COAST & HARBOR ENGINEERING

DRAFT
Coastal Engineering Analysis and Concept Design
WETA Redwood City Ferry Terminal, Redwood City, CA

1. Introduction

Coast & Harbor Engineering, Inc. (CHE) was contracted by the San Francisco Bay Area Water Emergency Transportation Authority (WETA) and KPFF Consulting Engineers (KPFF) to perform conceptual coastal engineering analysis and navigation channel design at the proposed WETA ferry terminal, Redwood City, California. Figure 1 shows the location of the proposed ferry terminal (coordinated with the Project Team), overlaid to a recent existing bathymetry (survey of May 2011).

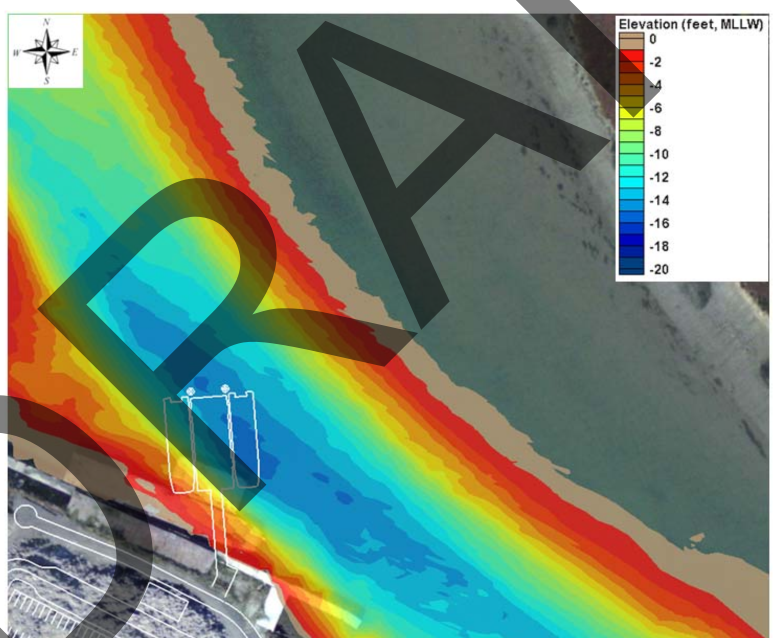

Figure 1. Proposed ferry terminal location

2. Coastal Conditions Evaluation

CHE evaluated coastal conditions at the project site to assist in determination of the optimal site configuration, as well as development of design parameters for the floats and navigation areas. CHE evaluated bathymetry/morphology, tides, winds and wind-waves. Tidal/river currents and vessel-generated pressure fields are not relevant design factors at the project site. The terminal is located in a no-wake zone, however passing small craft vessel wakes may be relevant for shore protection alternatives and are described in Section 3.

2.1. Site Bathymetry

The proposed ferry terminal site is located inside Westpoint Slough near the Port of Redwood City, CA. A hydrographic survey of the proposed channel and terminal areas was performed in May 2011. Survey data indicate bottom elevations up to -1 ft (MLLW) at the proposed terminal site. Figure 2 shows the existing site bathymetry data.

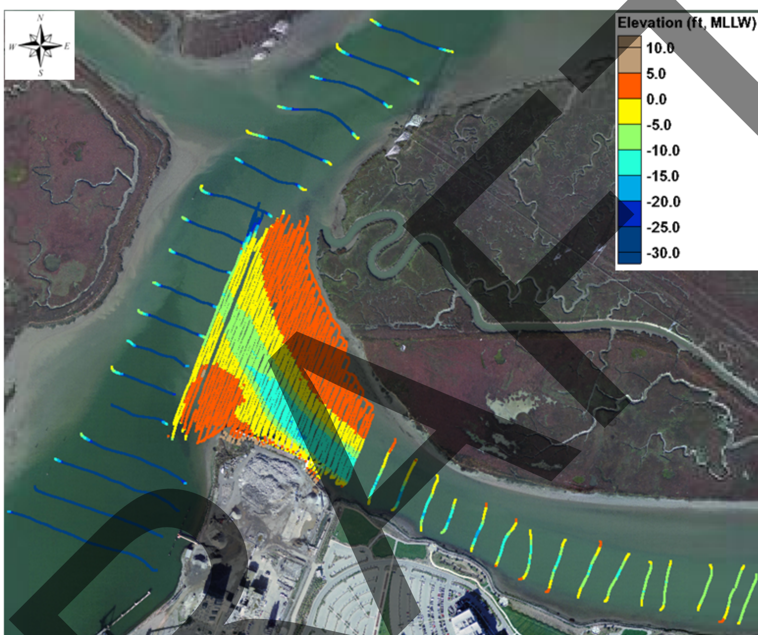

Figure 2. Existing site bathymetry (May 2011)

2.2. Tides

Tides at Redwood City are semi-diurnal (two low tides and two high tides each day) as in other areas of San Francisco Bay. Predicted tide data from the National Oceanic and Atmospheric Administration (NOAA) Redwood City Station 9414523 (Latitude 37° 30.4'N, Longitude 122° 12.6'W) were used to develop tidal elevation statistics. Table 1 shows the tidal datum information available for the Redwood City site. Tidal elevation statistics were developed using predicted tide data at Redwood City Station 9414523 and are shown as a histogram in Figure 3.

Table 1. Datum Elevations (ft, MLLW)

Datum	Elevation (ft, MLLW)
Highest Observed Water Level	10.85
MHHW	8.22
MHW	7.59
MSL	4.41
MTL	4.39
MLW	1.20
Lowest Observed Water Level	-2.57

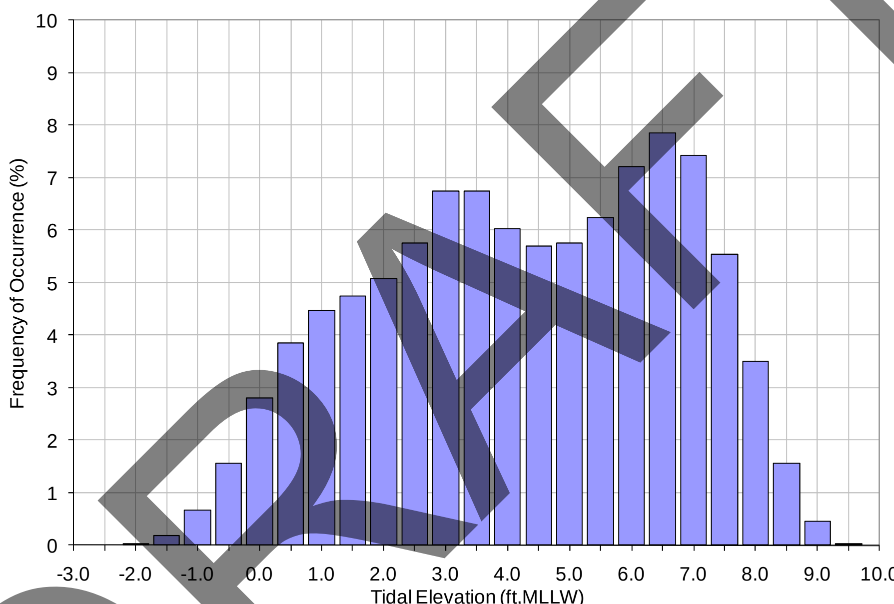

Figure 3. Tidal elevation distribution at Redwood City Station 9414523

2.3. Sea Level Rise

CHE performed literature review and independent analysis to provide sea level rise estimates based on available measured data as well as local sea level rise estimates made by the Bay Conservation and Development Commission (BCDC).

2.3.1. SLR Estimate Based on Measurements

Sea level rise in San Francisco Bay based on measured trends was evaluated using the San Francisco NOAA tide station (9414290) for the 110-year period from 1897 through 2006. Monthly mean sea levels during the period 1897 to 2006 were evaluated and only the sea level data following the 1906 earthquake were used. The sea level rise trend at San Francisco is presently 2 mm/year relative to datums for the NOAA tidal epoch 1983-2001. Evidence of accelerated sea level rise due to effects of global climate change is not yet detectable in the measured tide record. The NOAA data are the only direct measurements of the local relative sea level trend. Based on the measured sea level rise of 2 mm/yr, the sea level rise at the proposed ferry terminal over a 50-year period is estimated to be 0.33 ft (4 inches).

2.3.2. SLR Estimate from Bay Conservation and Development Commission

The Bay Conservation and Development Commission (BCDC) estimate of long-term eustatic sea level rise is presently 16 inches over the next 50 years (personal communication with Steve Goldbeck, BCDC, 2009). The BCDC estimate is speculative and based on predictions of events that have not yet occurred. CHE recommends adoption of the BCDC speculative estimate for the conceptual design phase of the project.

2.4. Winds

San Francisco Bay has an energetic wind climate, with winds at Redwood City predominantly from North and West. Wind analysis was performed to quantify the wind climate in the area, to determine the general wave climate for waves of concern and to develop extreme winds to be used as coastal and structural engineering design criteria. Wind analysis was conducted based on meteorological data collected on the roof of the USGS Marine Facility, located at the Port of Redwood City (Schemel, 2002) from 1993 to 2005. Figure 4 shows the distribution of measured wind speed and direction at Redwood City wind station in the form of a wind rose. The wind climate was used as input into wind-wave growth and transformation modeling for the development of the wave climate at the project site described in Section 2.5.1.

The Redwood City wind record consists of hourly wind speeds and directions (two-minute averages). These data were analyzed and the largest measured wind events were extracted. These extreme events were fit to a Weibull distribution, and sustained wind speeds were predicted for extreme events with recurrence intervals ranging from 2 to 50 years for all directions (measured clockwise from True North). Figure 5 shows the predicted extreme wind speeds for all return periods and directions. The 50-year winds from all directions were used as input into wind-wave growth and transformation modeling for the development of extreme waves at the project site described in Section 2.5.2.

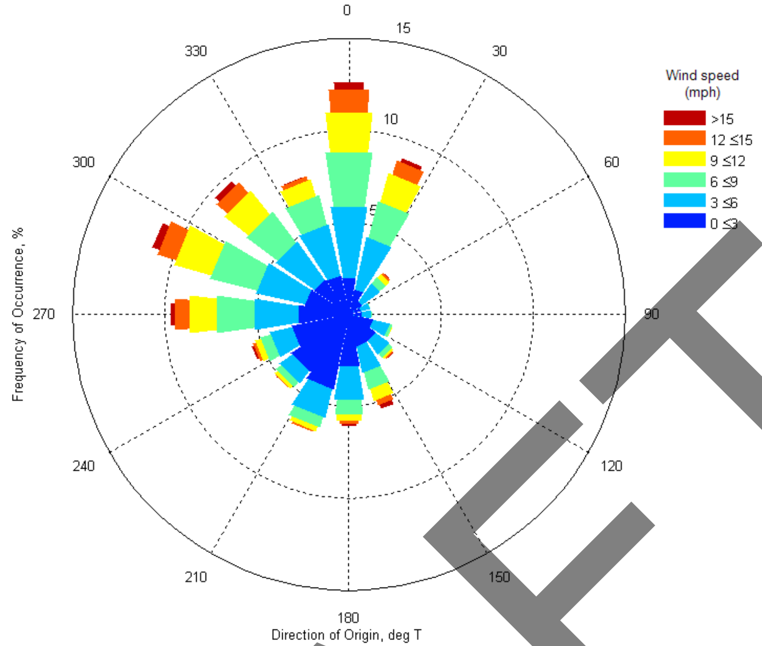

Figure 4. Wind speed and direction distribution (wind rose) at Port of Redwood City, 1993-2005

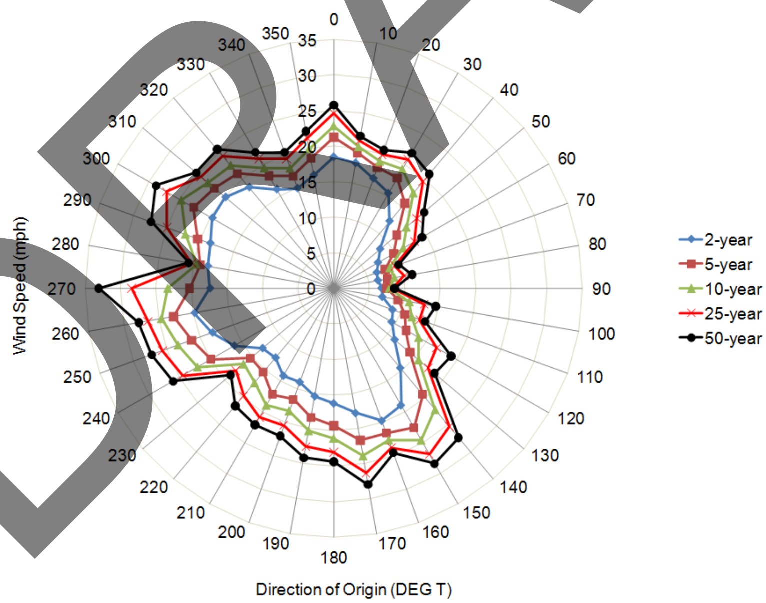

Figure 5. Extreme sustained wind speed and direction for return periods between 2 and 50 years

2.5. Wind-Waves

The wind-wave environment in San Francisco Bay is energetic due to the relatively strong winds moving over large distances and some areas with deep water. The design of the navigation channel, turning basin, and boarding floats are all affected by the size and direction of wind-waves arriving at the site. Therefore, wind-wave analysis was performed to determine the general wave climate for waves of concern, as well as extreme wave parameters for use in future design.

2.5.1. Wave Climate Analysis

The wind climate developed in Section 2.4 was used to develop wind-wave climate at the site. The wind climate was broken down into various combinations of wind speed and wind direction bins, each with its own probability of occurrence based on the data from the Redwood City wind station. Predicted tidal elevation data collected from the Redwood City tide station were broken down into different values, each with its own probability of occurrence. The combinations of wind speed and direction and tidal elevation were combined into a joint probability matrix (2,016 cases) for input into wind-wave growth and transformation modeling. Wind-wave growth and transformation modeling was performed using the two-dimensional spectral model SWAN (Holthuijsen et al., 2004).

Figure 6 (left) shows the SWAN input bathymetry for South San Francisco Bay, constructed using historical data from U.S. Army Corps of Engineers (USACE) and NOAA and recent survey data (May 2011), and a close-up near the terminal site (right). The results of the SWAN model included significant wave height (the average of the highest one-third of the waves) and peak wave period, as well as other parameters in the whole modeling domain.

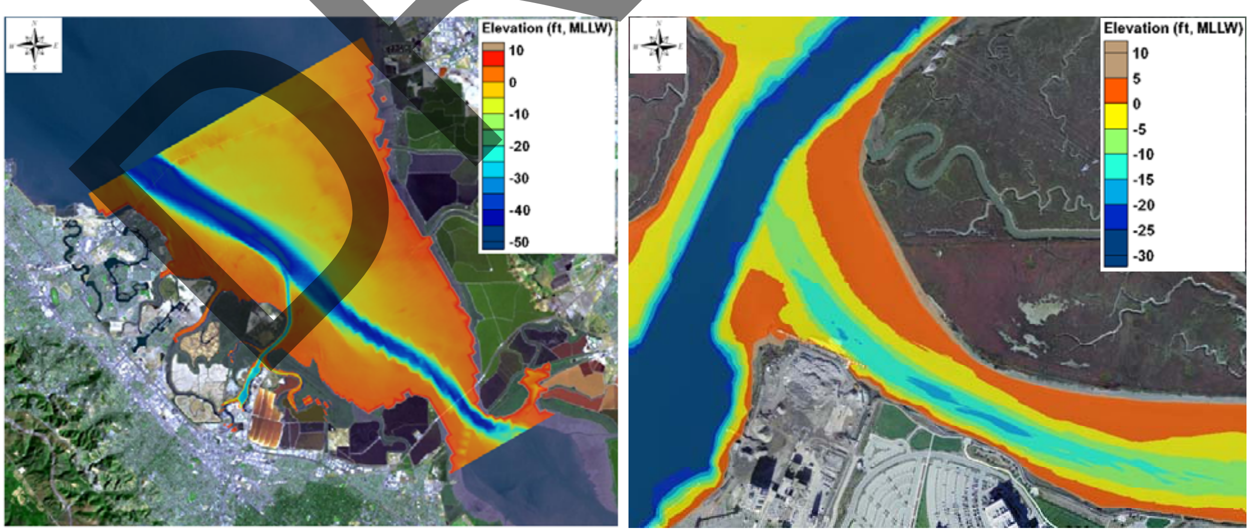

Figure 6. SWAN wind-wave modeling domain with bottom depth (left) and close-up at the project site (right)

The results of the wave climate analysis indicate that the cumulative frequency of occurrence of wave conditions having significant wave heights greater than 0.5 ft at the proposed location of the ferry terminal is negligible (<0.1%). Based on the frequency of occurrence of waves of concern at the project site, wave protection is not recommended from a daily operations perspective.

2.5.2. Wave Analysis for Design Events

The extreme wind event data developed in Section 2.4 were used to develop extreme wind-waves at the site. The extreme winds were used as input into the San Francisco Bay model for events with return periods of 50 years from all directions. Modeling was performed at a tidal elevation of 8.22 ft MLLW, which is equivalent to MHHW at Redwood City. Figure 7 shows significant wave heights at the project site for 50-year storm conditions from all directions.

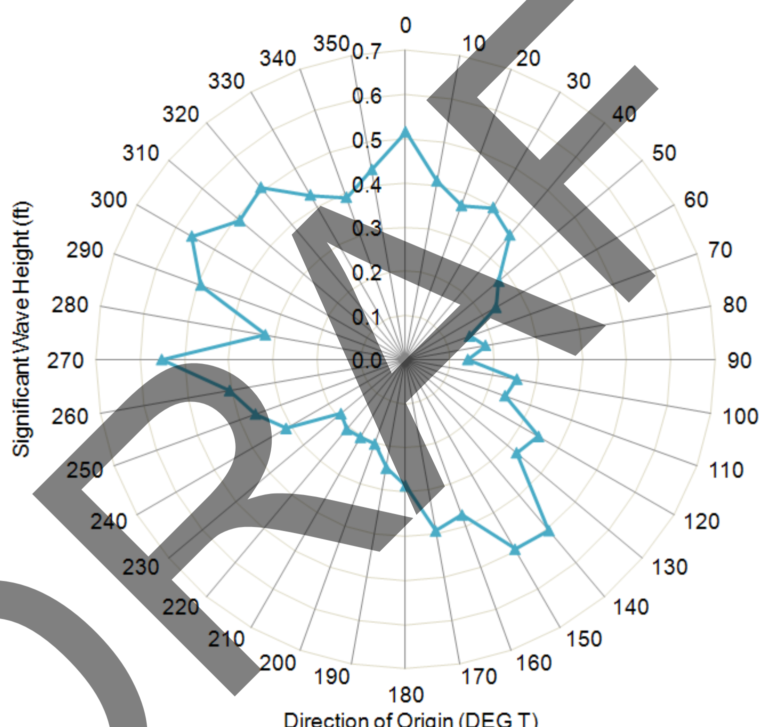

Figure 7. 50-year significant wave heights at the project site

2.6. Vessel Wakes

Vessel wakes at the terminal are not likely to be relevant for design of in-water terminal structures; however they may govern design of shoreline protection alternatives discussed in Section 3. These wakes may be generated by passing small craft in Westpoint Slough, ship and tug within Redwood Creek Channel, and to a lesser degree ferry arrivals and departures. Exhaustive analysis of expected heights and periods of these wakes is outside the scope of the present analysis. However, wake measurements were collected in Redwood Creek Channel during the period

12/18/2003 – 01/19/2004 (URS, 2004). Measurements showed maximum wake heights approximately 1.5 ft with typical periods of approximately 3.3 seconds. Tugs passing in Redwood Creek Channel are likely to generate wakes similar in magnitude arriving at the proposed terminal. This wave condition occurs infrequently (a few times per day at most) and therefore will not impact operations. This wake height and period combination is recommended for preliminary use during analysis of shoreline protection design alternatives.

3. Shoreline Protection

Based on the results of extreme wave analysis at the project site described in Section 2.5.2, extreme storm waves are not likely to control shoreline protection design criteria.

No scour protection is projected at this time on the north side of the turning basin, as the beach is relatively flat there. CHE expects some scouring of the slope in that area, resulting in flattening overall. Installation of rock or other scour protection on the wildlife refuge shoreline seems impractical. CHE suggests to address that issue in further phases of the design, if required by WETA.

The shoreline area near the proposed terminal will be exposed to ferry propwash and vessel wakes. Two shore protection alternatives are briefly discussed in this conceptual design phase: a “bioengineered” hybrid stabilization solution, and a rock revetment. Alternate “bioengineered” solutions may allow steeper slopes, reducing excavation and saving space within Westpoint Slough, and are likely to be attractive to environmental agencies. An example of this type of solution is shown in Figure 8.

Figure 8. Example of steep embankment stabilized with hybrid "biogengineered" shore protection solution

Although CHE believes alternate “bioengineered” shore protection solution could be a more environmentally friendly alternative than a rock revetment, it may be prudent to assume at this stage that a rock revetment is installed along a 400-ft section of shoreline near the project site with slope 1.5H:1V. This could be conservatively assumed to cost approximately $1,200 to $1,600 per lineal ft, for total cost $480,000 to $640,000. Development of the shore protection conceptual design is outside the current scope of work and therefore should be refined during the next phase of design.

4. Navigation Channel / Berth Conceptual Design

Navigation channel design consisted of evaluating the depth required at the navigation and berthing areas based on vessels and environmental criteria, as well as performing rudimentary maneuvering exercises. The design dredging depth was calculated using guidance from the Permanent International Association of Navigation Congresses (PIANC, 1997). The channel and berthing/maneuvering areas are all areas in which ferries will operate at no-wake speed. The following parameters were considered to calculate the desired channel depth: vessel draft, vessel trim, tidal disadvantage (minus tides)[1] and sedimentation allowance (see Section 4.2). Bathymetry data were then used to calculate required capital dredging volumes.

4.1. Design Vessel

The conceptual channel/berth depth was obtained assuming that the design vessel was a catamaran ferry with length 125 ft, beam 30 ft and maximum draft 7.6 ft.

4.2. Sedimentation Allowance

The conceptual channel/berth depth includes an allowance for future sedimentation to provide safe navigation for a period of time until maintenance dredging occurs. Sediment samples and borings have not yet been collected, and therefore the type of bottom material that exists along the channel alignment is unknown. The sedimentation rate at the site was estimated using a combination of anecdotal information and review of historical data. Figure 9 shows an aerial photo with callouts of all areas used for evaluation of sedimentation rates.

4.2.1. Anecdotal Information

Anecdotal information indicates that the sedimentation rates in Westpoint Slough are negligible (Westpoint Marina Harbormaster Mark Sanders, personal communication, 2011). Westpoint Slough is reported to naturally maintain depths between 12 and 16 ft (MLLW). Similar trends of very little sedimentation have been observed within Westpoint Marina.

[1] Tides at Redwood City are below -1.0 ft (MLLW) less than 0.5% of the time.

Figure 9. Location of areas used for evaluation of sedimentation rates

4.2.2. Historical Data

Historical dredging and sedimentation rate information for Redwood Creek Channel were also analyzed. Redwood Creek Channel has been dredged approximately every two to four years from 1955 to 1999. The dredged portion includes a 3.5-mile segment extending from the ship channel in San Francisco Bay to the Redwood City Yacht Harbor. It ranges from 300 to 400 ft wide with a dredged depth of 30 ft (MLLW). Dredged sediments have mostly consisted of silty clay. Between 1973 and 1999, the channel was dredged eight times and the reported average sedimentation rate ranged from 0.3 to 1.7 ft per year (PWA, 2000). The highest sedimentation occurred in a one-mile segment that includes the junctions of West Point Slough and Corkscrew Slough.

Analysis of recent data (USACE historical bathymetric surveys in the period May 2009 - May 2011) was performed and sedimentation rates were estimated in Redwood Creek Channel in an area approximately 350 ft wide and 1.7 miles long that includes the junctions of Westpoint Slough and Corkscrew Slough (see Figure 10). The average sedimentation rate agrees with the historical (1973 to 1999), and ranged from 0.3 to 1.7 ft per year, with the largest value occurring after a dredging event in October 2009.

Figure 10. Areas used for sedimentation rate evaluation

4.2.3. Summary and Recommendations

After review of anecdotal information, historical dredging records and analysis of recent USACE survey data, it is recommended that for the purposes of conceptual design a maximum sedimentation rate of 1.0 ft per year should be assumed for the ferry terminal berthing and maneuvering areas.

4.3. Channel and Turning Basin Dimensions

The design depth of the navigation areas were designed using guidance from PIANC (1997) and discussions with the Project Team. The channel side slopes were assumed to be constructed at a minimum 3H:1V slope. Figure 11 shows the maneuvering area for the proposed ferry terminal. The maneuvering area was designed using simplified maneuvering simulations and coordinated with WETA Operations. A berthing area depth of 12 ft (MLLW) was prescribed along with a design channel depth of 10 ft (MLLW) in the maneuvering area and channel exiting to Redwood Creek Channel.

Design channel depth of approximately 10 ft (MLLW) assumes annual maintenance dredging. Details of dredging depth calculation are provided below[2].

- Vessel maximum draft = 7.6 ft
- Vessel trim = 0.5 ft
- No waves
- Low speed (i.e. negligible squat)

[2] Note that although an additional ~0.3-0.7 ft of depth overall could be expected due to construction tolerances, this is not included in the dredging volume.

- 1-way traffic.
- Extreme low tide = -1 ft (MLLW).
- Advance maintenance dredging = 1 ft

The maneuvering area was designed using simplified maneuvering simulations to allow for safe small craft navigation in Westpoint Slough and minimize navigation impacts. The channel exiting to Redwood Creek Channel was preliminarily designed with width 100 ft. It should be noted that these dimensions were developed as conceptual estimates for planning purposes and to provide dredging volume estimates during conceptual design.

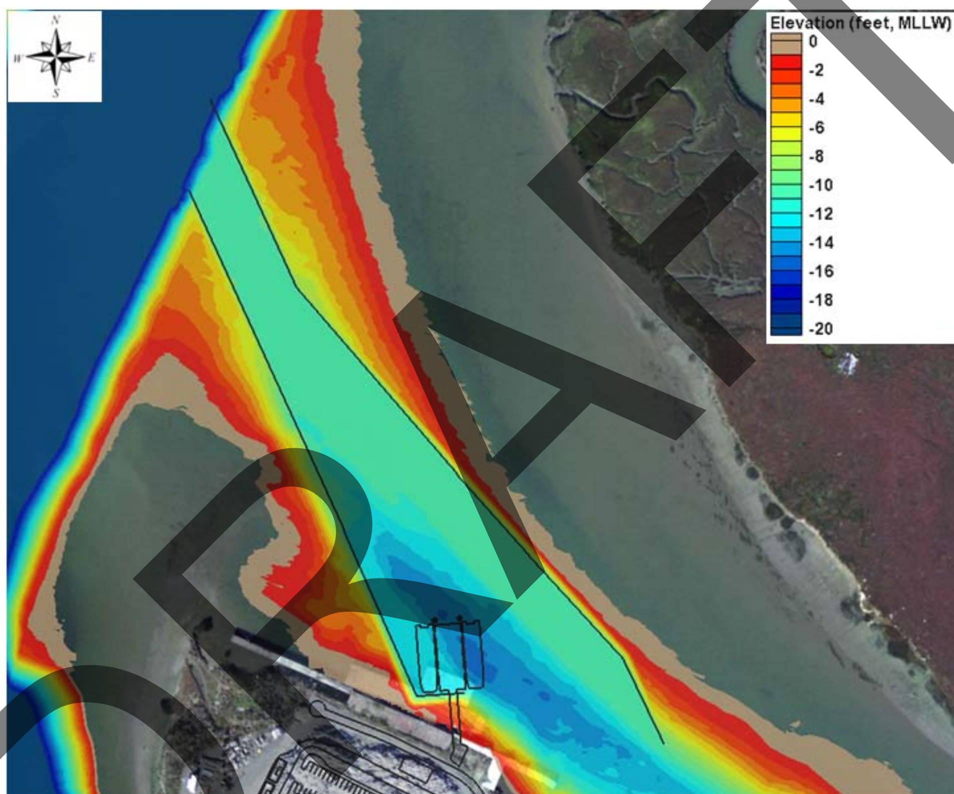

Figure 11. Conceptual berth and maneuvering area layout

Figure 12 shows sketches of ferry positions during maneuvering out of the berths (west berth at top, east berth at bottom). Maneuverability of the ferry in and out of the two berths was discussed and coordinated with WETA Operations.

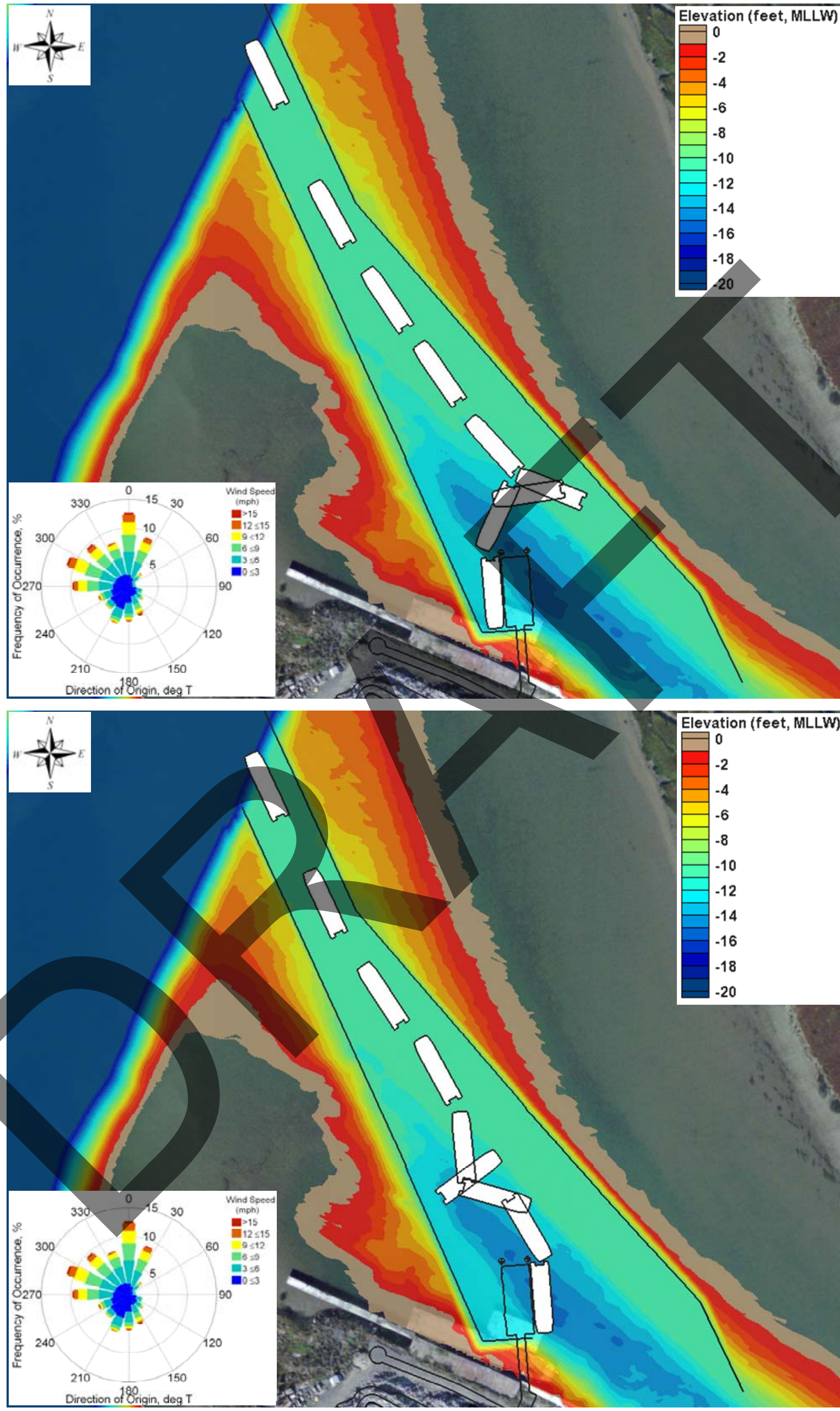

Figure 12. Ferry maneuvers during departure from the west (top) and east (bottom) berths

5. Dredging Volumes

Dredging volumes were calculated using the recent hydrographic survey data (see Section 2.1) and the conceptual maneuvering/berthing area design. The initial dredging volume was preliminarily calculated to be approximately 18,500 cubic yards, which includes advanced maintenance dredging (sedimentation allowance), but no volume associated with dredging construction tolerance.

If later geotechnical exploration indicates that the channel bottom is not medium sand as expected, the recommended 3H:1V slopes may require further flattening. Erosion of the slope and scouring from propwash may occur, and those materials would be removed by maintenance dredging over time. Considering the potential need for slopes flatter than 3H:1V, initial dredging volumes were calculated to be in the range 18,000 – 20,000 cubic yards.

For maintenance dredging estimates, it is recommended to assume a high unit cost, probably $40-50 per cubic yard, since volumes will be very low and disposal locations are uncertain at this stage. Assuming our maneuvering area of approximately 73,000 sq. ft (outer channel, length of approximately 500 ft from the intersection of Redwood Creek Channel with Westpoint Slough) undergoes 1 ft of sedimentation per year, dredging of 2,700 cubic yards would be required for a total cost of $160,000 including $25,000 mobilization per year. The advance maintenance dredging of 1 ft per year is only applied to the outer channel because the analysis reported in Section 4.2, including anecdotal information, shows that sedimentation rates farther inside Westpoint Slough are negligible.

During the next phases of design and depending on the feasibility of permitting, additional initial dredging depth may be considered in the outer entry channel of Westpoint Slough to allow a longer duration between required maintenance dredging cycles. This additional dredging depth may be included in future USACE maintenance dredging for the adjacent Redwood Creek Channel.

6. Conclusions

Conceptual coastal engineering design and analysis were performed in support of the WETA Redwood City ferry terminal conceptual design. Wind and tide analysis was performed, and wind-wave growth and transformation modeling was performed to evaluate the wave climate at the site and the need for wave protection. Results indicate that wave protection is not required for the terminal.

Shoreline protection alternatives were reviewed based on the extreme waves and vessel wakes at the site, and it was determined that either a rock revetment or a type of "bioengineered" stabilization solution would be feasible.

Coastal engineering analysis was performed to identify and recommend navigation channel, turning basin and berthing area dimensions. The recommended berthing area has depth of 12 ft (MLLW), the main channel (including the small craft navigation channel) has a depth of 10 ft (MLLW). A dredging volume estimate was developed and the initial dredging volume is approximately 18,000-20,000 cubic yards, inclusive of advanced maintenance dredging but excluding construction tolerances.

7. References

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