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Fir Island farm: estuary restoration project: designing for climate change and uncertainty in shoreline flood risk reduction and ecosystem restoration projects

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Fir Island Farm – Estuary Restoration

Designing for Climate Change Uncertainty in Shoreline Flood Risk Reduction and Ecosystem Restoration Projects

David Cline, PE, CFM

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Fir Island Farm – Project Overview

Fir Island

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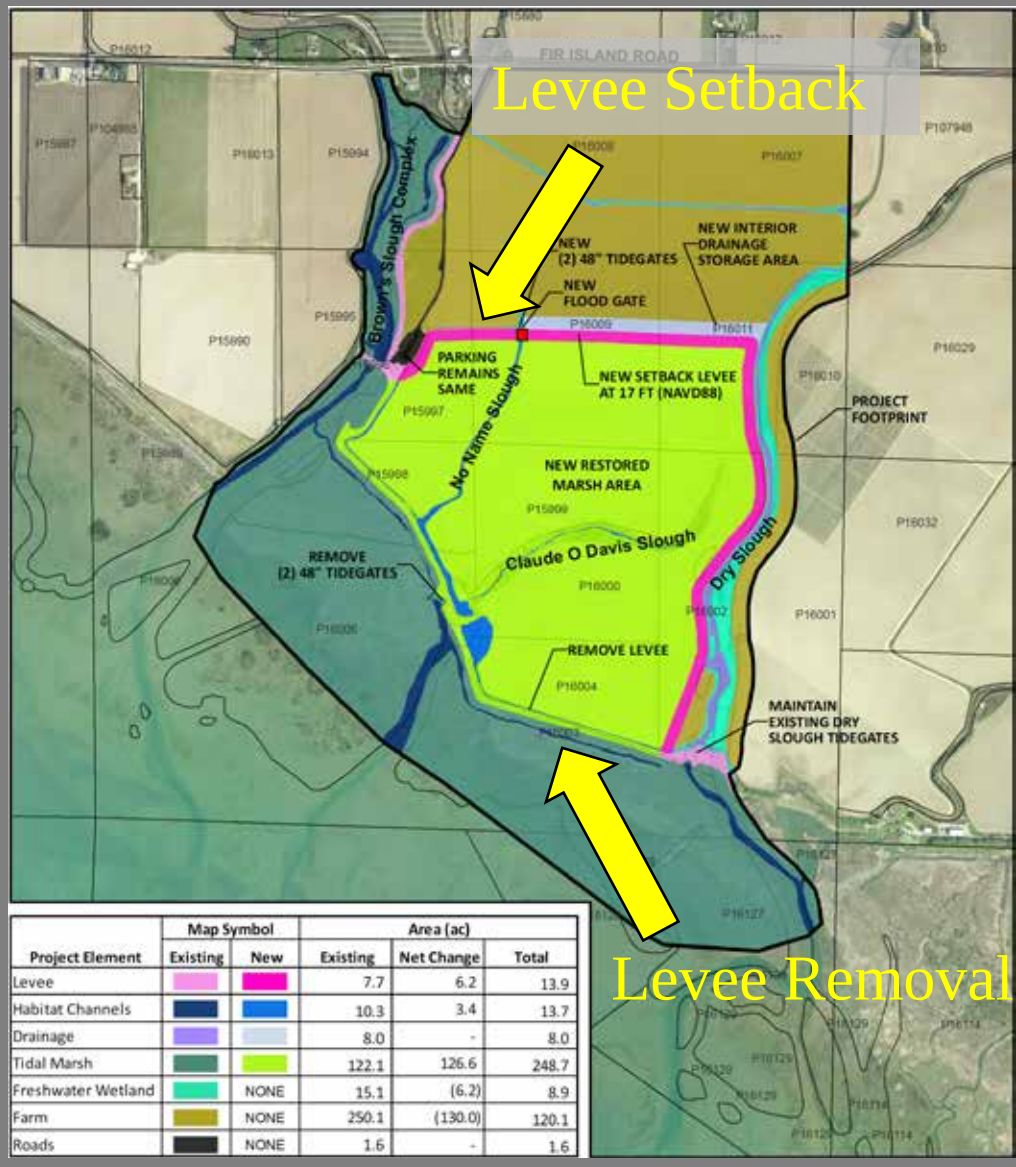
- Skagit River Delta
- 130 Acre Tidal Marsh Restoration
- 1-Mile Long Dike Setback
- Farm Drainage
  - 5-Acre Storage Pond
  - 9,000gpm Pump Station (Project Mitigation)
  - 5 Tidegates



Project Element	Map Symbol		Area (ac)		
	Existing	New	Existing	Net Change	Total
Levee			7.7	6.2	13.9
Habitat Channels			10.3	3.4	13.7
Drainage			8.0	-	8.0
Tidal Marsh			122.1	126.6	248.7
Freshwater Wetland		NONE	15.1	(6.2)	8.9
Farm		NONE	250.1	(130.0)	120.1
Roads		NONE	1.6	-	1.6

Fir Island Farm – Key Uncertainties

- Subsurface Soils
  - Layering
  - **Settlement**
  - **Seepage**
- Hydrology
  - **Surface Water**
  - **Groundwater**
  - **Farm Drainage Impacts**
- Hydrodynamics
  - Tidal / River Interface
  - **Tidal Tailwater Effect**
  - **Sea Level Rise**
  - Extreme wind / tide events
- Other Uncertainties
  - Vegetation / invasives
  - Sedimentation
  - **Natural LWD loading**
  - Cultural resources
  - Hazardous materials
  - Contractor claims
  - 3rd Party / neighbor claims
  - Socio-political impacts
  - Long Term O&M Costs

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Fir Island Farm – Key Design Uncertainties

- Levee / Dike Elevations
- Farm Drainage Tailwater / Seepage
- Wetland Vegetation and Large Woody Debris

Source: Jenga, 2017

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Fir Island Farm – Instrumentation

- Subsurface Explorations
  - CPTs
  - Geoprobes
  - Borings
- Surface and Groundwater Data Loggers (LTC)
  - Tidal
  - Interior (Farm) Drainage
  - Paired Groundwater
- Settlement Plates

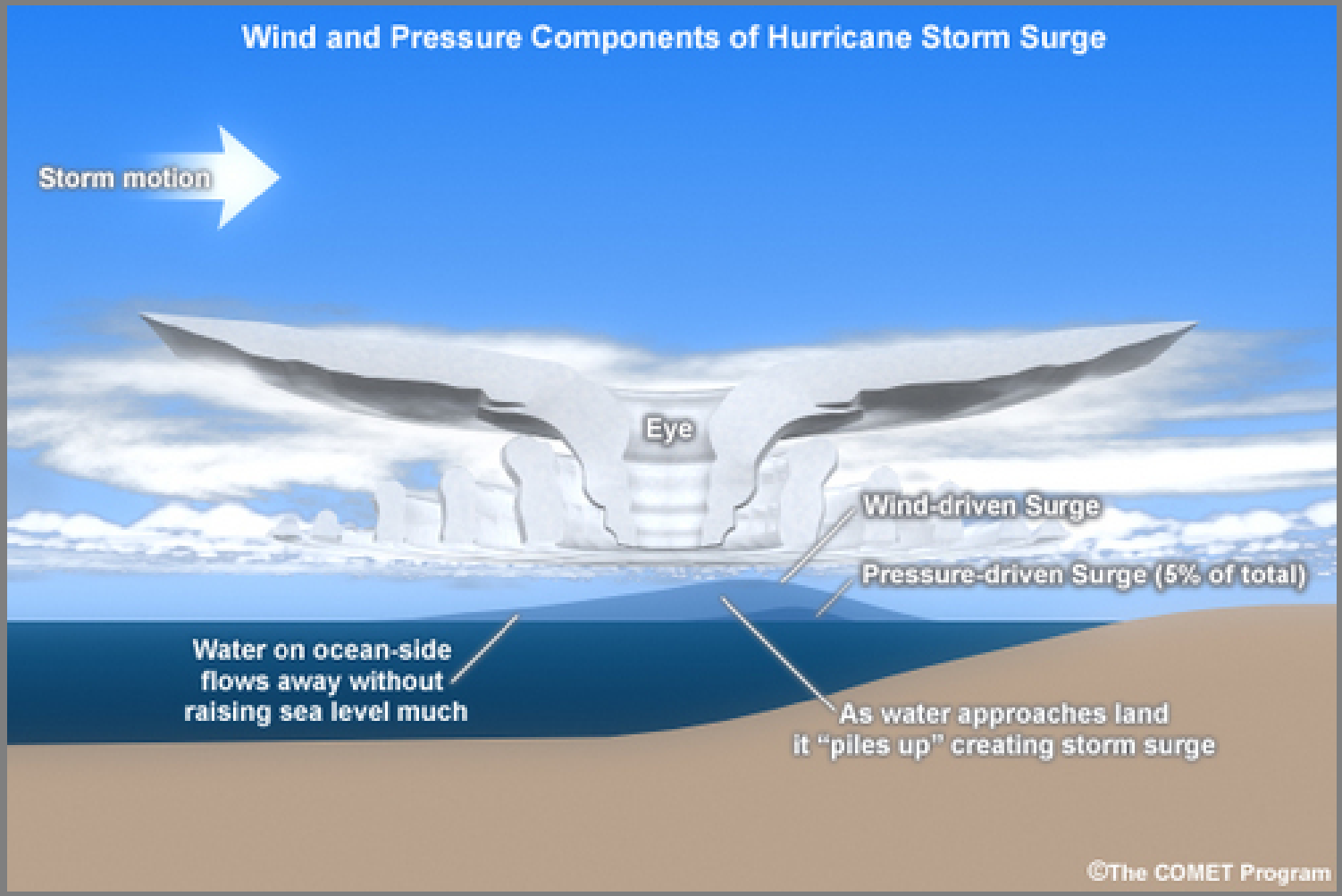
Dike Design Elevations
Estimate of Maximum Water Level

- Extreme tide (η_{HAT})
- Storm surge (η_{surge})
- Wind Wave / Runup (η_{wave})
- Sea level rise (η_{slr})
- Maximum water level (η_{max})
- Settlement (S) – Need to consider

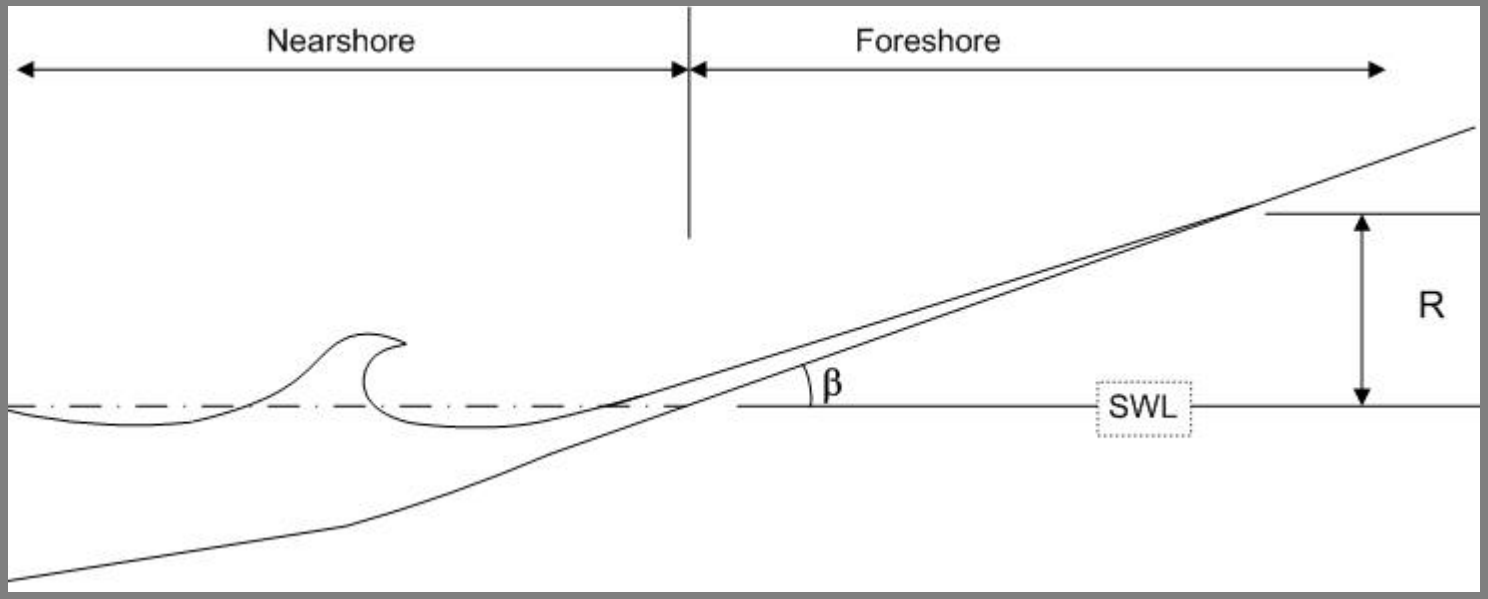
$$\eta_{max} = \eta_{tide} + \eta_{surge} + \eta_{wave} + \eta_{slr}$$

Extreme Tide (η_{HAT})

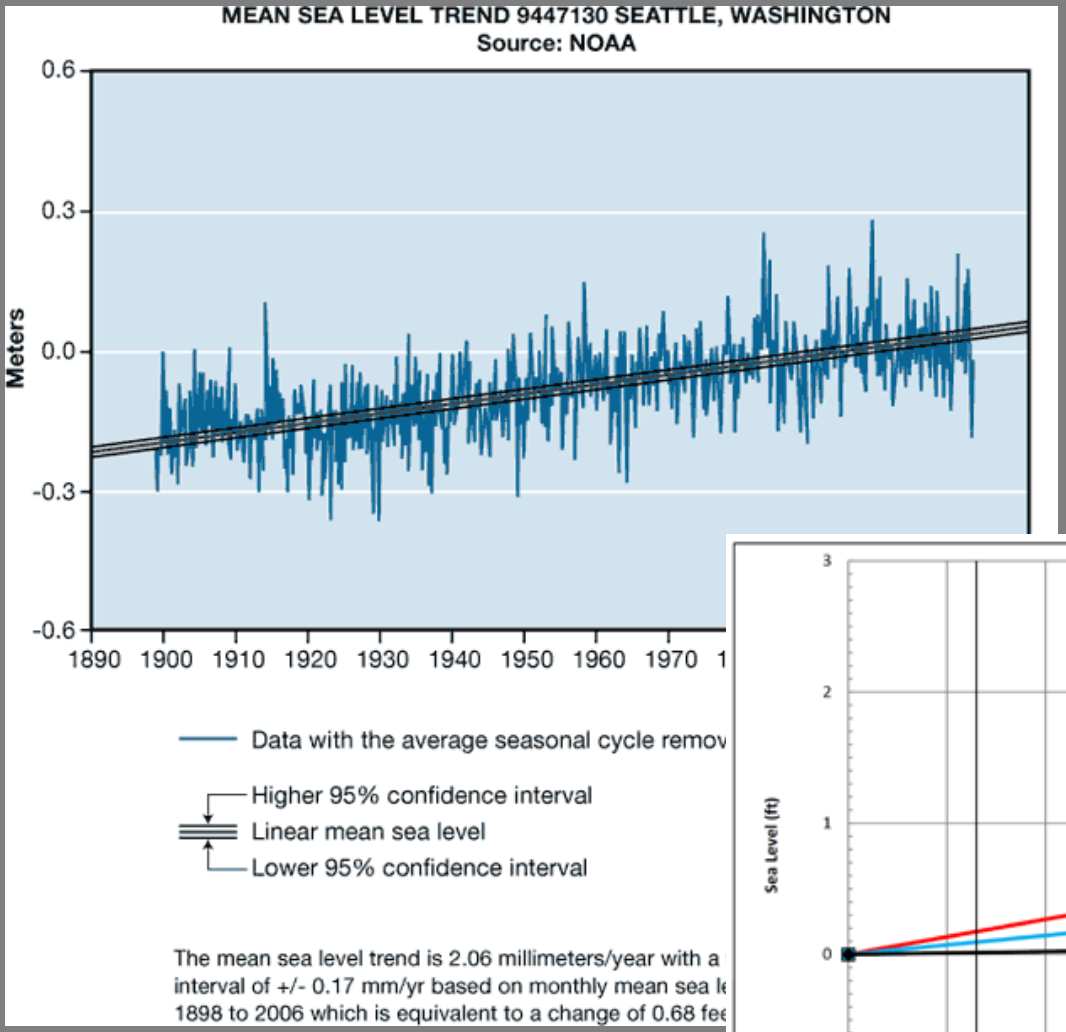
Storm Surge (η_{surge})

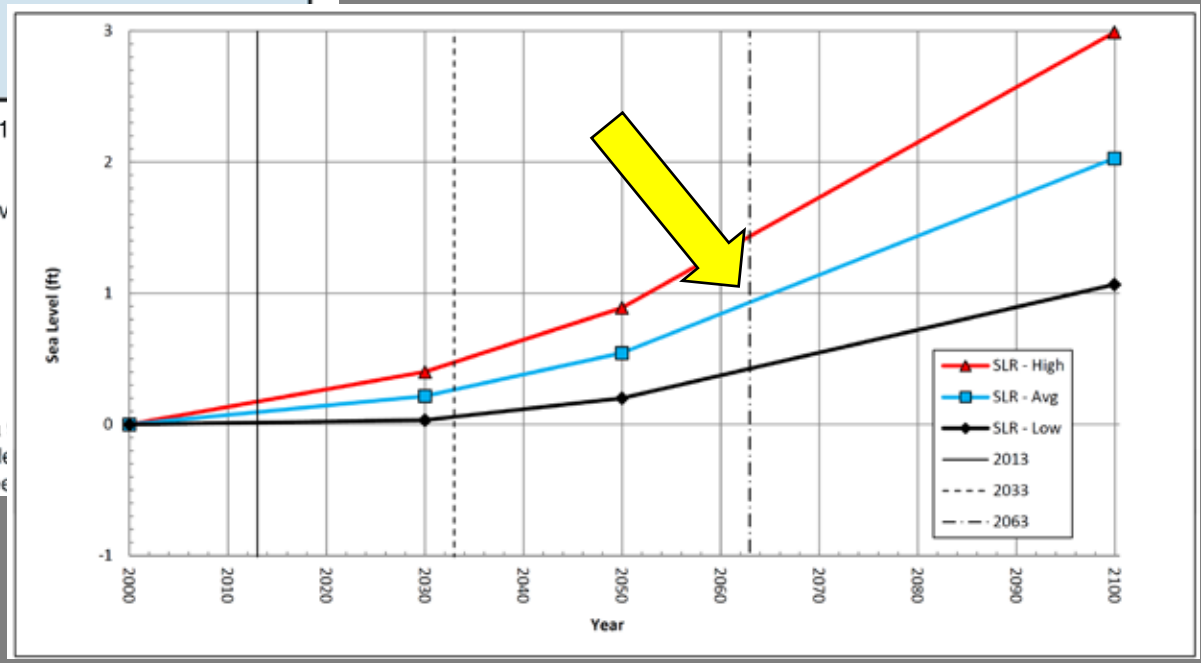


Wave Runup (η_{wave})

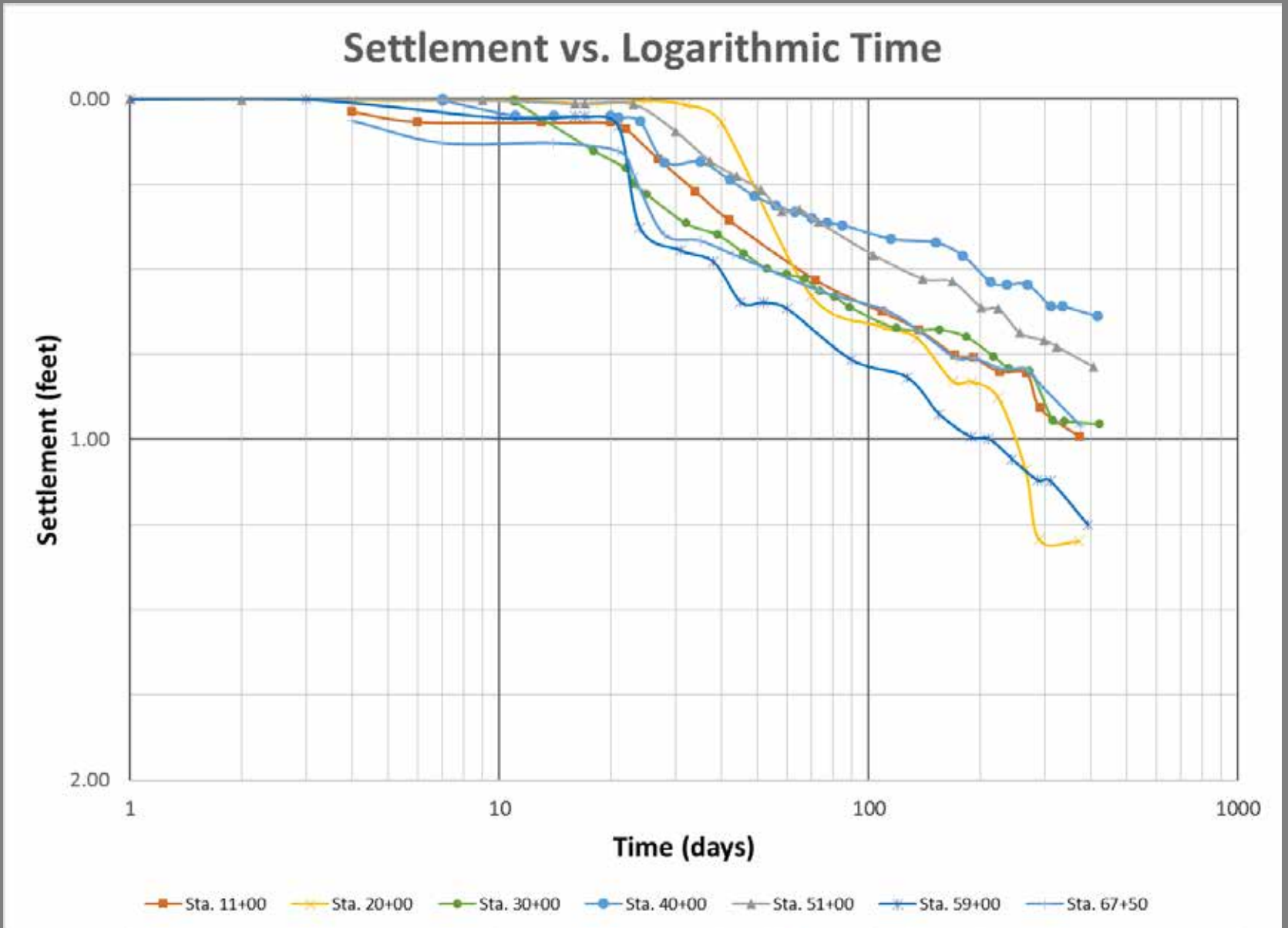


Sea Level Rise (η_{slr})





Settlement


Settlement vs. Logarithmic Time
0.00
1.00
2.00
Settlement (feet)
1
10
100
1000
Time (days)
Sta. 11+00
Sta. 20+00
Sta. 30+00
Sta. 40+00
Sta. 51+00
Sta. 59+00
Sta. 67+50

Tide, Surge, Wave, Sea Level Rise

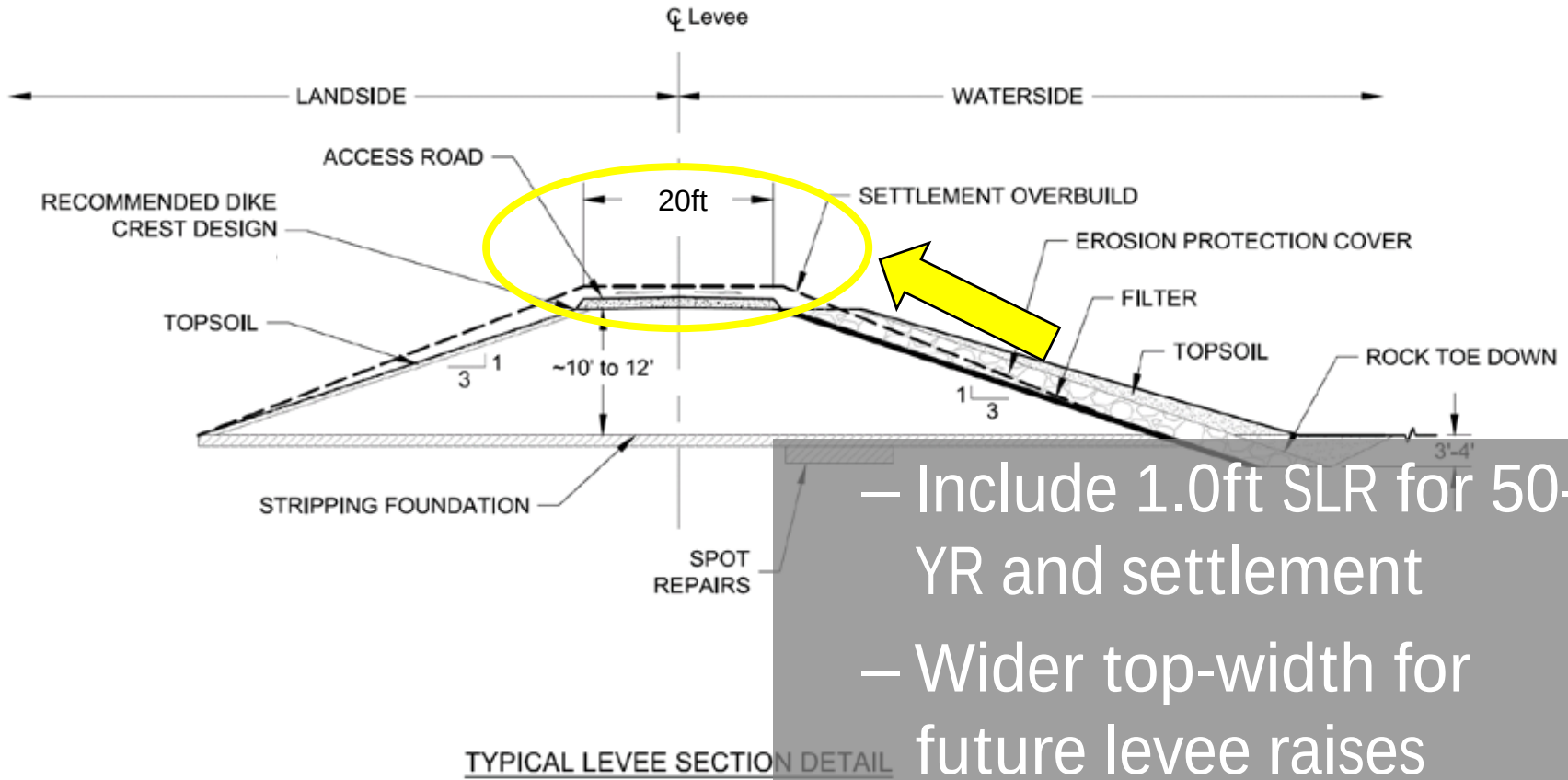
$$\eta_{design} = \eta_{HAT} + \eta_{surge} + \eta_{wave} + \eta_{slr}$$

Dike Design Elevation	NAVD88-ft	MLLW-ft
Extreme tide (η_{HAT})	11.28ft	13.41ft
Surge (η_{surge})	2.20ft	2.20ft
Wave runup (η_{wave})	0.54ft	0.54ft
Avg. Sea level rise @ Year 2063 (η_{slr}) +0.50ft	0.93ft	0.93ft
Target Design Elevations (η_{design})	**14.95ft**	**17.08ft**
Settlement (ft)*	~1.00ft	
Construction Design Elevations (ft)	**15.5ft**	**17.6ft**

MLLW to NAVD88 = MLLW – 2.13ft for Crescent Harbor Gage 9447952

* Indicates total estimated settlement

Levee Design Elevations & Widths



TYPICAL LEVEE SECTION DETAIL

- Include 1.0ft SLR for 50-YR and settlement
- Wider top-width for future levee raises

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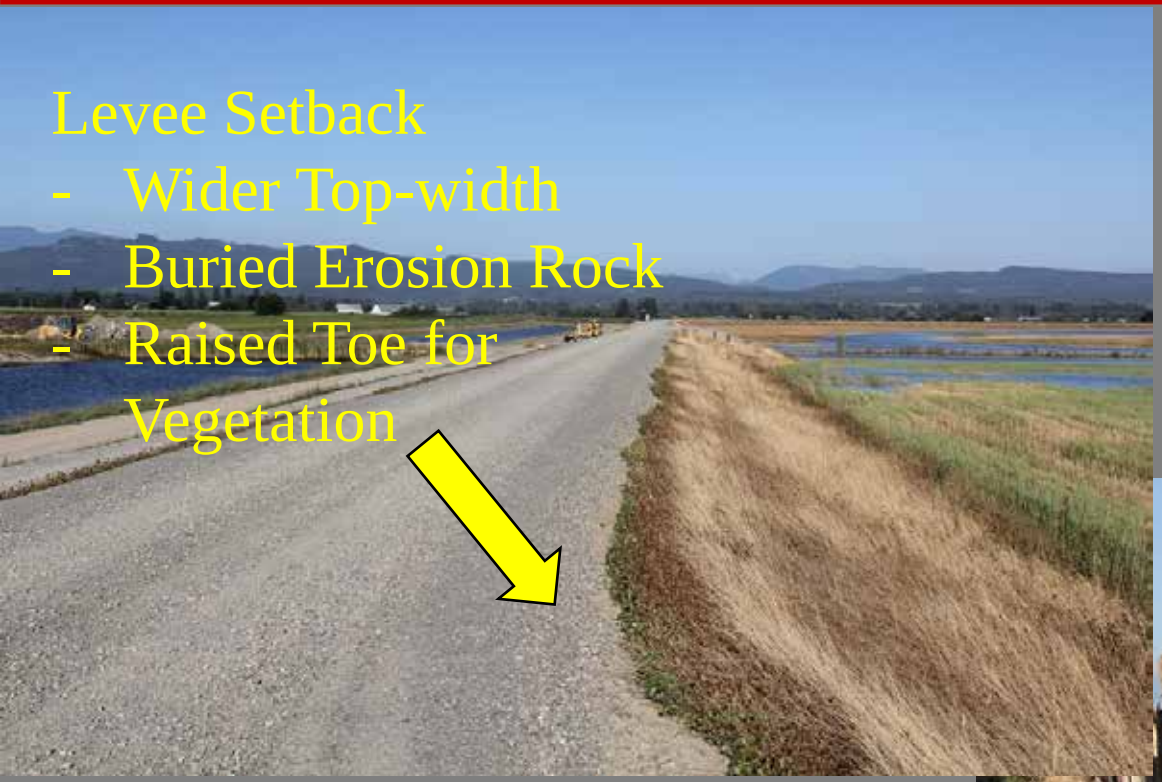
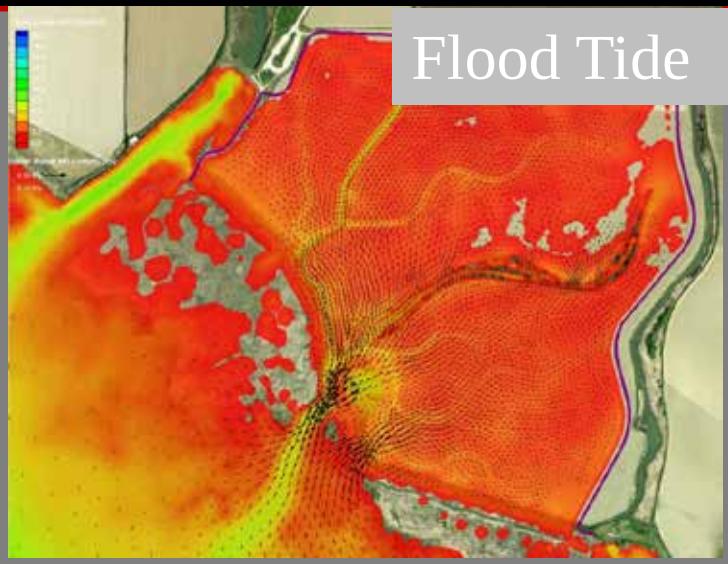
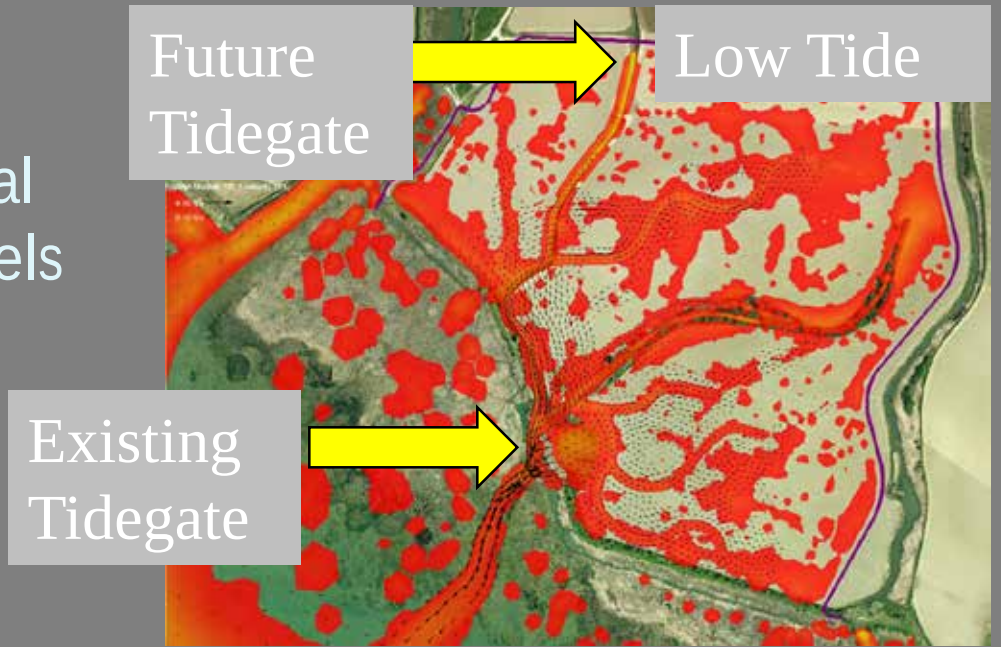
Fir Island Farm – Design Features



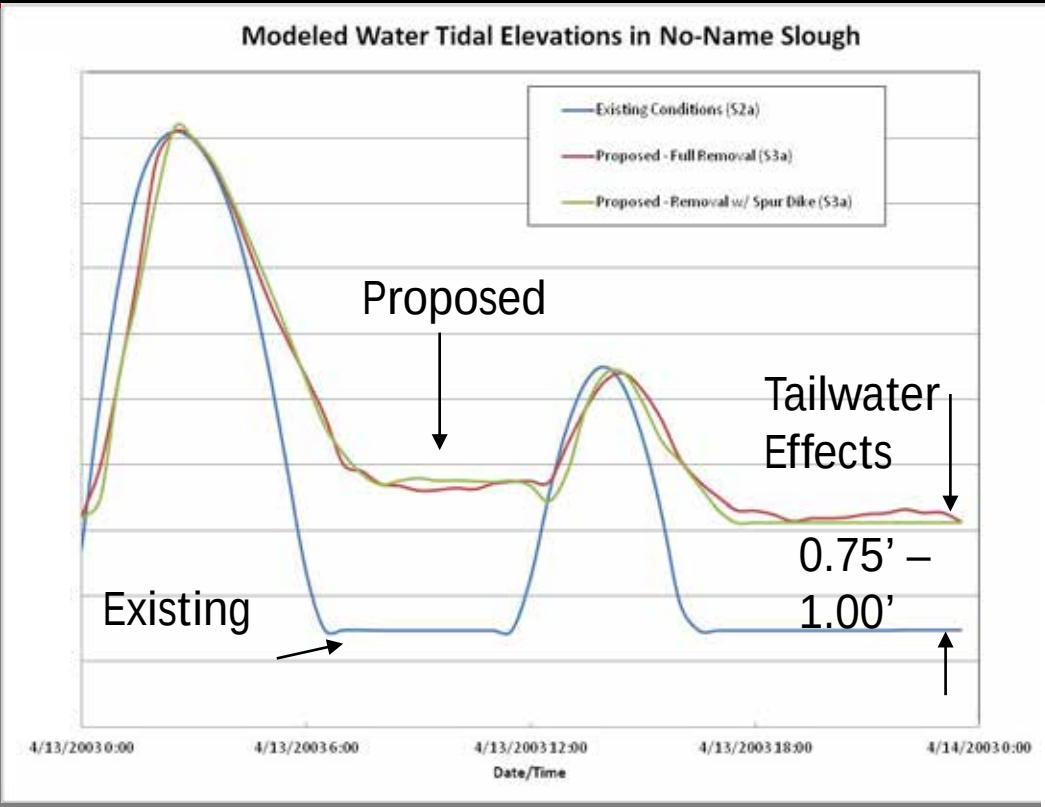
Drainage Design
Fir Island Farm – Modeling & Calibration

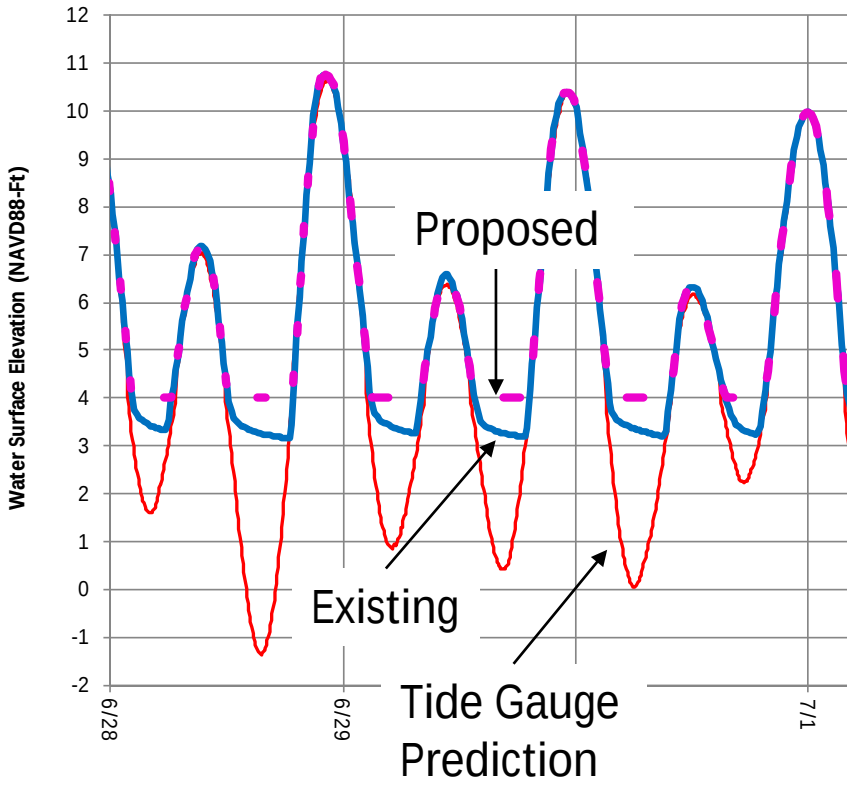
- Soils
  - Two primary layers
  - ~ Homogeneous
- Hydrology
  - Unique Tidal Signature
  - Narrow Tidegate Operating Range
  - Establish seasonal groundwater levels





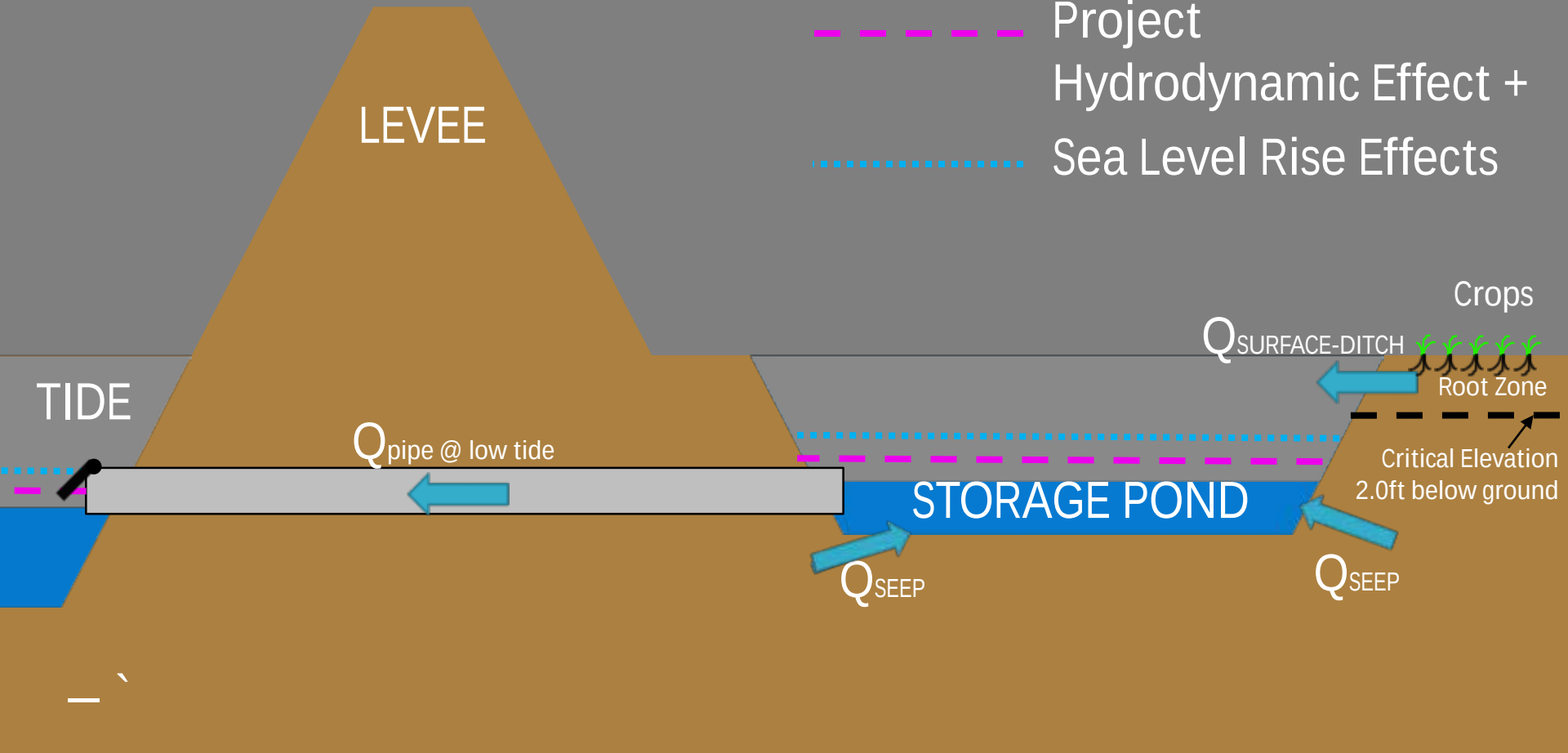
Fir Island Farm – Modeling & Calibration





Fir Island Farm – Hydrodynamic Impacts

– Tidal tailwater rise up to 1.0ft could impact 100 to 300 farm acres w/ gravity drainage only



Fir Island Farm – Drainage Design

Pump Station

Tidegates

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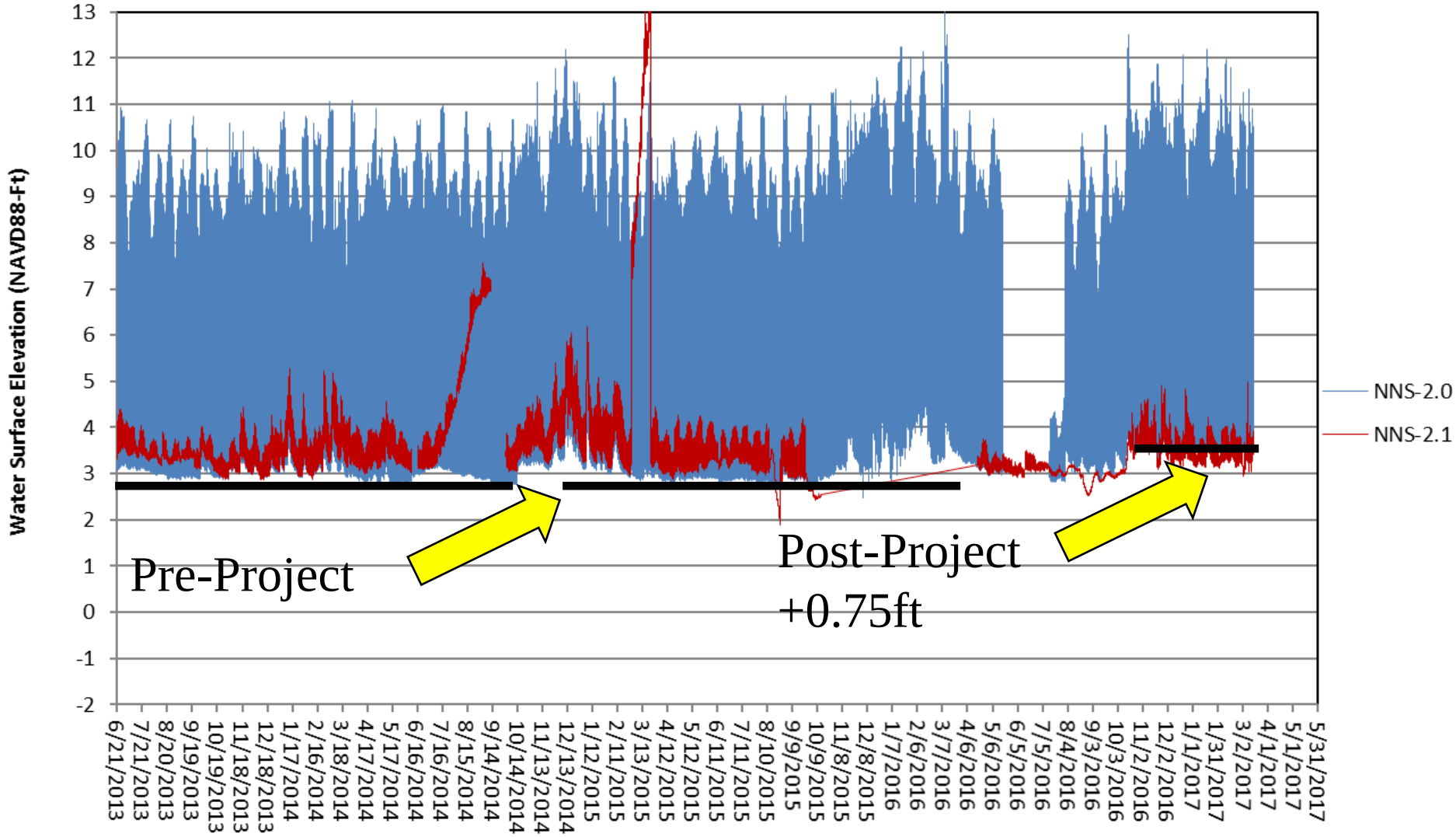
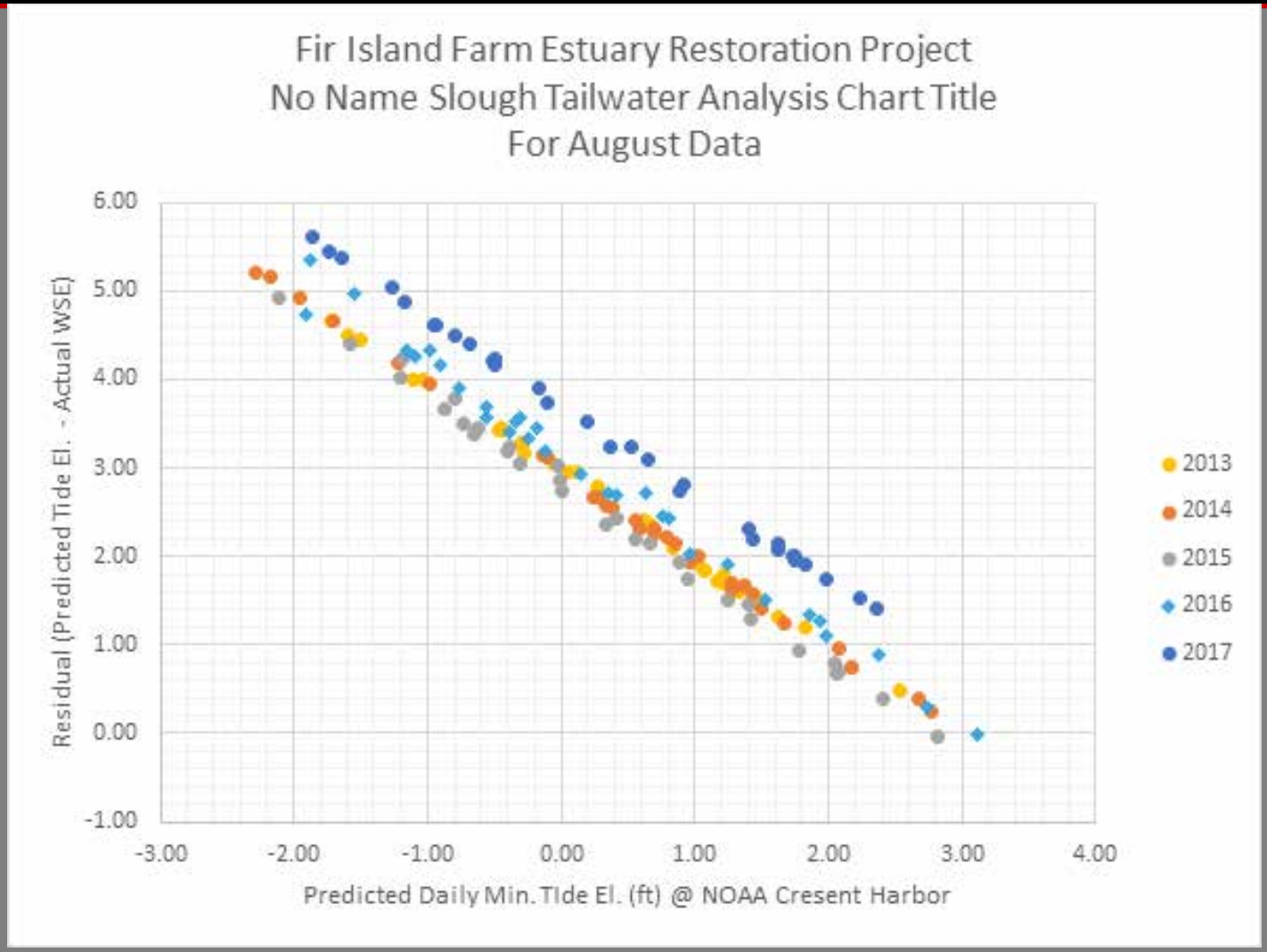
Fir Island Farm - Performance Monitoring



Fir Island Farm - Performance Monitoring



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Marsh Elevations
Erosion Protection, Vegetation & Wood

Fir Island – March 2016 Storm

Tidal Storm Surge
Peak Elevation 13.5ft
(NAVD88)

Fir Island Farm – Large Woody Debris

– Construction Contingency

  Contractor Change Order for Debris Management

Fir Island Farm
Tools to Address Design Uncertainties

- Site Characterization - Baseline
- Monitoring Instrumentation
- Numerical Modeling
- Flexible Designs
- Peer & Constructability Review
- Contingency Planning
- Adaptive Management
- Plan for Changes / Variability

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– Thank you.

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