Appendix G

Ship Wake and Morphology Assessment Report

The following appendix contains complex data and modeling output that may not meet Web Content Accessibility Guidelines (WCAG) AA accessibility guidelines. If you experience difficulty reading or interpreting any of the information on the following pages, please contact the Port of Redwood City at c-dsnaman@redwoodcityport.com or (650) 306-4150 to request a plain-text version, structured data table, or direct assistance.

APRIL 2025
CDM SMITH INC.

Port of Redwood City - Ferry Terminal Environmental Review

SHIP WAKE AND MORPHOLOGY ASSESSMENT REPORT

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SHIP WAKE AND MORPHOLOGY ASSESSMENT REPORT

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1 SUMMARY

The shoreline impacts of a proposed passenger ferry service linking Redwood City, Oakland, and San Francisco were analyzed as part of the environmental review process for the ferry terminal at the Port of Redwood City, CA. This investigation was undertaken to evaluate the potential morphological changes to the shoreline caused by wake generated by ferry transits and to identify strategies to mitigate these impacts.

As ferry transportation expands to meet regional connectivity and sustainability goals, understanding its environmental implications is critical. This study focuses on the hydrodynamic and morphological effects of ferry wake on the nearshore environment, particularly in areas along the ferry route near the Port of Redwood City.

The study involved the development and application of numerical models to analyze vessel wake propagation and associated shoreline profile changes. These models provided critical insights into the potential morphological impacts on the shoreline, enabling a thorough evaluation of the environmental implications of ferry operations; It included:

- Numerical Modeling of Vessel Wake: A hydrodynamic model was developed to simulate the wake generated by ferry transits. The model incorporated moving pressure fields representing vessel motion to generate time series of wake heights and periods at specific shoreline profiles along the route. These results were synthesized into composite datasets reflecting the ferry schedules.

- Morphological Modeling of Shoreline Profiles: The XBeach model was utilized to assess sediment transport and shoreline morphology changes. Simulations were conducted using cross-shore profiles extracted from topo-bathymetric data and supported by assumptions such as constant water level, uniform sediment characteristics, and no tidal variation. The simulation represented the equivalent of one year of ferry wake impacts.

The results of the study revealed the following insights:

- Wake Characteristics: Modeled ferry wakes had impacts at higher vessel speed (35 knots), with maximum heights ranging from 0.03 ft at Profile 8 with 7 knots speed and to 1.9 ft at Profile 4 with 35 knots speed. The wake height varies depending on the location and vessel speed. The lower speed modelled, 7 knots, showed minimal wake effects.

- Shoreline Morphology Changes: Profile changes were observed in areas exposed to higher wake energy, particularly at faster vessel speeds. Minimal changes were observed at profiles where the vessel speed was 7 knots.

To minimize adverse shoreline impacts while maintaining efficient ferry operations it is recommented a reduction in vessel speeds. Results showed that the vessel speed 7 knots resulted in insignificant shoreline erosion and profile changes.

2 Introduction

Considerable planning has been conducted by the Port of Redwood City in partnership with the City of Redwood City, the San Francisco Bay Area Water Emergency Transportation Authority (WETA) in association with the San Mateo County Transportation Authority (SMCTA) to support the implementation of a passenger ferry service linking Redwood City to Oakland and San Francisco.

The proposed project will establish a passenger ferry service operated by San Francisco Bay Ferry at the Port of Redwood City, connecting it with San Francisco and Oakland. This initiative aligns with regional goals to enhance transportation options, ease congestion, and create a more accessible and vibrant waterfront.

Redwood City has long been considered a potential ferry terminal site, with planning studies dating back to the early 2000s. WETA, which oversees ferry expansion, has identified the city as a priority in its 2050 Service Vision and Expansion Policy. Feasibility studies have confirmed the Pacific Shores/Westpoint Slough site as the best location for the terminal due to its favorable navigation conditions and reduced dredging requirements.

By integrating transportation, sustainability, and economic growth, this project plans to strengthen Redwood City's role in the regional transit network while enhancing public access to the waterfront.

2.1 Scope

This document summarizes the wake analysis and profile morphology analysis prepared as part of the environmental review services for the ferry terminal at Port of Redwood City, CA.

The wake and morphology analyses described here include the development of numerical models to evaluate the vessel wake and profile morphological changes along the ferry route and discussions on the simulation results. A very fine resolution numerical model was forced with moving pressure fields representing the motion of vessel to obtain time series of water level at locations along the shoreline profiles.

These time series were temporally super-imposed to obtain a composite time series according to the ferry operation schedule and then were converted to inputs required for the morphological modeling of shoreline profiles.

The main analysis objective was to identify the areas of any potential change to the shoreline and evaluate the impact of the passing ferries.

3 Data Basis

This section describes the data sources used as foundation for the analysis conducted in this study. It outlines relevant datasets, environmental conditions, and geographical details.

3.1 Bathymetry

Bathymetry was derived from two sources—USGS DEM and local topo-hydrographic surveys.

- **USGS DEM** (2023): A digital bathymetric model with 1/3 arc-second (approximately 10 m) resolution, derived from diverse source data. The DEM covers the conterminous United States, Hawaii, Puerto Rico, other territorial islands, and limited areas of Alaska. See Figure 3-1 (left) for extent of coverage available within the model domain used in this study.

- **Local Topo-Hydrographic Survey** (2023): Topo-bathymetric survey of area was conducted in August 2023 by (eTrac 2024). See Figure 3-1 (right) for data and extent.

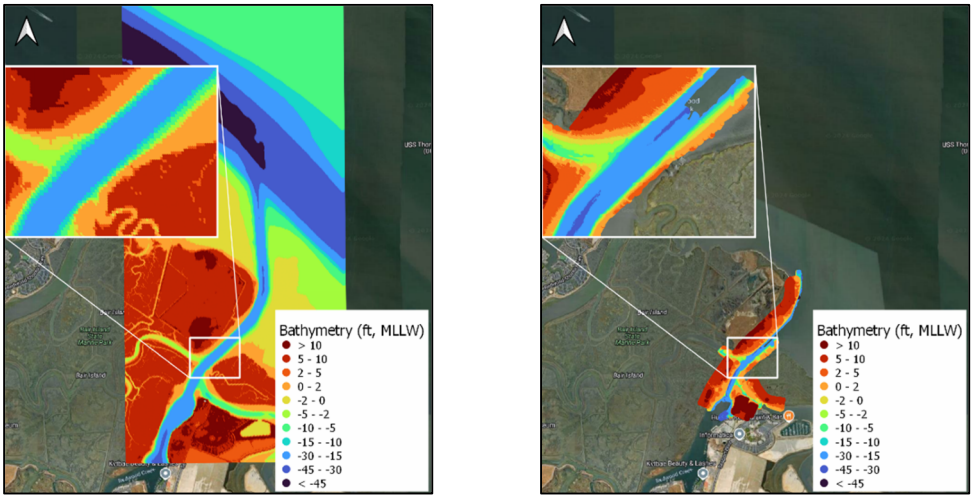


Figure 3-1 Bathymetry data obtained from USGS DEM (left) and topo-hydrographic survey (right).

3.2 Ferry Route

Since the ferry route is not operational yet, the route required for this study was based on the path taken by the ballpark pilot service conducted on September 15, 2024, shown in Figure 3-2. Figure 3-2 also overlaps the ten (10) locations where the changes in the cross-shore profile were analyzed.



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Figure 3-3 shows a screenshot of the ferry wake during the ballpark service. The video was used as a high-level visual guidance of the magnitude of the wake along the shoreline, associate with the respective ferry speed.



Figure 3-3 Ferry wake generated during ballpark pilot service in September 2024.

Figure 3-4 shows the generated ferry track for both incoming and outgoing ferry transits. Figure 3-2 shows that in the ballpark runs, the vessel speed was typically 35 knots in the bay up to

Point 5 and transitions to 6-7 knots within the channel leading to the Redwood City ferry terminal. During the outbound transit, the vessel speed was 6-7 knots within the channel up to Point 5 and transitions to 35 knots from that point onwards towards the bay.

The same speed transitions were maintained in the incoming and outgoing generated ferry tracks. The locations where the speed changes are also labelled in Figure 3-4.

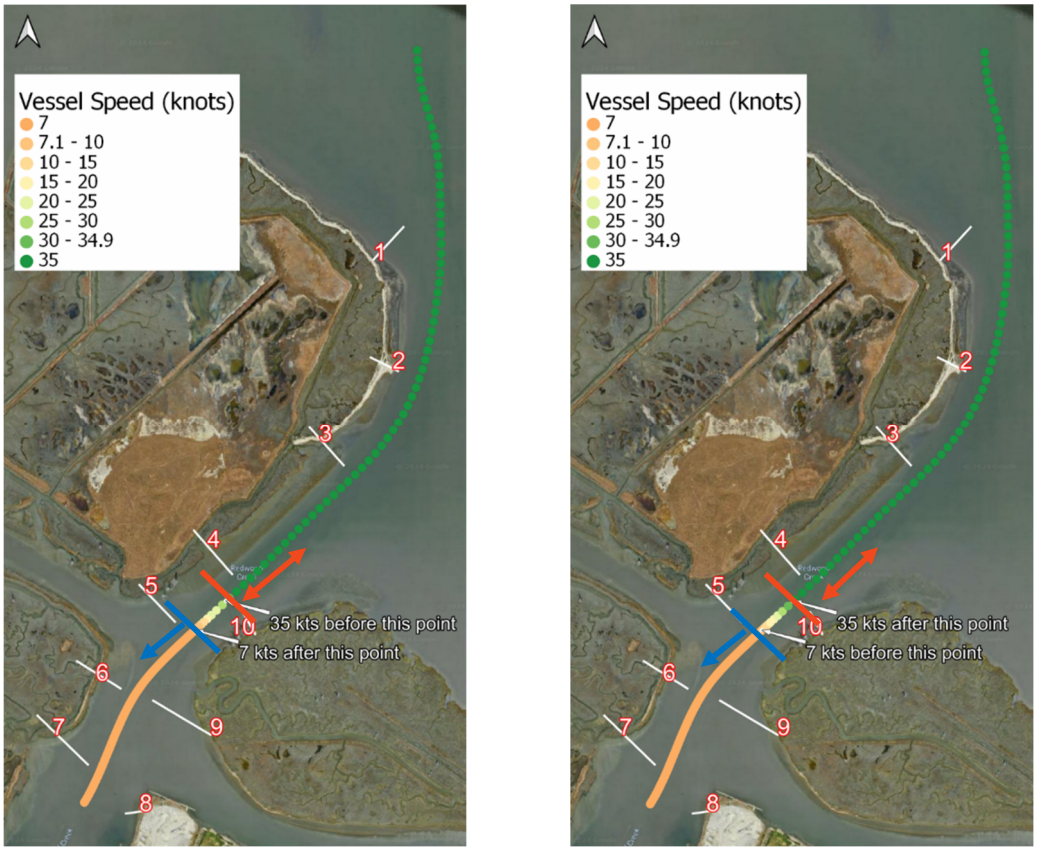


Figure 3-4 Incoming (left) and outgoing (right) ferry tracks.

3.3 Ferry Schedule

Vessel operation schedule followed the sample schedules specified in Ref (CDM Smith 2023). Oakland - Redwood City Sample Schedule (Weekdays) and San Francisco – Redwood City Sample Schedule (Weekdays and Weekends) are shown in Figure 3-5 and Figure 3-6, respectively.

Table 1: Oakland – Redwood City Sample Schedule (Weekdays)

Boat	Depart OAK	Arrive RWC	Depart RWC	Arrive OAK
Boat 1	6:15 AM	7:20 AM	7:30 AM	8:35 AM
Boat 2	7:20 AM	8:25 AM	8:35 AM	9:40 AM
Boat 1	9:20 AM	10:25 AM		
Boat 2	10:25 AM	11:30 AM		
Boat 1			2:20 PM	3:25 PM
Boat 2			3:00 PM	4:05 PM
Boat 1	4:10 PM	5:15 PM	5:25 PM	6:30 PM
Boat 2	4:50 PM	5:55 PM	6:05 PM	7:10 PM



Figure 5: Oakland - Redwood City Route Map

Figure 3-5 Oakland - Redwood City Sample Schedule (Weekdays) and Route (snapshot from Ref (CDM Smith 2023))

Table 2: San Francisco – Redwood City Sample Schedule (Weekdays)

Boat	Depart SF	Arrive RWC	Depart RWC	Arrive SF
Boat 1	5:50 AM	6:45 AM	6:55 AM	7:50 AM
Boat 2	6:20 AM	7:15 AM	7:25 AM	8:20 AM
Boat 1	8:35 AM	9:30 AM	9:40 AM	10:35 AM
Boat 2	9:05 AM	10:00 AM		
Boat 1			1:55 PM	2:50 PM
Boat 2			2:55 PM	3:50 PM
Boat 1	3:00 PM	3:55 PM	4:40 PM	5:35 PM
Boat 2	4:00 PM	4:55 PM	5:45 PM	6:40 PM

Table 3: San Francisco – Redwood City Sample Schedule (Weekends)

Boat	Depart SF	Arrive RWC	Depart RWC	Arrive SF
Boat 1	9:30 AM	10:25 AM	10:35 AM	11:30 AM
Boat 2	10:15 AM	11:10 AM	11:20 AM	12:15 PM
Boat 1	12:30 PM	1:25 PM	1:35 PM	2:30 PM
Boat 2	1:15 PM	2:10 PM	2:20 PM	3:15 PM
Boat 1	2:40 PM	3:35 PM		
Boat 3			2:00 PM	2:55 PM
Boat 4			3:15 PM	4:10 PM
Boat 3	3:05 PM	4:00 PM	5:00 PM	5:55 PM
Boat 2	3:25 PM	4:20 PM		
Boat 4	4:20 PM	5:15 PM	6:15 PM	7:10 PM
Boat 3	6:05 PM	7:00 PM	7:10 PM	8:05 PM
Boat 4	7:30 PM	8:15 PM	8:25 PM	9:20 PM

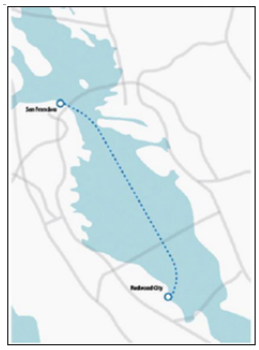


Figure 6: San Francisco - Redwood City Route Map

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3.4 Vessel Particulars

Information of the design vessel is listed in Figure 3-7 -Ref (CDM 2020).

Vessel Fleet

WETA's ferry fleet is composed of catamaran-style ships that can accommodate between 225 and 445 passengers. **Table 3-5** describes the characteristics of the controlling WETA vessel, which is the largest sized vessel type.

Table 3-5: Controlling Vessel Characteristics

Vessel	WETA NB445
Hull Type	Catamaran
Passenger Capacity	450 people
Displacement	225.1 long tons
Length at Waterline	144.3 ft.
Beam	39.4 ft.
Draft	4.92 ft.

Source: COWI, 2020

Figure 3-7 Design Vessel Information - Ref (CDM 2020)

3.5 Tidal Datums

The tidal elevations at the Project Site are taken from the NOAA Tide Station at Redwood City (#9414523) and are presented in Table 3-1

Table 3-1 Tidal elevations at the Project Site

Level / Datum	MLLW (ft)	NAVD88 (ft)
MHHW	8.20	7.02
MHW	7.57	6.39
MSL	4.40	3.22
MLW	1.20	0.02
MLLW	0.00	-1.18

4 Hydrodynamic Model

A local hydrodynamic model was developed using MIKE 21 Hydrodynamic (HD) module to quantify the effects of displacement wave, specifically the water flux generated by vessel movements as they pass through the study area. This section describes the methodology used to develop the model, including the key processes involved in setting up the simulation and a summary of the results of the MIKE 21 HD model.

4.1 Model Description

MIKE 21 HD model - Ref (DHI 2024) is a modeling system developed by DHI for two-dimensional (2D) free surface flows and can be applied to a wide range of hydraulic and related phenomena in lakes, estuaries, bays, coastal areas, and seas. This includes modeling of tidal hydraulics, wind and wave generated currents, storm surges, and flood waves. For a detailed software description see documentation for DHI MIKE 21 HD, Release 2024, which can be found online or requested from DHI.

The MIKE 21 HD model requires the following inputs:

- Bathymetry of the area
- Hydrographic boundary conditions (water levels, flow velocity components or fluxes)
- Wind and air pressure over the surface.
- Eddy viscosity and bed resistance (Manning number)

In one of the typical applications of MIKE 21 HD model, storm surge, i.e., water surface elevation, and current velocities during a hurricane can be determined by using 2D fields of pressure and wind velocity components obtained along the hurricane track. The 2D fields of pressure and wind velocity components vary in space and in time to represent the movement of the hurricane.

This application can be tailored in MIKE 21 HD model to allow vessel movement, in which the vessel motion is represented as a moving 2D pressure field. The 2D pressure field must be sufficient to create a surface depression imitating the presence of a vessel. The 2D pressure field representing a vessel will vary in space and in time to represent the vessel movement along its position track.

4.2 Modeling Methodology

The following methodology was adopted to evaluate the water surface elevation time series at the locations shown in Figure 3-2:

- Establishment of very fine resolution local hydrodynamic models—one for each incoming and outgoing passing vessel tracks, using bathymetries sourced from USGS and local surveys referenced in Section 3.1.
- Development of moving 2D pressure fields representing the motion of each of the vessel using MIKE 21 HD Passing Vessel tool.
- Force the local model with respective 2D pressure field.
- Extraction and analysis of time series of water level at locations shown in Figure 3-2.
- Creation of composite time series by temporally super-imposing incoming and outgoing water level time series according to the ferry operation schedule provided in Ref (CDM Smith 2023). Refer Section 3.3 for the schedule tables.
- The composite time series will be used as input to the morphologic (XBeach) model to evaluate changes in cross-shore profile.

4.3 Assumptions

This section outlines the key assumptions underlying the modelling methodology, which is designed to facilitate a comparative analysis of shoreline conditions with and without the influence of a passing ferry.

This analysis mainly focused on cross-shore sediment transport to evaluate the localized effects of ferry transits on the evolution of cross-shore profiles along the ferry route. To maintain a targeted and controlled scope, the study specifically examines cross-shore profiles in isolation. The influence of alongshore sediment transport and coastal vegetation dynamics has been excluded, as these factors are considered secondary in the context of a localized assessment. The exclusion of alongshore transport is particularly relevant in this case, as the primary objective is to discern relative changes in profile evolution that can be attributed directly to ferry-induced hydrodynamic forces.

The study aims to establish comparative trends across multiple locations identified for cross-shore profile analysis. A critical aspect of this investigation is assessing how variations in vessel speed along the route influence localized sedimentary changes. As such, broader environmental variables, including wind effects, tidal variations, and long-term sea level rise,

have not been incorporated into the model, ensuring that the results isolate the direct impact of the ferry. The focus was solely on how the passage of the vessel alters surface elevations and affects sediment transport dynamics.

Tidal variations, while recognized as a significant factor influencing morphological changes along the shoreline, were also not included in this study. Tidal fluctuations dictate the spatial extent of wave action and sediment movement, particularly around the waterline, which is where morphological changes are most pronounced. However, given that this study is structured as a comparative analysis—examining relative changes in sediment transport rather than absolute morphological evolution—tidal variability was controlled by using a constant mid-water level, specifically Mean Sea Level (MSL). This approach ensures that variations in profile evolution can be directly attributed to vessel-induced forces without the confounding effects of fluctuating water levels.

Similarly, while sea level rise plays a crucial role in long-term coastal evolution by shifting the location of the waterline and altering sediment dynamics, its exclusion from this study is justified. The primary reason is the study's relatively short timeframe—a one-year simulation—during which the impact of sea level rise is negligible. The focus remains on capturing the immediate and short-term variations in sediment transport patterns due to changes in vessel speed, rather than accounting for gradual, long-term geomorphological shifts.

Sediment sampling was not conducted along the ferry route and the shoreline.The shoreline sediment was assumed to consist of fine sand with a median grain size of 0.02 mm. Additionally, data limitations meant that Profiles 1, 9, and 10 relied on USGS DEM data rather than local surveys. Such data gap related to sediment and bathymetry data should be carefully considered when interpreting the results and applying them to shoreline management.

Additional research incorporating tidal variability, alongshore sediment transport, and vegetative effects could be undertaken to refine the assessment and improve the accuracy of estimates, although these factors are unlikely to affect the comparative understanding of the relative impacts of different ferry operation scenarios presented in this study.

In summary, the modelling methodology is structured to isolate the influence of ferry transits on cross-shore sediment transport while minimizing external variables that could introduce complexity or uncertainty. The assumptions applied ensure that the results effectively capture the relative differences in profile evolution across study locations, providing insight into the localized effects of vessel speed on shoreline morphology.

4.4 Model Domain and Mesh

The model domain and mesh used for incoming and outgoing passing vessel scenarios are shown in Figure 4-1. The model domains contain a segment of the navigation channel leading to Redwood City ferry terminal. Both meshes comprise quadrilateral elements of 2 m resolution along the vessel track. In areas outside the vessel track, triangular elements were used, whose side, i.e., mesh resolution was set to 10 m.

The model domains for respective tracks were extended backwards to the vessel trajectory, i.e., 'ramp-up' phase, to reduce any adverse surface fluctuation caused by a quickly moving pressure field within a constricted domain. The vessel speed is set to gradually increase from zero to actual value (35 knots in incoming and 7 knots in outgoing) in the span of these extensions.

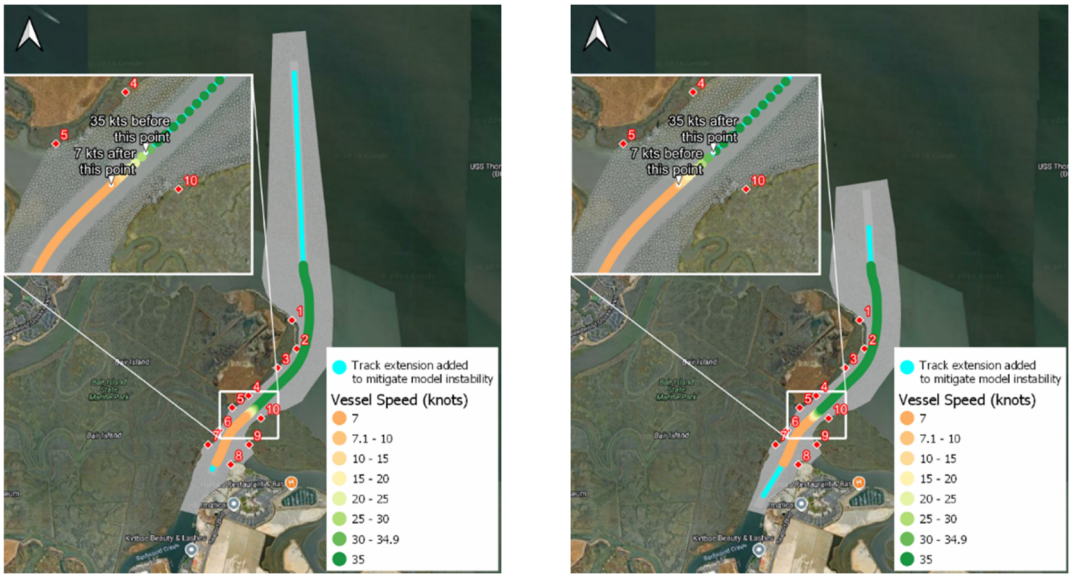


Figure 4-1 Hydrodynamic model mesh for incoming track (left) and outgoing track (right).

4.5 Water Level

Water level for the entire domain was set to Mean Sea Level, i.e., 4.40 ft-MLLW for both scenarios.

4.6 Pressure Field

The vessel movement along their respective tracks were specified as time-varying 2D pressure fields. The time-varying 2D pressure fields were generated using the PassingVessel numerical engine in MIKE 21 HD. The Passing Vessel numerical engine requires the vessel track, model mesh, vessel hull shape, and vessel draft as inputs.

The vessel tracks and model mesh used are as shown in Figure 3-4 and Figure 4-1. The hull shape for the passenger ferry was obtained by scaling a hull of a generic passenger vessel provided by DHI.

Scaling was performed along the vessel's principal axes to match the Length Overall (LOA), beam, and moulded depth values shown in Figure 3-7. Scaling coefficients used to obtain the hull used in the analysis are given in Table 4-1.

Table 4-1 Passing Vessel Hull Scaling Factors

Axis	Scale Factor
X	0.164
Y	0.372
Z	0.133

Figure 4-2 shows a sample snapshot of the pressure field generated in the model and the resultant surface elevation displacement. It can be noted that the PressureVessel numerical engine creates a 2D pressure field resulting in a surface displacement, i.e., vessel draft of 4.9 ft (see Figure 3-7).

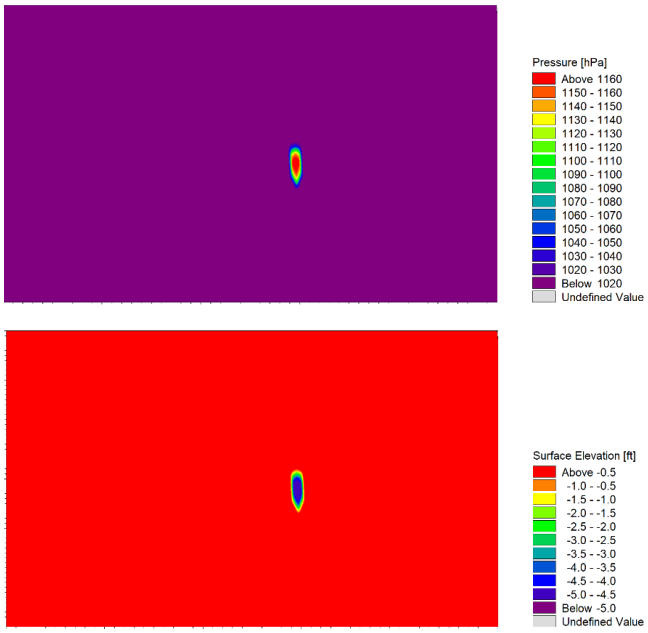


Figure 4-2 Pressure field representing the ferry (top) and the resultant displacement in water surface (bottom).

4.7 Initial Conditions

Spatially varying initial surface elevation field obtained from PassingVessel numerical engine was applied as the

4.8 Boundary Conditions

In both cases, the specified land boundary was specified as "Free Outflow". Model boundaries elsewhere

4.9 Model Results

The MIKE 21 HD model produces two-dimensional time series of water levels and water flux for the entire domain. These results show how much water moves throughout the project area as the ferry passes through the region. The results are later used as inputs for the shoreline profile morphological analysis.

Figure 4-3 presents a map of the instantaneous surface elevation as the incoming ferry approaches the bend at 35 knots, leading into the navigation channel from the bay. Additionally, Figure 4-3 includes the time series of water levels extracted at nearshore locations 1 to 10, with

their positions also indicated on the map. Figure 4-4 presents a map of the instantaneous surface elevation as the incoming ferry approaches the terminal at 7 knots.

Figure 4-5 shows a map of instantaneous surface elevation as the outgoing ferry enters the bay at 35 knots. Additionally, Figure 4-5 includes the time series of water levels extracted at nearshore locations 1 to 10, with their positions also indicated on the map. Figure 4-6 a map of instantaneous surface elevation as the outgoing ferry at 7 knots, shortly after it departs the terminal.

Figure 4-3 and Figure 4-5 indicate that every passing vessel wake wave is typically composed of one main wave form with smaller perturbations following it. The time period of main wave form is approximately 20-30 seconds.

Figure 4-3 to Figure 4-6 also show that the ship wake wave forms are mainly dependent on vessel speeds and that the directionality of the track, i.e., incoming or outgoing, has no impact on the wake wave generation.

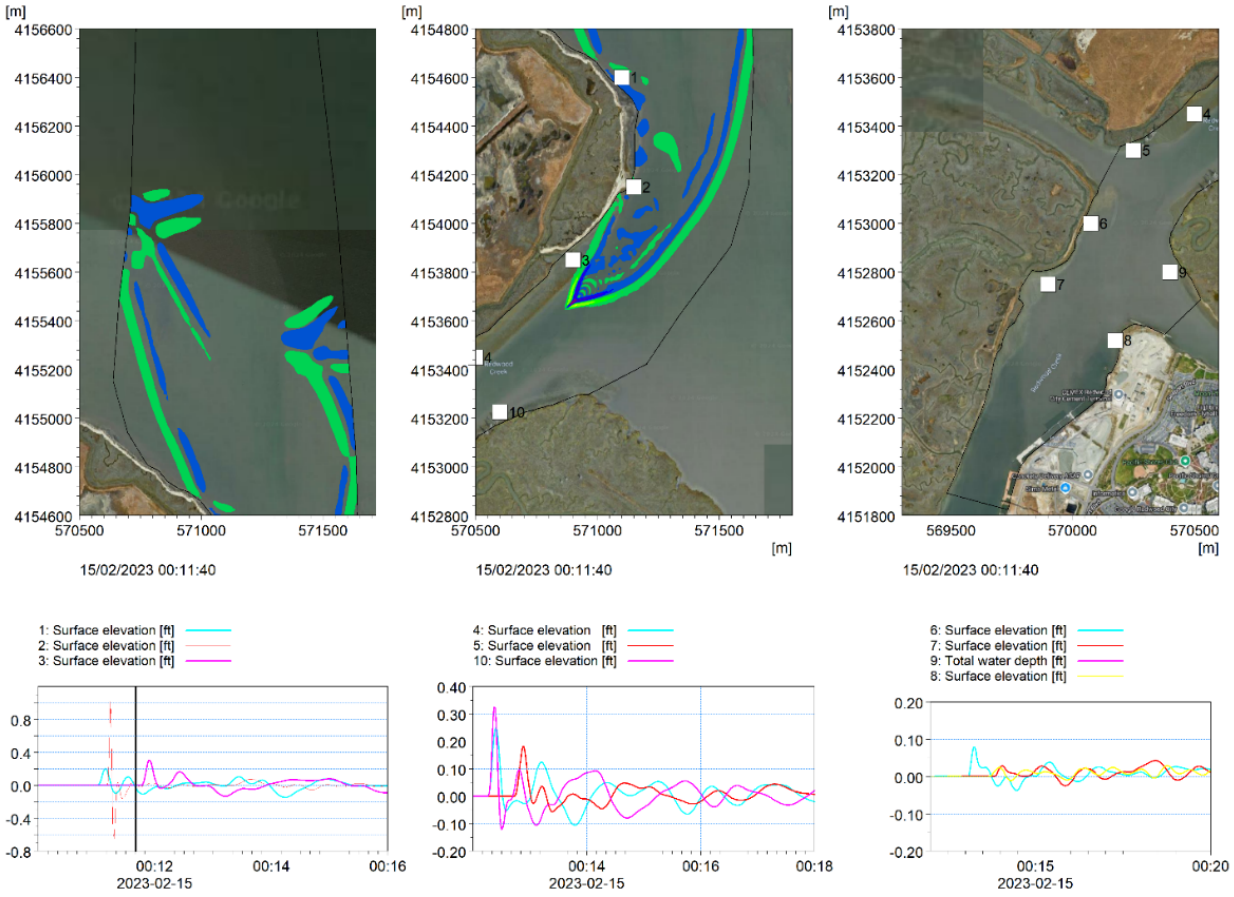


Figure 4-3 Instantaneous water surface elevation field during the incoming ferry transit at high speed.

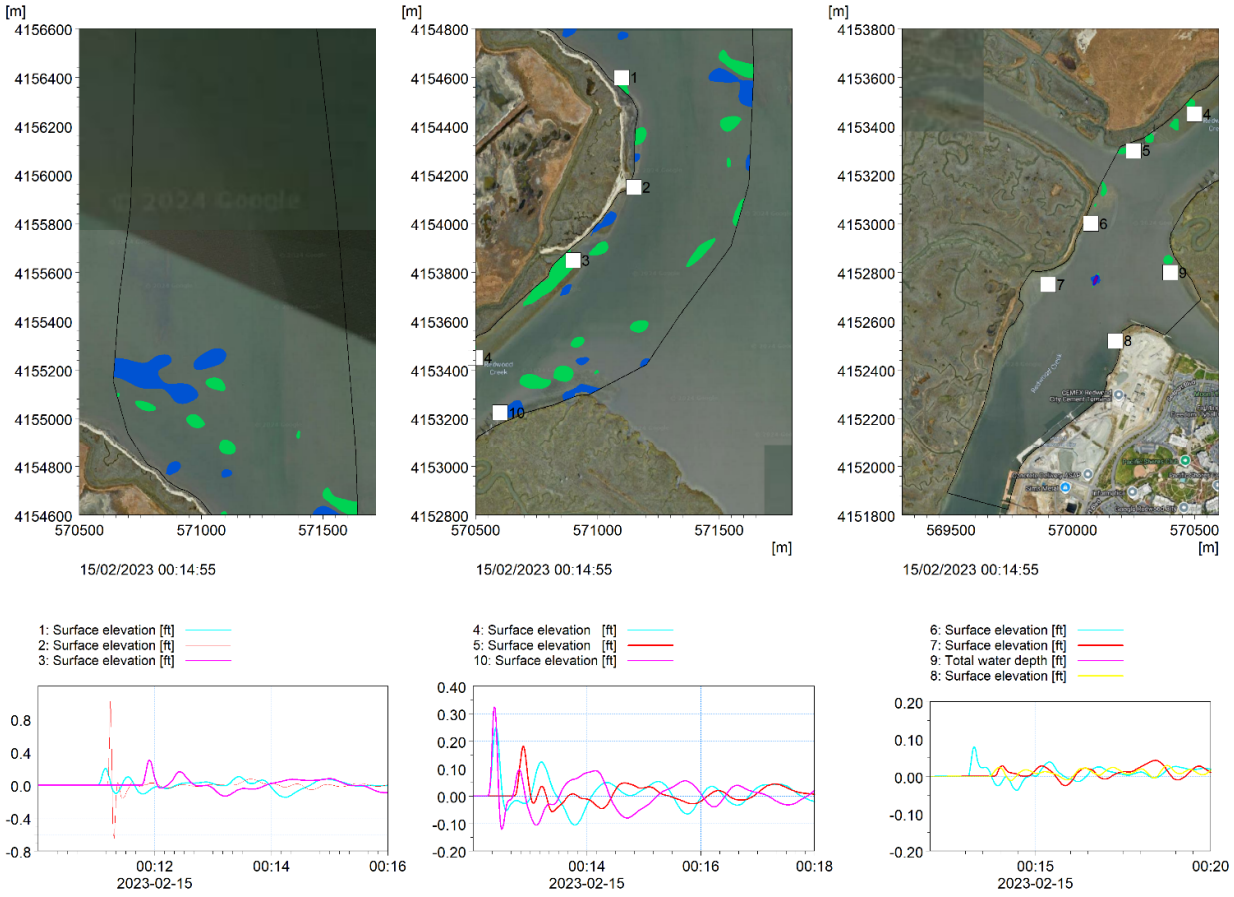


Figure 4-4 Instantaneous water surface elevation field during the incoming ferry transit at low speed.

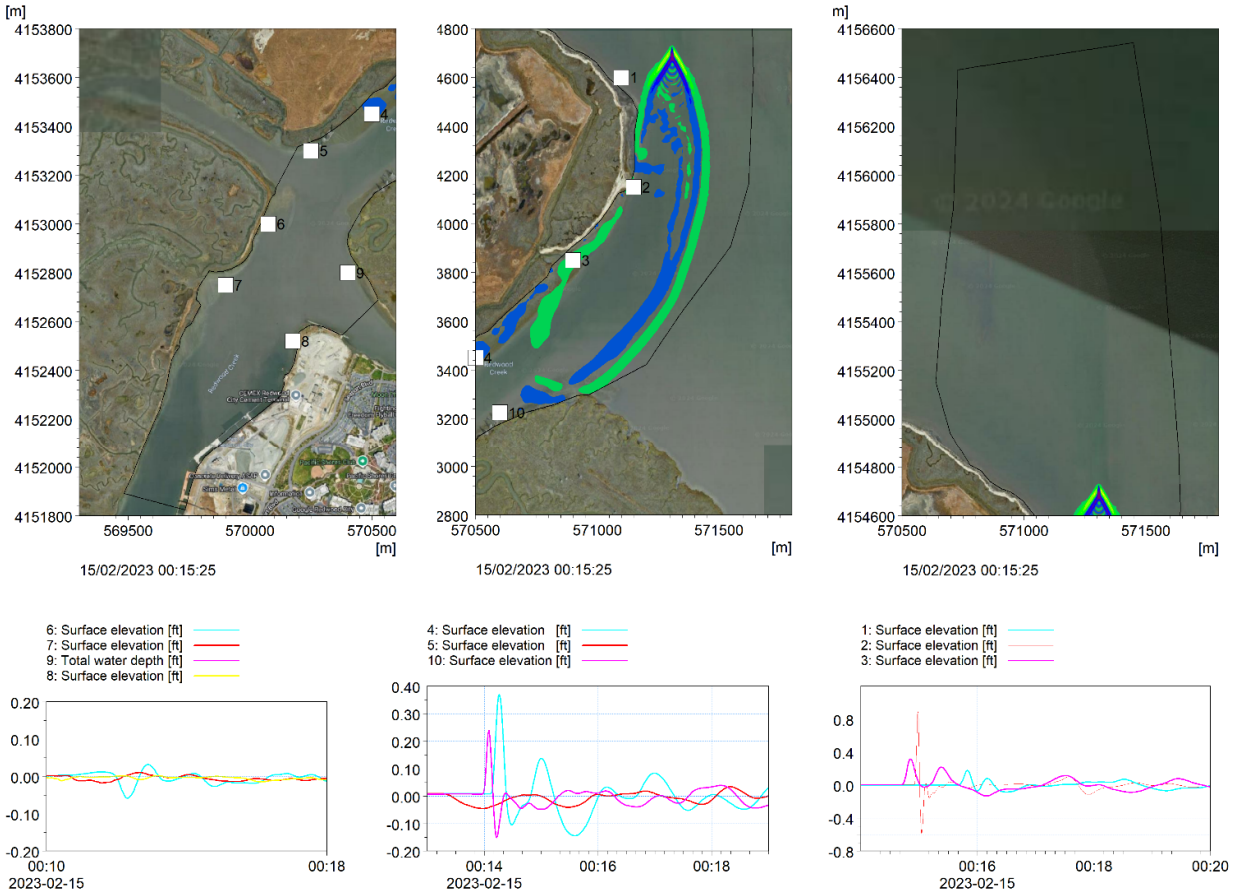


Figure 4-5 Instantaneous water surface elevation field during the outgoing ferry transit at high speed.

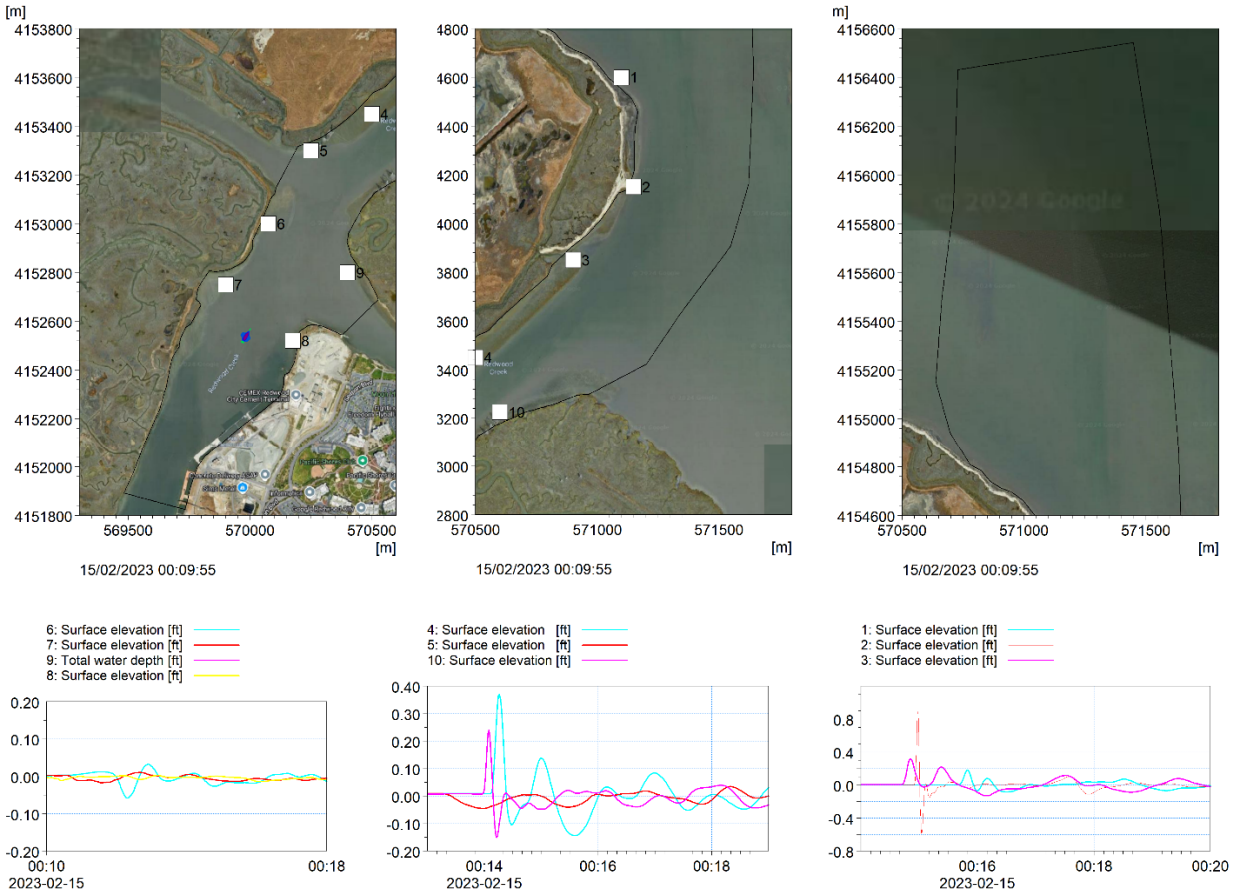


Figure 4-6 Instantaneous water surface elevation field during the outgoing ferry transit at low speed.

5 Shoreline Profile Morphological Analysis

The morphological analysis was performed using the numerical model XBeach to identify the areas of any potential change to the shoreline profiles and evaluate the impact of the passing ferries. This section describes the methodology, inputs, and a summary of the results.

5.1 Model Description

XBeach is a two-dimensional model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area, beaches, dunes and back barrier during storms. It is a public-domain model that has been developed with major funding from the US Army Corps of Engineers, Rijkswaterstaat and the European Union, supported by a consortium of UNESCO-IHE, Deltares, Delft University of Technology and the University of Miami. The model solves coupled 2D horizontal equations for wave propagation, flow, sediment transport and bottom changes, for varying (spectral) wave and flow boundary conditions.

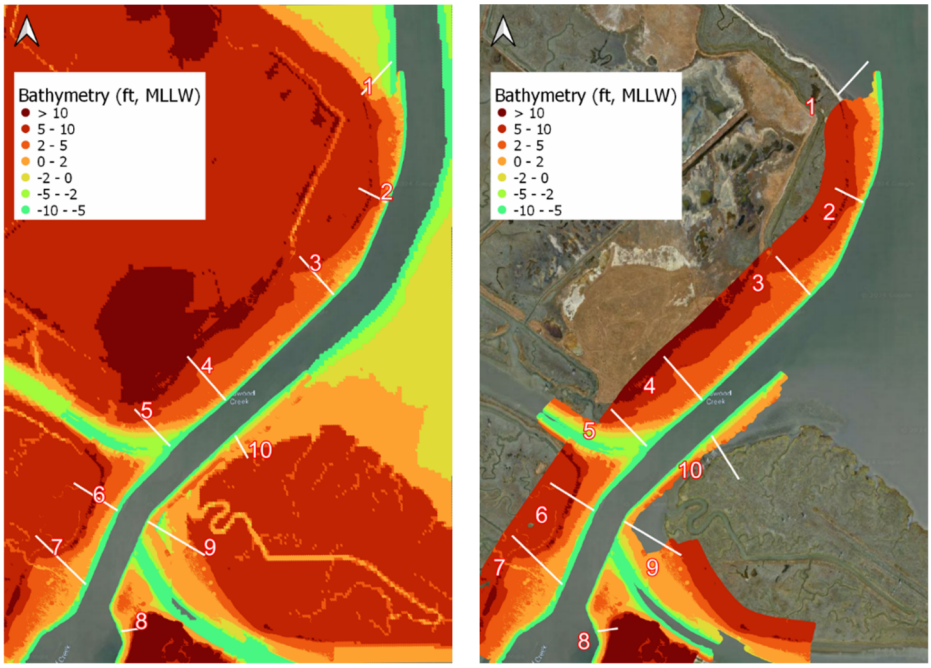
5.2 Modeling Methodology

The following methodology was adopted to evaluate the potential changes to the shoreline profiles at the locations shown in Figure 3-2:

- Extraction of profiles from the topo-bathymetric data.
- Establishment of effective wave height at the offshore end of each profile using results from the MIKE 21 HD models for incoming and outgoing transits.
- Determine the simulation time that can be considered equivalent to 1-year of passing vessel effects.
- Simulate the morphological changes for each profile at a constant water level of Mean Sea Level

5.3 Profiles

Figure 5-1 shows the topo-bathymetric data - Ref (eTrac 2024) available in relation to the sections of interest from the two sources described in Section 3.1. Figure 5-1 shows that Profiles 2 to 8 are entirely within the local survey data. However, portions of Profile 9, and entirety of Profiles 1 and 10 are outside the local survey data coverage. The data from USGS DEM data was used for those profiles.



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5.4 Bed Material

The shoreline bed material was assumed to be fine sand with median sediment size/diameter (D_{50}) of 0.02 mm.

5.5 Input Wave Parameters

MIKE 21 HD model results at the offshore end of each profile were extracted and used to create a day-long time series of wake waves following the ferry transit schedules provided in Section 3.3.

A combined table of ferry transit, obtained from information provided in Section 3.3, for weekday is provided in Table 5-1 and the same is provided in Table 5-2 for the weekend.

Table 5-1 Combined Ferry Schedule for Weekdays

Arrival Time	Departure Time	Start of Wake Wave	End of Wake Wave	Type of Transit
06:45		06:29	06:45	Incoming
	06:55	06:55	07:11	Outgoing
07:15		06:59	07:15	Incoming
07:20		07:04	07:20	Incoming
	07:25	07:25	07:41	Outgoing
	07:30	07:30	07:46	Outgoing
08:25		08:09	08:25	Incoming
	08:35	08:35	08:51	Outgoing
09:30		09:14	09:30	Incoming
	09:40	09:40	09:56	Outgoing
10:00		09:44	10:00	Incoming
10:25		10:09	10:25	Incoming
11:30		11:14	11:30	Incoming
	13:55	13:55	14:11	Outgoing
	14:20	14:20	14:36	Outgoing
	14:55	14:55	15:11	Outgoing
	17:00	17:00	17:16	Outgoing
15:55		15:39	15:55	Incoming
	16:40	16:40	16:56	Outgoing
16:55		16:39	16:55	Incoming
17:15		16:59	17:15	Incoming
	17:25	17:25	17:41	Outgoing
	17:45	17:45	18:01	Outgoing
17:55		17:39	17:55	Incoming
	18:05	18:05	18:21	Outgoing

UMrm 215K2 7oNrPt .2A LLH2dlT .Im 2foL2k Y t.E2

Arrival Time	Departure Time	Start of Wake Wave	End of Wake Wave	Type of Transit
10:25		10:09	10:25	Incoming
	10:35	10:35	10:51	Outgoing
11:10		10:54	11:10	Incoming
	11:20	11:20	11:36	Outgoing
13:25		13:09	13:25	Incoming
	13:35	13:35	13:51	Outgoing
14:10		13:54	14:10	Incoming
	14:00	14:00	14:16	Outgoing
	14:20	14:20	14:36	Outgoing
	15:15	15:15	15:31	Outgoing
15:35		15:19	15:35	Incoming
16:00		15:44	16:00	Incoming
16:20		16:04	16:20	Incoming
	17:00	17:00	17:16	Outgoing
17:15		16:59	17:15	Incoming
	18:15	18:15	18:31	Outgoing
19:00		18:44	19:00	Incoming
	19:10	19:10	19:26	Outgoing
20:15		19:59	20:15	Incoming
	20:25	20:25	20:41	Outgoing

Table 5-1 and Table 5-2 indicate that while there are 25 trips during the weekday, there are only 20 during the weekend. Hence the weekday schedule was used, conservatively, to create a day-long wake-wave time series at the offshore end of each profile. These timeseries are shown in Figure 5-2 to Figure 5-11, along with the section location.

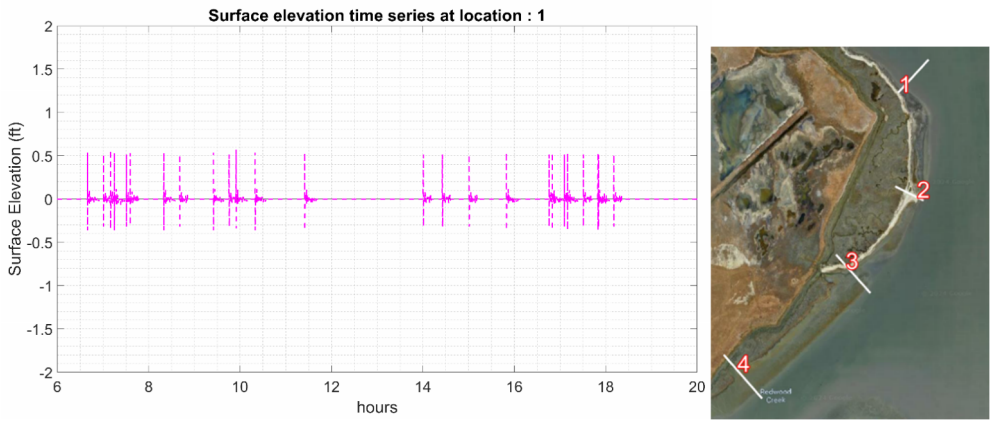
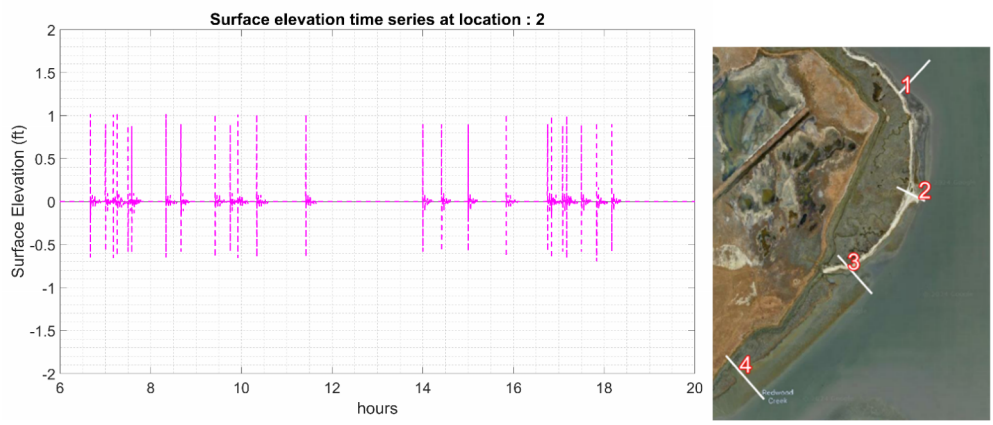
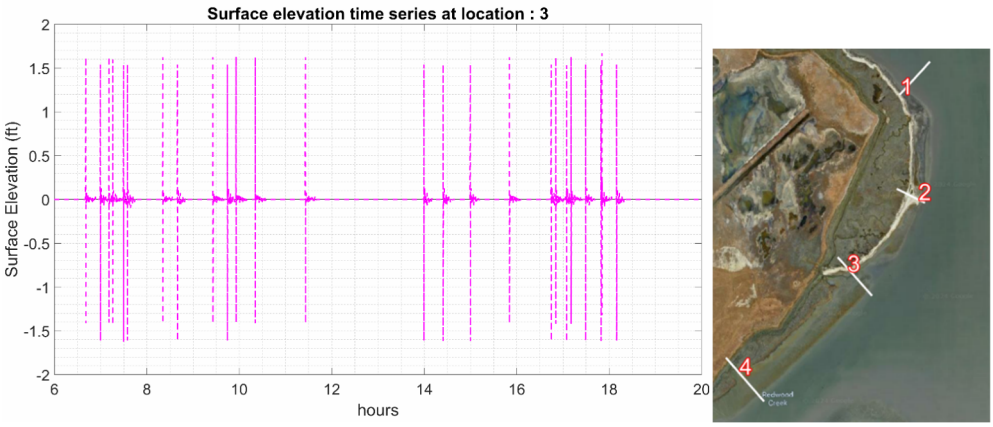


Figure 5-2 Wake wave time series over 24 hours of a weekday at offshore end of Profile 1.



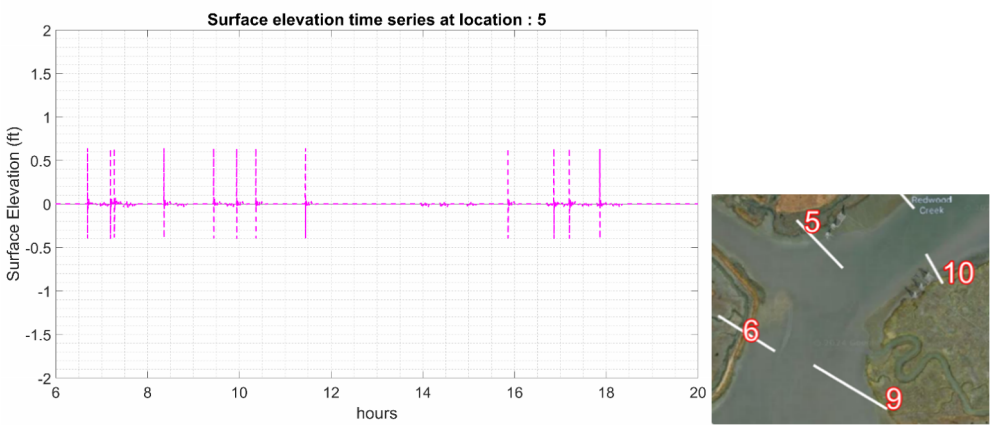
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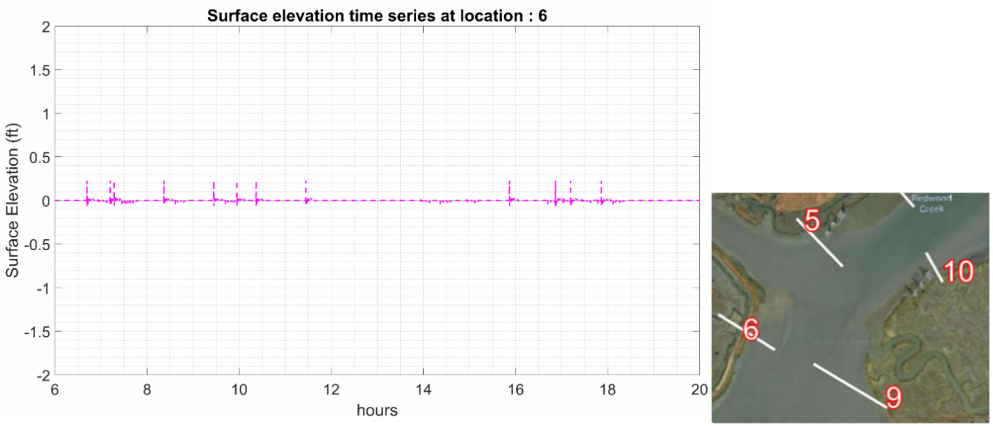
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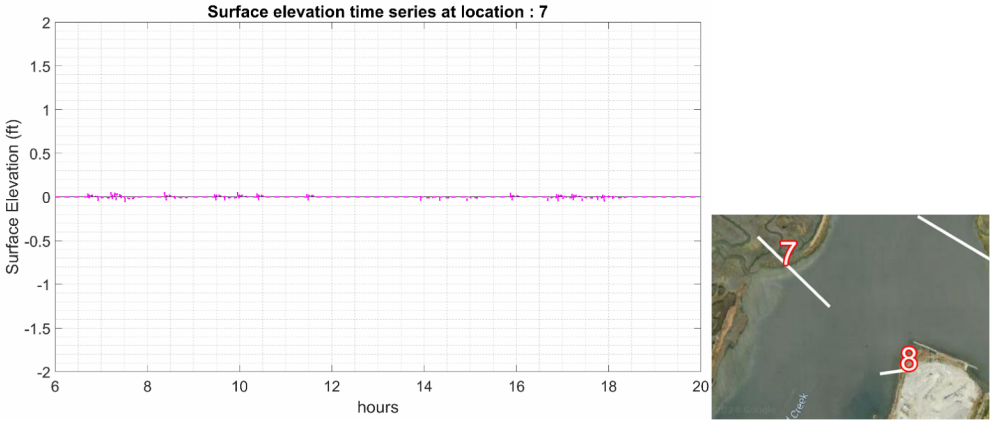
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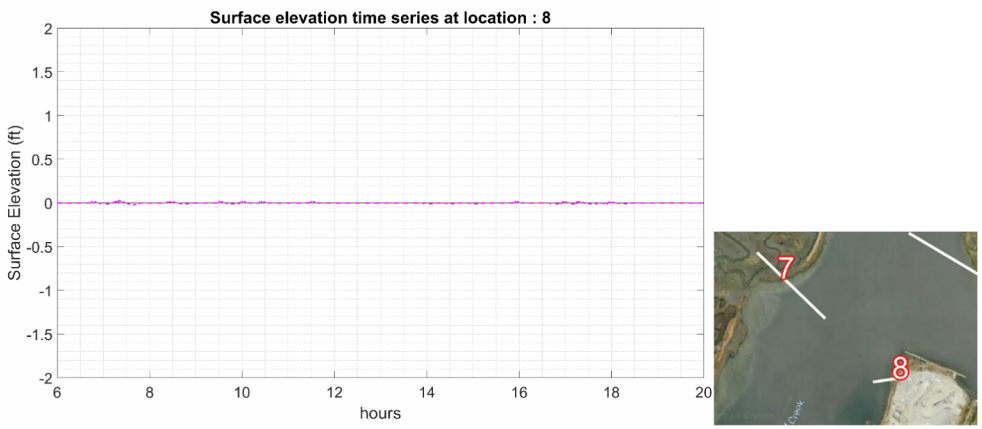
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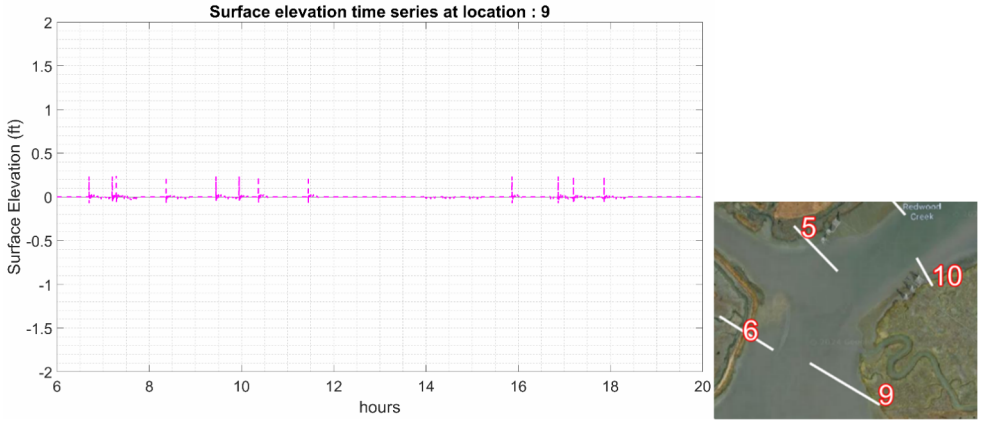
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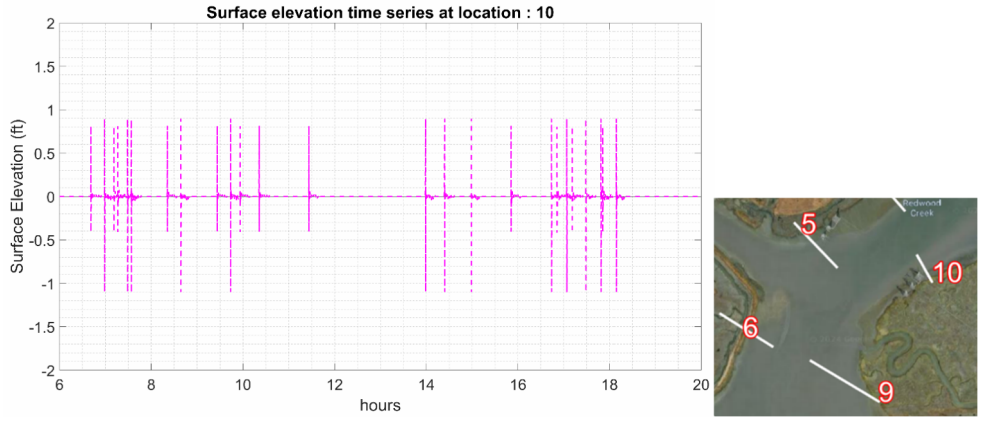
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APRIL 215B2 kMY 2GMv 2SPN 2E LP E2ov L2Kc2TolLE2of2M2G Y.MH2MS2offEToL 2 t.2of2+LofPm 2pW2



APRIL 215Ch2 kMY 2GMv 2SPN 2E LP E2ov L2Kc2TolLE2of2M2G Y.MH2MS2offEToL 2 t.2of2+LofPm 2BW2



APRIL 215CC2 kMY 2GMv 2SPN 2E LP E2ov L2Kc2TolLE2of2M2G Y.MH2MS2offEToL 2 t.2of2+LofPm 2ChW2

Table 5-3 summarizes the wave height of the main form at the offshore end each profile.

Table 5-3 Wake-height at different locations along the ferry route

Location	Vessel Speed (knots)	Height of main wave form (ft)
1	35	0.6
2	35	1.0
3	35	1.7
4	35	1.9
5	7	0.6
6	7	0.2
7	7	0.06
8	7	0.03
9	7	0.2
10	35	1.1

5.6 Simulation Duration

As seen in Section 4.9, the passing vessel wake wave is typically composed of one main wave form with smaller perturbations following it. Hence, it needs to be noted that such wave form cannot be defined using standard wave parameters. However, all morphological calculations are performed for waves with well defined parameters. The following method was adopted to convert the passing vessel wake wave into a form acceptable by the morphological numerical model, XBeach.

- There are approximately 24 wake waves every day on a typical weekday, each last for 20-30 seconds.
- 12 minutes of simulation time can consider equivalent to 24 h (1 day) of passing vessel wake wave effect.
- To represent 1 year, the simulation duration was determined to be 73 hours (365*12/60).
- The peak wave period was selected to be 25 seconds to align with the main wave form duration (20-30 seconds).

5.7 Water Level

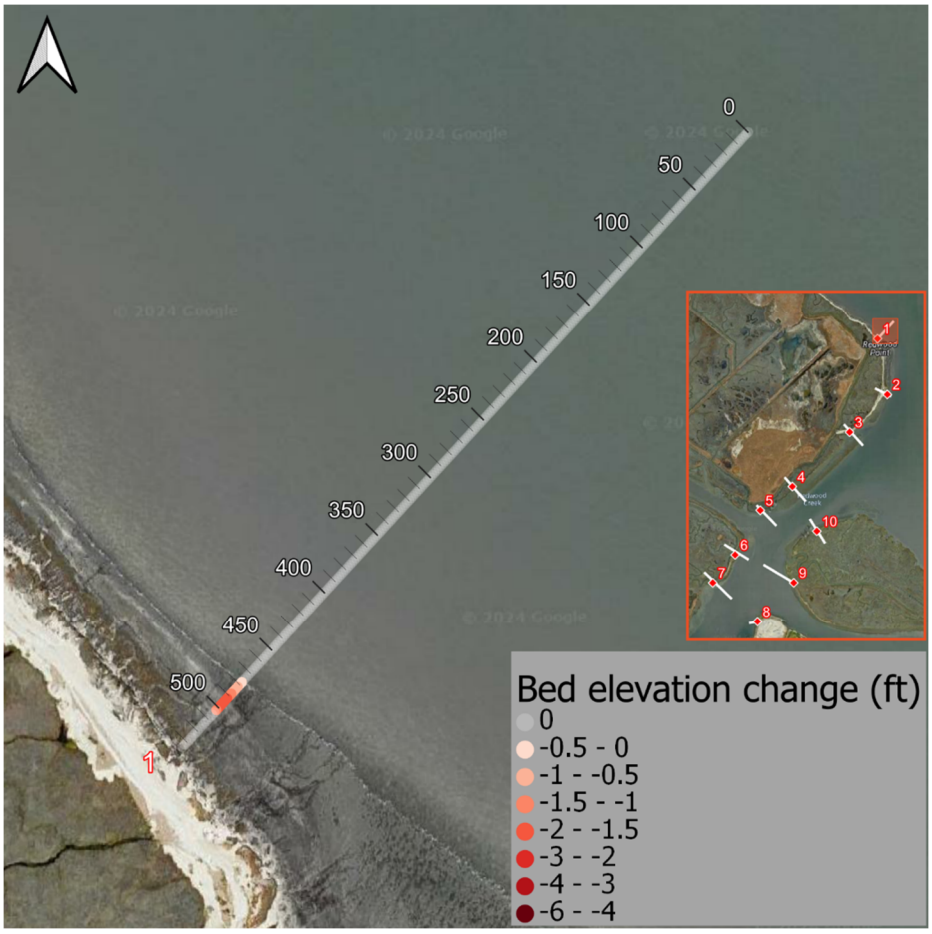
Water level for the morphological simulations was set to Mean Sea Level (4.40 ft-MLLW).

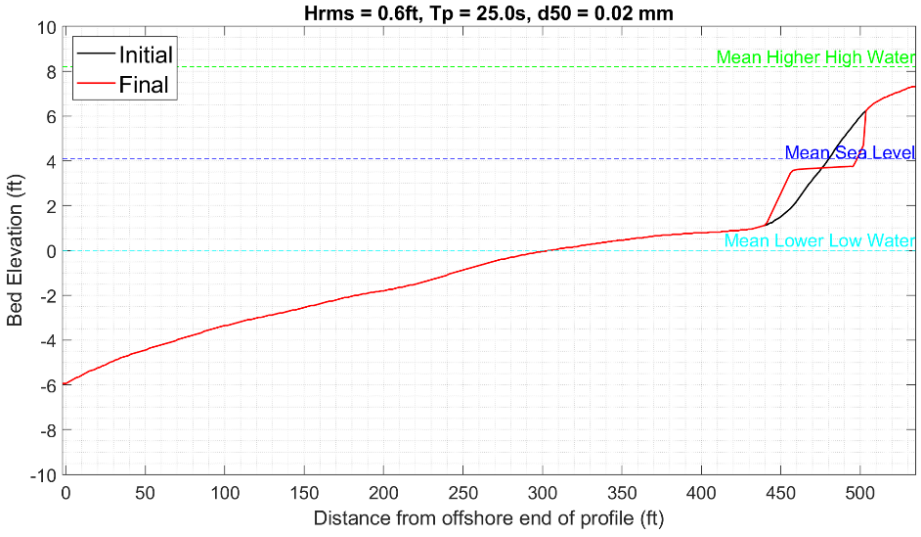
The varying tide will influence the pattern and locations of morphological change along the profile as the morphological changes are mostly centred around the water line. However, the results from this study are intended for use as a

comparative analysis, wherein the changes in profiles are to be analyzed to gauge the relative impact of passing vessel. Hence, the usage of a constant mid water level, i.e., Mean Sea Level.

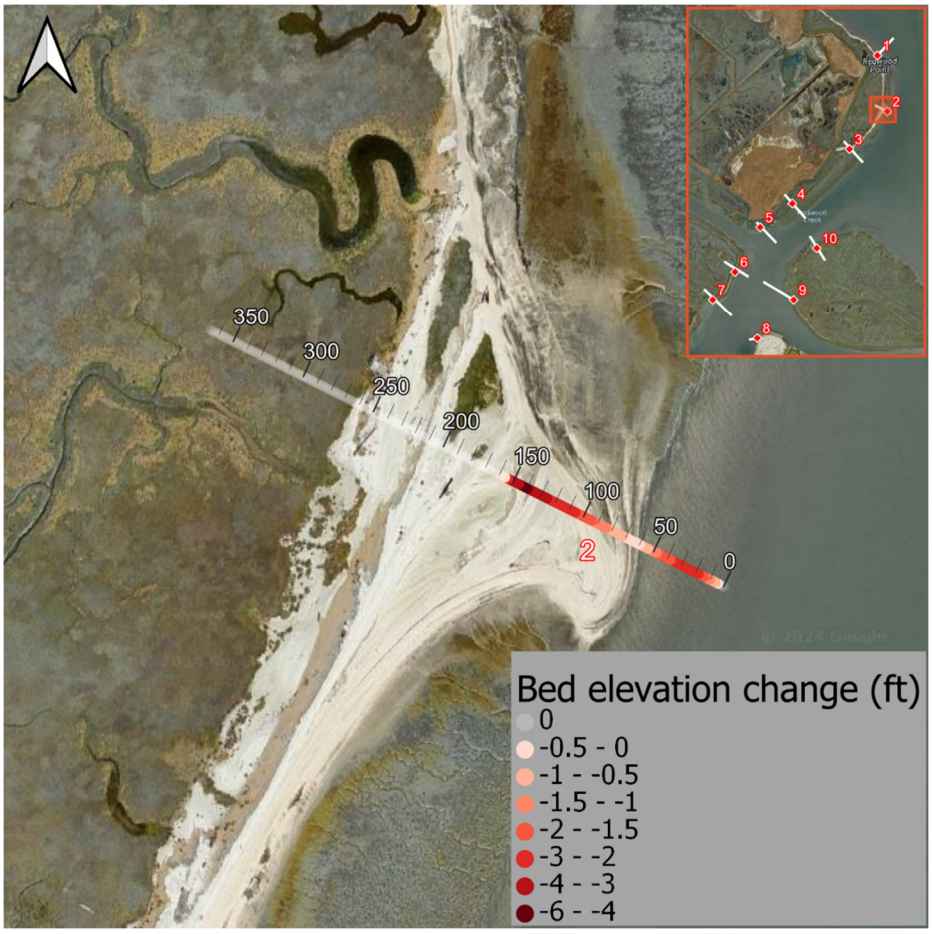
5.8 Model Results

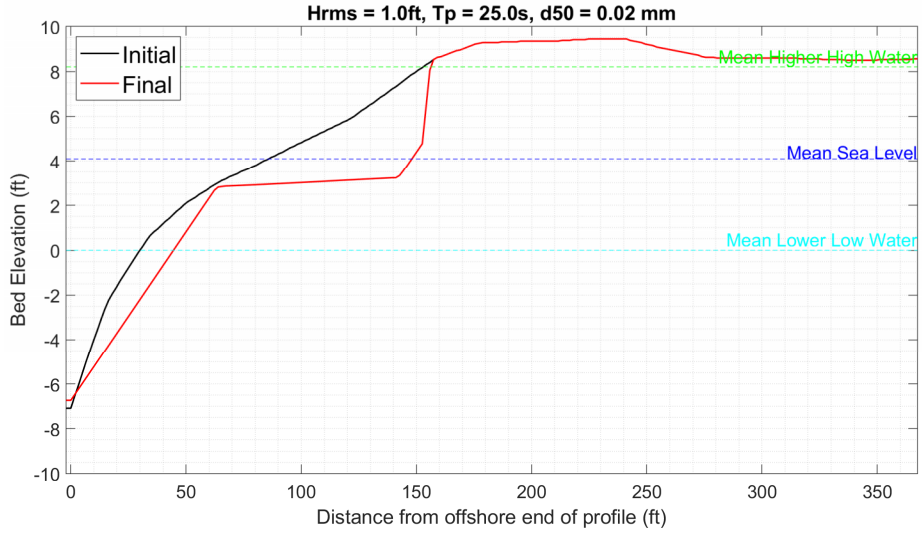
Figure 5-12 to Figure 5-20 show the estimated bed level change (plan and profile) after simulation of 73 hours, which is assumed to represent one year of passing vessel wake wave effect on the profiles.



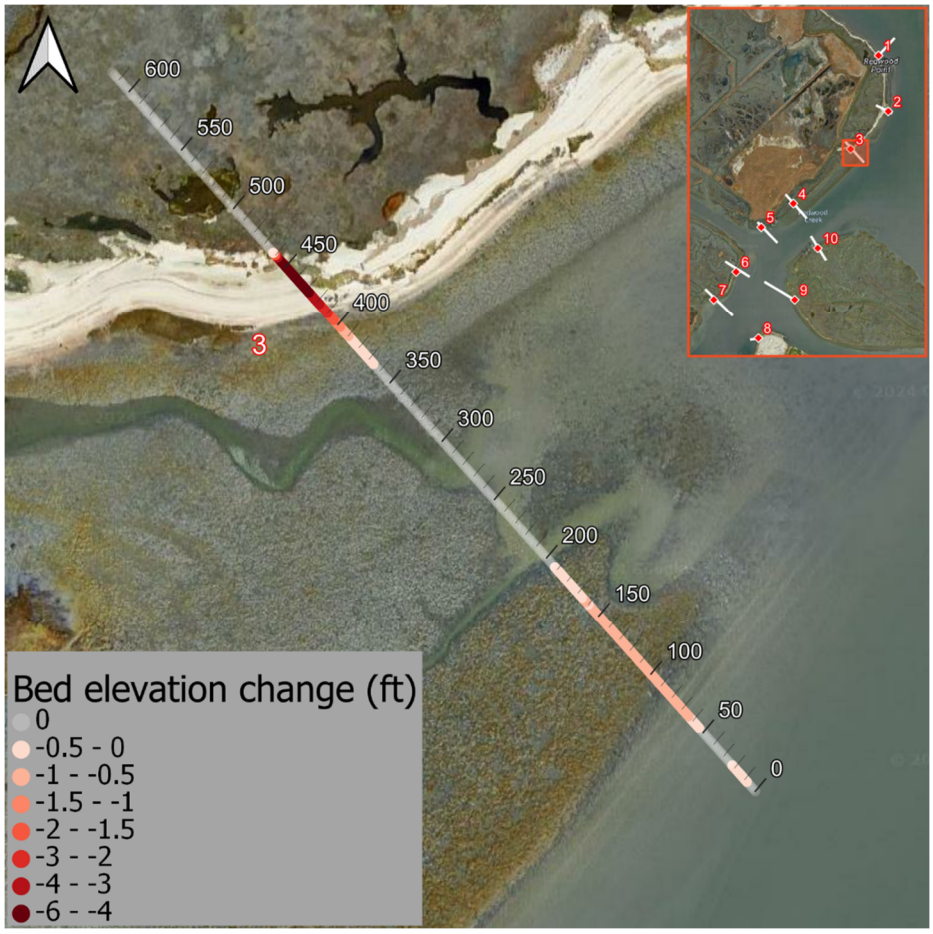


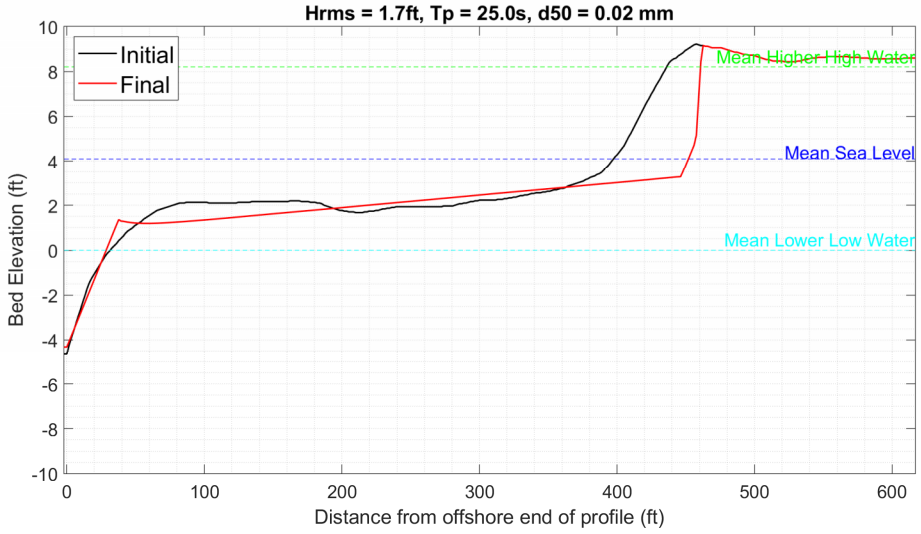
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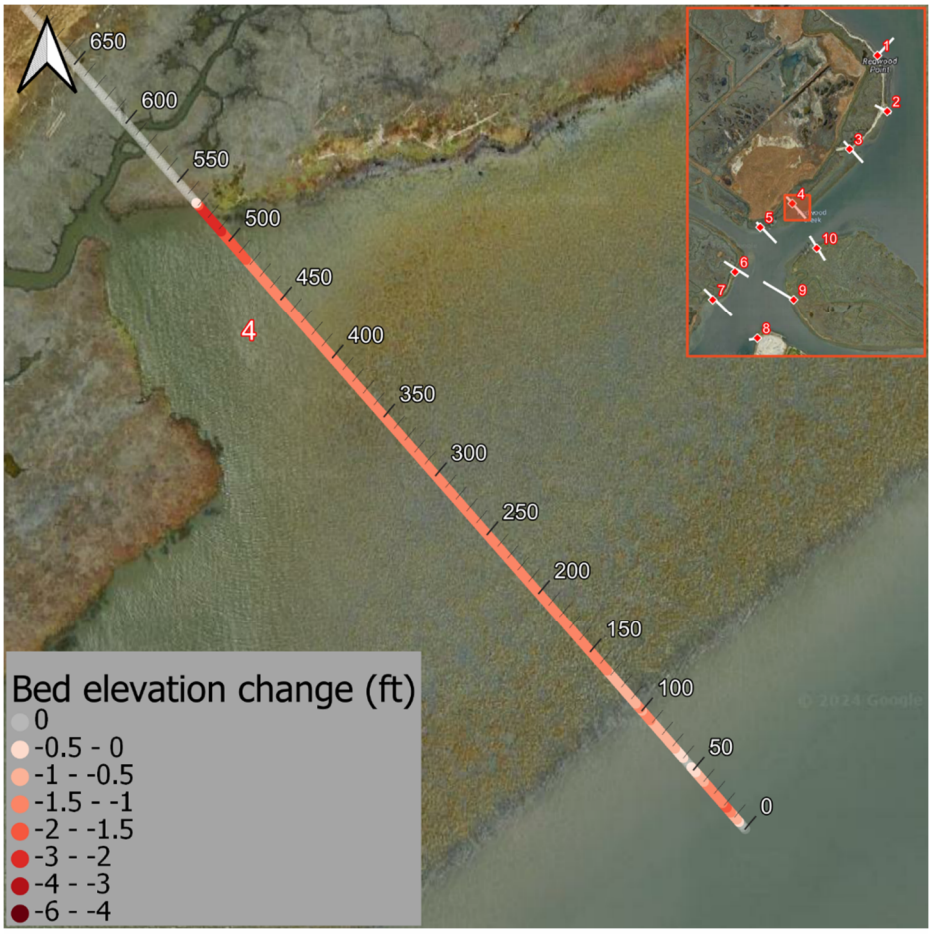


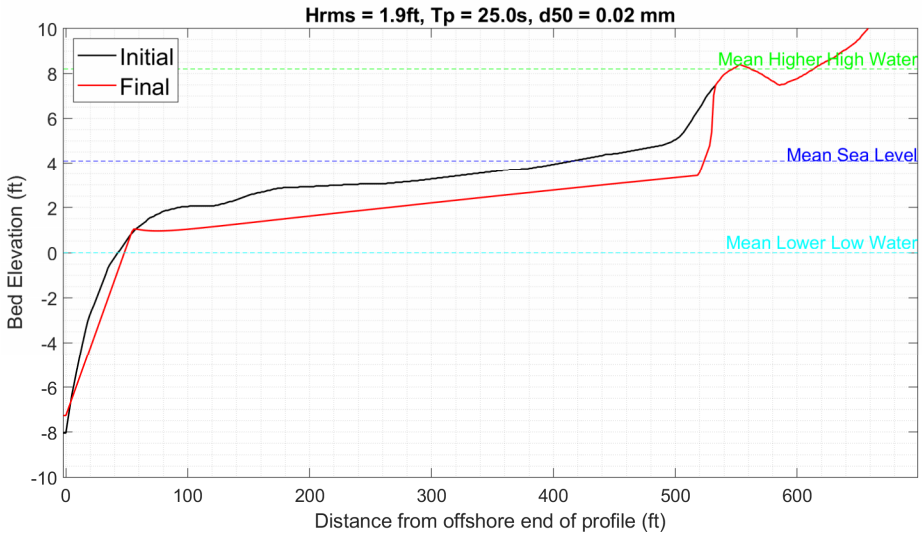
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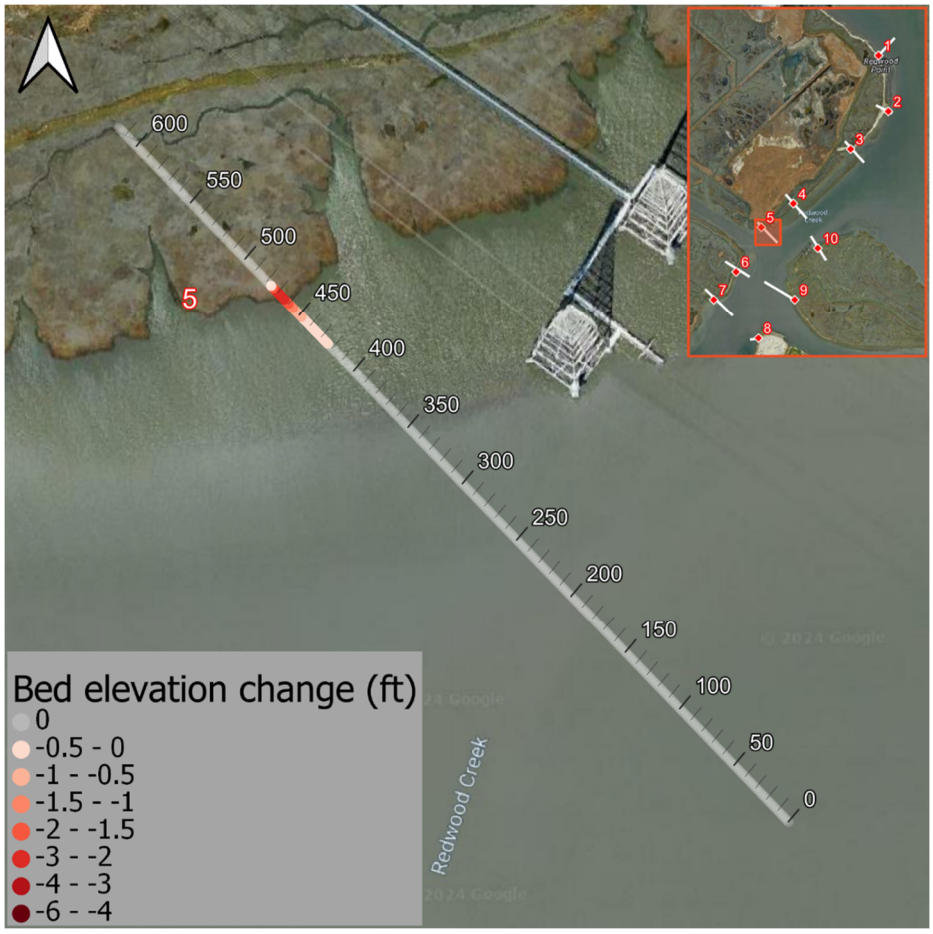


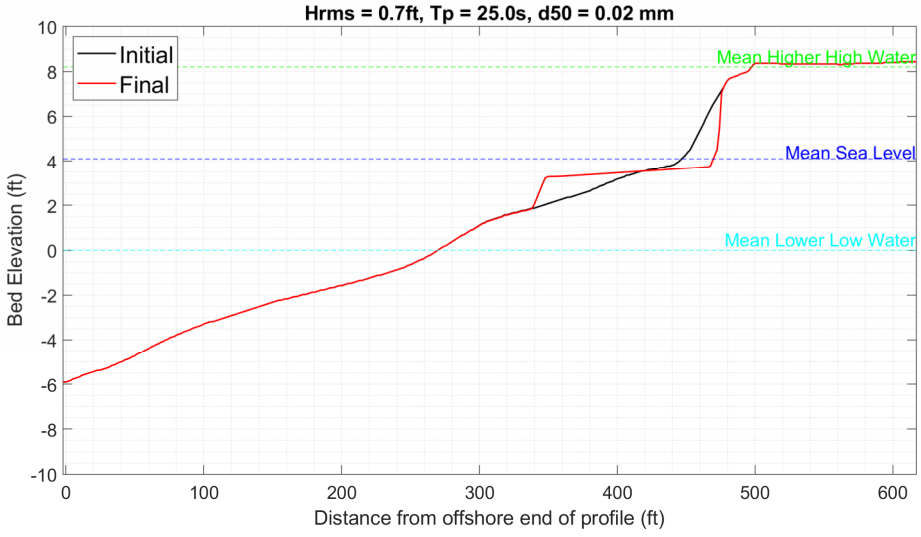
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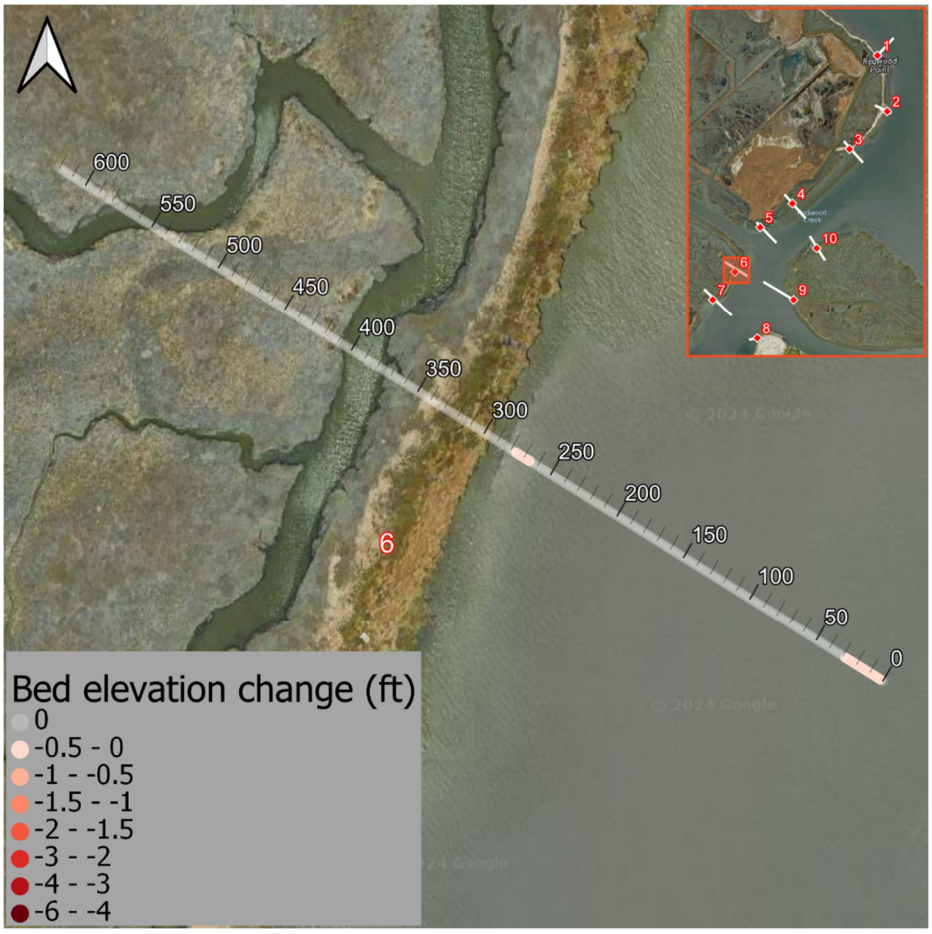


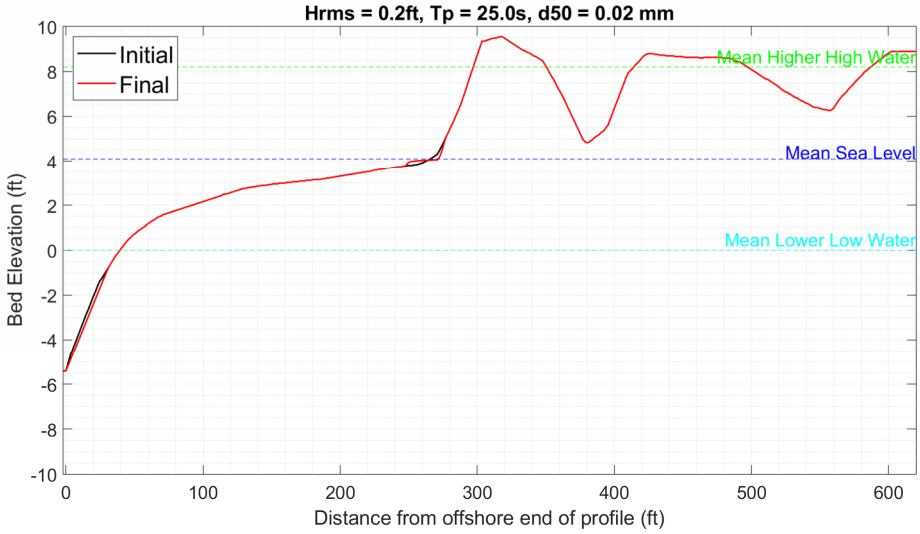
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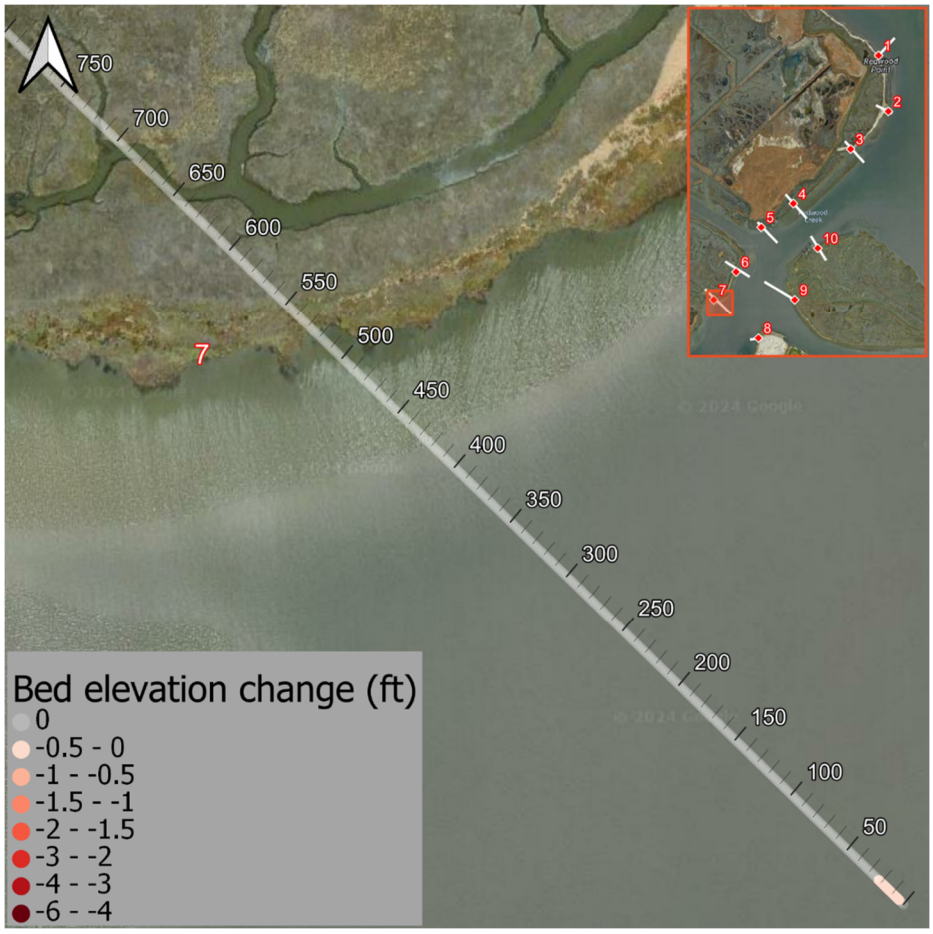


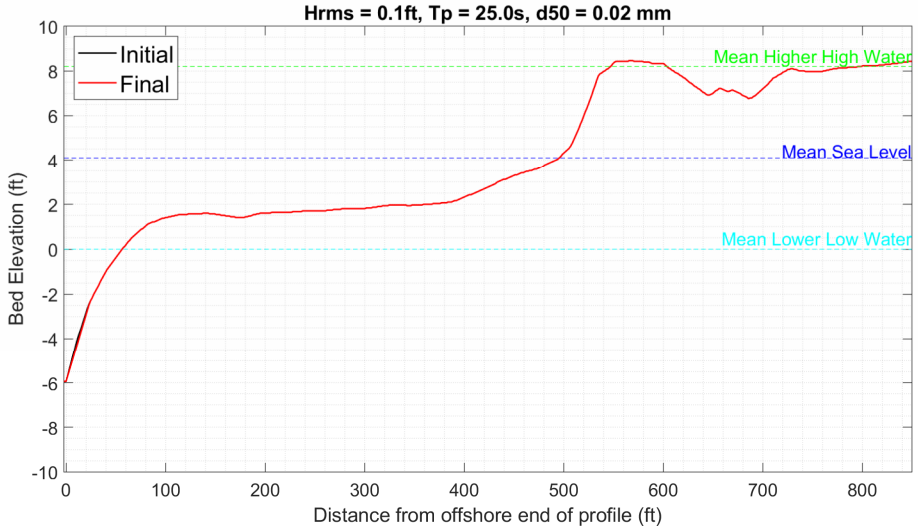
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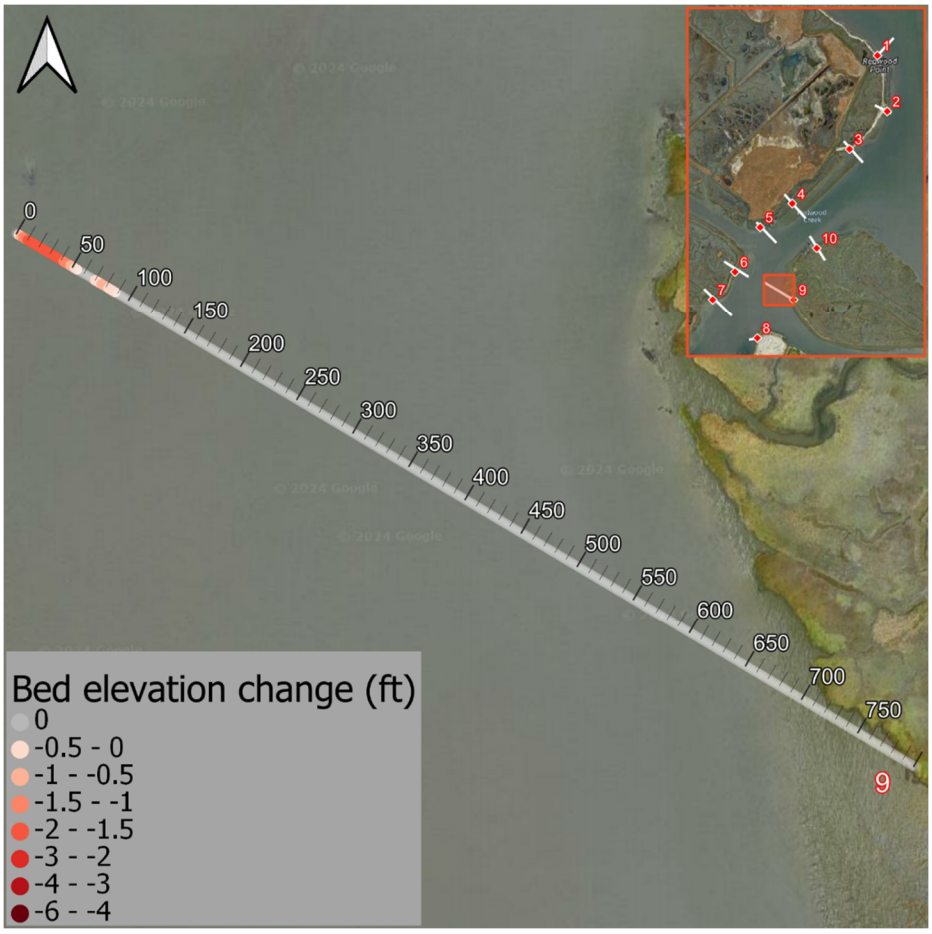


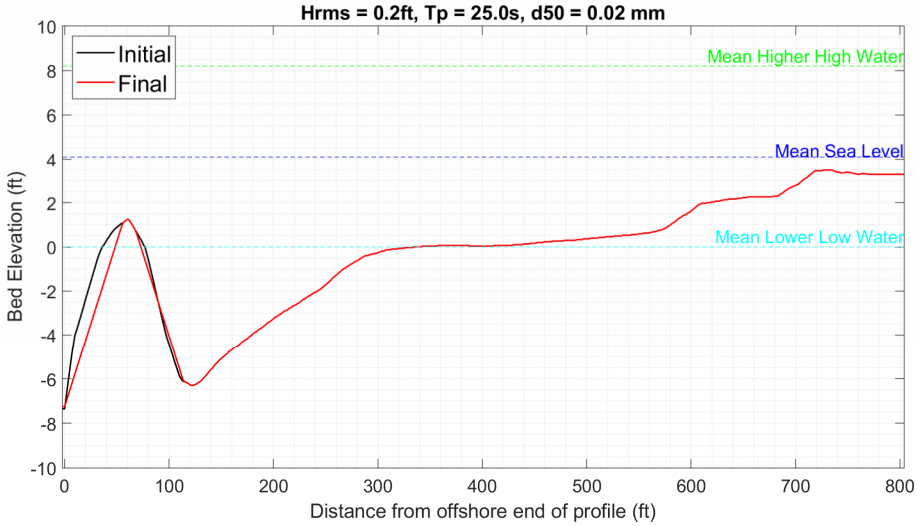
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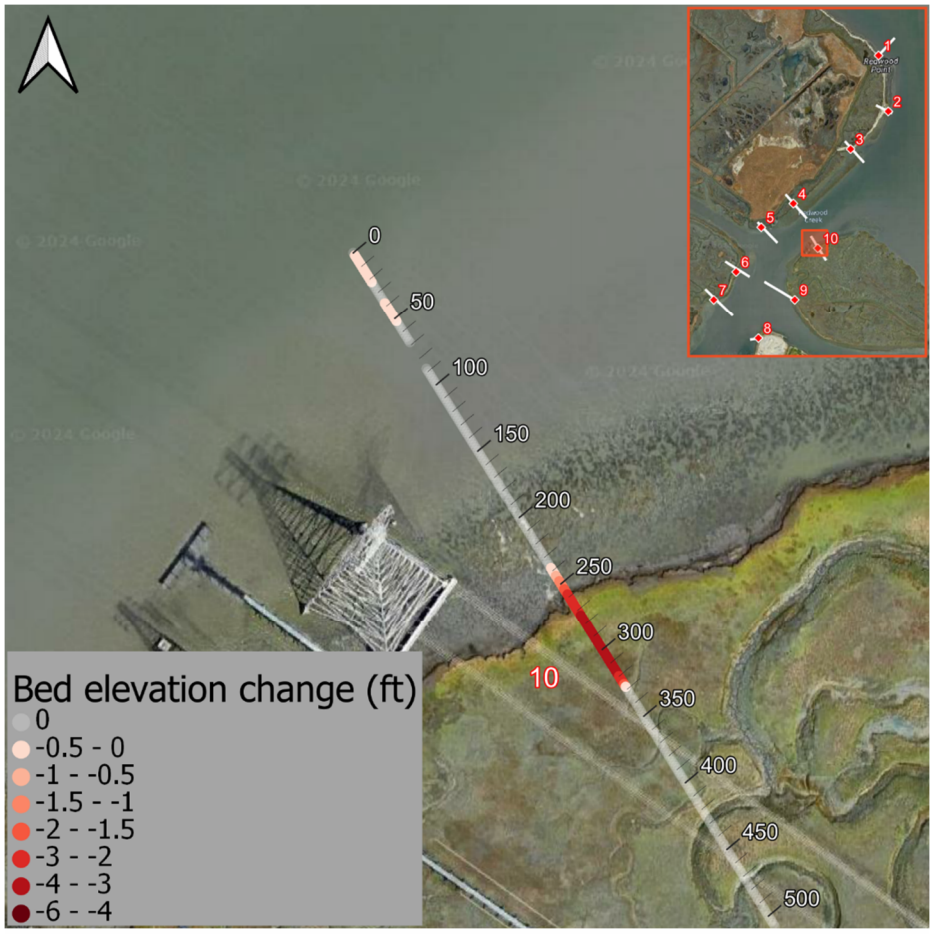


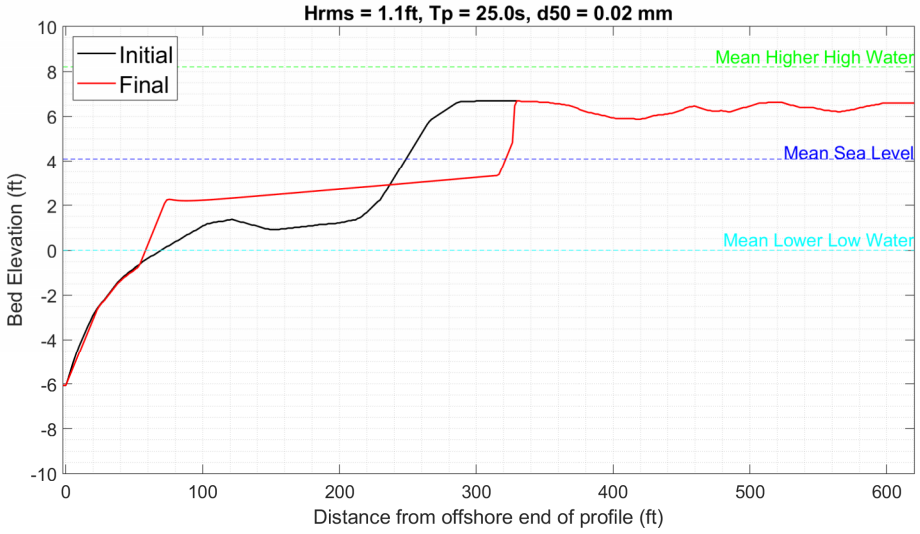
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6 Conclusion and Recommendations

This study employed numerical modeling techniques to evaluate the shoreline impacts of wake waves generated by a proposed ferry service linking Redwood City to Oakland and San Francisco. The findings provide valuable insights into the potential morphological changes along the ferry route and highlight key factors influencing shoreline stability.

The numerical simulations demonstrated that vessel speed is a critical factor influencing shoreline changes. Higher speeds resulted in pronounced morphological alterations, while lower speeds (less than 10 knots) had minimal impact on the profiles, suggesting operational adjustments as an effective mitigation strategy.

The analysis was based on several key assumptions listed in 4.3. As the objective of this study was to establish comparative trends between various locations identified for cross-shore profile analysis, wherein it is shown how the relative changes in profile evolution are influenced by changes in vessel speed along the route, these assumptions are likely to have negligible effects on the outcome of these conclusions.

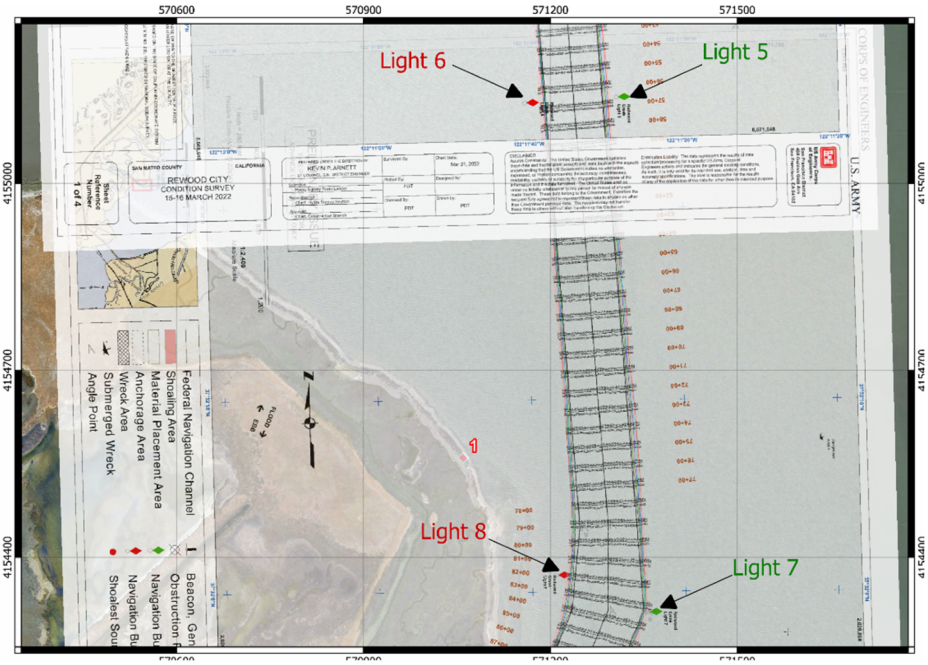
The study highlighted the importance of wake wave mitigation strategies. A reduction of ferry speed starting from Point 1, instead of the power lines location (close to profiles 5 and 10), is recommended (see Figure 6 1). The recommended speed is 7 knots, as the modeled results showed insignificant shoreline erosion and profile changes, similar to those already observed on the route beyond the power lines.

Figure 6-2 shows the proposed adjustment to the speed change location in relation to channel visual aids, based on an overlap between the profiles and the USACE Redwood City Condition Survey from 2022 USACE 2022). To minimize potential impacts on the shoreline, it is recommended that the speed transition occur at the position of Lights 5 and 6. This location provides an optimal balance considering the analysis conducted. In contrast, shifting the speed change to Lights 7 and 8 is not advisable, as these markers are already positioned too close to the shoreline. Implementing the change at this point could increase the risk of shoreline erosion, or other unintended effects on coastal stability.

Currently, the travel time from Point 1 to the power lines is approximately 2 minutes. Reducing the speed to 7 knots would increase the travel time in this section of the route from 2 to 9 minutes. The overall increase in ferry travel time due to this change would be approximately 7 minutes. This increase is an estimate based only on the vessel track modeled for this analysis. Any additional or reduction of travel time can be better defined by the ferry operators.



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This analysis investigated a specific ferry route (Figure 6-1) and evaluated the impact of vessel wake on the shoreline at two different speeds. Shoreline profiles were assessed before and after the equivalent of one year of vessel passages. The results indicated that at 35 knots, the vessel wake caused changes to the shoreline profile, whereas at 7 knots, the impact was minimal. No substantial changes were observed beyond Profile 1 (outside the channel), as the vessel's greater distance from the shoreline minimized its effect.

7 References

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DHI. 2024. *Hydrodynamic Module User Guide.*

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