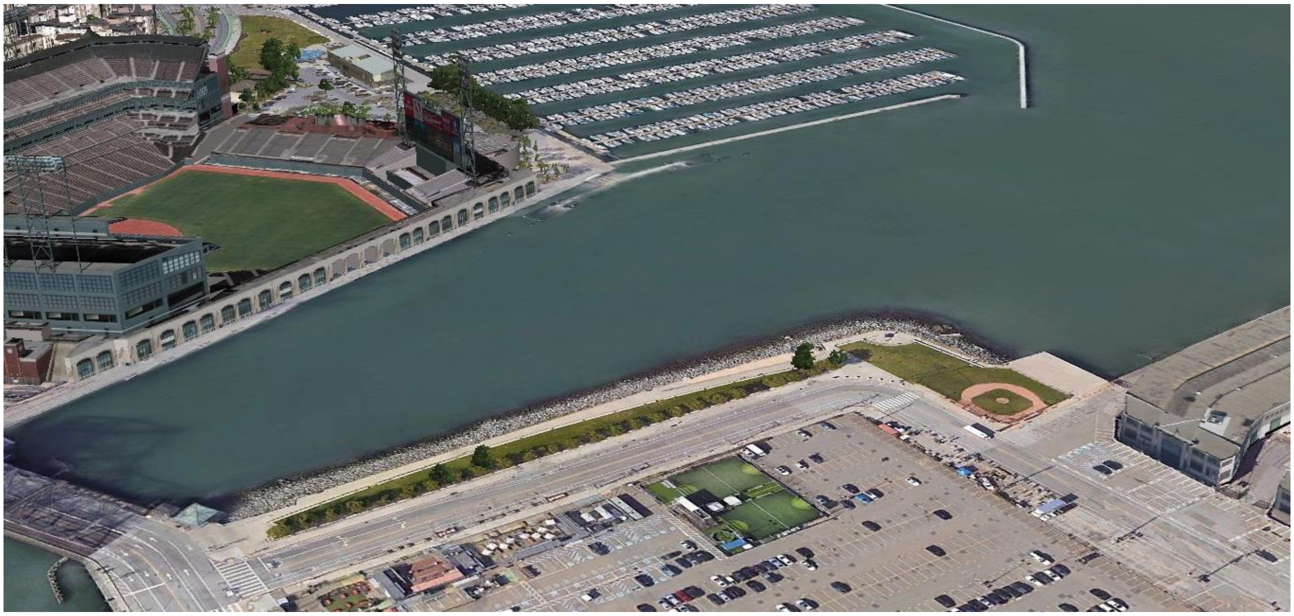
China Basin Park

Shoreline Engineering Assessment



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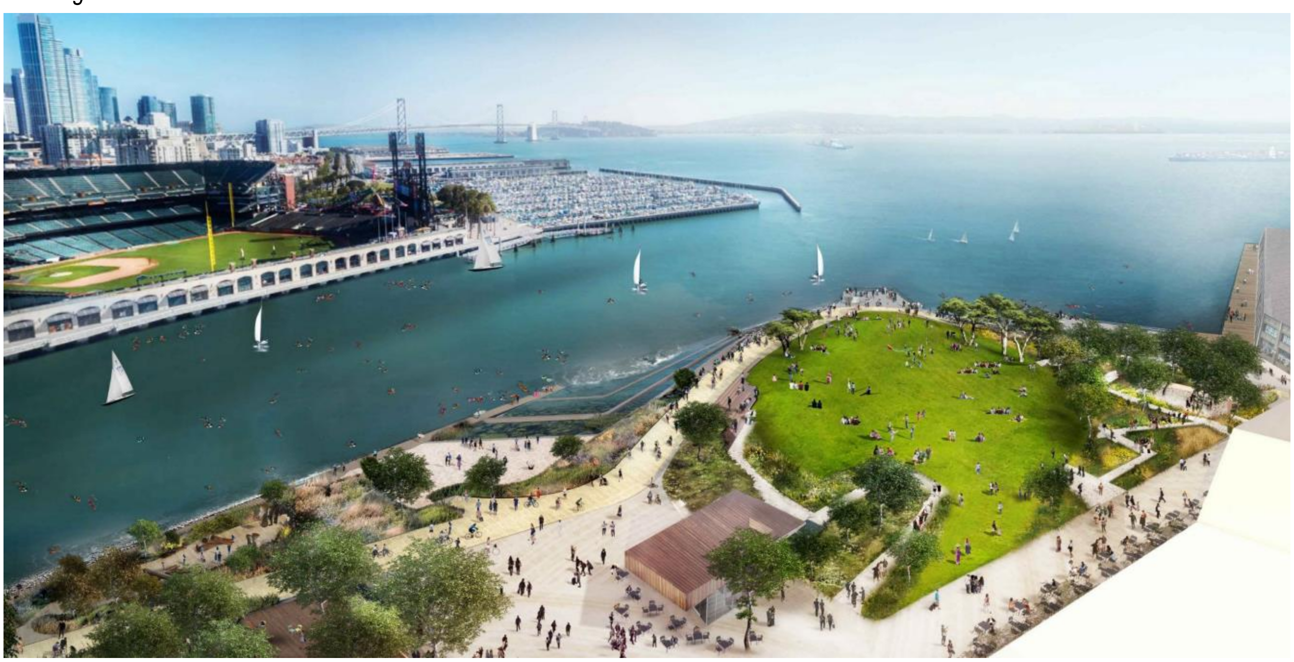

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May 2020

Document Verification

Client	Mission Rock Partners
Project name	Mission Rock Development Project
Document title	China Basin Park
Document subtitle	Shoreline Engineering Assessment
Status	Draft Report
Date	May 26, 2020
Project number	7530-03
File reference	

Revision	Description	Issued by	Date	Checked
00	Draft Report	M. Jorgensen	May 4, 2020	D. Trivedi
01	Revised Draft Report	M. Jorgensen	May 26, 2020	D. Trivedi

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Glossary

BFE	Base Flood Elevation
CCSF	City and County of San Francisco
EVA	Extreme Value Analysis
FEMA	Federal Emergency Management Agency
GEVD	Generalized Extreme Value Distribution
MN	Moffatt & Nichol
MRP	Mission Rock Partners
NAS	Naval Air Station
NFIP	National Flood Insurance Program
RCP	Representative Concentration Pathways
SWEL	Still Water Elevation

Executive Summary

This report defines the environmental conditions applicable to the China Basin Park (project) shoreline needed for the shoreline engineering, which includes:

- Project and site information
- Terrain elevations and shoreline topography
- Water levels
- Sea-level rise projections
- Wind statistics and wave action

The preliminary shoreline engineering includes assessment of:

- Flood and tsunami inundation hazards
- Sea-level rise vulnerability
- Design wave data and wave runup
- Design water levels
- Recommended elevations for design
- Functional evaluation of tidal shelves

1. Introduction

Moffatt & Nichol (M&N) was retained by Mission Rock Partners (MRP) to develop a shoreline engineering assessment for the Mission Rock China Basin Park project.

1.1. Project Background

China Basin Park is located on the Port of San Francisco's Seawall Lot 337 bounded by 3rd Street, Terry Francois Boulevard, and Mission Rock Street. The majority of the Mission Bay neighborhood was reclaimed between 1880 and 1906. The park will create about 5 acres of new public open space and improved public waterfront access along China Basin and at Pier 48. Figure 1-1 provides an overview of China Basin and vicinity.

Figure 1-1: Overview of China Basin Park and vicinity.

2. Environmental Conditions

2.1. Water Levels

Astronomical tides in San Francisco Bay occur twice each lunar day, characterized by a semidiurnal inequality (i.e., a difference in heights of successive high waters or low waters) as shown on (Figure 2-1). Changes in winds and barometric conditions can cause variations in the tide level from day to day, which are not included in daily tide predictions for the area.

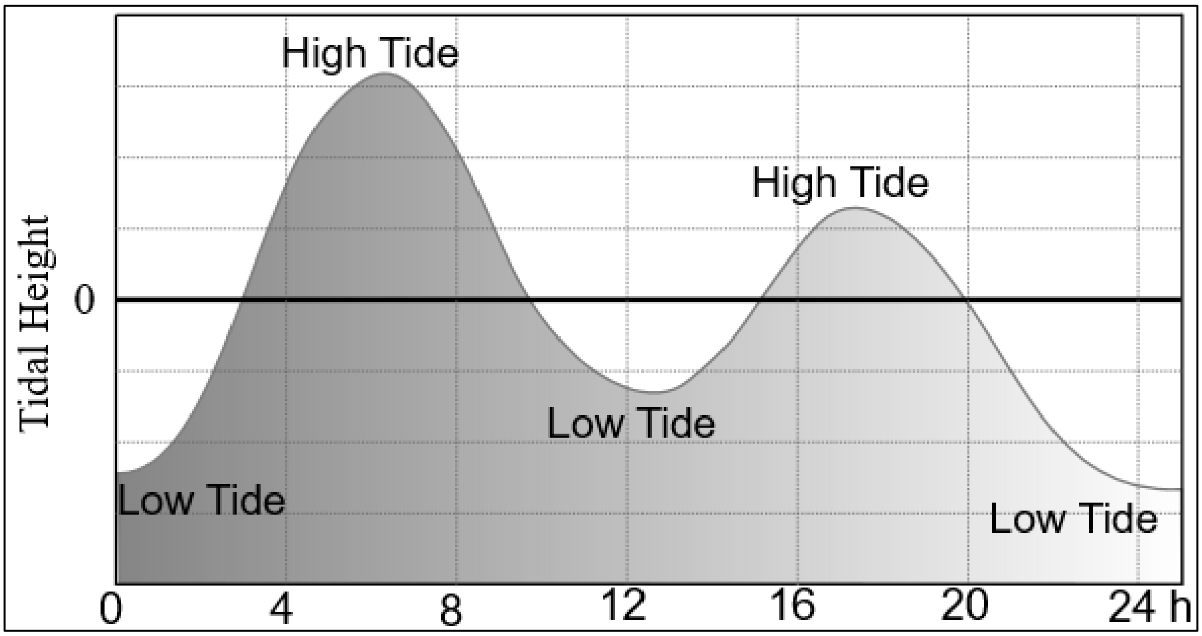

Figure 2-1: Typical daily tidal progression for mixed semi-diurnal tides.

There is no tide gage in the immediate vicinity of the project site; tidal datums from Pier 22½, the closest representative NOAA tide gage, are based on a few months of data only from the 1970’s. However, the San Francisco Public Utilities Commission (SFPUC) in 2014 adopted a study performed for their Sewer System Improvement Program (SFPUC 2014), which was based primarily on a Bay-wide study by FEMA in 2012 (BakerAECOM 2012). The FEMA study relied upon numerical modeling to estimate water levels; results indicate a MHHW value of 6.3’ NAVD and a 100-yr still water level value of 9.7’ NAVD. Since the SFPUC study has been entered into the record as the study to use for Inundation Mapping and Climate Change evaluation, this report references the SFPUC study rather than NOAA data.

Significant tidal datum planes in the vicinity of the project site, based on the SFPUC study are shown in Table 2-1, both in terms of NAVD as well as Mission Bay Datum (MBD).

Table 2-1: Water levels at China Basin, *SFPUC (2014)*.

Datum Plane	Elevation (feet) NAVD88 Datum	Elevation (feet) Mission Bay Datum [1]
100-yr Return Period Still Water Level	+9.7	98.4
King Tide [2]	+7.3	96.0
Mean Higher High Water (MHHW)	+6.3	95.0
Mean High Water (MHW)	+5.8	94.5
Mean Sea Level (MSL)	+3.2	91.9
Mean Low Water (MLW)	+0.9	89.6
North American Vertical Datum (NAVD88)	0.0	88.7
Mean Lower Low Water (MLLW)	-0.2	88.5

[1] Mission Bay Datum (MBD) is a local vertical datum that has been used by the City. It is equal to City Datum plus 100 feet. To convert from NAVD, add 88.7 feet.

[2] King tides are the approximate highest tides that occur in a given year (2 to 3 times) when lunar and solar gravitational effects coincide.

2.2. Sea-Level Rise

Comprehensive guidance for California was first developed by the National Research Council, *NRC (2012)*. The guidance relied on the best available science at the time to identify a range of sea-level rise scenarios including high, low, and intermediate projections, taking into account regional factors such as El Niño and extreme storm events that affect ocean levels, precipitation, and storm surge. This approach allowed planners to understand the full range of possible impacts that can be reasonably expected based on the best available science, and build an understanding of the overall risk posed by potential future sea-level rise.

Current guidance for California recommends evaluation of sea-level rise (SLR) impacts using a scenario-based analysis. This method is founded on the approach by the Intergovernmental Panel on Climate Change (IPCC) to understand how sea-level rise and other drivers interact to threaten health, safety, and resources of coastal communities. This guidance is summarized in *OPC (2018),* which represents the best available science and has been adopted for this assessment.

IPCC climate change scenarios are expressed in terms of Representative Concentration Pathways (RCPs). RCP 8.5 projects a future with the highest greenhouse gas emissions, high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and GHG emissions. Some estimates of current emissions are tracking close to RCP 8.5.

Table 2-2 summarizes the sea-level rise scenarios from *OPC (2018)* for San Francisco, which are applicable to China Basin. The columns outlined in dark blue reflects the OPC guidance for risk levels, which include low risk aversion, medium to high risk aversion, and extreme risk aversion. The *High Emissions, Medium – High Risk Aversion* scenario was adopted for this assessment. This scenario has a 1-in-200 chance of unfolding. Table 2-3 summarizes the sea-level rise projection for this scenario.

Table 2-2: Sea-Level Rise Projections for San Francisco, *OPC (2018).*

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3 -	0.5	0.6	0.8	1.0
	2040	0.6	0.5 -	0.8	1.0	1.3	1.8
	2050	0.9	0.6 -	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6 -	1.3	1.6	2.4	
High emissions	2060	1.1	0.8 -	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8 -	1.5	1.9	3.1	
High emissions	2070	1.4	1.0 -	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9 -	1.8	2.3	3.9	
High emissions	2080	1.7	1.2 -	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0 -	2.1	2.8	4.7	
High emissions	2090	2.1	1.4 -	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0 -	2.4	3.2	5.7	
High emissions	2100	2.5	1.6 -	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2 -	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9 -	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2 -	2.8	3.9	7.4	
High emissions	2120	3	2.2 -	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3 -	3.1	4.4	8.5	
High emissions	2130	3.3	2.4 -	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3 -	3.4	4.9	9.7	
High emissions	2140	3.7	2.6 -	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3 -	3.8	5.5	11.0	
High emissions	2150	4.1	2.8 -	5.8	5.7	13.0	21.9

Table 2-3 Sea-level rise projection for China Basin Park.

Time Period	High Emissions, Medium – High Risk Aversion Scenario
2030	0.8 ft
2040	1.3 ft
2050	1.9 ft
2060	2.6 ft
2070	3.5 ft
2080	4.5 ft
2090	5.6 ft
2100	6.9 ft

2.3. Wind Statistics

Wind data representative of the South-Central Bay was collected from NOAA Station 9414750 at the Alameda Naval Air Station (NAS), which is located approximately 4.5 miles east of the project site. Wind data recorded at Alameda is representative of conditions over the central bay. The Alameda wind gauge provides hourly observations of wind speed and wind direction since 1945.

Annual and seasonal wind roses based on Alameda wind data are provided in Figure 2-2 and Figure 2-3. The annual wind rose shows that winds are predominately from the west. The seasonal wind roses show that there is some variation of the predominant wind direction throughout the year. Over the winter months (Dec-Jan-Feb) there is an increased frequency of winds from the north and southeast associated with winter storms.

The prevailing wind speeds and directions give an idea about daily and seasonal conditions, while extreme wind conditions are needed to determine design conditions for wind waves. Figure 2-4 shows the primary compass directions over the open bay where wind-waves can develop. Wave action along the China Basin Park shoreline is primarily associated with winds from the northeast, east, and southeast (solid lines in Figure 2-4). The breakwaters protecting the South Beach Harbor marina shield China Basin against waves from northerly and north-northeasterly directions (dashed lines). The abutment under Pier 50 created as part of the Mission Rock Terminal construction shields China Basin against waves from southerly to south-southeasterly directions (dashed lines). The primary directions from China Basin that have open water across the Bay over which wind-waves can develop are to the northeast (NE), east (E) and southeast (SE) as indicated in Figure 2-5. Extreme Value Analysis (EVA) was undertaken based on the selection of annual maximum winds for 68 years of recorded wind data. A Generalized Extreme Value Distribution (GEVD) was developed to determine extreme wind speeds by direction.

Table 2-4 summarizes wind speeds from directions northeast, east, and southeast with recurrence intervals of 1, 2, 5, 10, 25, 50, and 100 years on average. The second column in the table indicates the percent annual chance of the respective wind event occurring in a given year.

Table 2-4: Wind speed extremes for China Basin derived from Alameda NAS wind data.

Recurrence Interval (years)	Percent Annual Chance	Wind Speed (knots) and Direction (from)		
		NE	E	SE
1	100%	15.0	12.0	24.0
2	50%	18.2	15.2	28.6
5	20%	22.5	19.7	34.1
10	10%	25.0	23.0	37.2
25	4%	27.7	27.4	40.6
50	2%	29.5	31.0	42.9
100	1%	31.1	34.8	45.0

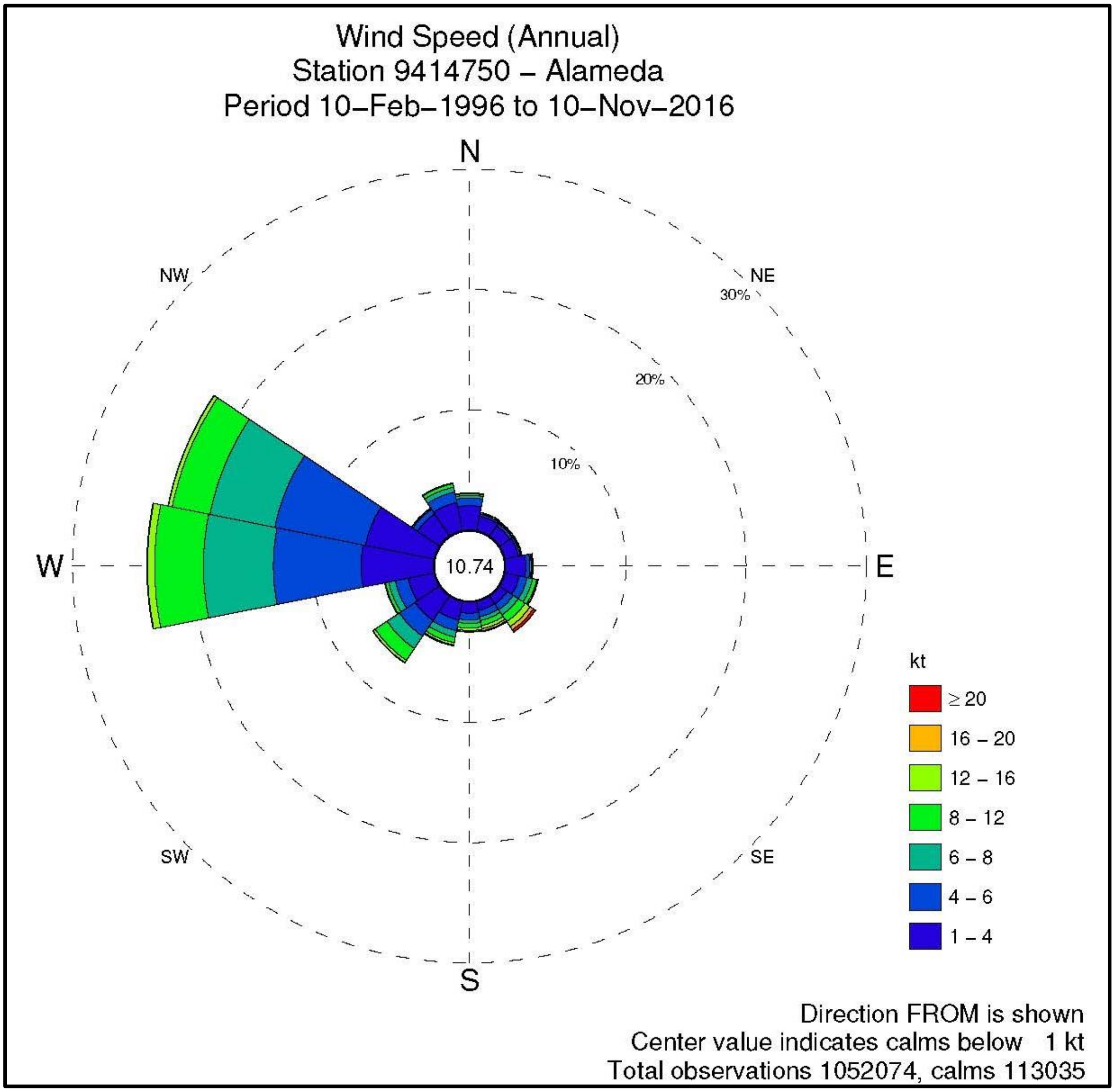

Figure 2-2: Annual wind rose, Alameda NAS.

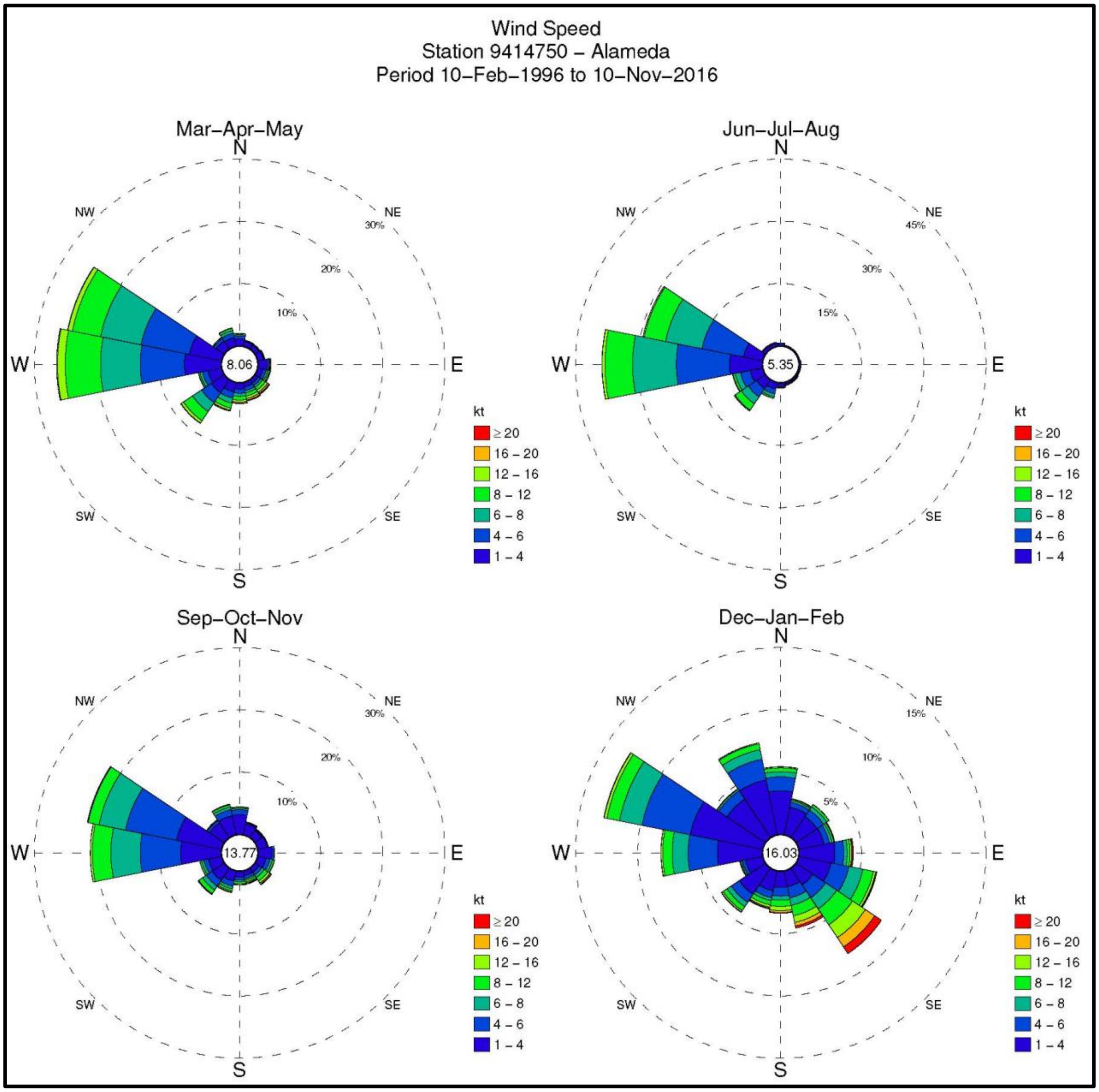

Figure 2-3: Seasonal wind roses, Alameda NAS.

2.4. Wave Action

The shoreline at China Basin Park is exposed to waves generated by local winds within San Francisco Bay. Waves generated in the Pacific Ocean, both sea and swell, undergo considerable refraction and diffraction upon passing through the Golden Gate with the result that they are greatly reduced in height when entering the Bay. Therefore, these waves are not a factor in the shoreline engineering design for China Basin.

Analysis of the configuration of San Francisco Bay and the wind conditions described in Section 2.3 results in the definition of three principal wave exposures, the northeast (NE) direction, east direction (E), and the southeast (SE) direction (solid lines indicated in Figure 2-4). The SE exposure is associated with the long overwater fetch to the south and the strong southerly winds characteristic of winter storms. The NE exposure is limited to certain narrow fetches by Yerba Buena Island into the northern portions of the Bay and is associated with the strong northerly winds characteristic of spring. The shoreline is well protected from northerly exposure by the breakwaters protecting the South Beach Harbor marina. The shoreline is similarly protected from southerly exposure, due to its orientation at McCovey Cove and the Mission Rock Terminal to the South (see Figure 2-5). The remaining concern is limited to the easterly exposure with its relatively short fetch and infrequent winds, and to ship wake from passing vessels, which occurs year-round.

The conditions in deep water for the site's wave exposure were determined by recognized hindcast procedures, since no other wave data is available. The procedures included statistical analysis of historical wind data, the determination of an effective fetch for wave generation, and the prediction of corresponding wave heights and periods associated with various return periods. The results are summarized in Table 2-5 for the significant wave height, which is defined as the average height of the 1/3 highest waves in a sea more fully described by a wave spectrum. The maximum wave height is about 1.8 times the value given for the significant wave height. Table 2-5 summarizes the governing wave conditions which are associated with winds from the southeast. Locations for the wave data along the shoreline are indicated in Figure 2-6. Additional wave data is provided in Appendix A.

The wave conditions presented in Table 2-5 describe the wave conditions near the China Basin Park shoreline as they approach the site from the deepwater portions of the bay, estimated based on the wind speeds from Table 2-4. Upon entering shoal water, the waves are altered in height and length. Furthermore, pier structures in the vicinity modify the incident waves resulting in variable wave conditions depending on location within the site. In particular, the solid core of the Mission Rock Terminal (Pier 50) to the south affords some wave protection.

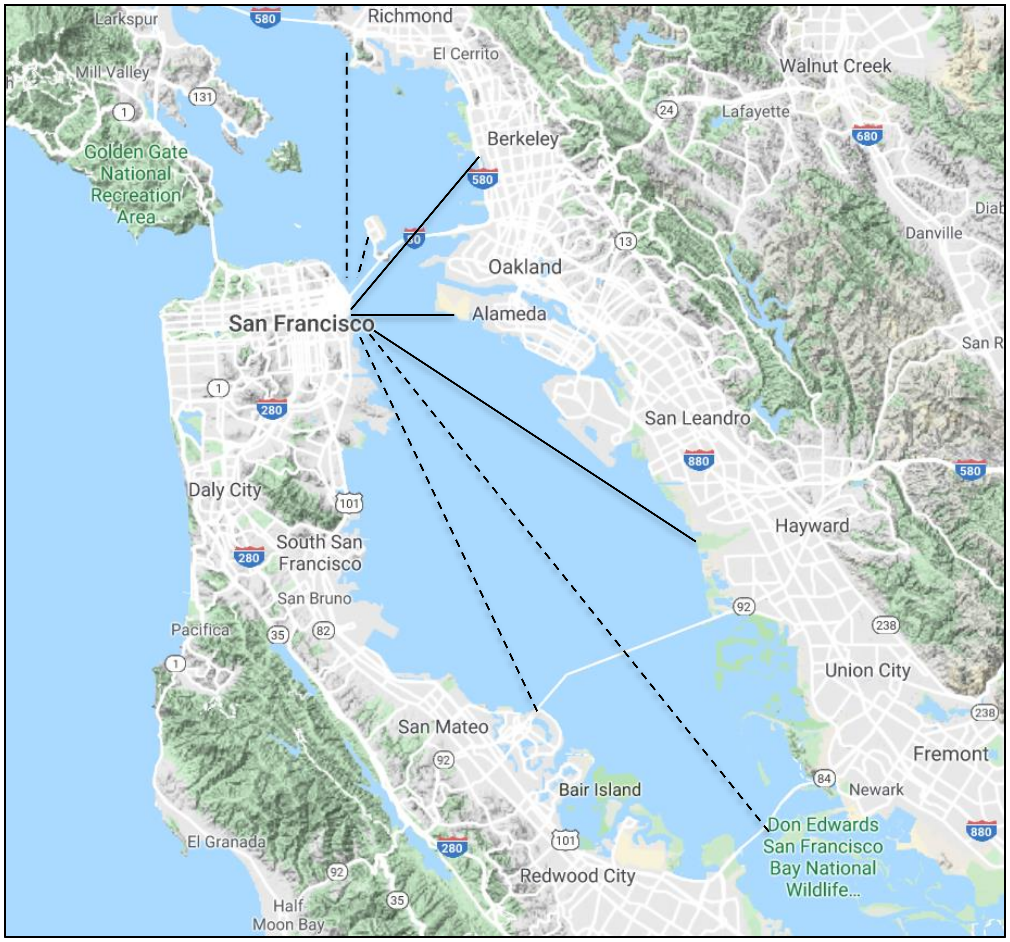

Figure 2-4: Overwater fetch distances associated with wind-wave exposure at China Basin.

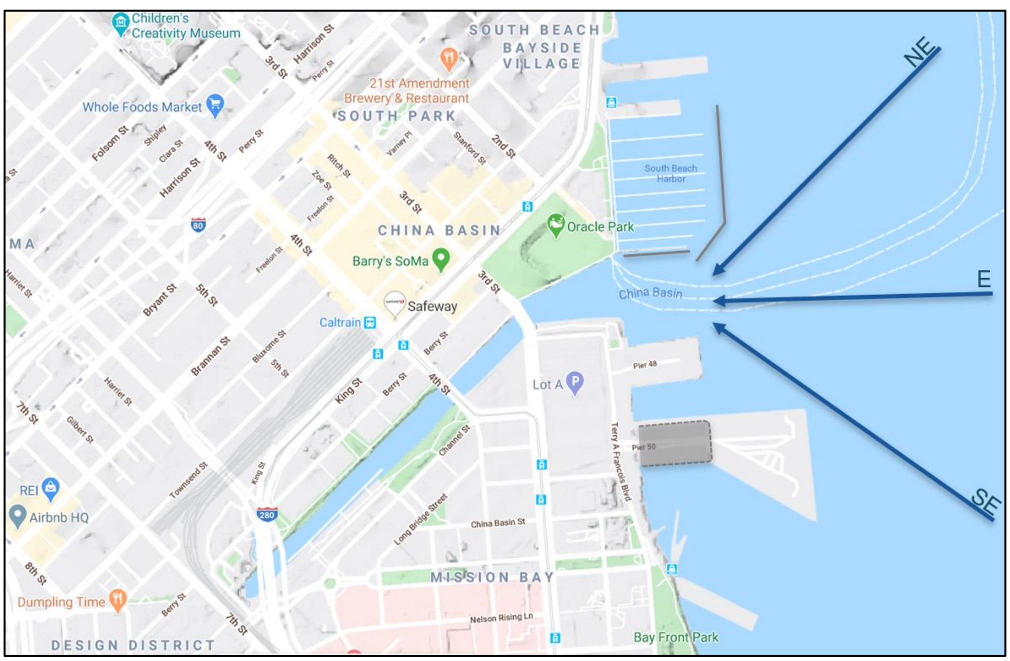

Figure 2-5: China Basin wave exposure.

Table 2-5: Wave data for China Basin Park shoreline.

Location	Recurrence Interval (years)						
	1	2	5	10	25	50	100
	Significant Wave Height (feet)						
# 1	0.9	1.1	1.3	1.4	1.6	1.6	1.7
# 2	1.1	1.3	1.6	1.7	2.0	2.1	2.1
# 3	1.4	1.7	2.1	2.2	2.5	2.5	2.6
# 4	1.6	2.0	2.4	2.6	2.8	2.9	3.0
# 5	2.5	3.0	3.7	4.0	4.6	4.9	5.1
# 6	2.5	3.1	3.7	4.0	4.7	4.9	5.1

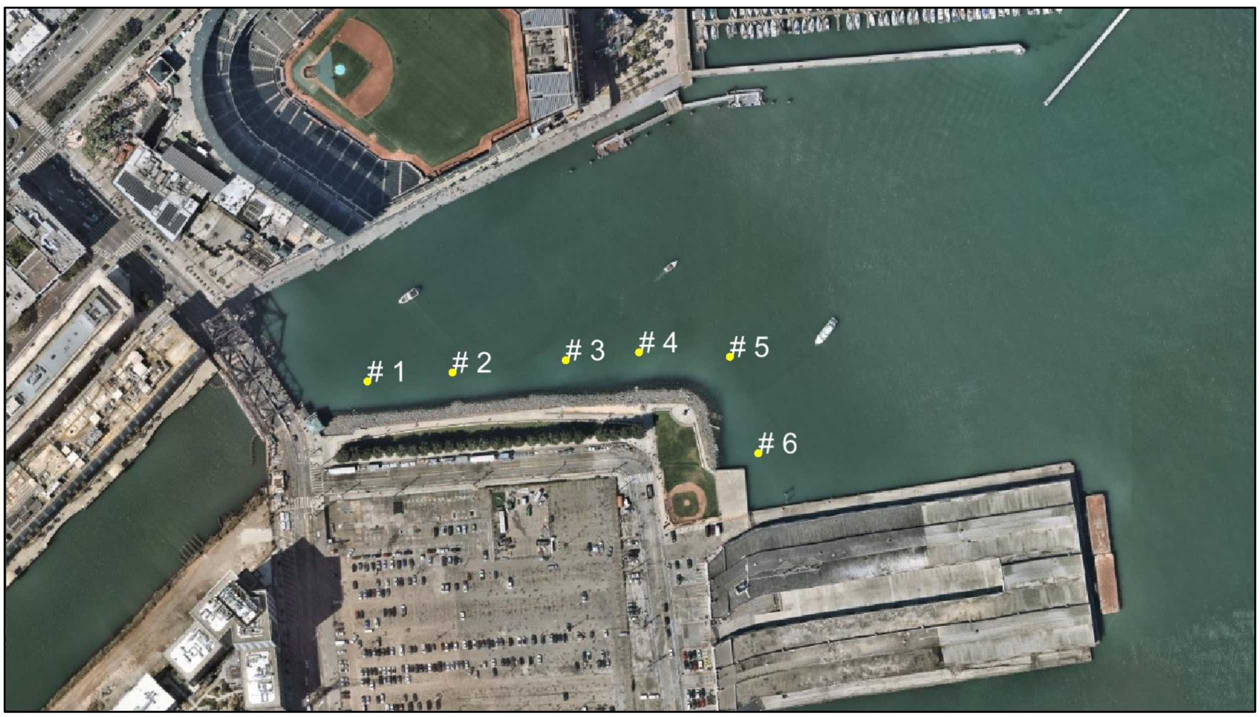

Figure 2-6: China Basin wave data locations.

2.4.1. Ship Wake

Waves generated by passing vessels (ship wake) are a function of the size of the vessel, the vessel's speed, and the distance of the vessel's sailing line from the site, among other factors. The waves produced by representative vessels in the Bay passing China Basin are given in Table 2-6. Vessels in McCovey Cove, though closer to the site, should be moving too slowly to generate any concern over their wake. These waves are not a controlling factor in structural design of the facilities, but are a factor in boat launch operation, at the waters edge along the shoreline, and at the Cove Access Ramp and Tidal Shelves, as these waves affect the site throughout the year.

Table 2-6: Estimated ship wake waves.

Vessel Displacement (tons)	Vessel Speed (knots)	Vessel Distance (feet)	Maximum Wave Height (feet)	Peak Wave Period (seconds)
2,000	13	1,000	1.4	4.1
3,000	15	1,000	2.0	5.1
4,000	15	1,000	2.1	5.1
4,000	15	2,000	1.6	5.1

Figure 2-7 provides an overview of the wake pattern produced by a vessel in transit. Due to the vessel's forward movement water is displaced and a varying pressure distribution develops along the hull of the vessel. An increased pressure is produced at the bow and stern and a pressure drop is experienced along the midsection. The associated pressure gradients produce waves that propagate out from the bow and the stern of the vessel. As a vessel makes its transit along a sailing line, it will produce a characteristic V-shape system of waves conventionally termed vessel wake. The narrow band along the sailing line is also termed wake and refers to the trail of turbulent water left by the passage of the vessel.

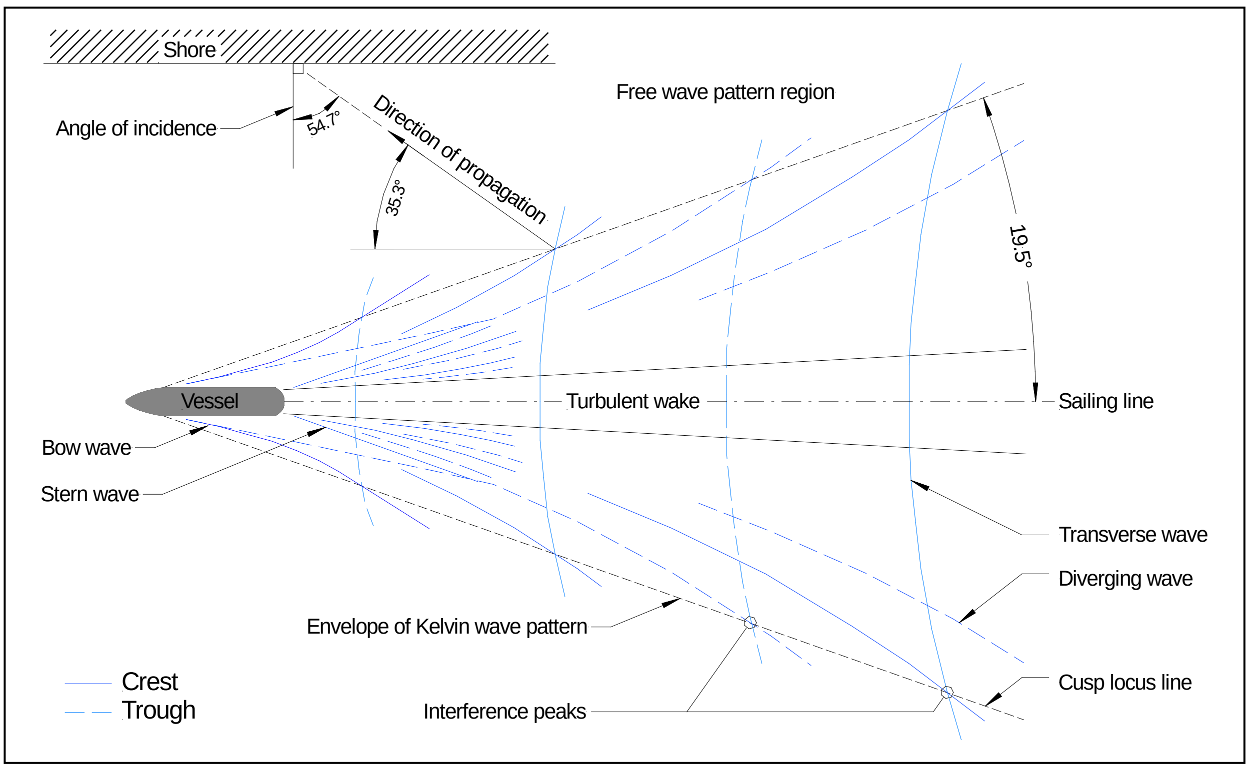

Figure 2-7: Vessel wake pattern.

At the head of the vessel, a bow wave forms and a second wave system radiates out from the stern. Both the bow wave and the stern wave produce a pattern of diverging waves which propagate away from the sailing line at an angle of approximately 35.3°. The envelope of the diverging and transverse waves is known as a Kelvin wave pattern. In Figure 2-7, wave crests are indicated with solid blue lines, while the trough of waves are denoted by dashed blue lines. Where the crests of diverging waves intersect with the crests of transverse waves, the two wave systems interfere by superposition to produce a higher wave crest. Likewise, a deeper trough occurs where the troughs of diverging and transverse waves intersect. These interference peaks propagate along a line termed the cusp locus line, which forms an angle of approximately 19.5° relative to the sailing line.

A detailed derivation of vessel wake is highly complex as it depends on the particular hull shape of the vessel and its frictional resistance during transit. It is only with modern computational methods that solutions of the underlying equations of physics are starting to develop, although the mathematics involved are extensive and computationally very intensive. The bulk of the present research has focused on developing semi-empirical relationships to describe the overall characteristics of vessel wakes. The main parameters governing vessel wake formation are identified to be:

- The speed of the vessel, with increasing speed producing an increase in wave heights.
- The water depth, with decreasing water depth producing an increase in wave heights.
- The Froude Number, which relates the above parameters to the celerity (travel speed) of a shallow-water wave, and, in the case of deep water, to the overall dimension of the vessel.

Additionally, other parameters that affect wake formation include the vessel's hull shape, draft, underkeel clearance, and the confinement of the water body surrounding the vessel. However, their influence on wake formation is less understood.

Figure 2-8 and Figure 2-9 provide examples of the vessel tracks for northbound and southbound vessels. The characteristic V-shape of the wake is outlined by the dashed white lines. Diverging wake waves are indicated in dark blue and transverse wake waves in light blue. Most important in these figures is the directly of wave propagation, which is indicated by the white arrow in each figure.

For vessels traveling northbound (Figure 2-8), it can be seen that the direction of wake wave propagation is towards the South Beach Harbor and McCovey Cove. In this case, wake waves would not be incident on the shore along China Basin Park. The shoreline would also be protected from wake waves arriving from further south due to the presence of Pier 48 and the original Mission Rock island. Wake waves could diffract around the point and propagate towards the China Basin Water Channel, but these waves would run parallel to the China Basin Park shoreline and not produce significant runup on the shore.

Figure 2-9 shows an example of the wake pattern that could associated with southbound vessels. In this case the direction of wake wave propagation is towards Pier 48 and Pier 50. The breakwater surrounding the South Beach Harbor protects China basin from wake wave exposure. There would be no direct incidence of wake waves along the China Basin Park shoreline.

It can therefore be concluded that the China Basin Park shoreline is well protected against vessel wake, and exposure to wake waves is not a significant concern.

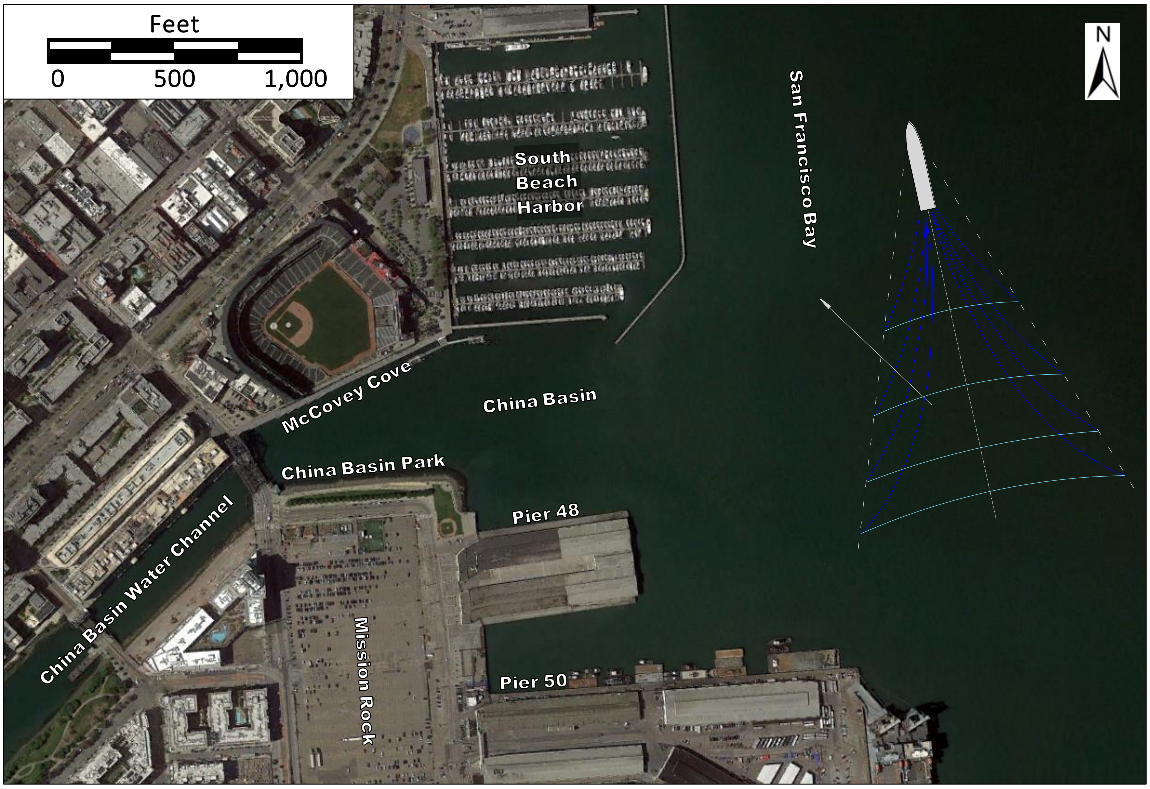

Figure 2-8: Passing vessel wake incidence for northbound vessels.

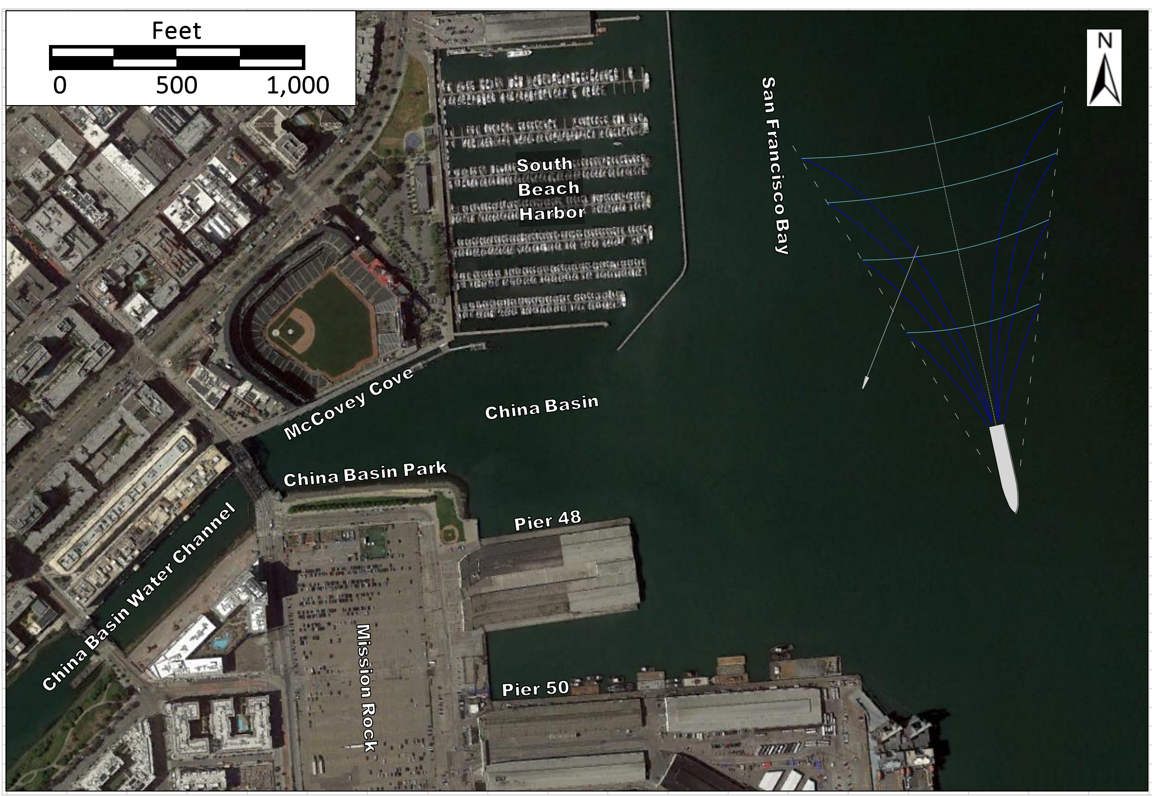

Figure 2-9: Passing vessel wake incidence for southbound vessels.

2.5. Wave Runup Over Tidal Shelves

As assessment of the potential for wave runup over the tidal shelves is provided in the following. The analysis focuses on determining the Total Water Level (TWL), i.e. the highest level the water surface can reach due to a combination of high tide and wave runup. As will be illustrated in the following, the tidal shelves attenuate incident waves due to the presence of the walls, due to the stepwise geometry of the shelves, and due to the overall mild slope of the feature.

Figure 2-10 illustrates the wave exposure during the FEMA one-percent annual chance base flood event. This is the governing FEMA flood scenario for the Bay at China Basin Park, which features a high flood stage of the Bay due to high tide, El Niño effects and low barometric pressure due to a passing storm. In this scenario, there is limited wave incidence at China Basin.

Figure 2-10 shows that in this scenario, the tidal shelves would be submerged and waves would be able to propagate to the shoreline without substantial attenuation. The estimated wave runup elevation is +10.2 feet NAVD88. This analysis includes wave reflection at the end wall, which increases the wave height at the shoreline. The figure shows that there could be limited wave runup at the shoreline, which would be limited to an approximately 10-ft wide band along the shoreline. This amount of runup could likely be mitigated by a curb along the shoreline, which would also prevent the upland material from migrating into the tidal shelf basin, which could happen due to wave overtopping and also due to regular foot traffic.

Figure 2-11 provides an example of the amount of wave exposure that could occur during windy conditions over the Bay coinciding with a king tide (or high tide) condition. The wave shape to the right in the figure indicates the wave length and magnitude of incident waves. It should be noted that it is the largest wave that is portrayed in the figure. Windy conditions will produce irregular seas consisting of a wide range of wave lengths and differing wave heights. The magnitude of such waves are characterized by the significant wave height, H_S, which is representative of the average of the 1/3 highest of the waves. This statistical average is close to what would be reported by visual observation as the wave height. The maximum height of individual waves in the wave field can be estimated as $H_{max} = 1.8 \times H_S$. It is this maximum wave height envelope that is shown in the figures.

Figure 2-11 shows that in the event of wave action occurring during high tides and king tides, the tidal shelves would attenuate the incident waves significantly. Even with the wave reflection that would occur at the end wall, there would likely be no wave overtopping of significance.

Figure 2-12 shows the extreme condition of 100-year return period waves incident of the tidal shelves. This scenario is representative of conditions that could every 100 years on average and would be for strong easterly wind developing waves over the Bay with direct incidence into China Basin. This case would also represent waves developing over the South Bay due to south-southwesterly wind. The water level is assumed to be around Mean High Water, which is a reasonable assumption in this case.

It can be seen that waves would be reduced substantially in height as they wash over the tidal shelves. Waves would wash over the inshore tidal shelf, but there would likely not be overtopping of the end wall. If sea-level rise becomes significant, the likely adaptation would be to incorporate a taller curb or parapet along the tidal shelf end wall.

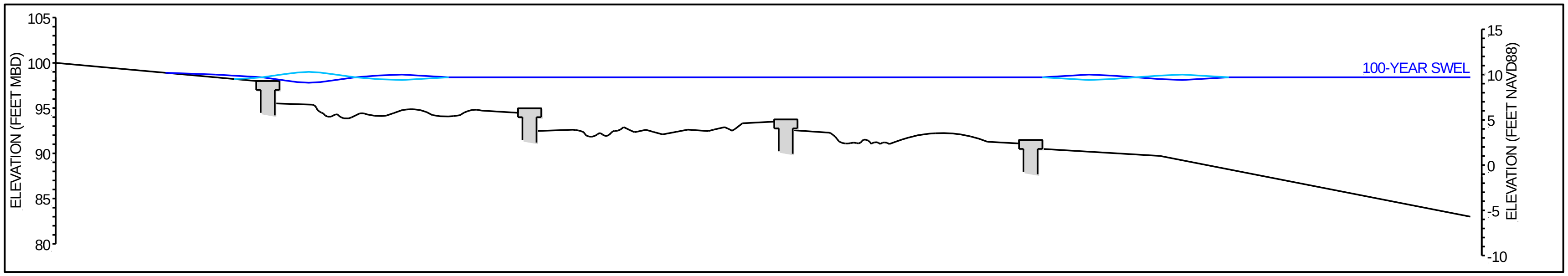

Figure 2-10: Wave exposure during TWL

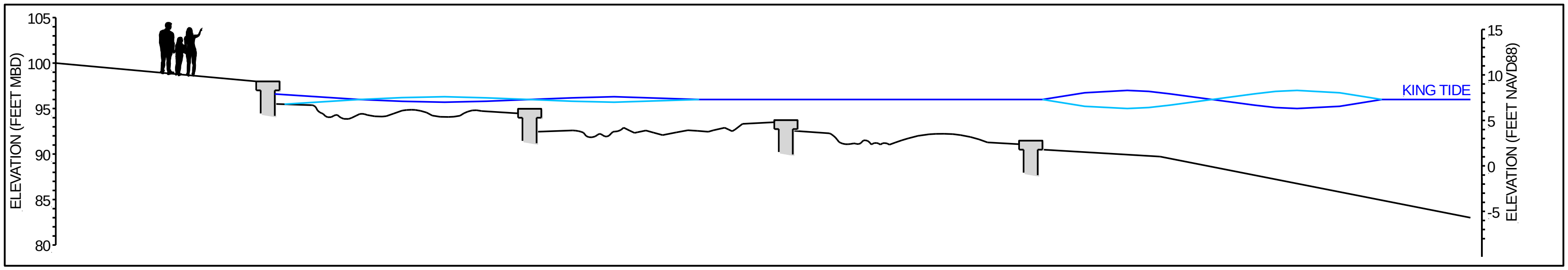

Figure 2-11: Attenuation of wave action during king tides.

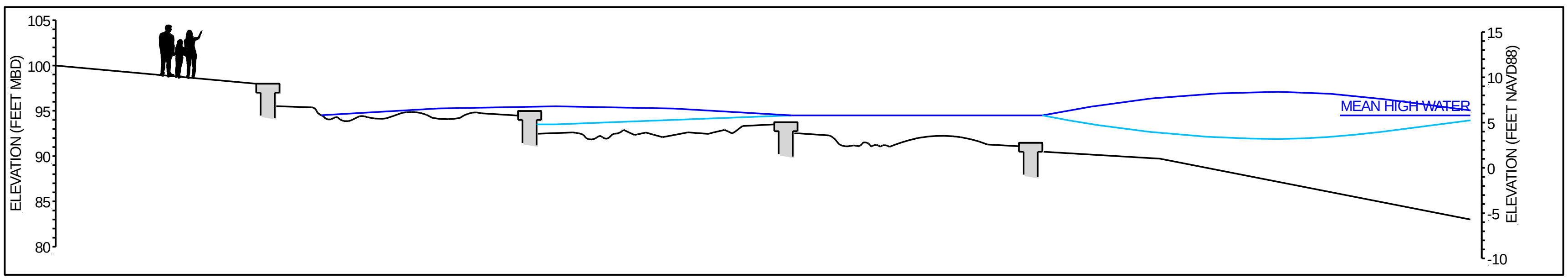

Figure 2-12: Wave attenuation for 100-year wave condition.

2.6. Flood Hazards

Information on current-day exposure to flood hazards is provided in this section. Federal standards for flood hazards are promulgated under the National Flood Insurance Program (NFIP). The flood hazard is expressed as the FEMA 1% Annual Chance Base Flood Elevation (BFE).

Figure 2-13 shows the extent of inundation associated with the FEMA 1% Annual Chance Base Flood in the vicinity of China Basin. The 1% Annual Chance Flood would occur every 100 years on average. Affected areas are shaded in blue. The figure also delineates the 0.2% Annual Chance Floodplain indicated by the tan areas, which indicates flood impacts that would occur every 500 years on average.

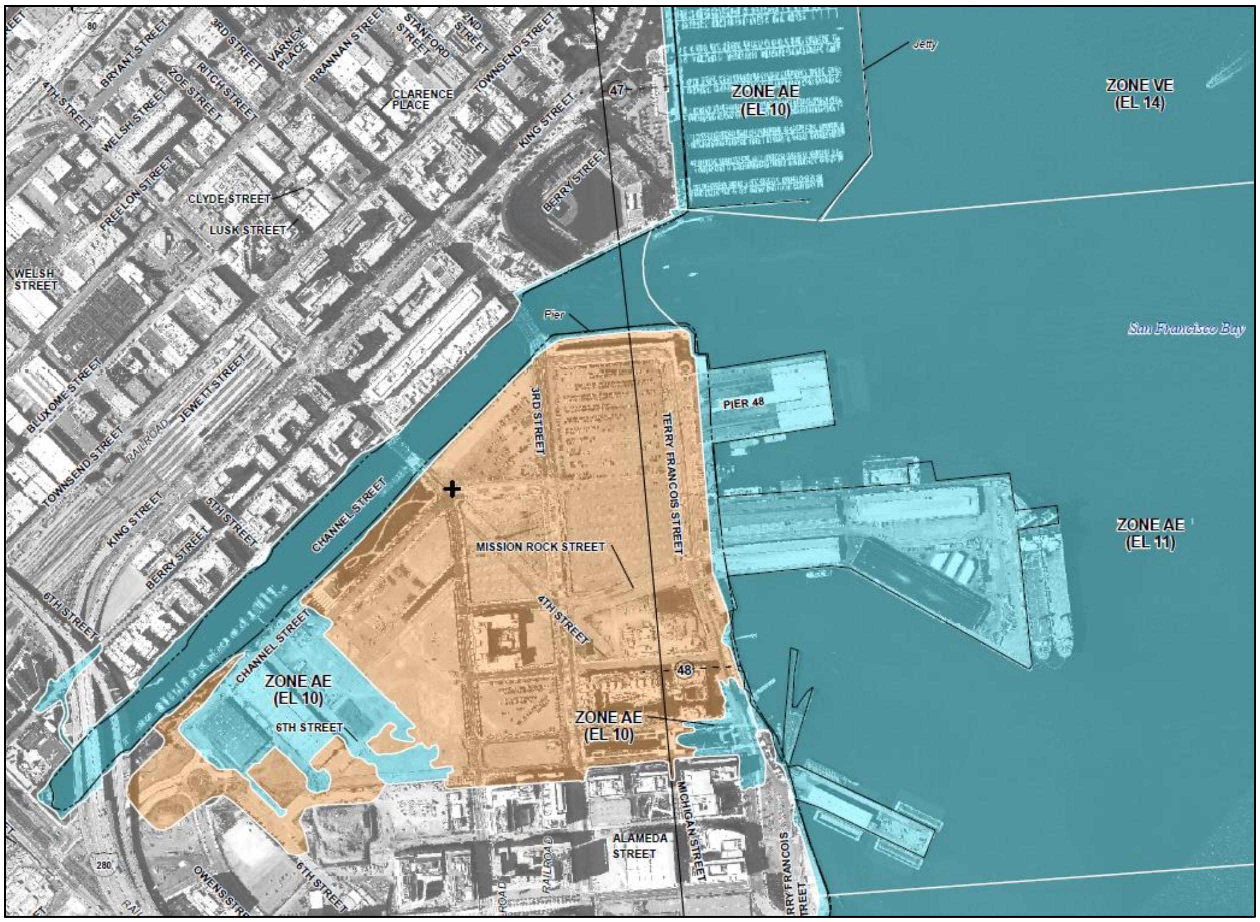

Figure 2-13: Inundation extents associated with 1% Annual Chance BFE (blue) and 0.2% floodplain (tan).

The mapping shows that while the site could be impacted by the 0.2% annual chance flood event, no essential structures will be located in the 1% annual chance floodplain, where Inundation would be limited to the shoreline areas.

Flooding associated with the 1% annual chance flood is a combination of high water level due to tides, El Niño effect, and low barometric pressure. Wave action is another factor that adds to the flood hazards. The Still Water Elevation (SWEL) for the 1% annual chance flood scenario is +9.7 feet NAVD88 per Table 2-1. On FEMA Flood Insurance Rate Maps (FIRMs) such as the one shown in Figure 2-13, the Total Water Level (TWL), which accounts for the high water level, wave action, and wave runup at the shoreline is rounded to the nearest whole foot which is termed the Base Flood Elevation (BFE). For example, the flooding indicated between Channel Street and 6th Street is therefore shown as *Zone AE (EL 10),* which is the SWEL of +9.7 feet NAVD88 rounded to +10 feet. The figure also shows that the BFE along the Bay side is slightly higher at *Zone AE (EL 11)*, which is due to a higher degree of wave action out in the Bay and wave runup along the shoreline.

Similarly, the FIRM (Figure 2-13) indicates a BFE of *Zone VE (EL 14)* in the Bay by the South Beach Harbor marina, which is due to wave reflection and wave runup at the vertical wall panel breakwater protecting the marina. On the protected side within the marina, the BFE is *Zone AE (EL 10)*, i.e. the SWEL rounded to the nearest whole foot and no wave action. For reference, the *AE* designation indicates that a Base Flood Elevation has been determined by a detailed analysis. The *VE* designation indicates areas with a high velocity water hazard associated with waves greater than 3 feet.

The distinction between flooding from a static water level, denoted by the SWEL, versus a dynamic water level denoted by TWL is important to note when assessing Inundation risk for China Basin Park. This is described in more detail below.

2.6.1. Inundation vs Storm-Induced Flooding

The SWEL elevation includes effects of astronomical tides, storm surges, and tsunamis over the period of observation. It represents a static water surface elevation that persists for a prolonged period (several hours at a time).

The TWL elevation represents the superposition of wind waves, Pacific swell, ship wake, and wave runup at any given SWEL. The TWL represents a dynamic water level that may occur for only a few seconds at a time, albeit repeatedly over the period of a storm. It is the highest elevation reached by the water, however short-lived it is.

Both SWEL and TWL are defined as elevations that have a 1% probability of being exceeded in any given year. A shoreline area exceeded by the SWEL constitutes an inundation or large-scale flooding scenario whereas embankments exceeded by TWL elevation constitutes an overtopping scenario that could lead to transient (short-term) wave over-wash for a limited distance landward of the shoreline if the storm duration is prolonged. The wave over-wash distance depends on the difference between the embankment elevation and the wave profile.

On FEMA Flood Insurance Rate Maps (FIRMs), FEMA uses the term Base Flood Elevation (BFE), which can be either the same as SWEL (where wave effects are negligible) or TWL (where effects of waves can be significant). For shoreline areas where waves overtop the top of embankment, FEMA incorporates TWL into their Risk Analysis to identify the risk of wave related damage to shore adjacent facilities. However, the purpose of FIRMs and BFE is to indicate flood risk from an insurance perspective, rather than to assess impacts to recreation for a Park such as China Basin Park.

For China Basin Park, the SWEL and TWL are identical for the east-west shoreline along Mission Creek. For the short segment of north-south aligned shoreline, the TWL exceeds the SWEL by 1-ft due to waves. The effect of transient over-wash from waves would extend only a few feet landward of the SWEL line rather than extend west into the Park.

2.7. Tsunami Hazards

Calculations of runup due to seismic sea waves (tsunamis) of distant origin have been made for San Francisco Bay by the U.S. Army Waterways Experiment Station. This information is used to ascertain water levels for protection of in-water structures from tsunami affects. The values presented are water levels that would be exceeded, on average, once per 100 and once per 500 years. The statistical effect of the astronomical tides on tsunami runup was recognized in the analysis. The results are summarized in Table 2-7.

Table 2-7: Estimated tsunami hazards for China Basin.

Recurrence Interval (years)	Percent Annual Chance (%)	Tsunami Runup Elevation (feet NAVD88)
100	1.0%	+8.2
500	0.2%	+11.4

More recent studies by Borerro, et al. in connection with assessing the risk to Marine Oil Terminals in the Bay produced conservative estimates of tsunami wave heights at a number of Bayfront locations including the Presidio. The reported maximum wave height of 14.4 ft at the Golden Gate should not be confused with the extreme water level, which requires that this wave height be combined with the tide at the time of the peak wave. The City and County of San Francisco (CCSF) Emergency Response Plan reports this as a “runup” value for emergency preparedness planning purposes. The CalEMA Tsunami Inundation Map (Figure 2-14) shows the site as within a tsunami runup area and indicates flooding up to an elevation of about 12.7 ft NAVD88. The recurrence interval of the event is not estimated since the seismic event represents a worst-case scenario, primarily for emergency planning purposes.

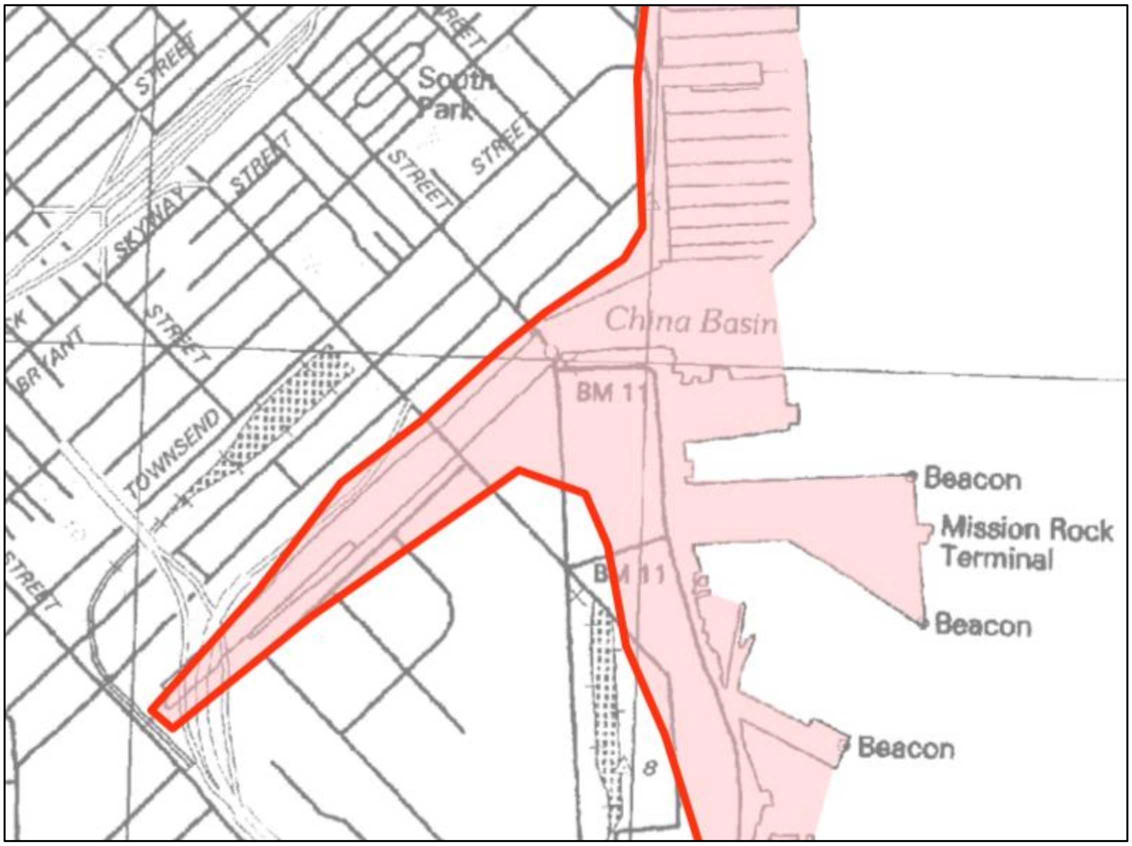

Figure 2-14: Tsunami inundation map for emergency planning, *CalEMA (2009)*.

2.8. Inundation Maps Showing Sea-Level Rise Vulnerability

Detailed inundation maps for post-project construction conditions for MHHW, King Tides, and the BFE are attached in Appendix B. The maps use the following elevations.

Table 2-8: Tidal Datums with Sea Level Rise (ft, NAVD88)

Tidal Plane	Present	Medium – High Risk Aversion Projections[1]			H++ Scenario
		2050 (1.9' SLR)	2070 (3.5' SLR)	2100 (6.9' SLR)	
BFE (SWEL)	+9.7	+11.6	+13.2	+16.6	+19.9
BFE (TWL)[2]	+10.7	+12.6	+14.2	+17.6	+20.9
King Tide	+7.3	+9.2	+10.8	+14.2	+17.5
MHHW	+6.3	+8.2	+9.8	+13.2	+16.5

[1] High Emissions Scenarios

[2] For shoreline segment between Pier 48 and Overlook structure. Not used for Mapping

2.9. Inundation of Tidal Shelves

Submergence of the tidal shelves for the present-day conditions, and due to projected sea-level rise, is described in the following.

Figure 2-15 shows the vertical extent of tidal shelves 1 through 4 as indicated on the drawings. The vertical height shown in the figure is representative of the wetted portion of each tidal shelf. The bottom of each box is representative of the invert elevation of the respective tidal shelf. The sequence of the tidal shelves is staggered and shifted to the right to show the overlap that exists between tidal shelves in terms of their wetted elevation range.

The yellow, pink, purple, and plum curves indicate the percentage amount of submergence for present-day conditions (2020) and as projected with sea-level rise by 2050, 2075, and 2100 for the *1-in-200 Chance, Medium to High Risk Aversion* OPC projection with high emissions. The water level variation portrayed by the curves was developed based on 40 years of actual tide data and therefore covers regularly occurring tides, annual king tides, and rare extremes with very low or very high tides encountered in the past 40 years.

As an example, the lowest tidal shelf (Tidal Shelf 4) would be submerged 97% of the time in the present-day condition. Conversely, the amount of time the tidal shelf would be subject to drying would be 3% of the time. This is to say that only very low tides would drop below the invert elevation of this tidal shelf. Given the projected sea-level rise, the bottom invert of this shelf would become sub-tidal by 2050.

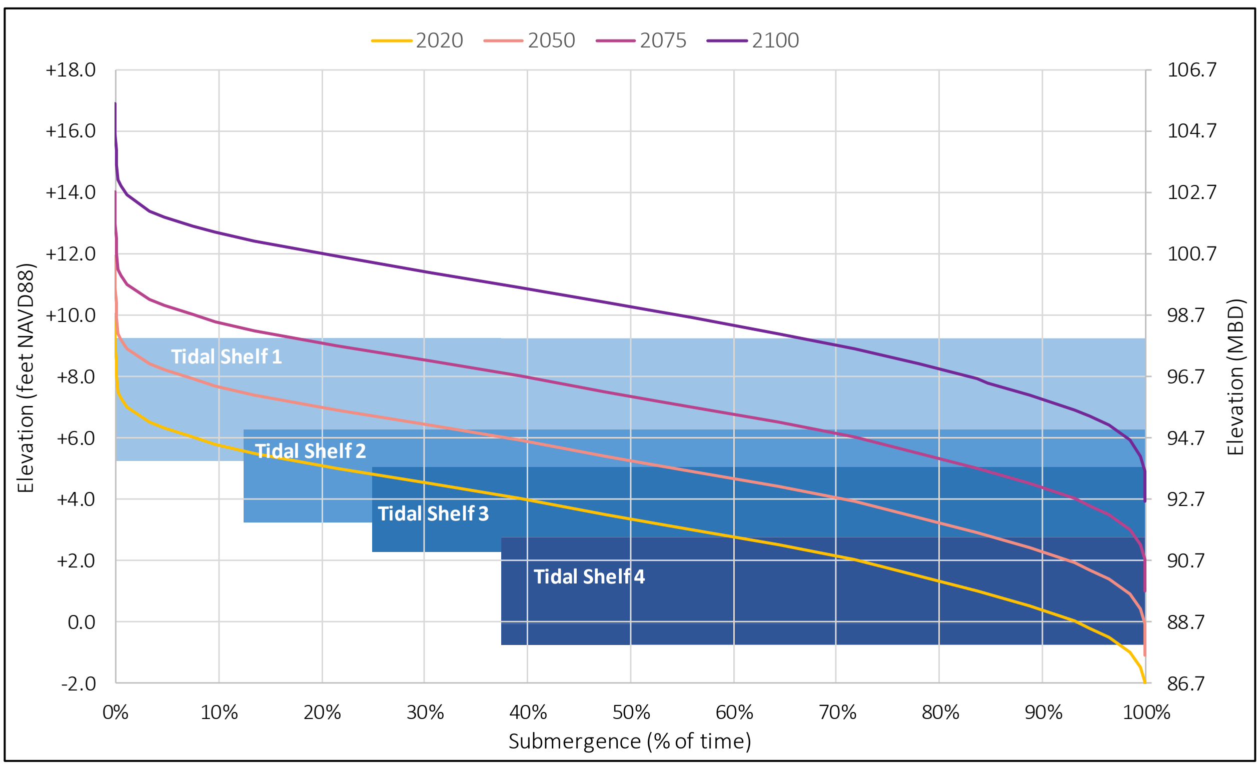

Figure 2-15: Submergence of tidal shelves.

Similarly, the upper tidal shelf (Tidal Shelf 1) would be submerged 18% of the time in the present-day condition. The tidal shelf would be resilient to sea-level rise out to 2050 (pink line), corresponding to a projected sea-level rise of 1.9 feet. Terrain above the upper tidal shelf would consequently be inundated beyond 2050 if subject to the projected sea-level rise. The likely adaptation could be to: 1) initially incorporate a curb at the crest of the tidal shelf; 2) incorporate a parapet wall along the crest of the tidal shelf; or adapt the terrain and site features at these elevations to intertidal habitat. Table 2-9 highlights the percentage of time the tidal shelves would be submerged present-day and by 2050, 2075, and 2100.

Table 2-9: Submergence of tidal shelves, present-day and with projected sea-level rise.

Tidal Shelf	Submergence (percent of the time) by Year			
	2020	2050	2075	2100
1	18%	50%	81%	100%
2	51%	80%	97%	100%
3	68%	90%	99%	100%
4	97%	100%	100%	100%

2.10. Adaptation to Address Sea-Level Rise Vulnerability

The project is being designed to be resilient to 2050. All park elements are being raised to elevations such that inundation will not affect park uses until that time. Proposed habitat features will respond to the change in inundation frequency of the tidal shelves as described in the habitat Assessment (WRA 2020).

An Adaptation Plan for higher sea levels is shown in Appendix C.

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Cal-EMA (2009). *California Official Tsunami Inundation Maps.* Tsunami Inundation Map for Emergency Planning. State of California, City and County of San Francisco. San Francisco North Quadrangle, San Francisco South Quadrangle. Scale 1:24,000. California Emergency Management Agency (Cal-EMA), California Geological Society (CGS), University of Southern California (USC). July 15, 2009. https://www.conservation.ca.gov/cgs/tsunami/maps

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OPC (2018). *State of California Sea-Level Rise Guidance.* California Ocean Protection Council, 2018 Update.

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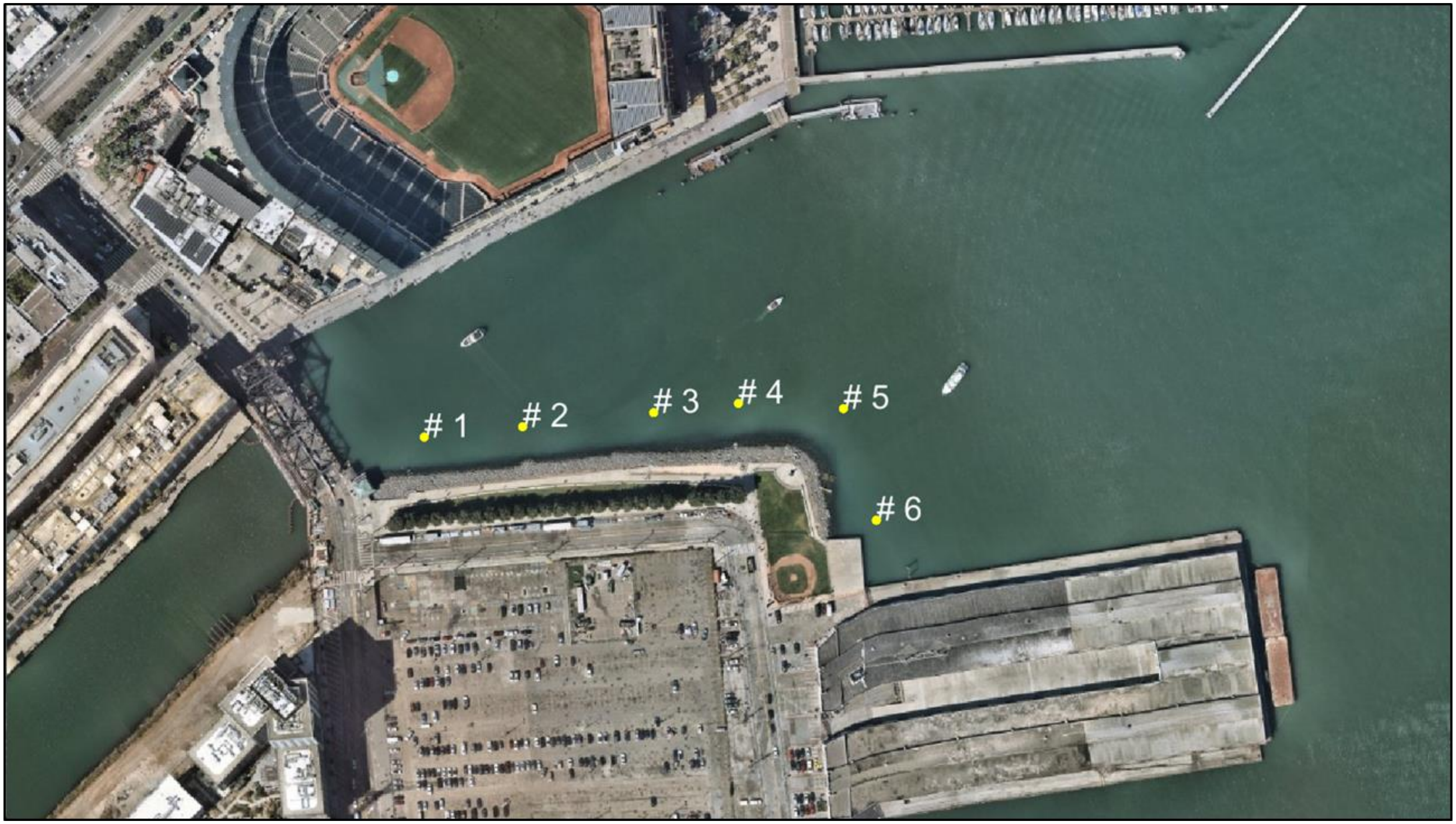
Appendix A – Wave Data



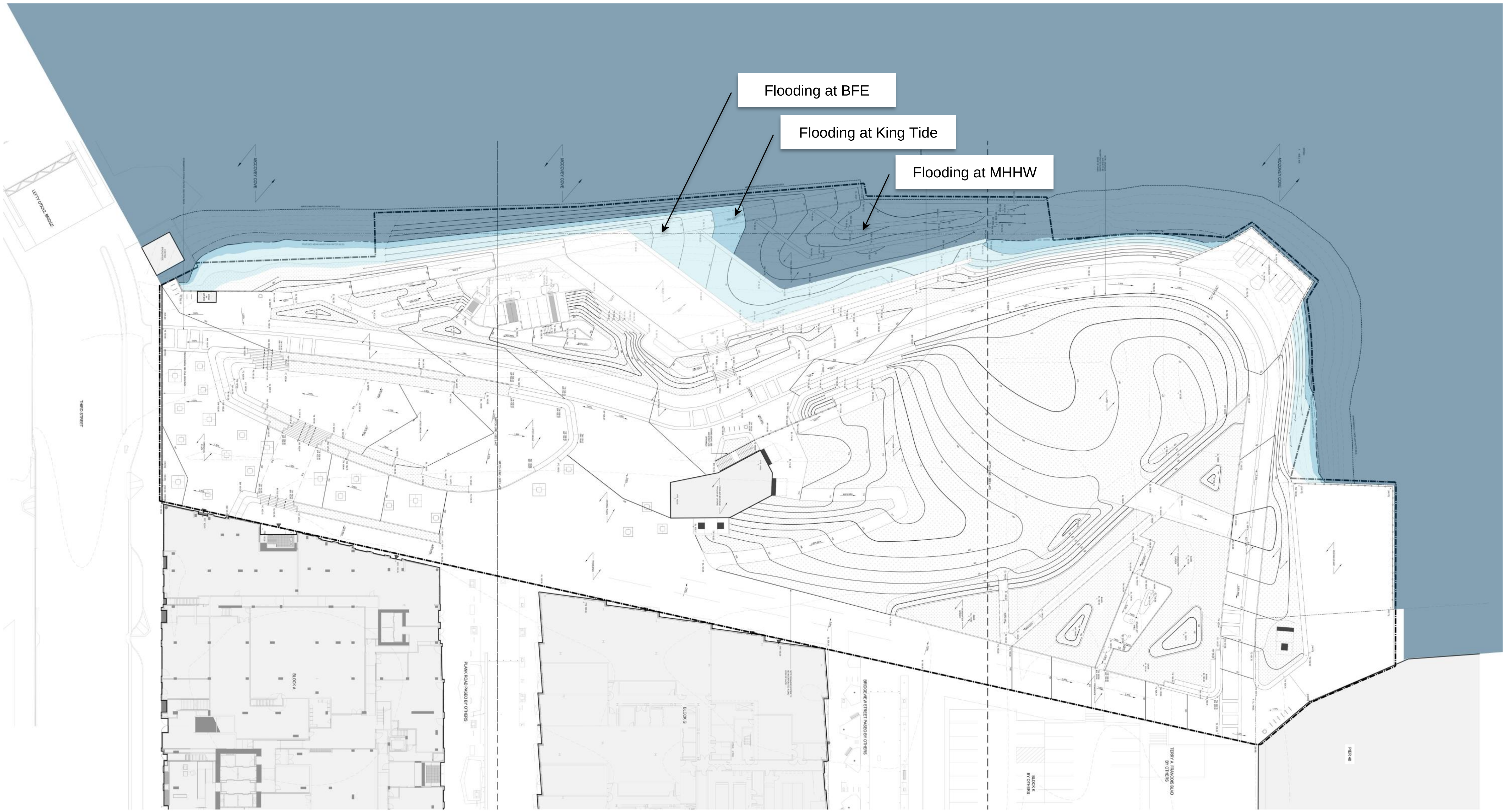
Wave data locations.

	North-Easterly Wind (knots)						
Speed	15.0	18.2	22.5	25.0	27.7	29.5	31.1
	Significant Wave Height (ft)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	0.2	0.3	0.4	0.4	0.5	0.6	0.6
# 2	0.2	0.3	0.4	0.5	0.6	0.7	0.7
# 3	0.3	0.4	0.6	0.7	0.8	0.9	0.9
# 4	0.3	0.5	0.7	0.8	1.0	1.1	1.1
# 5	0.4	0.6	0.9	1.0	1.2	1.3	1.4
# 6	0.6	0.8	1.2	1.3	1.5	1.6	1.7
	Peak Wave Period (s)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	1.2	1.4	1.7	1.8	2.0	2.0	2.1
# 2	1.3	1.6	1.8	2.0	2.1	2.2	2.3
# 3	1.4	1.7	2.1	2.3	2.4	2.5	2.6
# 4	1.6	1.9	2.3	2.5	2.7	2.8	2.8
# 5	1.8	2.1	2.6	2.8	2.8	2.8	2.8
# 6	2.1	2.5	2.8	2.8	2.8	2.8	2.9
	Mean Wave Direction (°N)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	224°	229°	233°	234°	235°	236°	236°
# 2	224°	228°	232°	233°	234°	234°	234°
# 3	228°	231°	234°	235°	235°	236°	236°
# 4	231°	234°	237°	238°	238°	239°	239°
# 5	237°	240°	243°	245°	246°	246°	247°
# 6	231°	234°	236°	237°	238°	238°	239°
	Wave Runup (feet)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	0.3	0.4	0.6	0.7	0.8	0.8	0.9
# 2	0.4	0.5	0.7	0.9	1.0	1.1	1.1
# 3	0.1	0.1	0.1	0.2	0.2	0.2	0.2
# 4	0.5	0.7	1.0	1.2	1.4	1.5	1.6
# 5	0.6	0.9	1.2	1.4	1.5	1.6	1.7
# 6	1.1	1.6	2.2	2.5	2.8	3.0	3.2

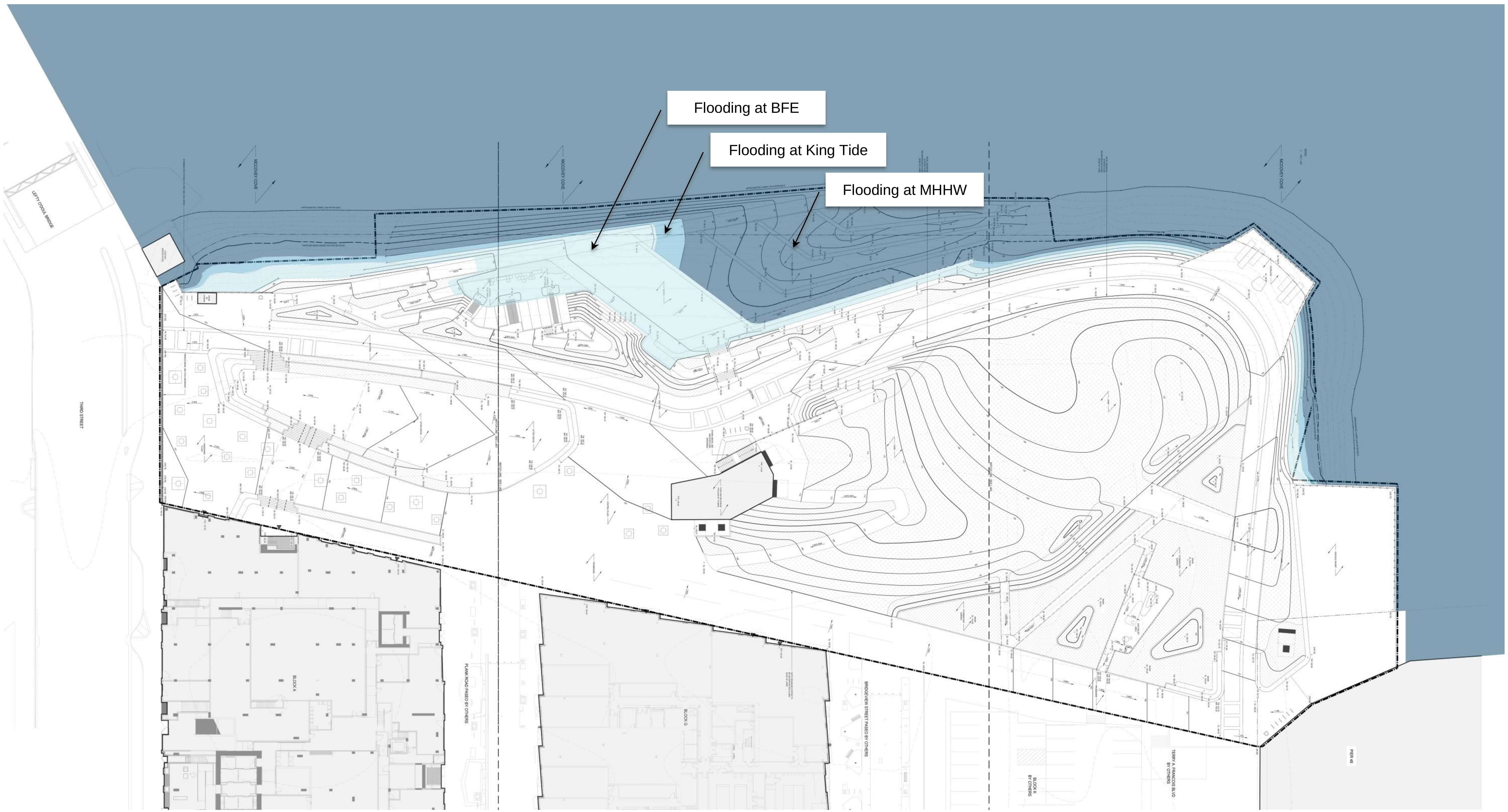
	Easterly Wind (knots)						
Speed	12.0	15.2	19.7	23.0	27.4	31.0	34.8
	Significant Wave Height (ft)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	0.3	0.6	0.9	1.1	1.4	1.6	1.8
# 2	0.4	0.6	1.0	1.3	1.7	1.9	2.1
# 3	0.5	0.8	1.3	1.7	2.1	2.4	2.7
# 4	0.6	1.0	1.6	2.0	2.5	2.8	3.2
# 5	0.7	1.2	1.9	2.4	3.0	3.4	3.8
# 6	0.7	1.2	1.9	2.3	2.9	3.3	3.7
	Peak Wave Period (s)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	1.6	2.1	2.6	2.8	3.0	3.3	3.6
# 2	1.7	2.2	2.8	3.0	3.1	3.4	3.8
# 3	1.9	2.5	2.8	3.0	3.3	3.3	3.7
# 4	2.2	2.8	2.8	3.0	3.3	3.3	3.7
# 5	2.4	2.8	2.8	3.0	3.3	3.3	3.7
# 6	2.4	2.8	2.8	3.0	3.2	3.3	3.3
	Mean Wave Direction (°N)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	246°	244°	241°	239°	238°	237°	236°
# 2	246°	244°	241°	239°	238°	237°	236°
# 3	253°	250°	246°	245°	243°	242°	242°
# 4	262°	259°	255°	254°	252°	251°	250°
# 5	280°	278°	275°	273°	272°	272°	271°
# 6	277°	275°	272°	271°	269°	269°	269°
	Wave Runup (feet)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	0.5	0.8	1.3	1.6	1.9	2.3	2.6
# 2	0.6	1.0	1.7	2.1	2.5	2.9	3.4
# 3	0.1	0.2	0.3	0.3	0.4	0.4	0.5
# 4	0.8	1.4	1.8	2.1	2.6	2.8	3.4
# 5	0.9	1.4	1.8	2.2	2.7	2.9	3.4
# 6	1.4	2.3	3.5	4.3	5.3	6.0	6.4

	South-Easterly Wind (knots)						
Speed	24.0	28.6	34.1	37.2	40.6	42.9	45.0
	Significant Wave Height (ft)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	0.9	1.1	1.3	1.4	1.6	1.6	1.7
# 2	1.1	1.3	1.6	1.7	2.0	2.1	2.1
# 3	1.4	1.7	2.1	2.2	2.5	2.5	2.6
# 4	1.6	2.0	2.4	2.6	2.8	2.9	3.0
# 5	2.5	3.0	3.7	4.0	4.6	4.9	5.1
# 6	2.5	3.1	3.7	4.0	4.7	4.9	5.1
	Peak Wave Period (s)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	2.6	2.8	3.1	3.2	3.5	3.6	3.6
# 2	2.8	3.2	3.5	3.7	3.9	4.0	4.0
# 3	3.2	3.6	3.9	4.1	4.3	4.4	4.5
# 4	3.4	3.8	4.2	4.3	4.3	4.5	4.6
# 5	3.7	4.2	4.8	4.8	4.8	4.8	5.6
# 6	3.8	4.2	4.4	4.8	4.8	4.8	5.0
	Mean Wave Direction (°N)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	269°	268°	267°	267°	267°	266°	266°
# 2	266°	264°	264°	263°	263°	263°	262°
# 3	273°	271°	271°	271°	270°	270°	269°
# 4	276°	275°	274°	274°	274°	273°	272°
# 5	299°	297°	297°	296°	296°	296°	294°
# 6	294°	293°	292°	292°	291°	291°	290°
	Wave Runup (feet)						
RP (years)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
# 1	0.7	0.8	0.9	0.9	1.0	1.0	1.1
# 2	0.9	1.1	1.2	1.3	1.3	1.4	1.5
# 3	0.2	0.2	0.3	0.3	0.3	0.3	0.3
# 4	1.7	2.1	2.3	2.4	2.6	2.6	2.7
# 5	2.4	2.9	3.3	3.5	3.7	3.8	4.1
# 6	3.3	4.1	4.6	4.9	5.3	5.6	6.2

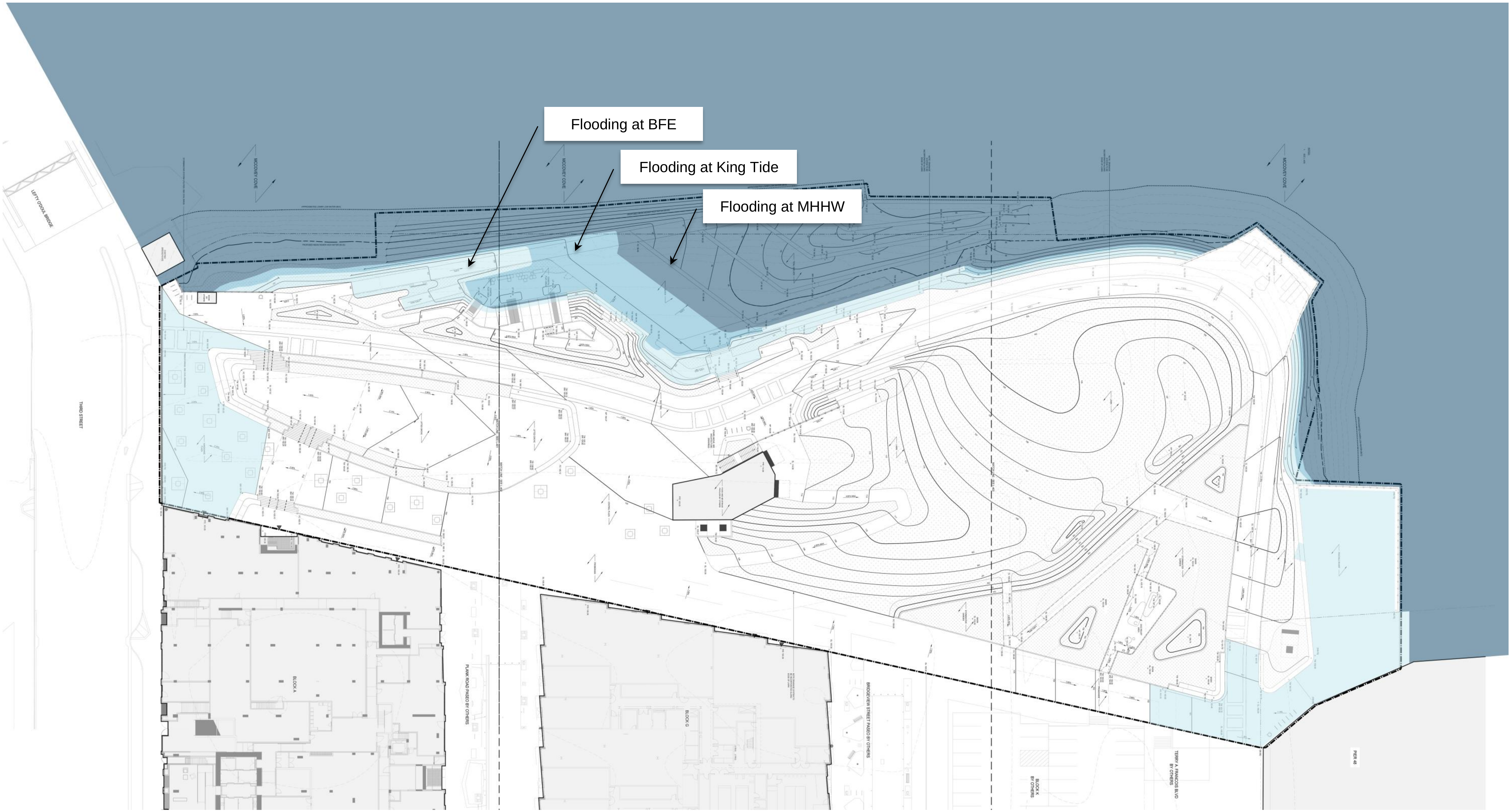
Appendix B – Inundation Maps



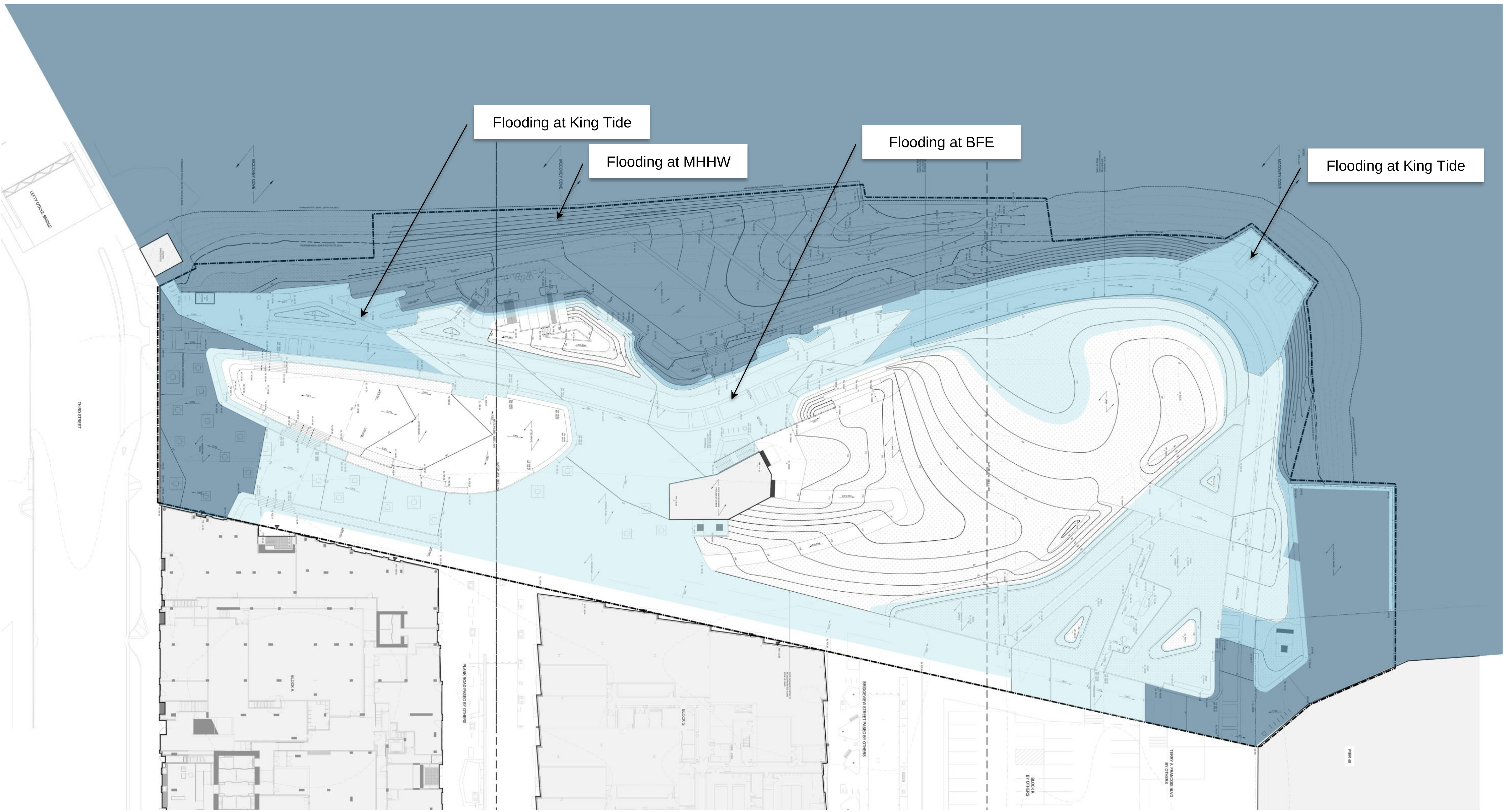
Inundation Extents – Post Construction (~ 2020) [Source: SCAPE Landscape Architecture 2020]



Inundation Extents – 2050 [Source: SCAPE Landscape Architecture 2020]



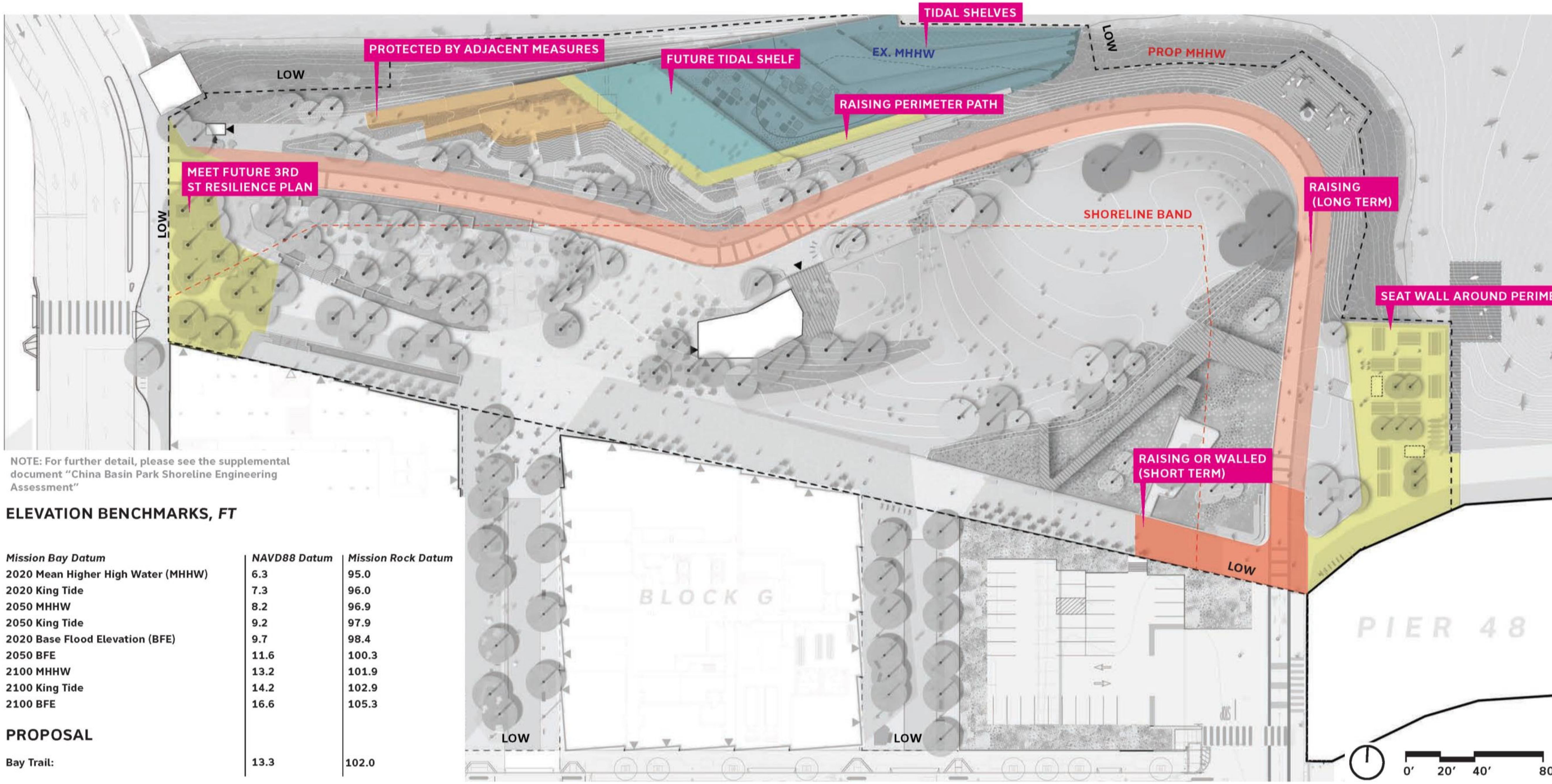
Inundation Extents – 2075 [Source: SCAPE Landscape Architecture 2020]



Inundation Extents – 2100 [Source: SCAPE Landscape Architecture 2020]

Appendix C – Adaptation Plan for SLR Beyond 2050

SEA LEVEL RISE PROGRAM STRATEGY



ELEVATION BENCHMARKS, *FT*

Mission Bay Datum	*NAVD88 Datum*	*Mission Rock Datum*
2020 Mean Higher High Water (MHHW)	6.3	95.0
2020 King Tide	7.3	96.0
2050 MHHW	8.2	96.9
2050 King Tide	9.2	97.9
2020 Base Flood Elevation (BFE)	9.7	98.4
2050 BFE	11.6	100.3
2100 MHHW	13.2	101.9
2100 King Tide	14.2	102.9
2100 BFE	16.6	105.3
PROPOSAL		
Bay Trail:	13.3	102.0

Adaptation Plan Beyond 2050 [Source: SCAPE Landscape Architecture 2020]