

Technical Memorandum

Project:	Leque Island – Dike Removal and Erosion Assessment		
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1 Introduction

The following document summarizes the results of a conceptual-level Island dike removal and erosion assessment at Leque Island, conducted by Mott MacDonald (MM). The Leque Island Dike (“Leque Dike”) removal is being considered as part of an estuarine habitat restoration project on Leque Island, coordinated by the Washington Department of Fish and Wildlife (WDFW) and Ducks Unlimited (DU). This planned estuarine habitat restoration includes the full or partial removal of the Leque Dike, resulting in the restoration of tidal exchange on Leque Island. Across from the Leque Dike, on the other side of West Pass, a city owned dike (“City Dike”) extends from the WSDOT bridge to Saratoga Drive (approximately 2,000 feet).

Currently, the Leque Dike appears to shelter most of the City Dike from coastal wave attack. This study was conducted because it appeared a partial or full removal of the Leque Dike could potentially expose a length of the City Dike to increased risk of wave damage or coastal flooding. The location of the project site in relation to the City of Stanwood, and the layout of the existing Leque Dike and City Dike are shown in Figure 1¹. The objectives of this study are to determine the following:

1. Will the City-owned Dike overtop and fail due to changes in wave climate or storm surge if the Leque Dike is fully removed?
2. To maintain the current level of protection to the City, does a portion of the Leque Island Dike need to remain? Alternatively, would the City Dike need to be raised or otherwise upgraded?
3. If part of the Leque Dike does need to remain, what changes to the Leque Dike are required?



Figure 1. Locations of the Leque Dike and City Dike. Note: Figure is for illustrative purposes, entirety of Leque Dike and City Dike is not shown.

¹ Armor rock can be found along scattered the toe and adjacent shoreline of the City Dike, but it is not continuous along the length of the City Dike.

This study included the compilation and review of existing data, engineering analysis, development of alternatives, and assessment of project objectives. This analysis was conducted after the recent Zis a Ba restoration project was completed. Any effect on changes to wave climate or flood regime because of the Zis a Ba project was outside the scope of this study. The appendix attached to this technical memo provides supporting information on the data analysis and the results presented in this document, which was previously presented to WDFW and DU.

2 Existing Data Compilation and Review

Data collected for the feasibility study included LiDAR topographic surveys from the United States Geological Survey (USGS) and Pacific Northwest National Laboratories (PNNL), bathymetric surveys from the National Oceanic and Atmospheric Administration (NOAA), aerial photographs, site visit photographs, reports from previous analysis by Pacific Northwest National Laboratory (PNNL), tidal channel design engineering plans (from DU), Federal Emergency Management Agency (FEMA) flood maps, and an MM internal wave model database. The data were processed, reviewed, and organized for further analysis and assessment.

3 Analysis & Results

Engineering analysis was conducted to establish the effects on the City Dike caused by the full or partial removal of the Leque Island Dike. Based on review of FEMA flood maps and topographic elevations of the City Dike, it was determined the area landward of the City Dike is already in the 100-yr floodplain due to riverine flooding (see appendix for details). Therefore, the Leque Dike only provides protection from wave attack to the City Dike, and does not provide flood or storm surge protection to the City Dike. To reflect this understanding, the criteria to evaluate the effects of the partial or full removal of the Leque Dike on the City Dike were updated to:

- *As a result of the partial or full removal of the Leque Dike, any differences to the current level of protection from storm waves, to the City of Stanwood, must be negligible.*



Figure 2. Recommended approximate locations for the endpoints of the Leque Dike after modifications.

Coastal engineering analysis (see appendix for details) indicates that the full removal of the Leque Dike will result in a higher risk of increased storm waves at the City Dike, which could result in overtopping and scour of the City Dike during storm conditions. Upgrading the City Dike could potentially address these issues, but specific recommendations for this alternative were not included in the scope of work for this study. Potential upgrades could involve raising the dike elevation and installation of new armor rock as scour protection.

Relative only to the course of action involving the Leque Dike, and assuming no modifications to the City Dike, it has been determined that the full removal of the Leque Dike is not a feasible alternative. To result in negligible changes in wave climate at the City Dike, and to maintain the current level of protection to the City, the recommended portion of the existing Leque Dike to remain is shown in Figure 2².

This portion of the dike to remain (as shown in Figure 2) should be modified to account for increased risk of storm wave attack due to restoration actions at the remainder of Leque Island. The seaward edge of the dike should be constructed at approximately 4H:1V slope, depending on construction material and vegetation. Turf reinforcement mats may be appropriate to strengthen dike before vegetation can mature. More detailed analysis should be conducted to confirm material excavated at Leque Island can be re-used for dike modifications. See appendix for details.

Tidal channel outlets through the northern side of the Leque Dike may be feasible, provided the design of the outlets results in only negligible change in wave climate at the City Dike. To meet this criterion a conceptual level alternative including overlapping earthen dikes was developed by WDFW/DU to act as breakwaters, and is shown in Figure 3. In this case only negligible wave energy propagates through the tidal channel gap. Empirical analysis of the concept³ indicates that it meets the required wave protection criteria. This layout was based in part on the recommended dike geometry⁴, and tidal channel geometry provided by DU.

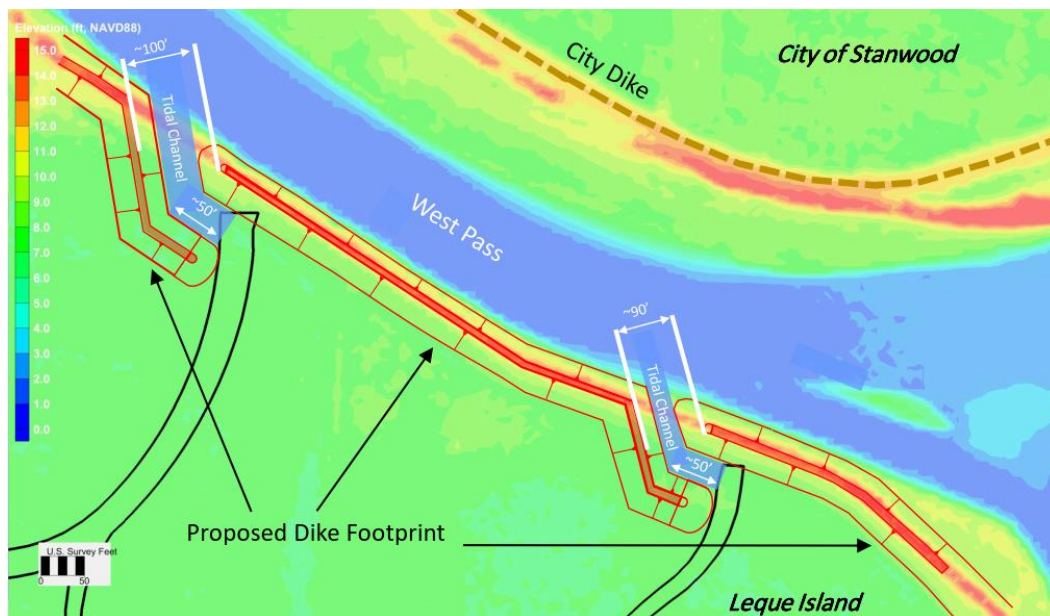


Figure 3. Proposed partial removal of Leque Dike and tidal channel alternative layout.
Note: Scale is approximate, exact tidal channel and outlet locations/orientations may vary.

² Analysis assumes the west end of the Leque Dike is connected to the roadway embankment.

³ Numerical modeling was determined not to be required for this conceptual analysis.

⁴ Similar to the MM developed detached breakwater alternative shown in the Appendix.

To confirm the feasibility of implementing a tidal channel gap, or gaps, a hydraulic analysis of the potential tidal channel gaps on the portion of the Leque Dike that will remain must be conducted. Hydraulic analysis is needed to optimize tidal channel gap orientation and to determine the risks of scour due to hydraulic conditions. If the two tidal channel gaps shown in Figure 3 are removed from the Leque Dike alternative (e.g., no gaps in the Leque Dike), no further hydraulic analysis is required.

4 Assessment

Results of a feasibility assessment indicate a full Leque Dike removal would result in a change in the wave climate at the City Dike. This estimated change in wave climate could increase the risk for flooding and potential for failure of the City Dike. Therefore, assuming no upgrades to the City Dike, a portion of the Leque Dike should remain, and be modified to account for changes in wave climate due to restoration actions. If tidal channel gaps are installed in this section of dike, a portion of the dike should be oriented to act as a breakwater at each outlet to protect the City Dike. An analysis of the hydraulics at each tidal channel/gap and an understanding of the associated scour risks and orientation must be performed before design and construction if tidal channels are planned for the remaining portion of the Leque Dike.

Appendix A

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MACDONALD

Leque Island: Progress Update

Dike Removal &
Erosion Assessment

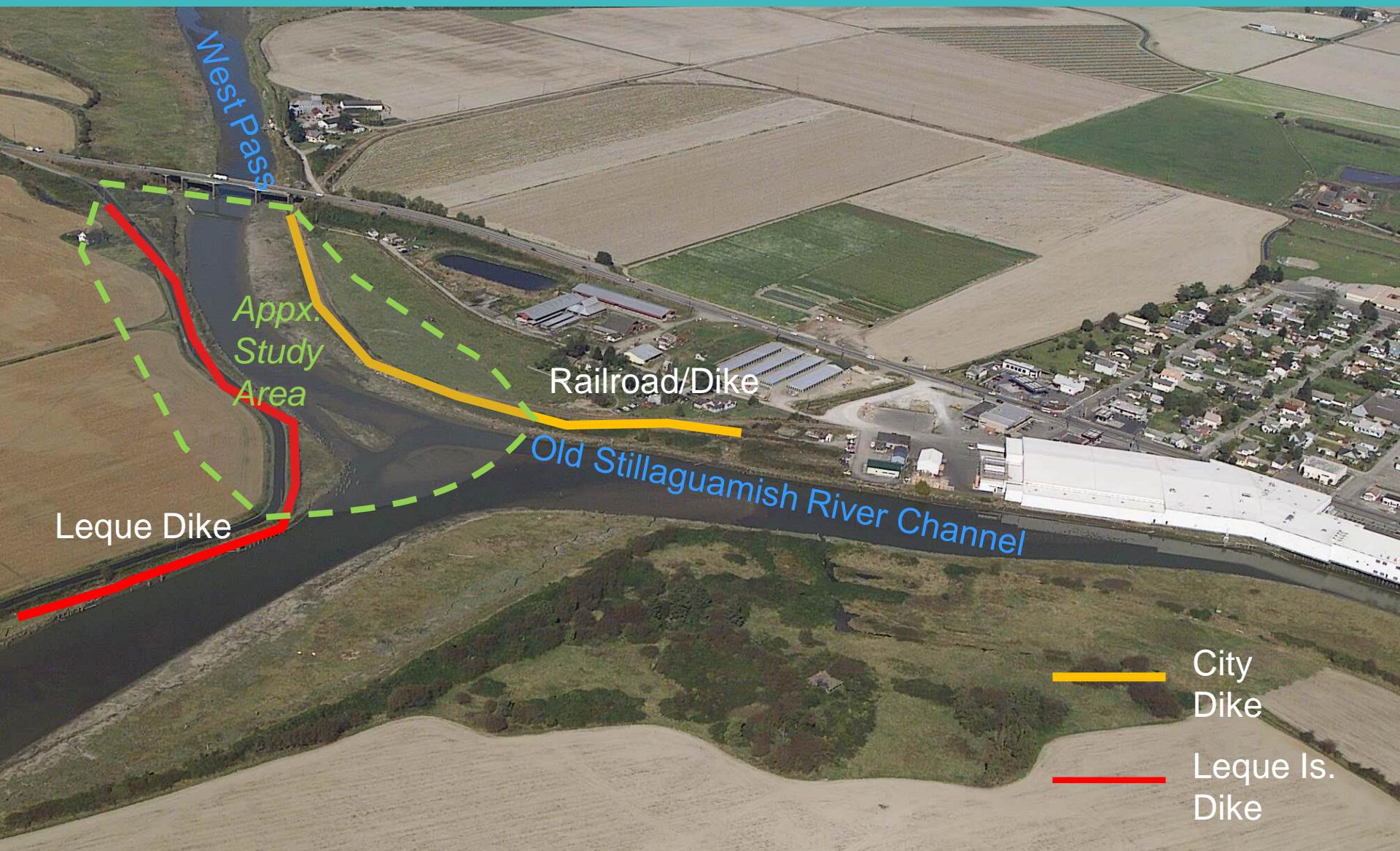
Ducks Unlimited



Purpose and Need

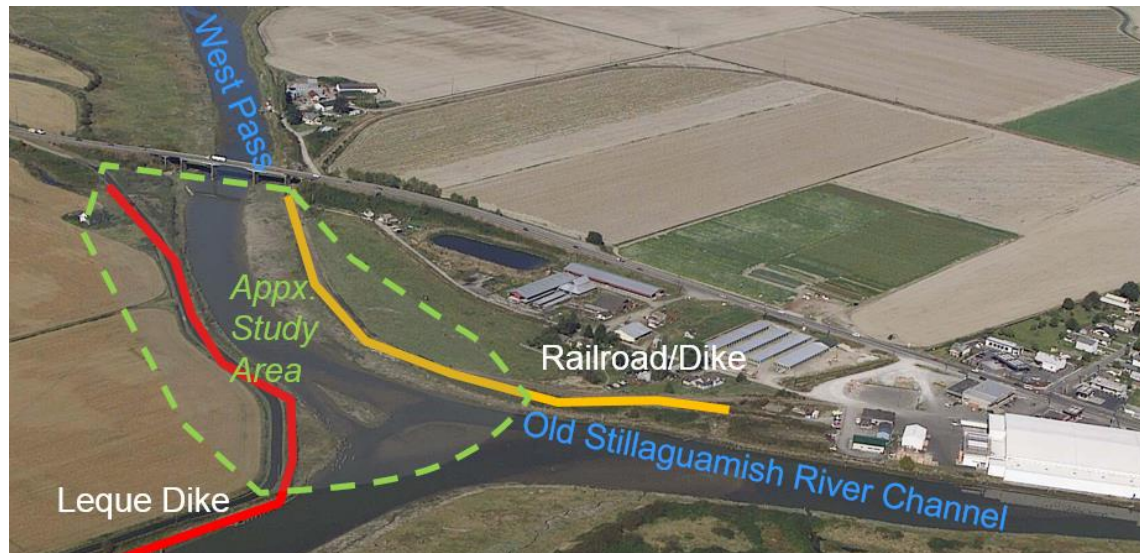
- **Leque Island dike to be removed (full or partial)**
- **Evaluate effect on coastal flood protection for City of Stanwood**
- **Provide conceptual-level engineering recommendations**

Project Site



Project Background

- Leque Island dike shelters the majority of the City of Stanwood dike from wave action
- Removing Leque Island dike exposes a significantly larger length of the city-owned dike (railroad) to waves and storm surge



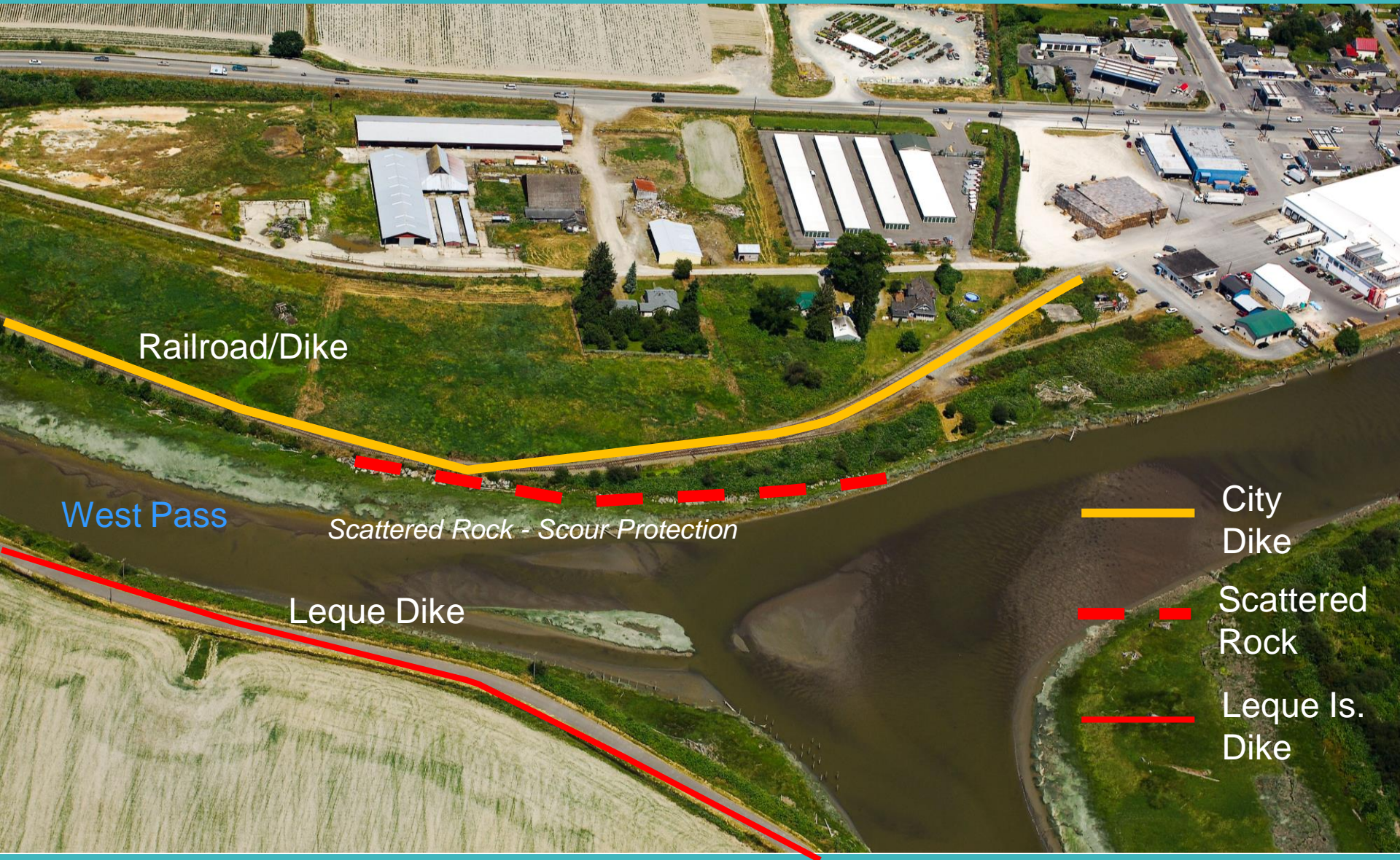
Project Objectives

- **Will the city-owned dike overtop and fail due to changes in wave climate if the Leque Island dike is fully removed?**
- **To maintain performance of the city-owned dike, does a portion of the Leque Island dike need to remain?**
- **If a part of the dike needs to remain, how much, and what changes are required?**

Site Vicinity



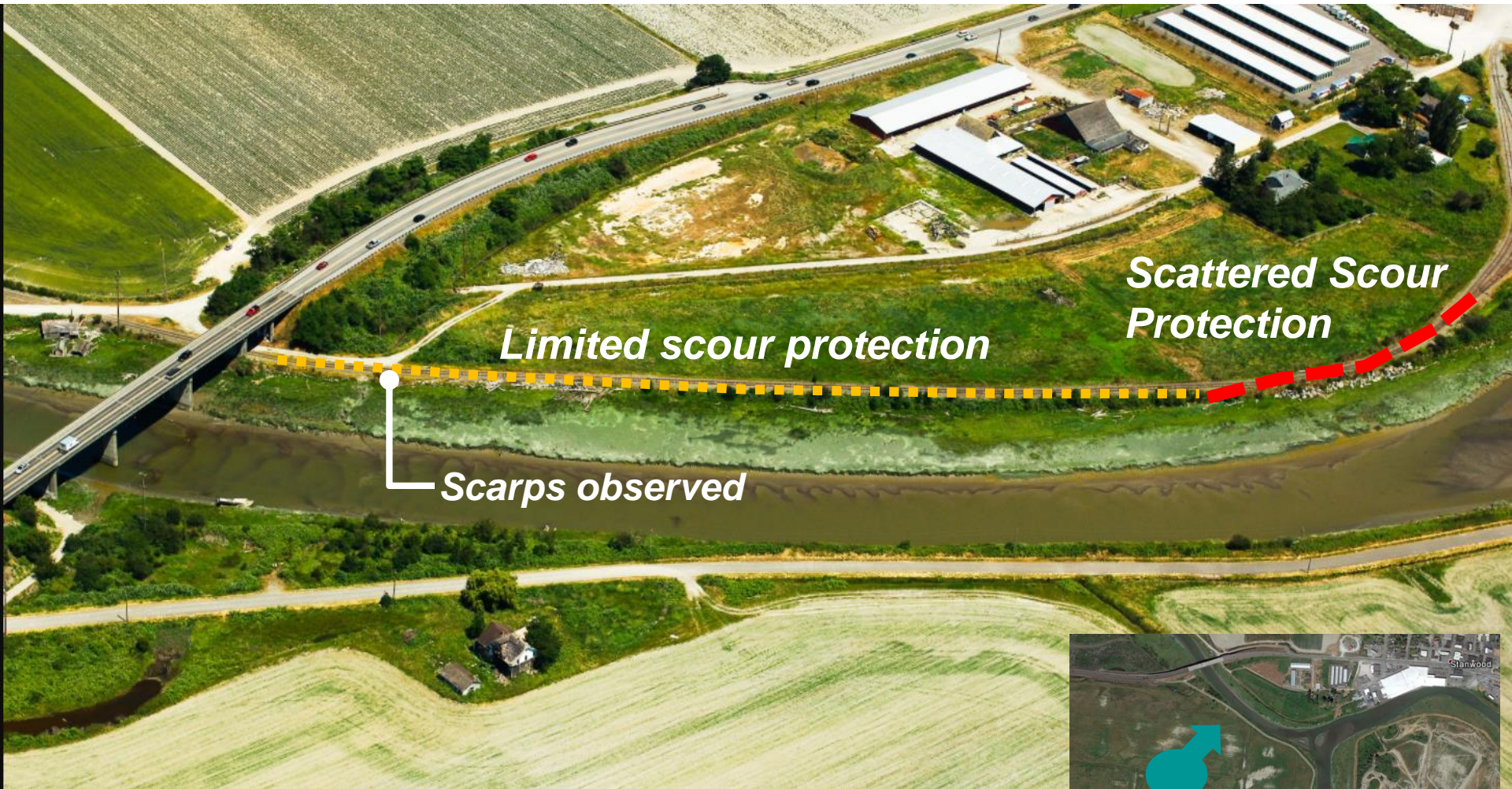
Existing Dikes



Existing Scour Protection



Site Conditions



Flooding Types

FEMA's flood risk maps represent the combined effects of flood hazards.

**Riverine
Flooding**

**Levee
Analysis**

**Alluvial
Fans**

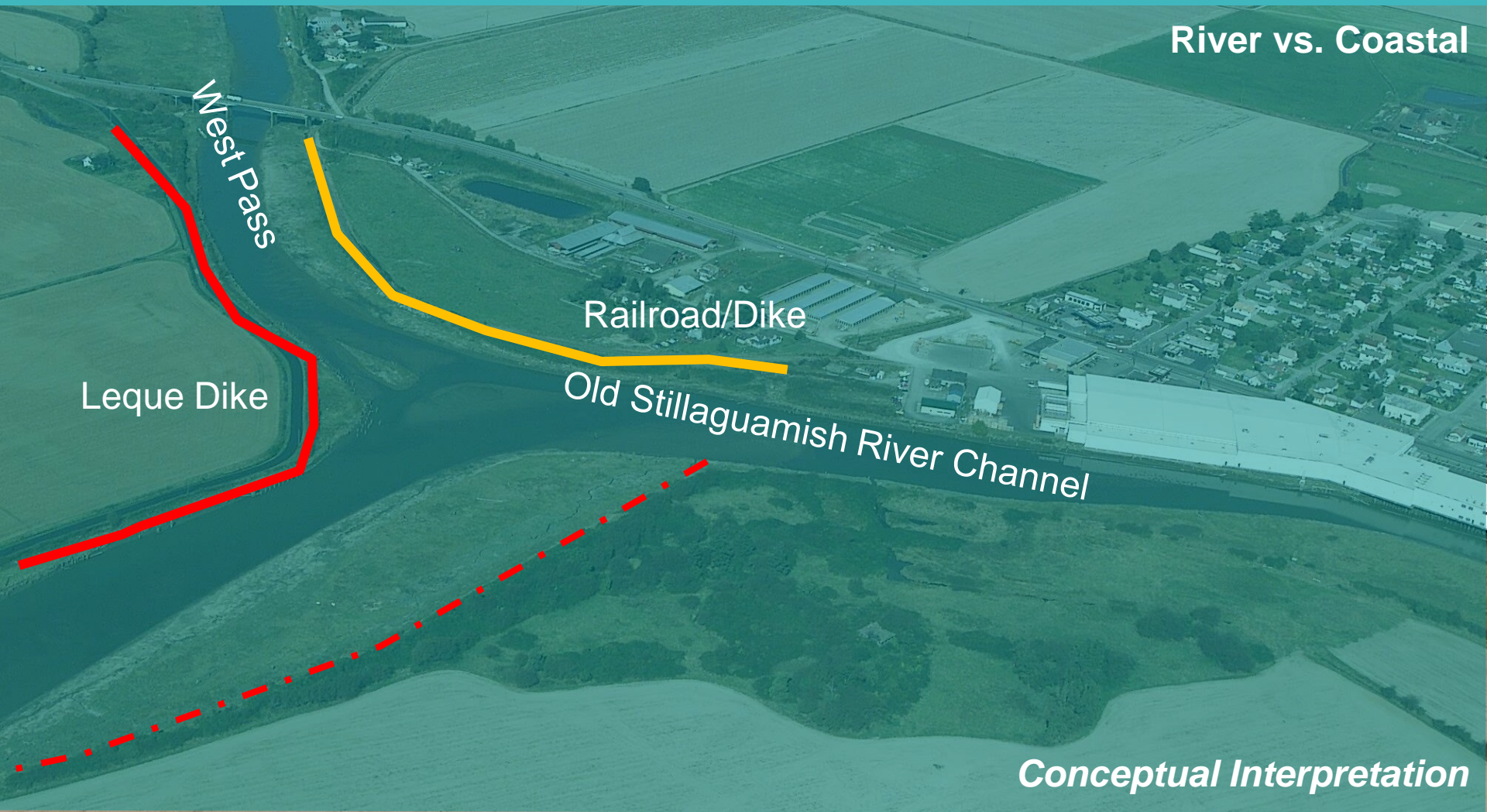
**Wave
Run-Up**

**Storm
Surge**

**Coastal
Flooding**



100-Year Flood (FEMA Present)



100-Year Flood – Coastal (Present)

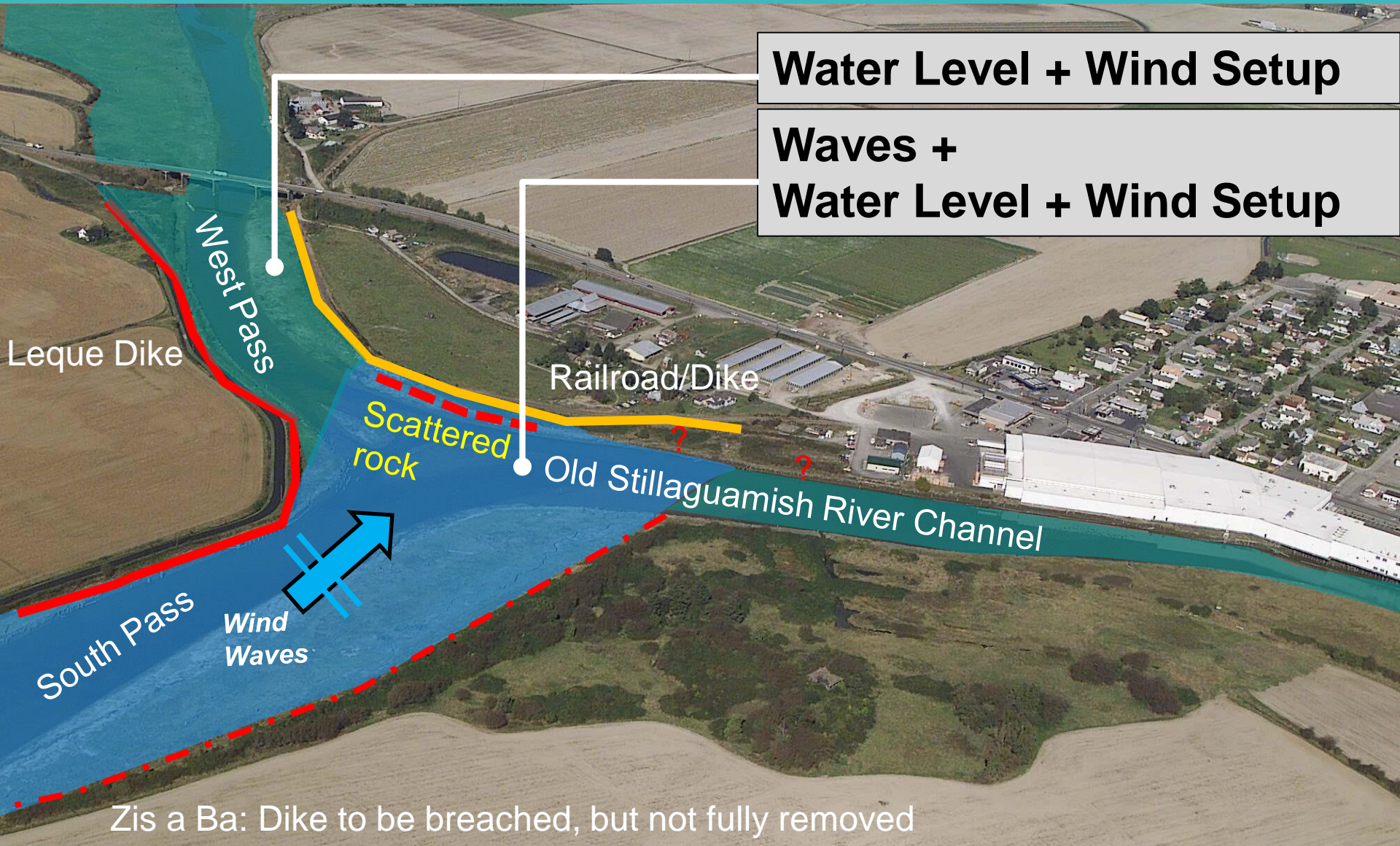


**Water Level + Wind Setup
(Riverine)**

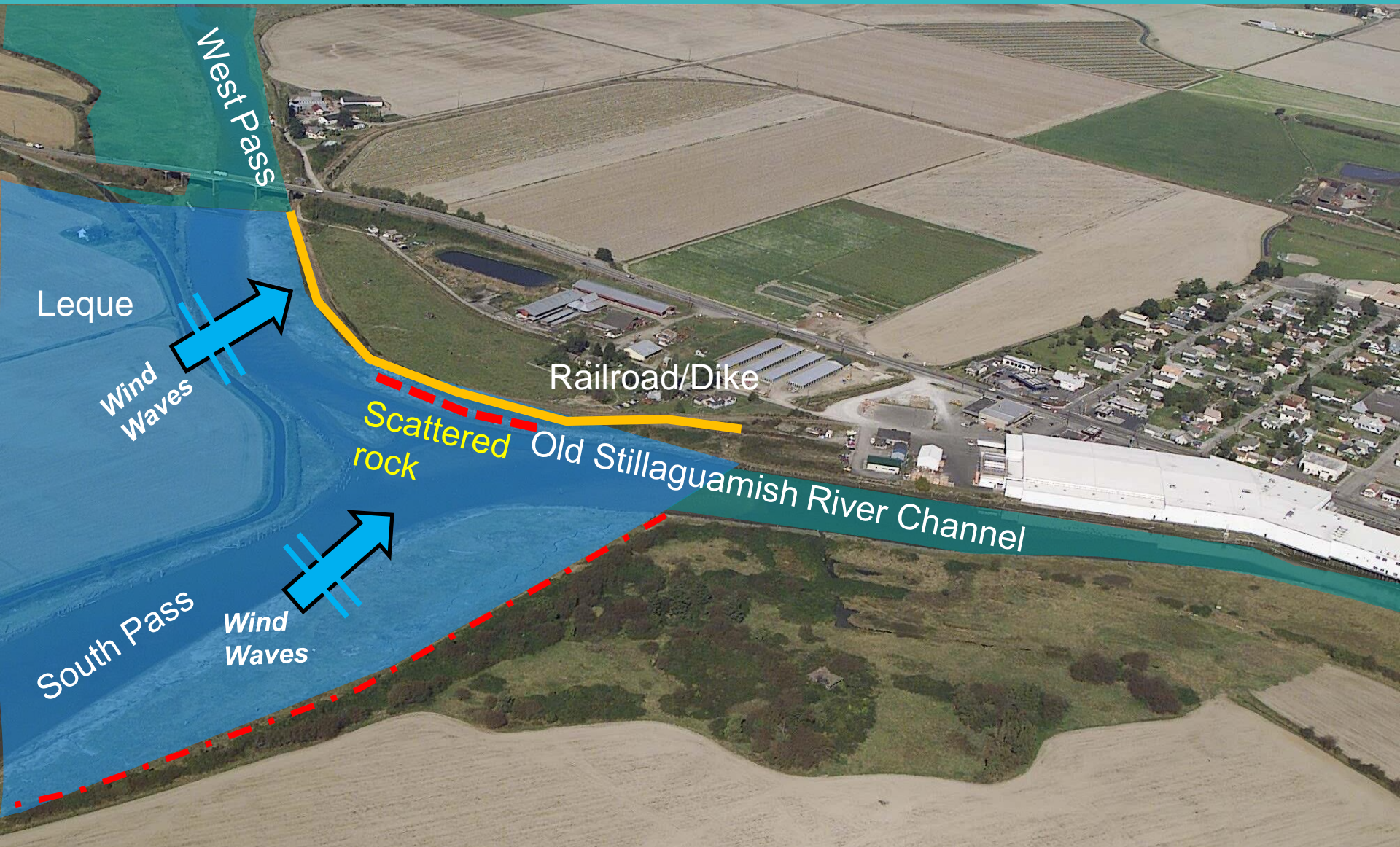


**Waves +
Water Level + Wind Setup
(Coastal)**

100-Year Flood – Coastal (Present)



100-Year Flood – Coastal (No Dike)



Existing Conditions Summary

- **Area inland of City-owned dike currently in FEMA 100-year flood plain.**
- **Leque Island does not protect against riverine flooding.**
- **Area of city-owned dike (likely exposed to waves) appears to have scour protection (large rocks).**
- **Majority of city-owned dike does not have scour protection, and has shown evidence of scarps forming due to localized wave attack.**

Dike Overtopping Assessment

- Use FEMA guidance to evaluate dike performance (not standards).
- Methodology is applicable.

Applicable Investigations

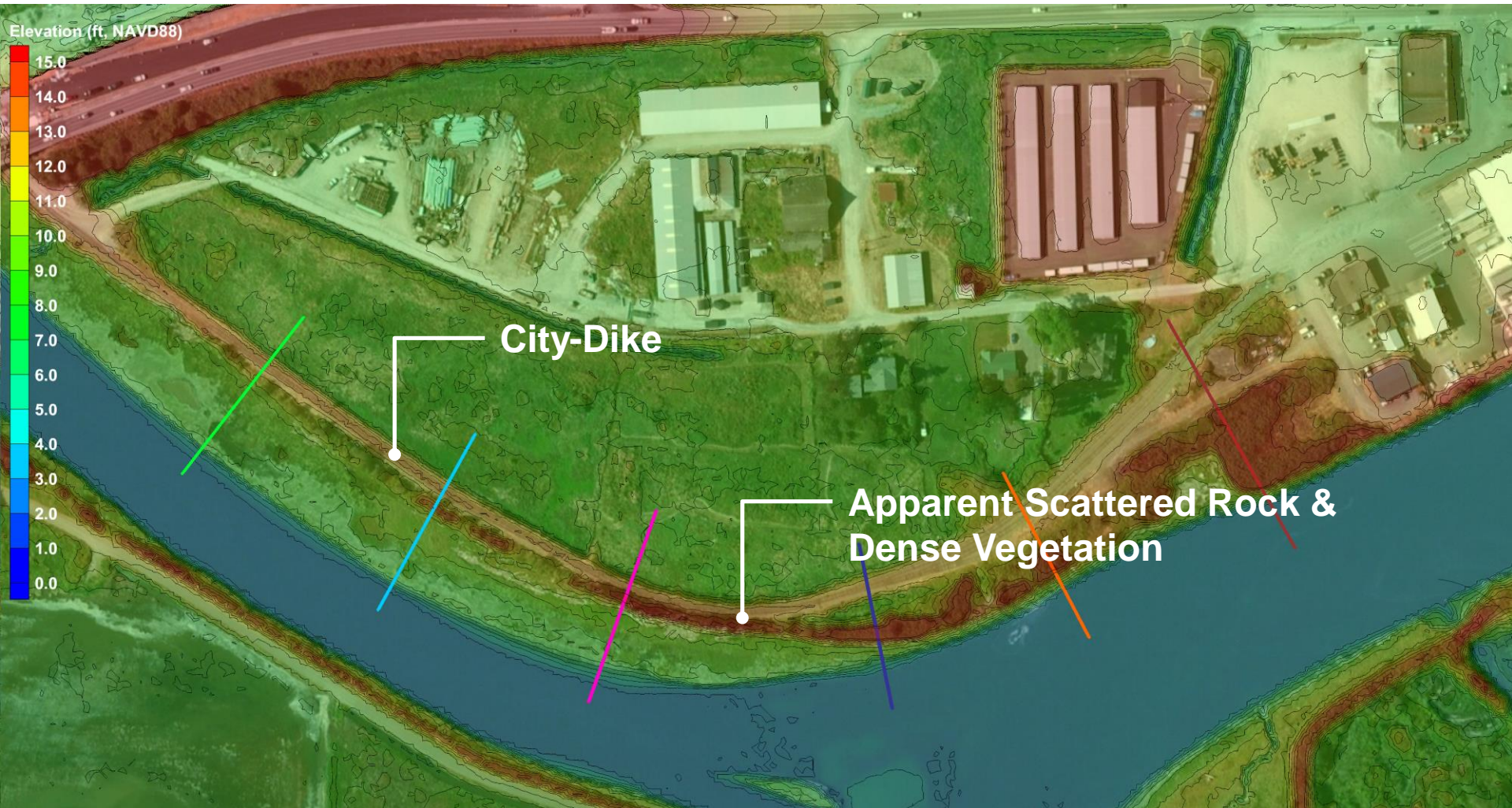
Freeboard above base flood elev.

Closures and openings

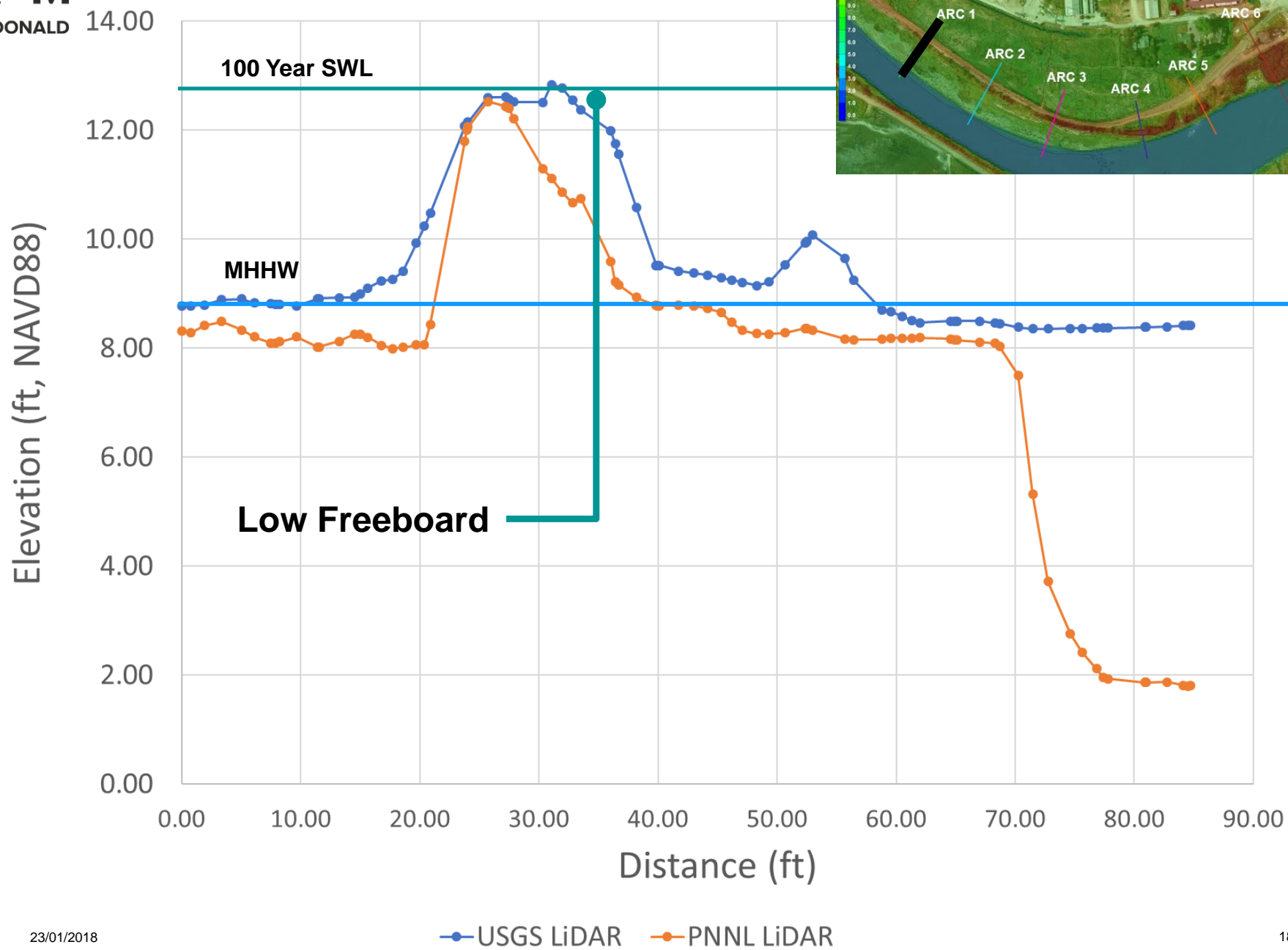
Embankment Protection (evaluated in next phase)

Embankment and Foundation Stability (evaluated in next phase)

Ground Elevations (Lidar)



Cross-Section #1

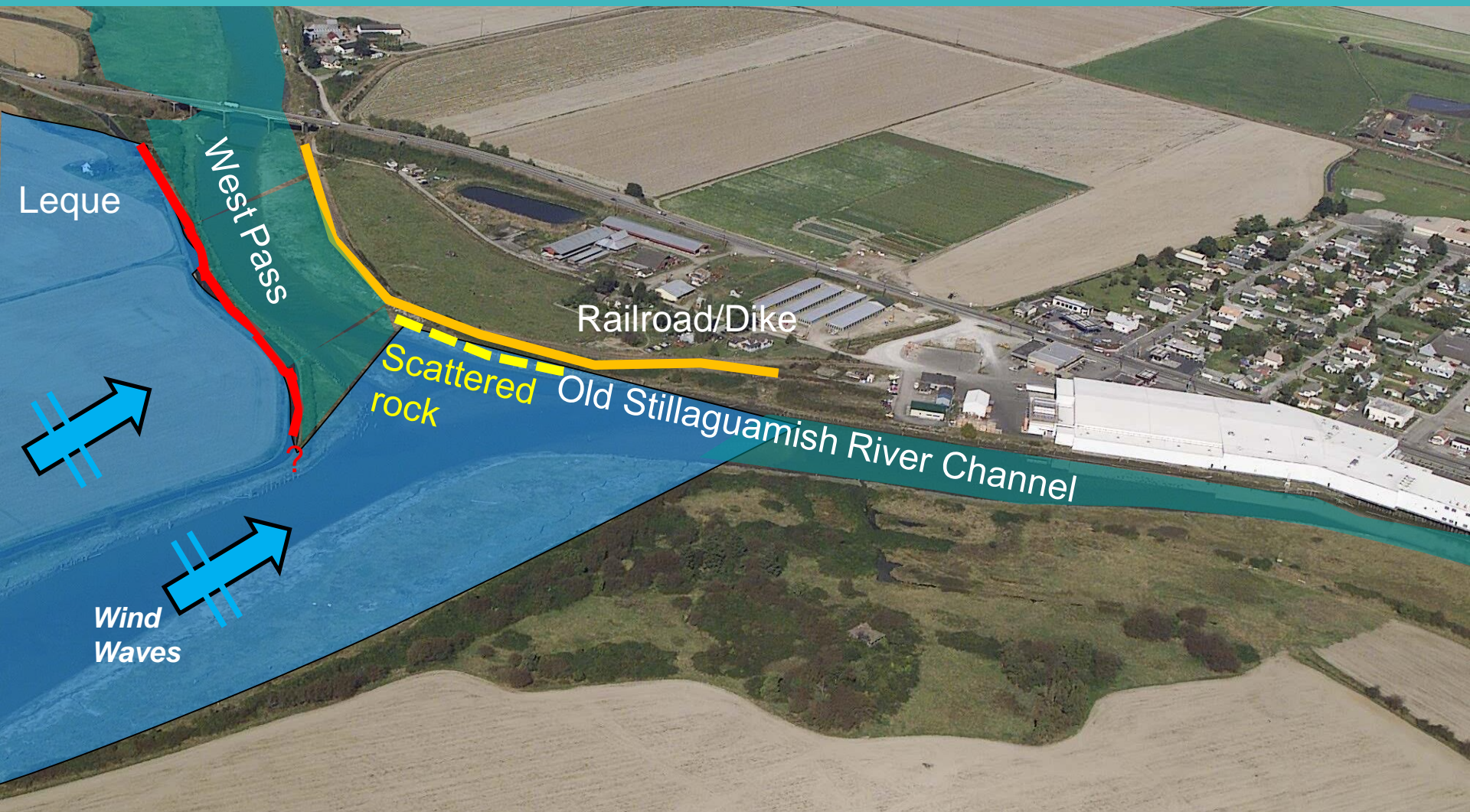


Preliminary Takeaways

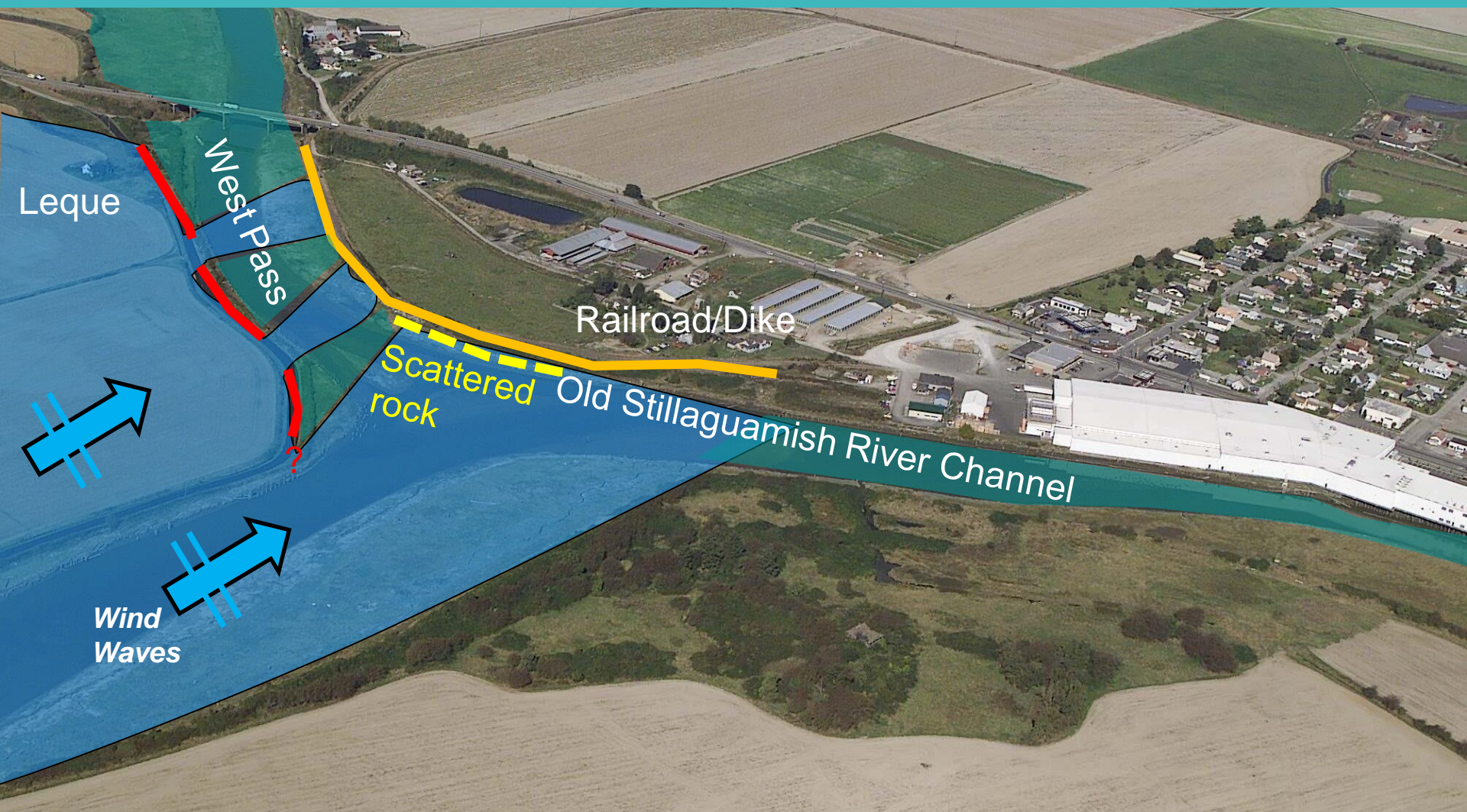
Existing city-dike does not currently provide wave protection, or built to survive wave impact

- **TASK 1: Will the city-owned dike overtop and fail due to changes in wave climate if the Leque Island dike is fully removed?**
 - Yes
- **TASK 1, 2: To maintain performance of the city-owned dike, does a portion of the Leque Island dike need to remain (as breakwater)?**
 - Yes, without modifications to city-dike

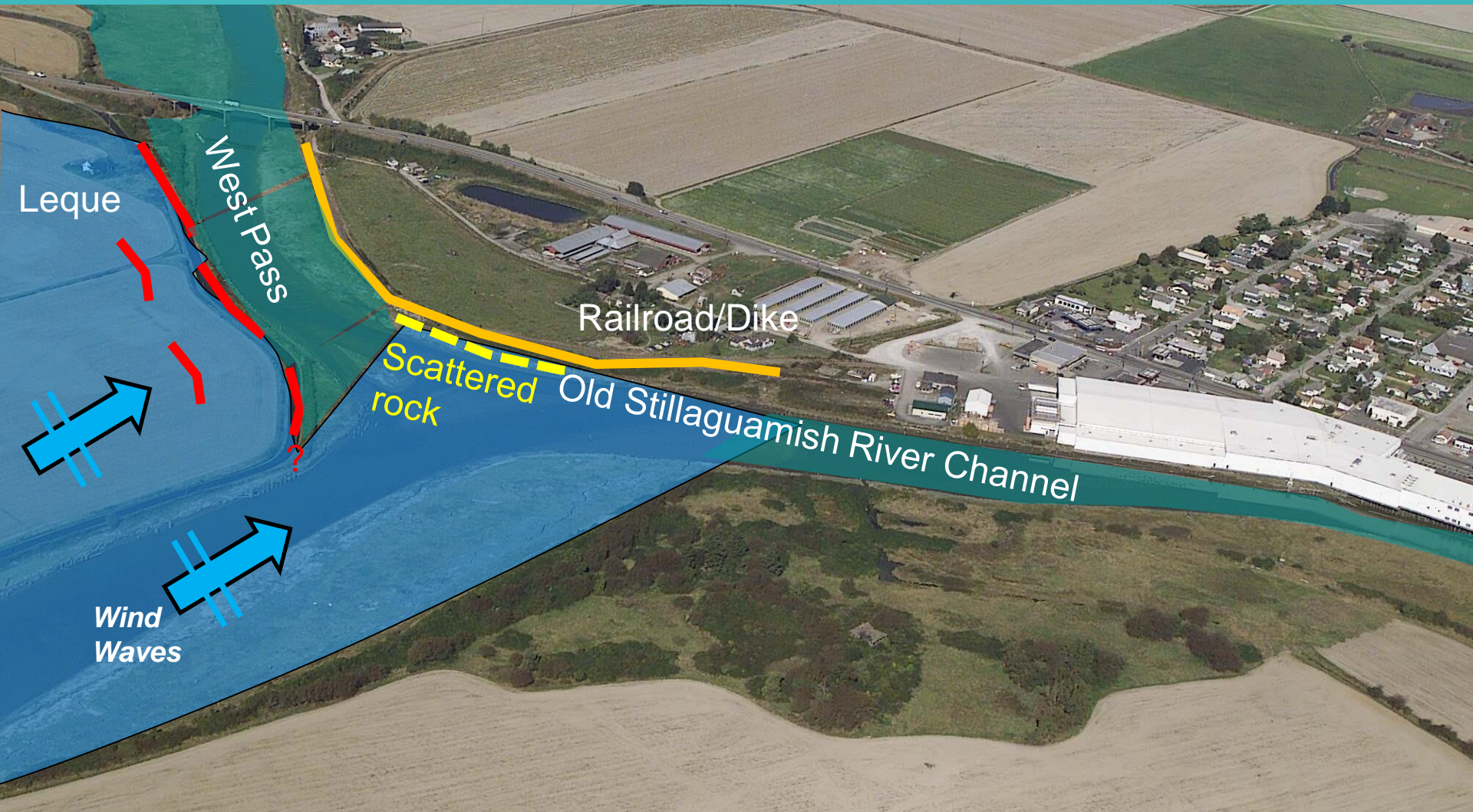
Conceptual Alternatives Investigation



Conceptual Alternatives Investigation



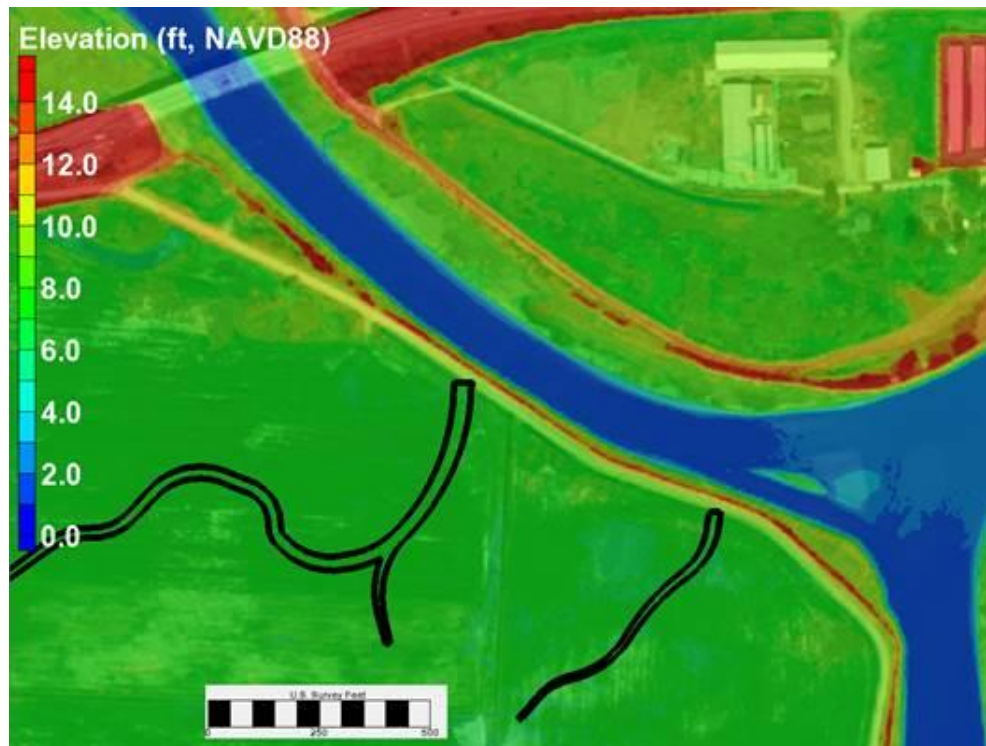
Conceptual Alternatives Investigation



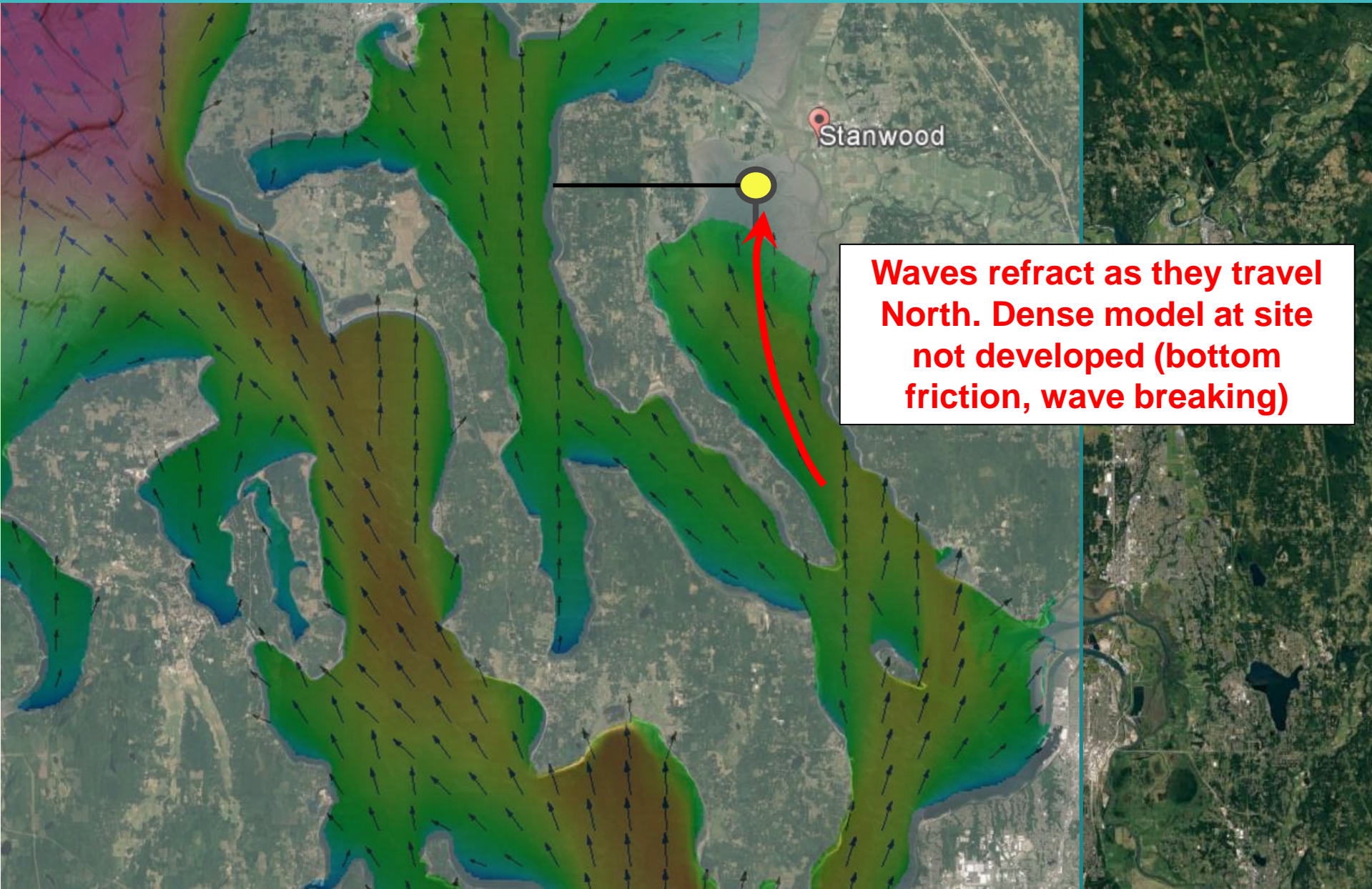
Conceptual Alternatives Investigation

- Tidal channels feasible?

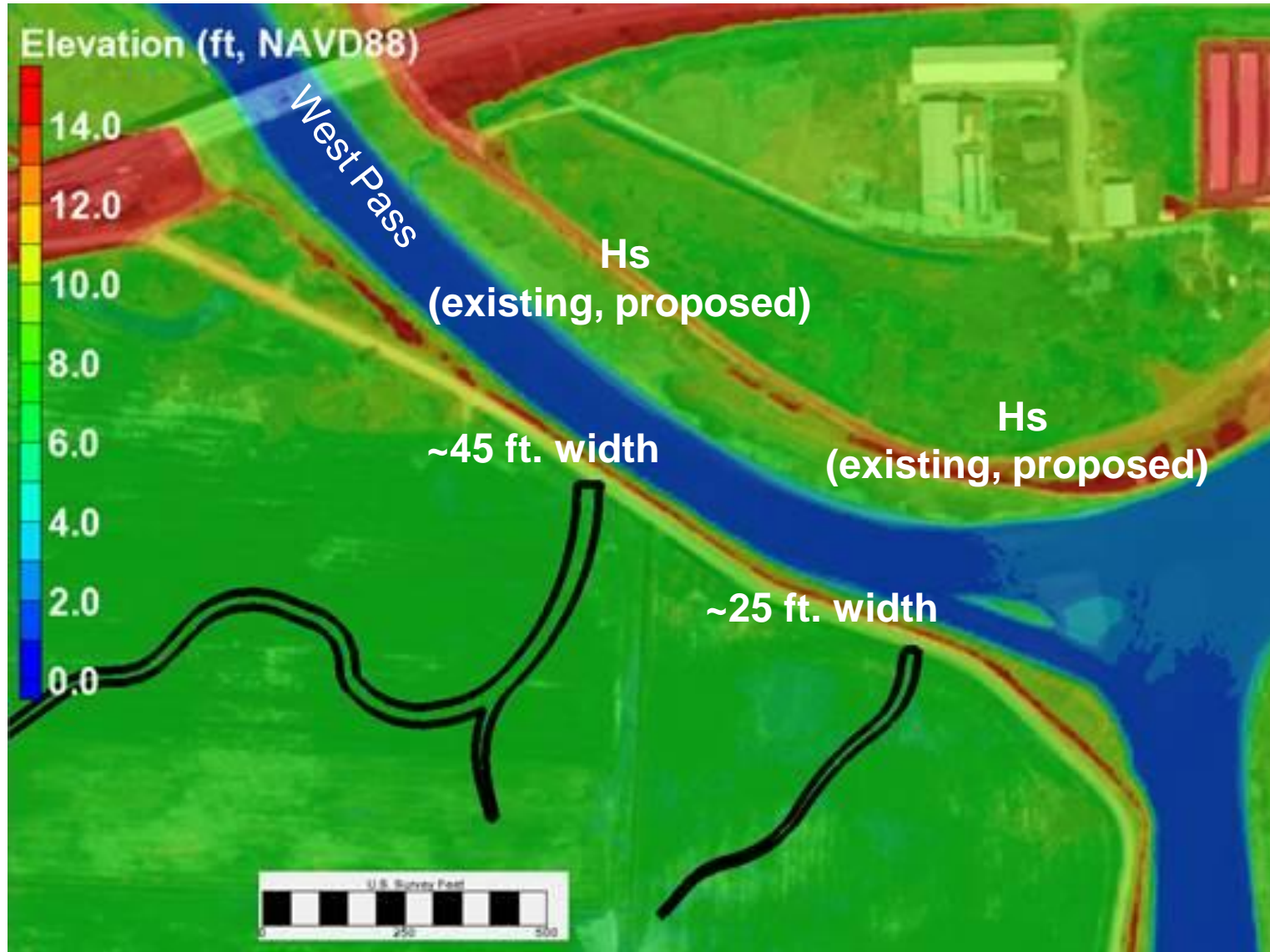
- Maintain existing protection level for city
- → Evaluate change in wave conditions due to partial Leque-dike removal



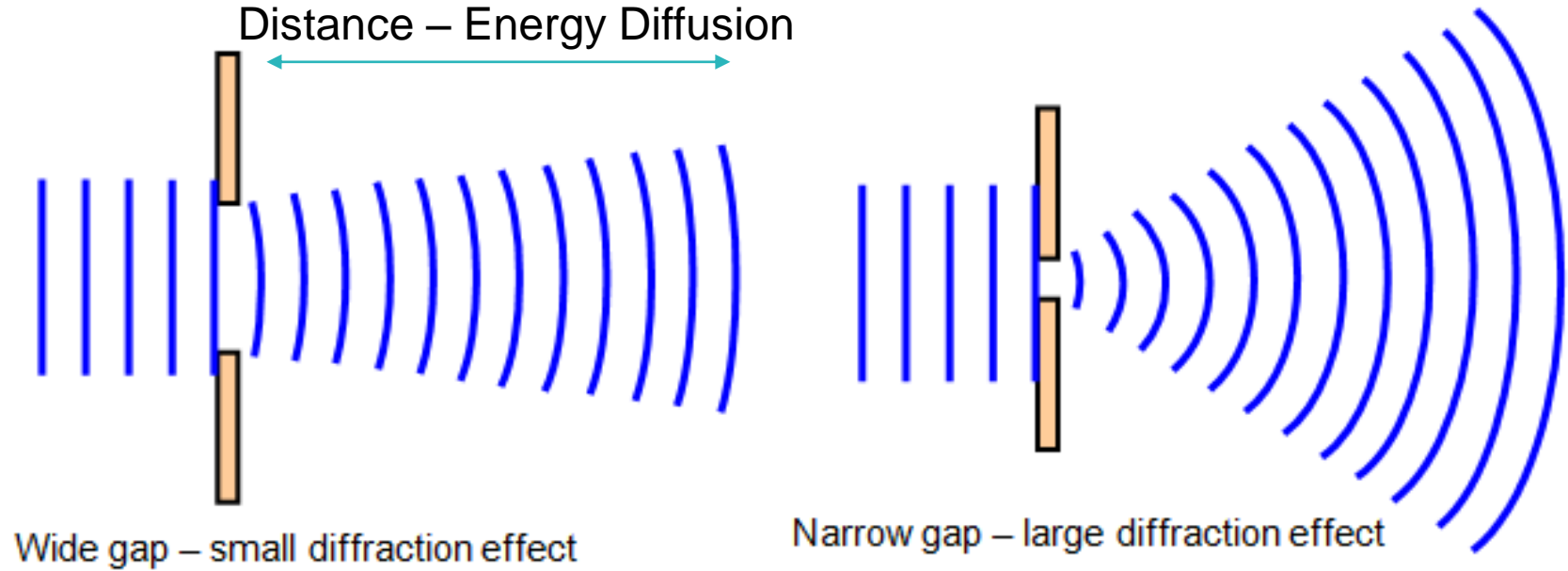
Existing MM Puget Sound Extreme Waves



Tidal Channel Layout



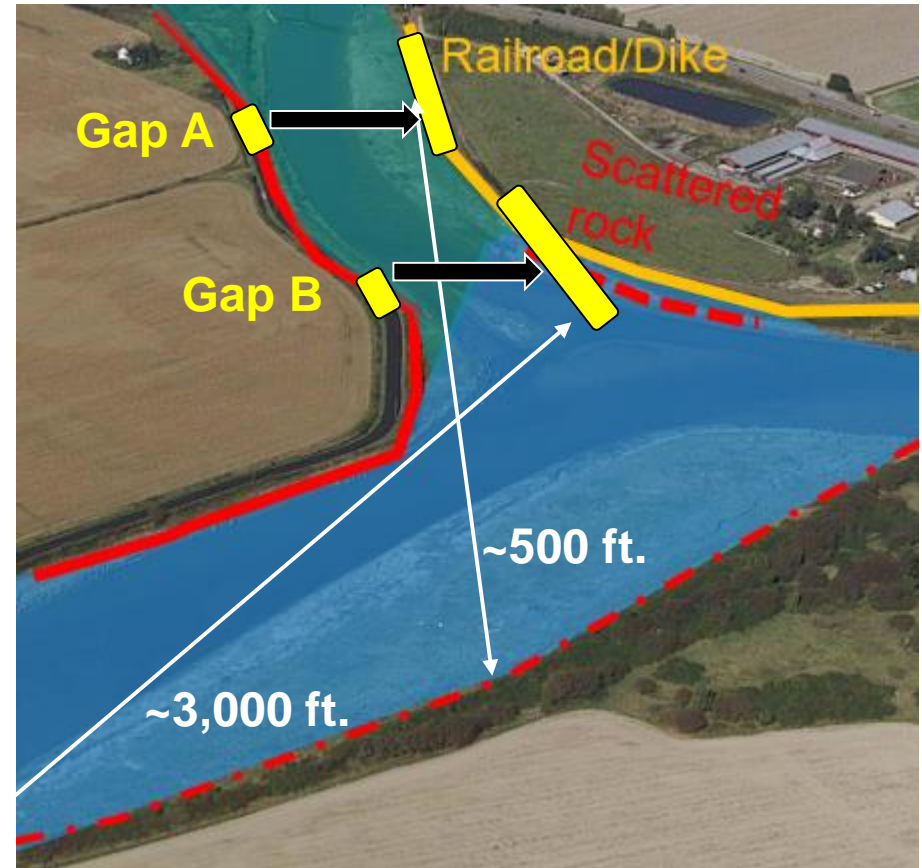
Estimated Future Wave Climate



Wave Evaluation

Analysis

- Simplified fetch analysis using USACE empirical methods
- Conceptual-level comparative assessment (50-year storm)
 - Area lee of Gap A:
 - Fetch: 500 feet
 - Hs Existing = ~0.6 feet
 - Hs Proposed: ~1.2-1.9 ft.
 - Area lee of Gap B:
 - Fetch: 3,000 feet
 - Hs Existing: ~1.3 feet
 - Hs Proposed: 1.2-1.9 ft.



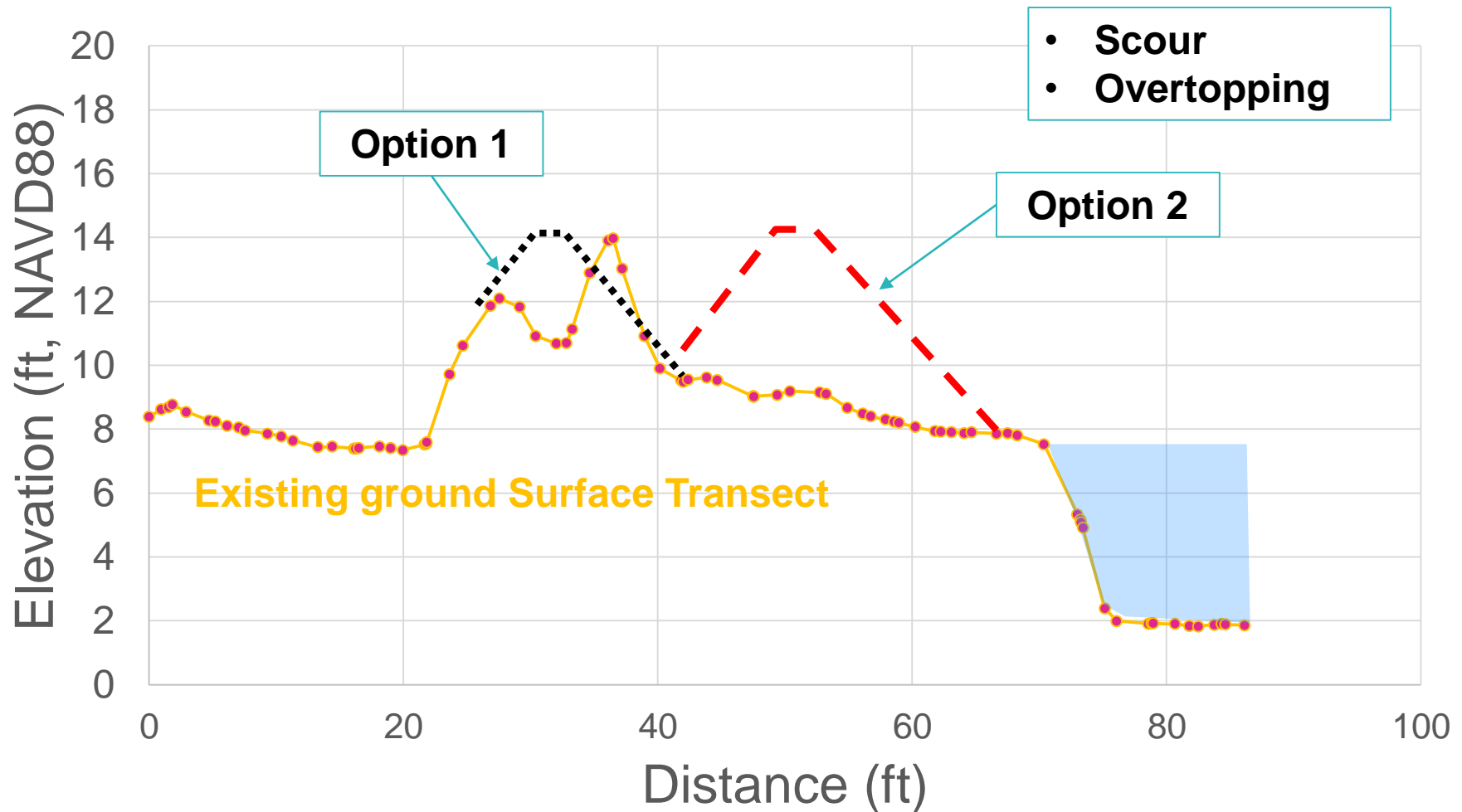
Assessment:

- Gap A: Significant increase at city-dike likely, relative to existing
- Gap B: Similar, but likely larger wave height at city dike relative to existing

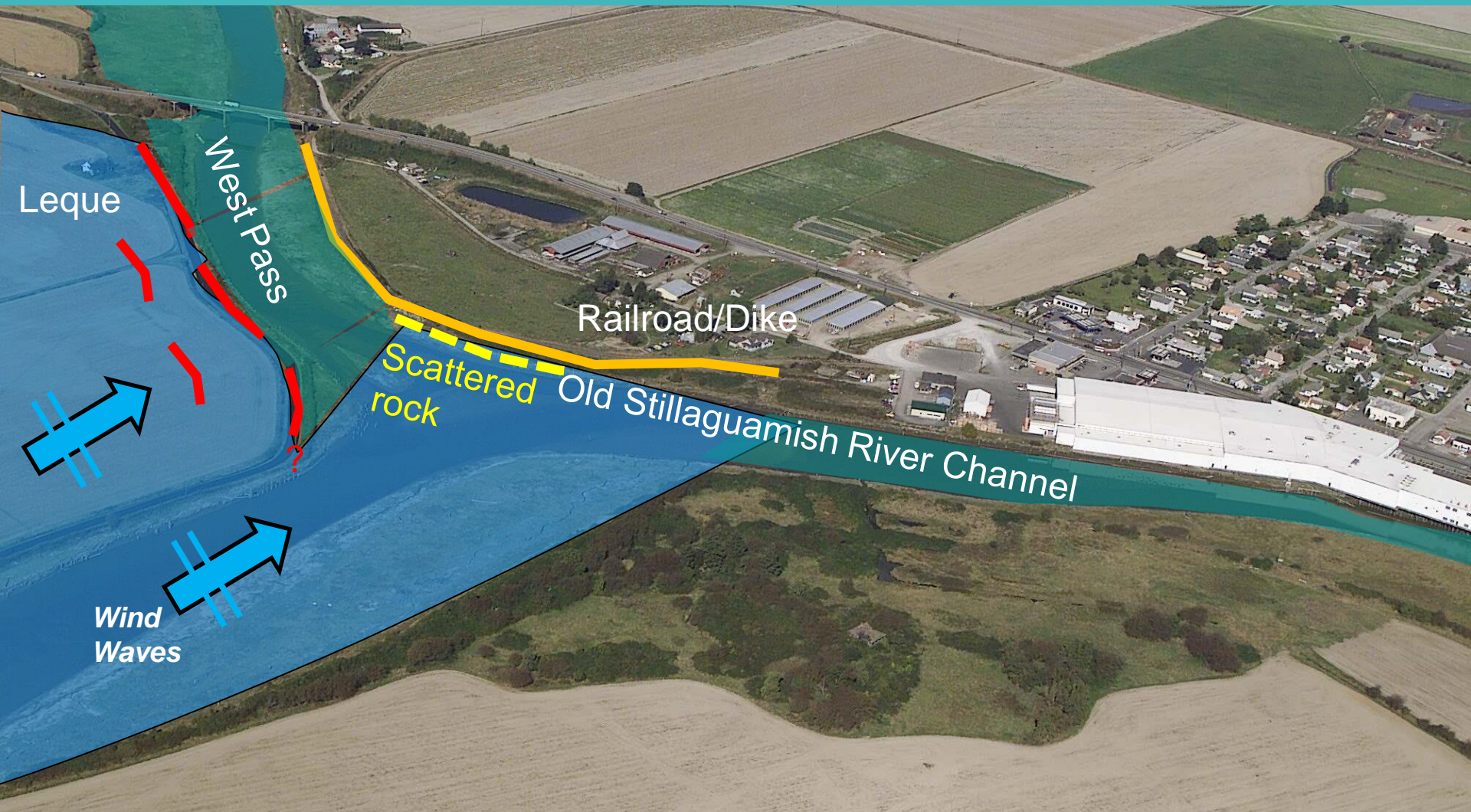
Results

- Erosion and overtopping protection needed at City-Dike

Potential Localized City-Dike Modification

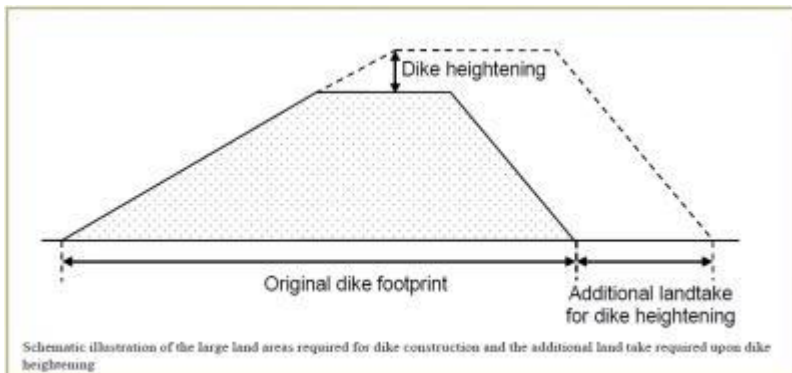
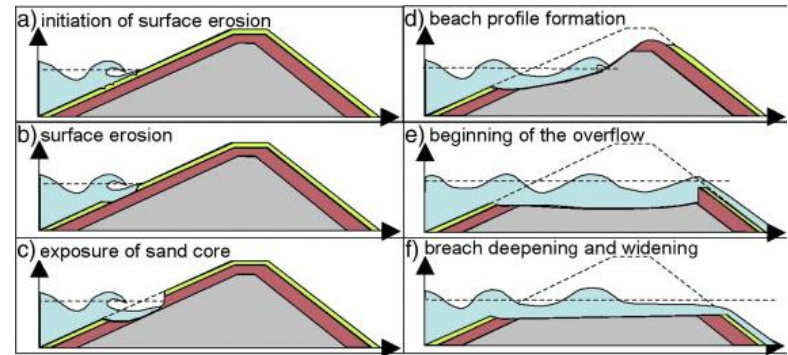


Conceptual Alternatives Investigation



Dike - Contributing Factors

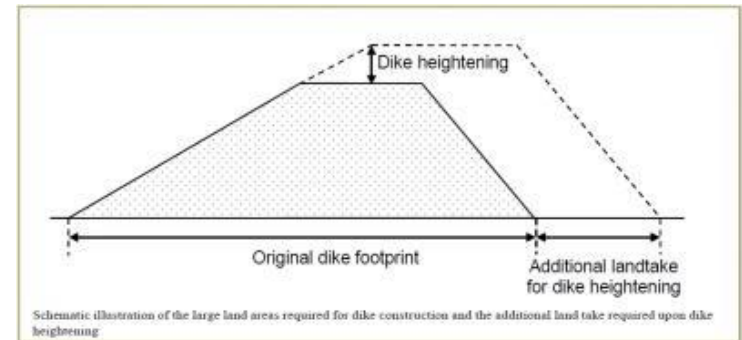
- Waves
- Water levels
- Dike crest elevation
- Dike material
- Dike footprint
- Overtopping/Armoring



- **Performance:** Intended purpose is a breakwater. Not intended to protect against flooding on landward side. At high water levels, water will be both landward and seaward.
- **Existing Conditions:** LiDAR provided by PNNL
- **Geotechnical:** Provided by DU
- **Water Levels:** Similar on seaward and landward sides
- **Overtopping risk:** USACE Coastal Hydraulics Lab & European dike design guidelines
- **Maintenance:** Assumed to be minimal. Increased maintenance acceptance may result in lower cost dike
- **Material:** Assumed that material re-use is preferred. Concrete or marine mattress may be required at transitions
- **Maintain existing wave protection:** May require detached berm breakwater at tidal channels

Coastal Dike Design: Key Guidelines

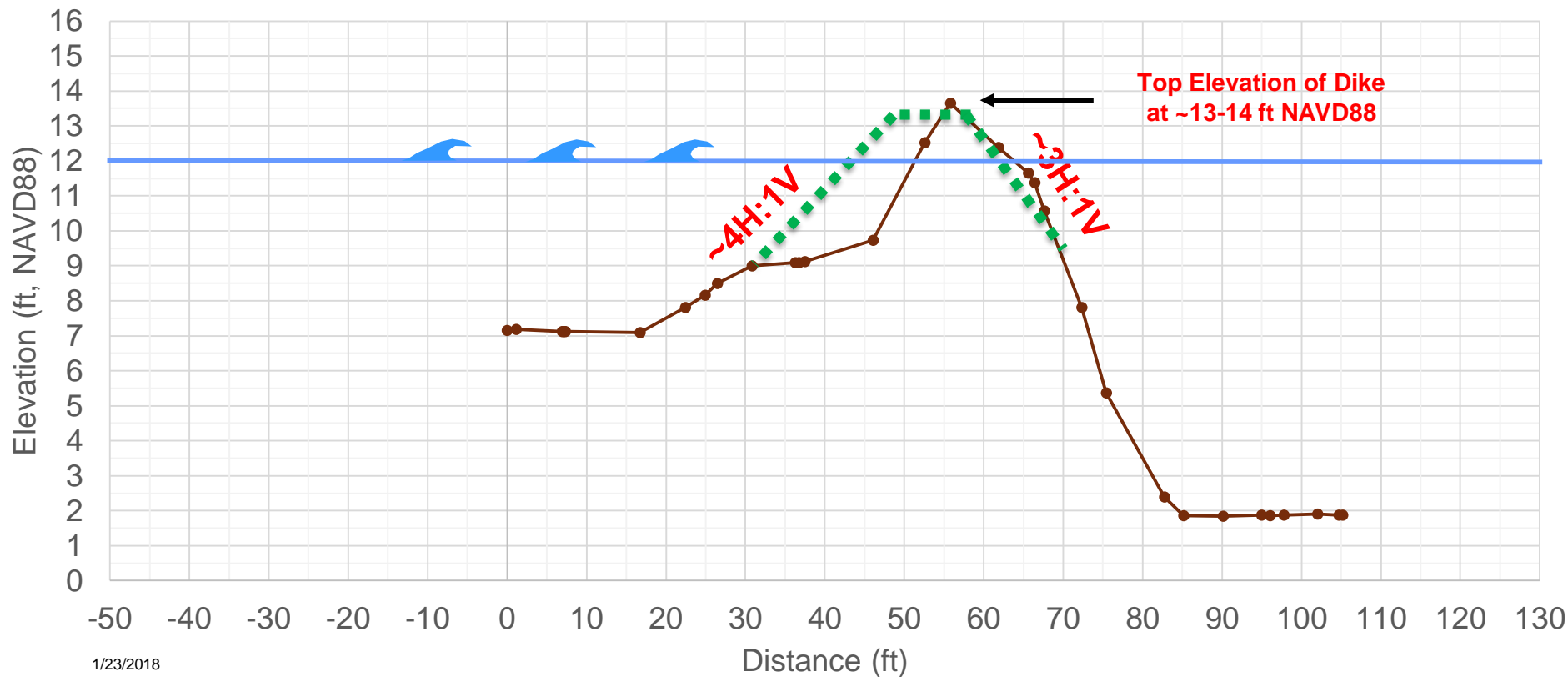
- **Crest elevation/Overtopping:**
 - Limiting rate: $0.1 - 2.8 \text{ ft}^3/\text{sec}$
 - Armoring required if overtopping rate exceeded
- **Slope:**
 - Grass: Typically 4H:1V.
 - Steeper slopes → greater damage/maintenance, typically used on rivers rather than coasts
 - Marine Mattress: ~2H:1V
- **Armoring:**
 - Required if significant overtopping
 - Potentially required at transitions
- **Material:**
 - Outer layer: no greater than 35% sand
 - Core layer: Better performance with cohesive material
 - Marine mattress and Turf reinforcement mats: additional protection
- **Vegetation:**
 - Dense root systems critical
 - Non-fertilized grass reported better performance
 - Variety of species



Conceptual Leque Diike Profile

Assumptions

- Grass topping with dense roots
- Cohesive material core
- 100-year Hs: ~3-4 feet
- Not intended to preclude flooding
- Damage: some may occur in 100-year storm



Geotechnical Conditions: Leque Island

4.2 SOIL SURVEY

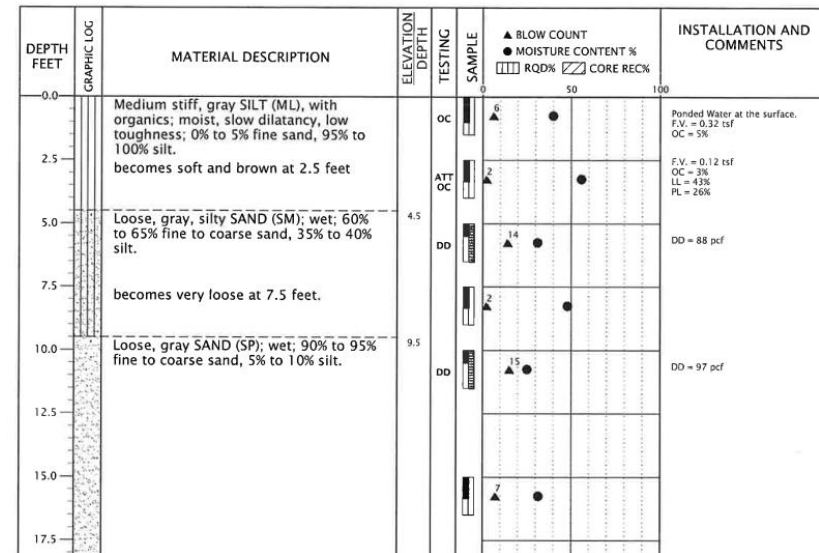
The surficial soil deposits within the interior of the island are identified on the local soil survey map (NRCS, 2005) as mainly Puget Silty Clay Loam and Tidal Fluvaquents. A soil survey map of NRCS within the project area is presented on Figure 3.

Based on the NRCS description, the Puget Silty Clay Loam formed in alluvium. The surficial layer is dark gray-brown silty clay loam approximately 9 inches thick and is underlain to a depth of 60 inches or more by green-gray to gray silty clay loam. Permeability is reported to be slow. The Puget Silty Clay Loam is described as consisting of 85 to 95 percent silt- and clay-sized particles, with a liquid limit varying from 25 to 45 and a plasticity index between 5 and 20. The Puget Silty Clay Loam is not identified by the NRCS as being an "organic soil".

Tidal Fluvaquents are generally present within the historic abandoned river channels in the northern interior of the island and surrounding the island on the outside of the perimeter embankments. The soil typically consists of light gray to gray, stratified discontinuous layers and lenses of silt loam and stratified sand to silty clay with 45 to 90 percent of fines and liquid limits varying from 25 to 45 percent and a very low plasticity index. It is generally poorly drained and a salt-affected soil on tidal flats.

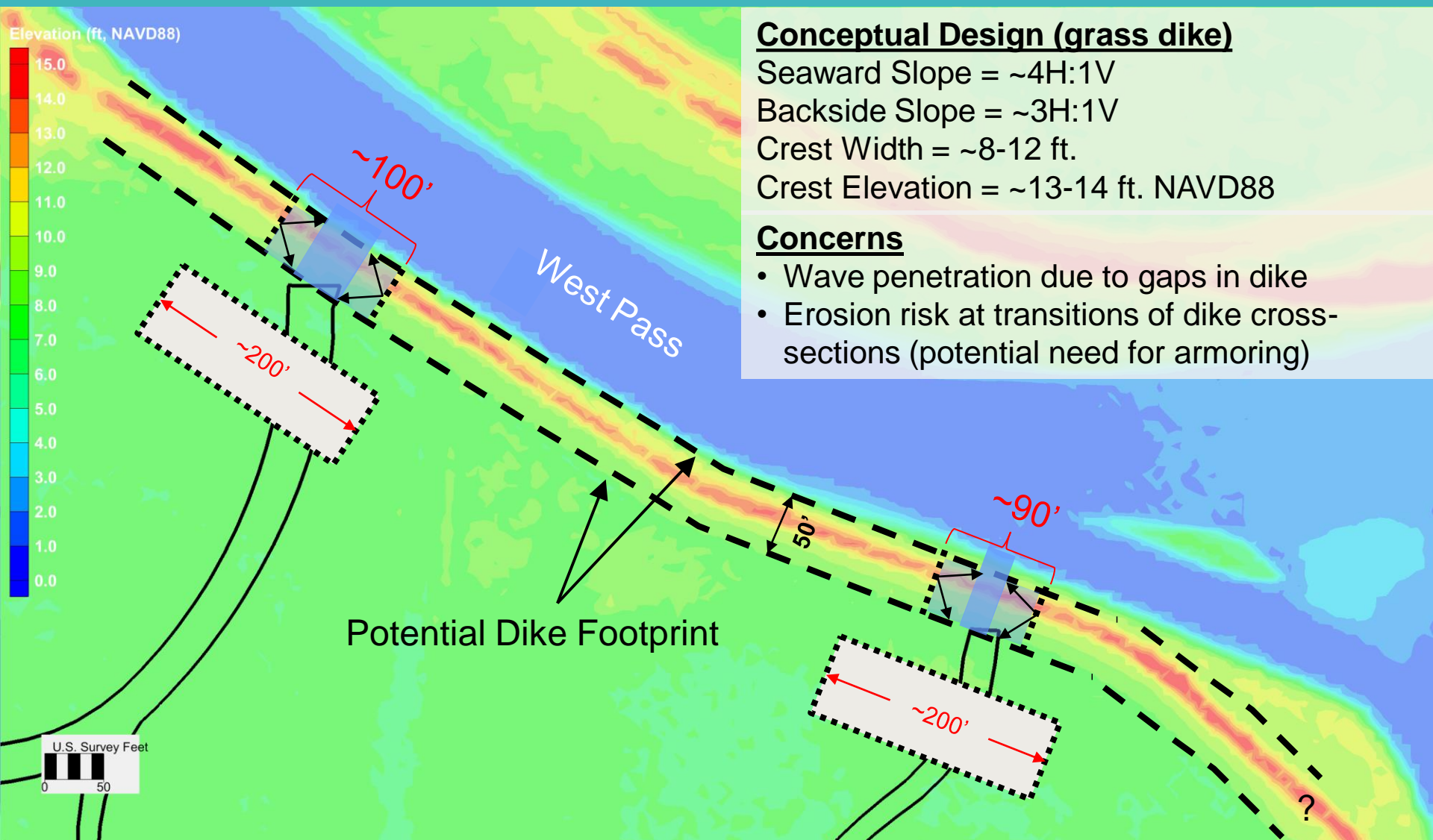
4.4.2 Silt/Clayey Silt

The surficial soil typically consists of organic-rich soil a few inches thick that grades to a stiff silt to clayey silt with trace sand, organics and roots. The organic content decreases with depth. The silty/clayey silt generally extends to depths varying from 2 to 6 feet BGS.



- Loamy, silty, clayey soil. Appears to be fairly cohesive.
- Some sandy material found subsurface
 - Appears generally good material for dike re-use
 - More detailed analysis likely needed

Potential Leque Dike Footprint



Conceptual Design (grass dike)

Seaward Slope = $\sim 4H:1V$

Backside Slope = $\sim 3H:1V$

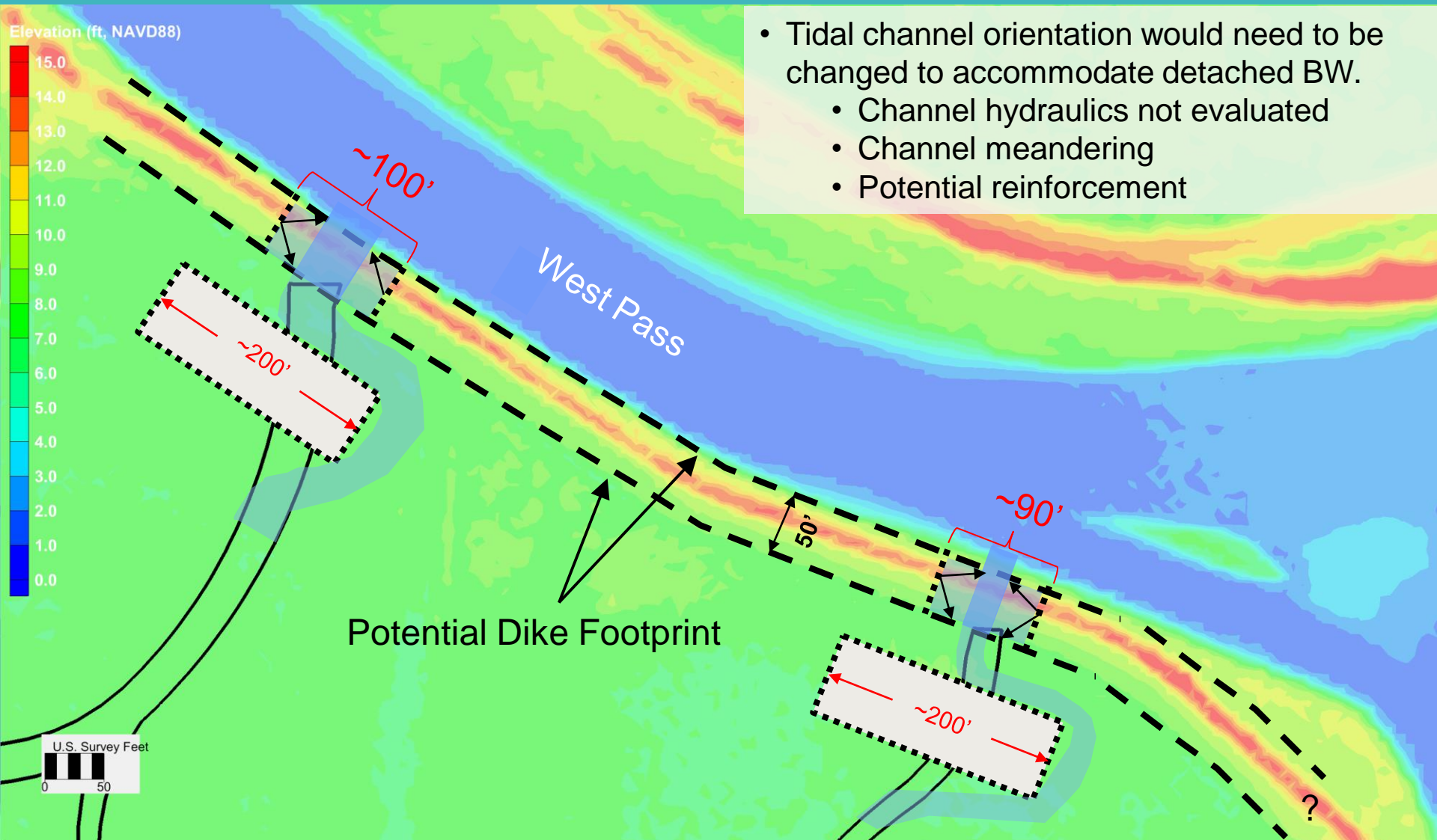
Crest Width = $\sim 8-12$ ft.

Crest Elevation = $\sim 13-14$ ft. NAVD88

Concerns

- Wave penetration due to gaps in dike
- Erosion risk at transitions of dike cross-sections (potential need for armoring)

Potential Leque Dike Footprint



Summary

- **Existing:** Leque dike protects City-dike from wave scour and overtopping. City dike primarily exposed to riverine flooding, not intended to protect against coastal wave scour/overtopping.
- **Coastal Protection:** Full removal of Leque dike would require modifications to city-dike to provide same level of coastal protection landward of city-dike.
- **Leque Island Dike Recommendations:** A portion of the dike should remain along West Pass. Modification of the existing dike is recommended, and likely use existing soil, depending on sand content. Vegetation is required. Dike crest similar to existing, width extended to minimize scour risk.
- **Partial Leque Island Dike Removal:** Wave propagation through gaps in Leque Island dike (tidal channels) would likely require localized modification to the city-owned dike. To provide same level of existing protection it could require significant construction.
- **Detached Berm Breakwater:** To maintain existing level of protection at city-dike berms required at tidal channels. Requires investigation of channel hydraulics. May require armoring or marine mattress at transitions
- **Next Steps:**
 - Decision on tidal channels
 - Recommendations for Leque Dike extents (north/south)
 - Brief technical memo with appendix

Project Objectives

- **TASK 1: Will the city-owned dike overtop and fail due to changes in wave climate if the Leque Island dike is fully removed?**
 - Yes
- **TASK 1, 2: To maintain performance of the city-owned dike, does a portion of the Leque Island dike need to remain?**
 - Yes
- **TASK 2: If a part of the dike needs to remain, how much, and what changes are required?**
 - Crest elevation increase → Footprint increase. Extent of removal dependent (in part) on tidal channels.

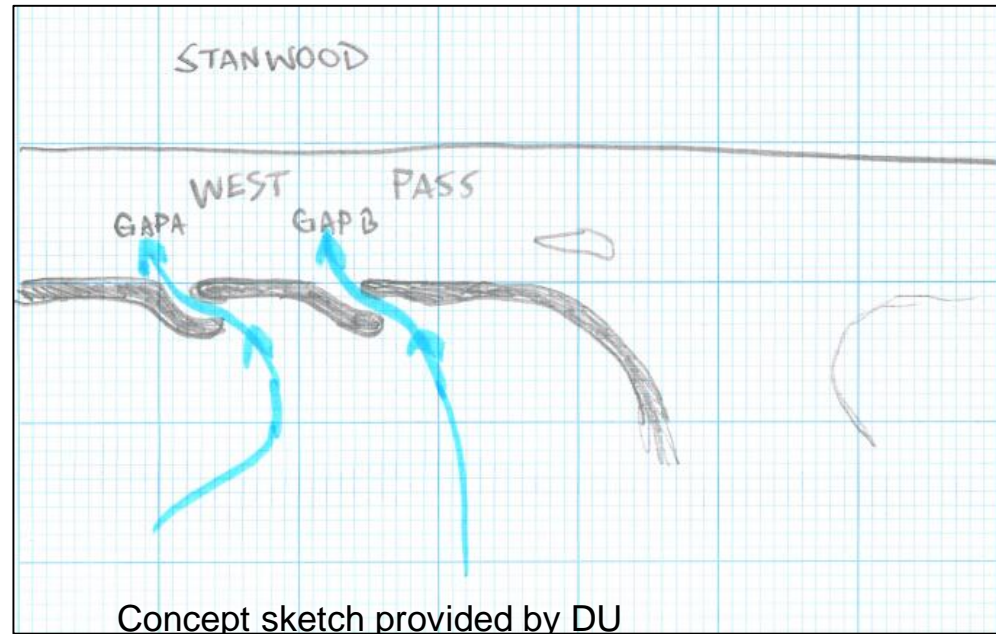
Supplemental Slides

Supplemental Slide Set

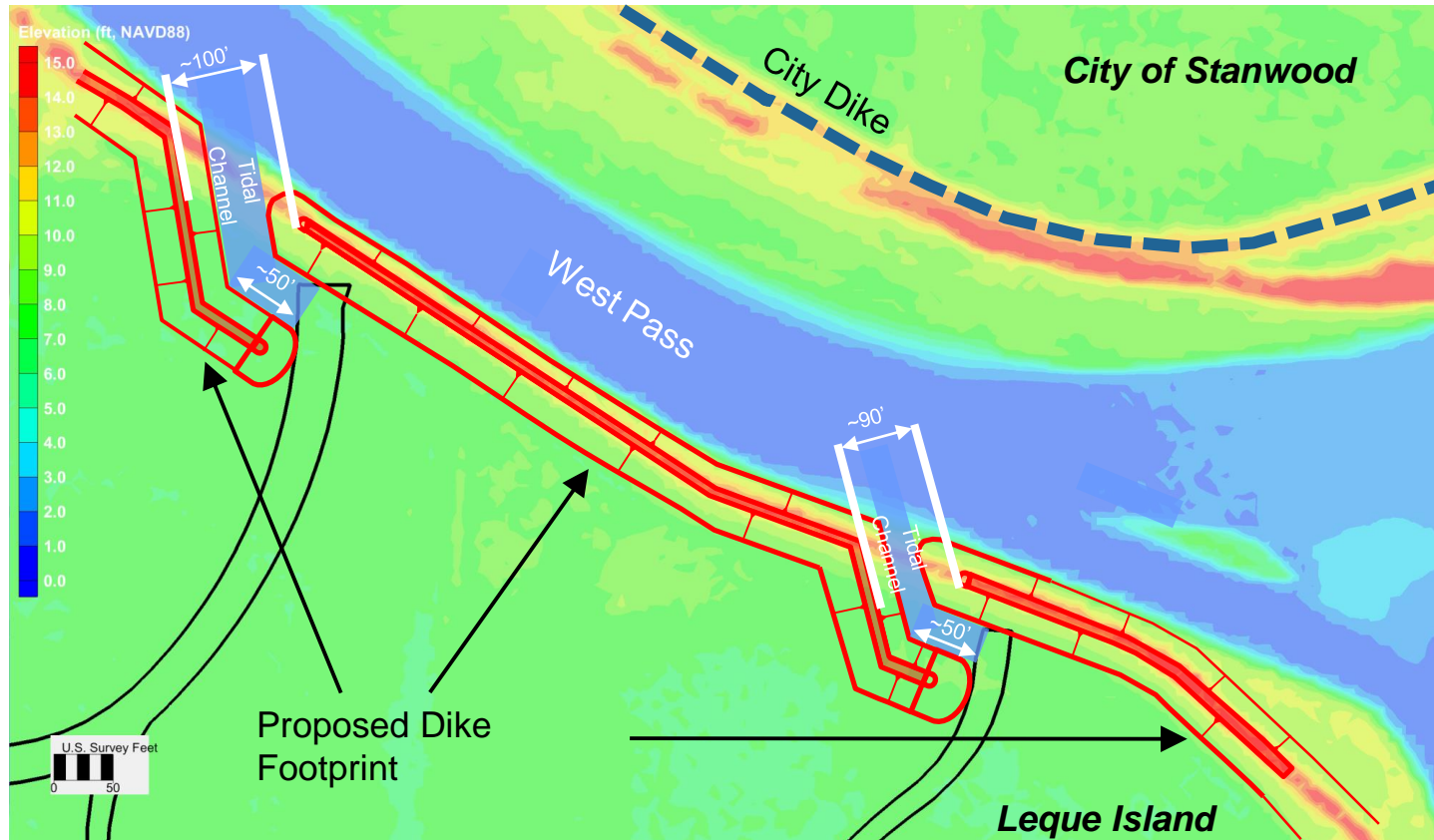
Feasibility Assessment: Alternate Tidal Channel Breakwater/Berm Configuration

Purpose:

Determine if tidal channel configuration proposed by DU/WDFW is feasible for Leque dike.

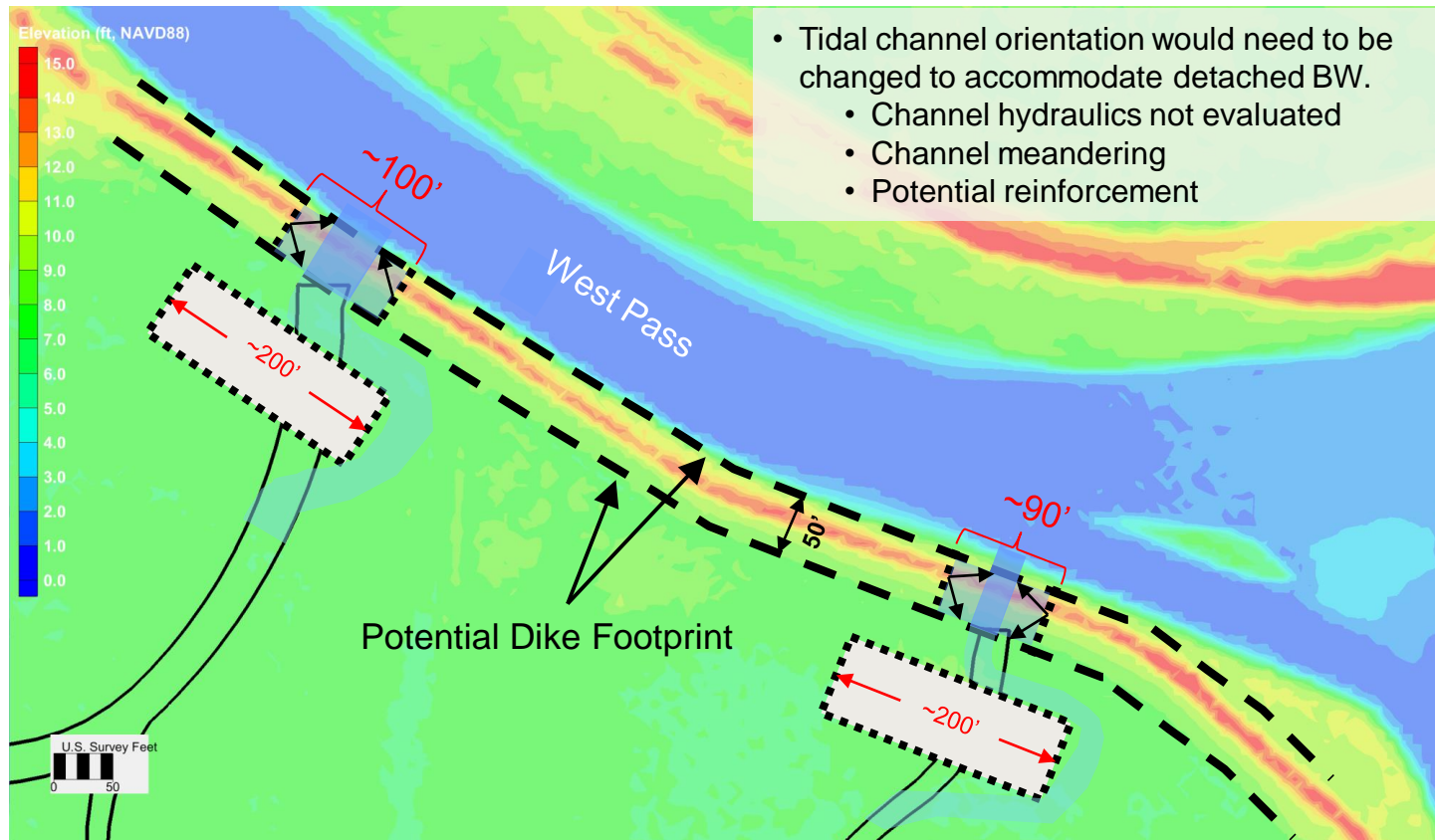


Potential Leque Dike Tidal Channel Gap Concept (by DU/WDFW)



Notes: Scale is approximate. Exact tidal channel and outlet locations/orientations may vary

Potential Leque Dike Tidal Channel Gap Concept (by MM)



Is WDFW/DU Concept Alternative Feasible?

- The WDFW/DU concept meets required wave protection criteria at City Dike (similar to MM developed detached breakwater alternative), and appears to be geometrically feasible.
- In order to prove feasibility of tidal channels for either the DU or MM tidal channel gap concepts, the hydraulics in the tidal channels must be analyzed (not part of this SOW). Potential sour risks must be addressed prior to design/construction.
- The tidal channel dike outlet size, geometry, and need for scour protection, need to be determined based in a hydraulic analysis to ensure tidal channel outlet stability.
- If the two tidal channel gaps in this segment of the Leque dike are removed from the design, no further hydraulic analysis is required.

Dike Extents

