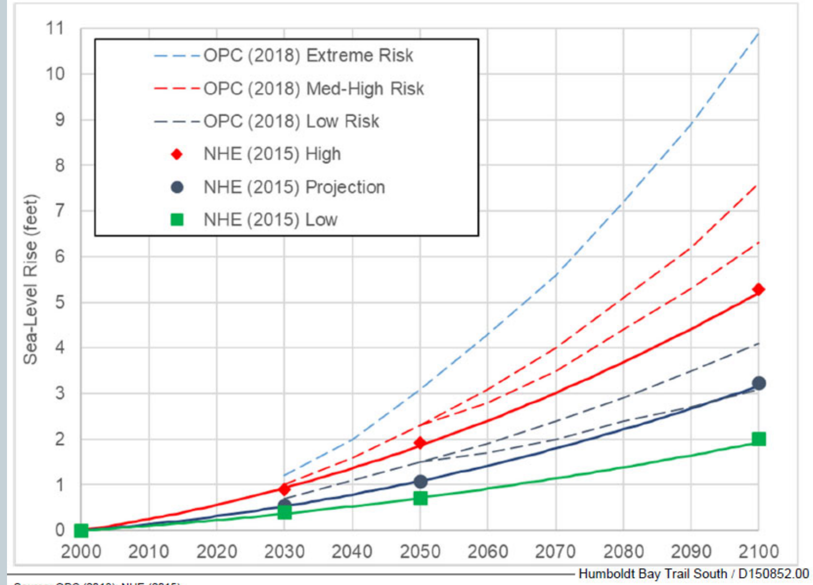
SLR Report for Humboldt Bay Trail South

Table 2
OPC (2018) State Guidance: Projected Sea-Level Rise for the Humboldt Bay North Spit in Feet

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…		5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.6	0.5 -	0.7	0.8	1	1.2
	2040	0.9	0.7 -	1.1	1.2	1.6	2.0
	2050	1.2	0.9 -	1.5	1.7	2.3	3.1
Low emissions	2060	1.3	1.0 -	1.7	2	2.8	
High emissions	2060	1.5	1.2 -	1.9	2.2	3.1	4.3
Low emissions	2070	1.6	1.2 -	2	2.4	3.5	
High emissions	2070	1.9	1.4 -	2.4	2.9	4	5.6
Low emissions	2080	1.8	1.4 -	2.4	2.9	4.4	
High emissions	2080	2.3	1.7 -	2.9	3.5	5.1	7.2
Low emissions	2090	2.1	1.5 -	2.7	3.4	5.3	
High emissions	2090	2.7	2.0 -	3.5	4.3	6.2	8.9
Low emissions	2100	2.3	1.7 -	3.1	3.9	6.3	
High emissions	2100	3.1	2.3 -	4.1	5.1	7.6	10.9
Low emissions	2110*	2.5	1.9 -	3.3	4.2	7.1	
High emissions	2110*	3.3	2.6 -	4.3	5.2	8	12.7
Low emissions	2120	2.7	2.0 -	3.7	4.8	8.2	
High emissions	2120	3.7	2.9 -	4.9	6.1	9.4	15.0
Low emissions	2130	3	2.1 -	4	5.3	9.4	
High emissions	2130	4.2	3.1 -	5.5	6.9	10.9	17.4
Low emissions	2140	3.2	2.3 -	4.4	5.9	10.7	
High emissions	2140	4.6	3.4 -	6.2	7.8	12.5	20.1
Low emissions	2150	3.4	2.3 -	4.8	6.6	12.1	
High emissions	2150	5	3.7 -	6.8	8.7	14.1	23.0

Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.

Source: OPC (2018)



Source: OPC (2018); NHE (2015)

Figure 4
Comparison of new OPC (2018) Sea-Level Rise Guidance for the Humboldt Bay North Spit to NHE (2015) Projections

Table 3
Sea-Level Rise Scenarios Used for Humboldt Bay Trail Assessment

Time Horizon	2040-2050	2060-2070	2080-2100
Sea-Level Rise Amount (feet)	1 foot	2 feet	3 feet

SLR Report for Humboldt Bay Trail South

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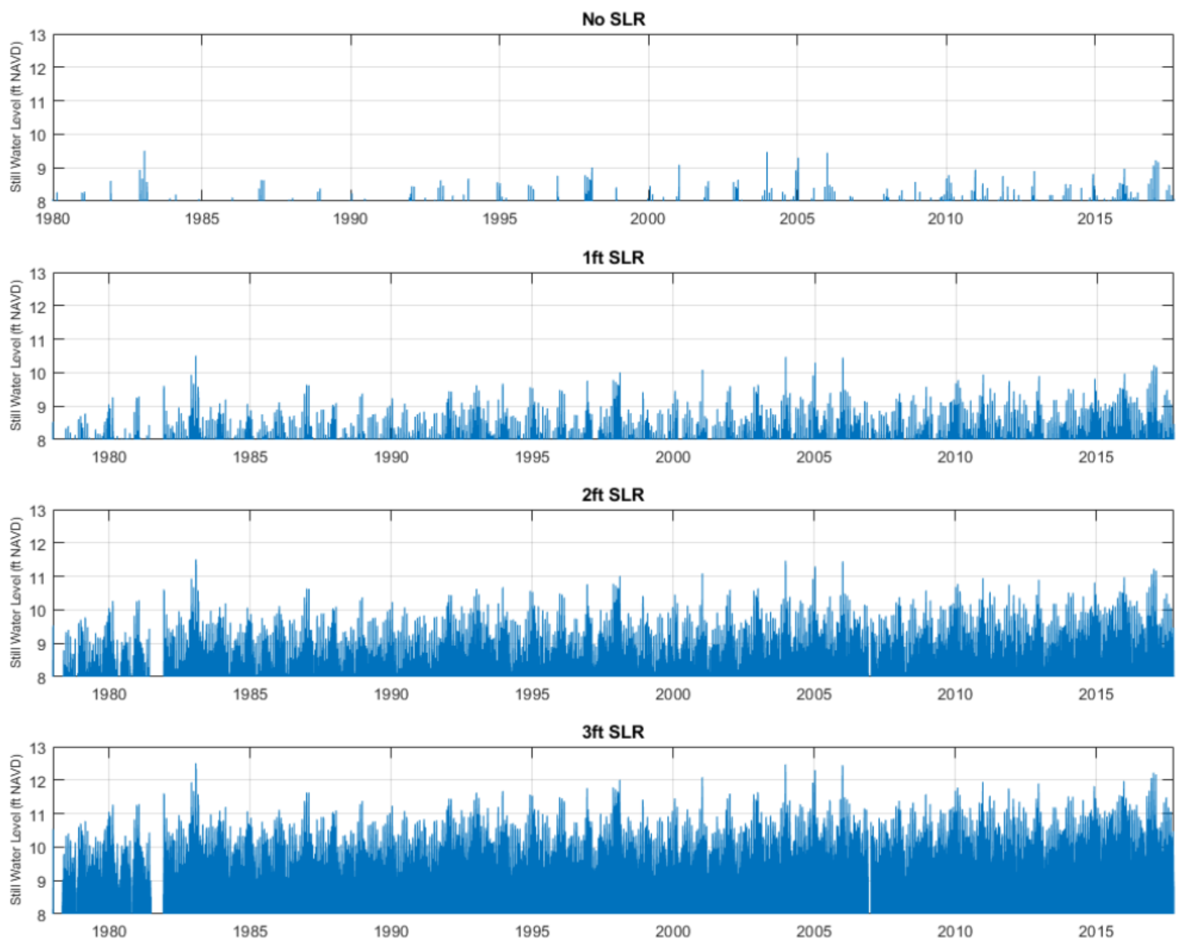
Hazard Impact Evaluation Criteria

1) Trail Usability (Stillwater Flooding) >0.5 feet inundation
2) Trail Usability (Wave Overtopping) >0.22 cfs/linear foot
3) Trail Damage from Wave Overtopping >0.54 cfs/linear foot

Frequency Analysis



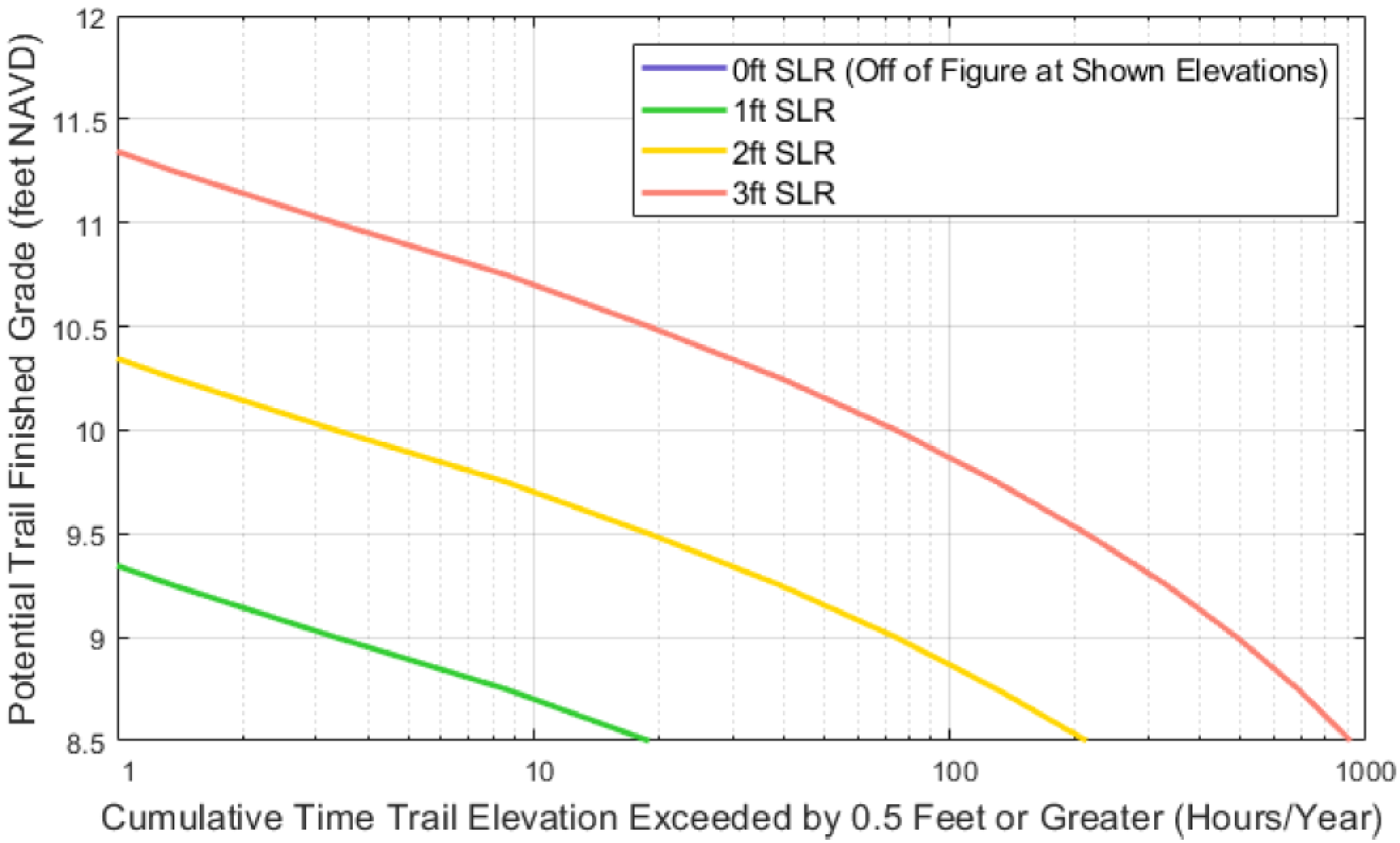
Humboldt Bay Trail South / D150852.00

SOURCE: NOAA

Figure 15

Tidal Still Water Level Time Series with Sea-Level Rise

Frequency Analysis



Humboldt Bay Trail South / D150852.00

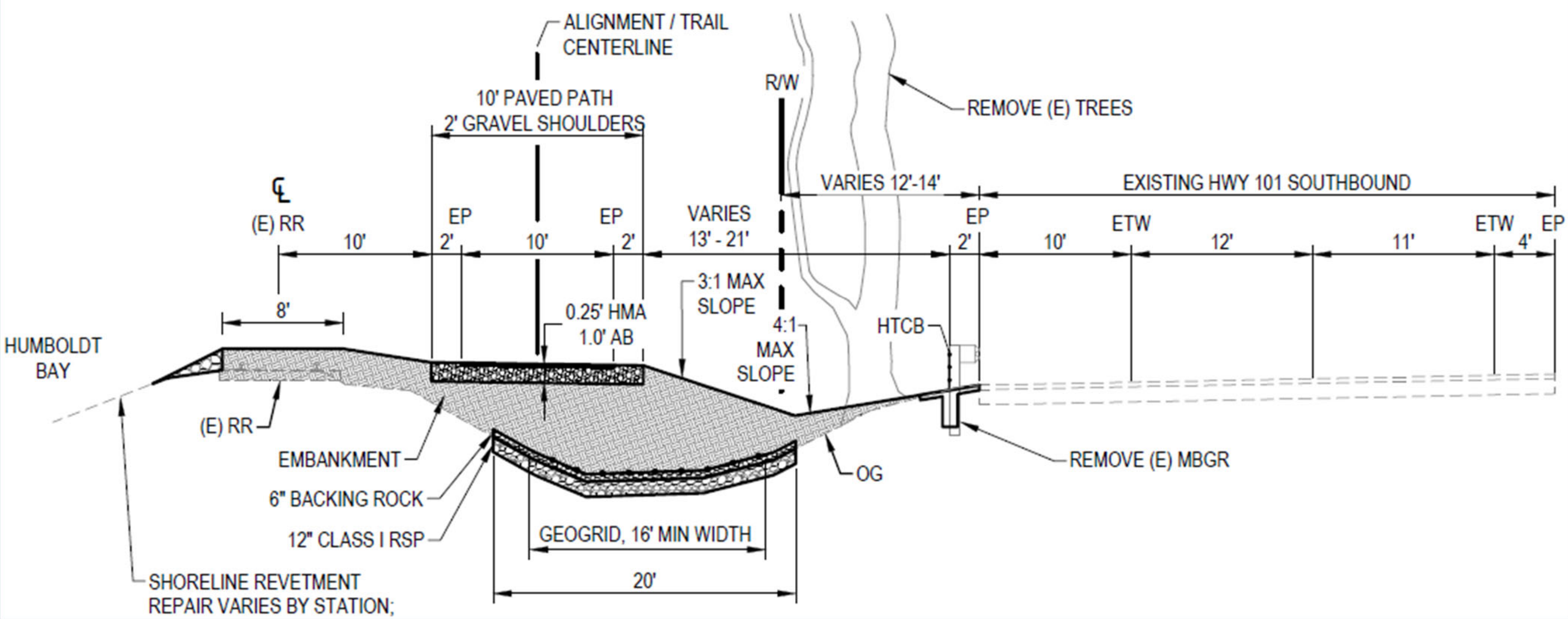
SOURCE: NOAA

Figure 16

Cumulative amount of time that trail is inundated by 0.5 foot

Design Section for Most Vulnerable Area

Feature	Existing	Future
Railroad	9.6-10.3 ft	11.5 ft
Trail	n/a	10.5 ft



Note: Design section reflects 60% level of completion; permit applications to be submitted March 2020

Sea Level Rise Adaptation Measures for Humboldt Bay Trail South

1. Repair shoreline protection and rail prism where currently damaged
2. Raise railroad grade in most vulnerable segment
3. Leave space to accommodate future raising of railroad grade
4. Establish minimum trail elevation
5. Incorporate rock and hardened surfaces to improve resilience to wave overwash
6. Explore drainage improvements within ditch between Highway 101 and railroad/trail
7. Explore feasibility of adding natural shoreline infrastructure
8. Assume the need for future adaptation measures

Adaptation: Discussion

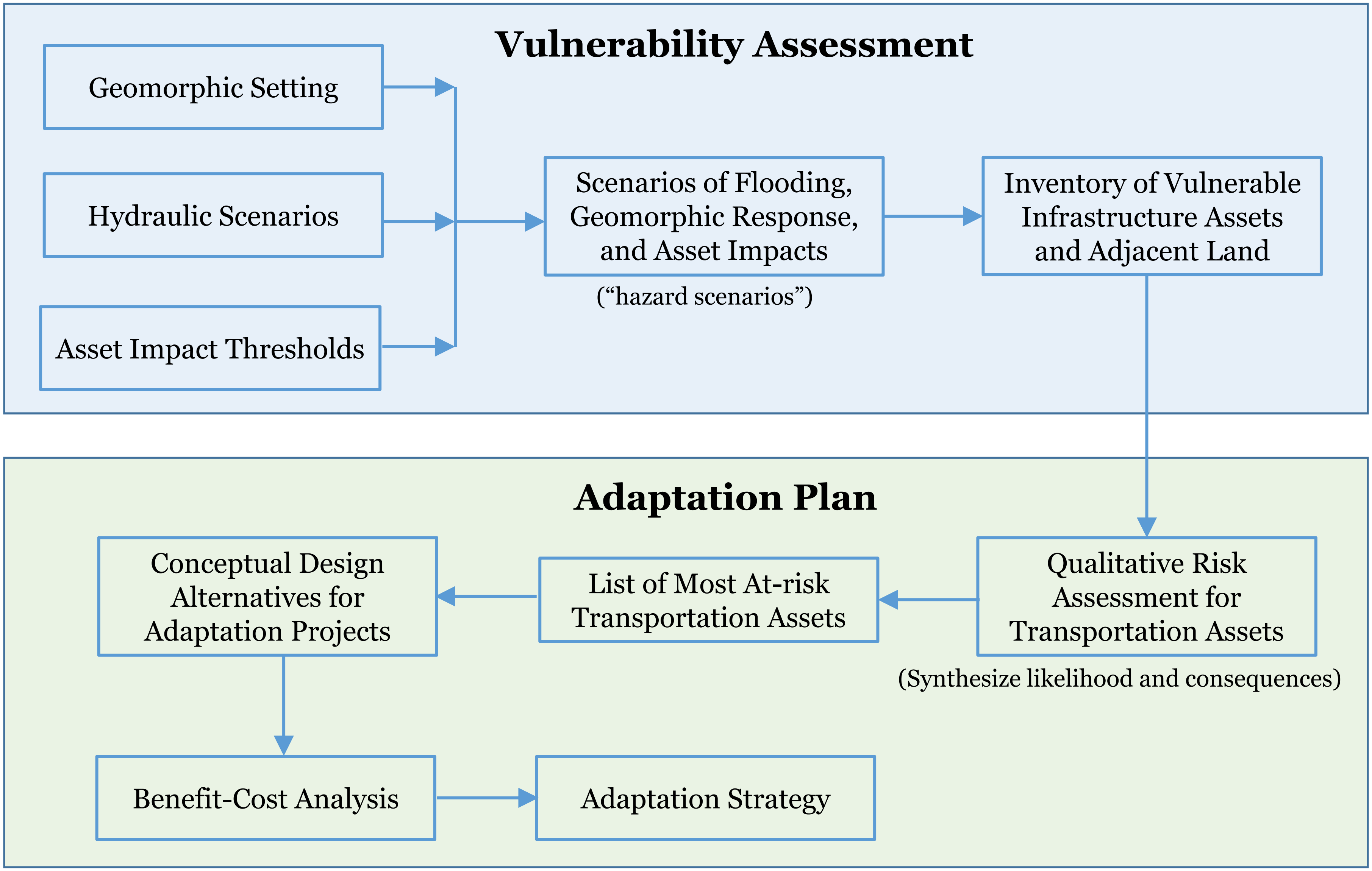
Overview

- This study will develop conceptual designs and budgetary costs for at least four adaptation projects
- The intent is to focus on transportation assets which are most at-risk

Opportunities for feedback

- What locations are of highest concern for flooding risks?
- What flood hazard scenarios should guide the project design?
- Should we be thinking small, medium, big, or super-big?
- What project concepts should be explored?

Sea Level Rise Adaptation Planning Flow Diagram



Guiding Principles

1. Landscape-scale and process-based evaluation
2. Risk management approach
3. Apply best available science
4. Engage stakeholders
5. Aim to maximize multi-benefit projects and nature-based solutions
6. Multiple lines of defense
7. Adaptive management

Next Steps

Timeline

- March-May: Synthesize hazard scenarios and complete vulnerability assessment
- April-October: Landowner and stakeholder outreach
- May: Shift to adaptation planning portion of the study
- October: Second workshop?
- December: Completion

Opportunities for feedback on vulnerability assessment:

1. Written feedback by March 27, 2020 (hseemann@co.humboldt.ca.us)
2. Request follow-up meeting

Thank you