Noyo Center for Marine Science Marine Field Station

Sea Level Rise Adaptation Study

PREPARED FOR EHDD | NCMS
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Image courtesy of Noyo Center Marine Field Station

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Glossary

‘	feet
AE	{FEMA FIRM}
Approx.	Approximately
ASCE	American Society of Civil Engineers
Ave	Avenue
BFE	Base Flood Elevation
Cal	California
DART	Deep-ocean Assessment and Reporting of Tsunamis
ehdd	EHDD Architecture
El.	Elevation
EVA	Extreme Value Analysis
FEMA	Federal Emergency Management Agency
FFE	Finish Floor Elevation
FG	Finished Grade
FIPS	Federal Information Processing Standards
FIRM	{FEMA} Flood Insurance Rate Map
FIS	Flood Insurance Study
ft	feet
Isl.	Island
KT	King tide
LiDAR	Light Detection and Ranging
m	Meters
M&N	Moffatt & Nichol
MLLW	Mean Lower Low Water
N	North / Northern
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NCMS	Noyo Center for Marine Science
NOAA	National Oceanic and Atmospheric Administration
OES	Office of Emergency Services
OPC	{California} Ocean Protection Council
PMEL	Pacific Marine Environmental Laboratory
R.	Range
RP	Return Period {event frequency}
S	South
SLR	Sea Level Rise
St	Street
U.S.	United States
USACE	U. S. Army Corps of Engineers
USGS	United States Geological Survey
VE	{FEMA FIRM} Area of Velocity Hazard
YR	Year

1. Introduction

Moffatt & Nichol (M&N) was retained by EHDD Architecture (ehdd) to develop a Sea Level Rise (SLR) adaptation study and assist with development of conceptual design alternatives for SLR adaptation of the Noyo Marine Science Center (NCMS) Marine Field Station building and associated infrastructure.

The Marine Field Station is located on the Noyo Harbor waterfront at 32430 N. Harbor Dr, Fort Bragg, CA 95437. The main building and elements of the facility are located on land and include an entryway, lobby, kitchen, storage, laboratory facilities, shed, utility yard, parking, and side yard. The facility meeting room and terrace are located on an over water deck supported on piles, fronted by a 60-ft floating dock which provides waterside access. This study provides an assessment of the potential vulnerability of the Marine Field Station to inundation and flood hazards associated with king tides, ocean swells, tsunamis, and storm surge exacerbated by SLR.

1.1. SLR Resilience

A regional City of Fort Bragg SLR, Tsunami Hazard, and Erosion Resilience Strategy assessment was prepared by ESA/ARUP (2025). The assessment examined SLR in increments, assuming 1 foot of SLR occurring by 2050 (near term), 3 feet of SLR occurring by 2070-2100 (intermediate term) and 6 feet of SLR beyond 2100 (long term). The study evaluated these specific amounts of SLR to identify thresholds at which assets would become vulnerable and identified vulnerable facilities at Noyo Harbor.

The ESA/ARUP (2025) analysis estimated that the Noyo Center Marine Field Station would be impacted in a 100-year flood event (present-day) and could be subject to tidal inundation with 3 feet of SLR. The study identified seven key operational goals for Noyo Harbor having a potential to be impacted by SLR. Of these operational goals, the two that affect the Noyo Center Marine Field Station include:

- Operational Goal 2. Ability of vessels to safely enter/exit the harbor; and
- Operational Goal 7. Maintaining business continuity for all non-emergency harbor operations.

Regarding potential tsunami hazards, the ESA/ARUP (2025) study mapped the Noyo Center Marine Field Station as vulnerable to tsunami hazards with recurrence intervals of 200 years and higher.

2. Basis of Analysis

2.1. Project Location

Figure 2-1 shows the location of the NCMS Marine Field Station circled in red.

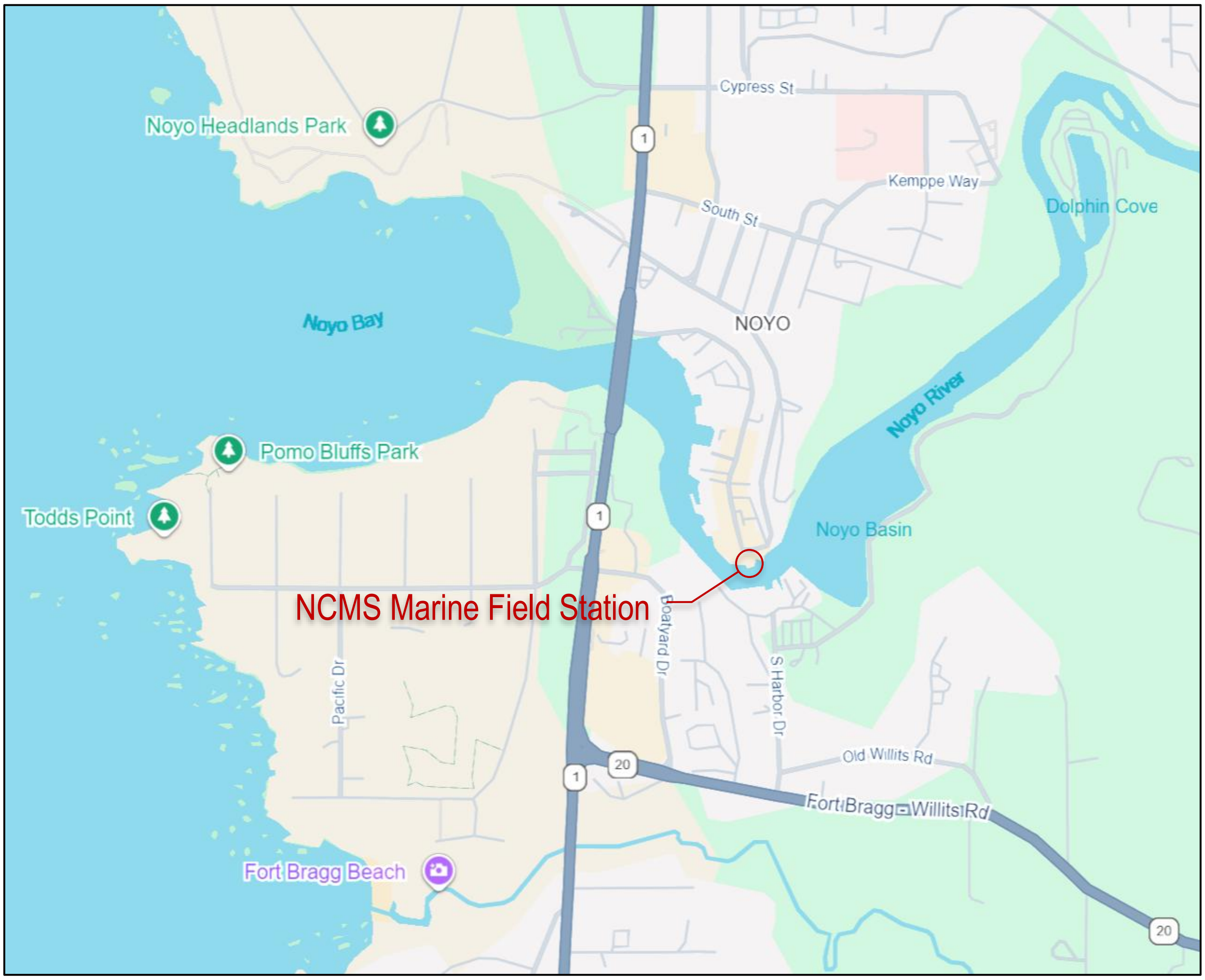


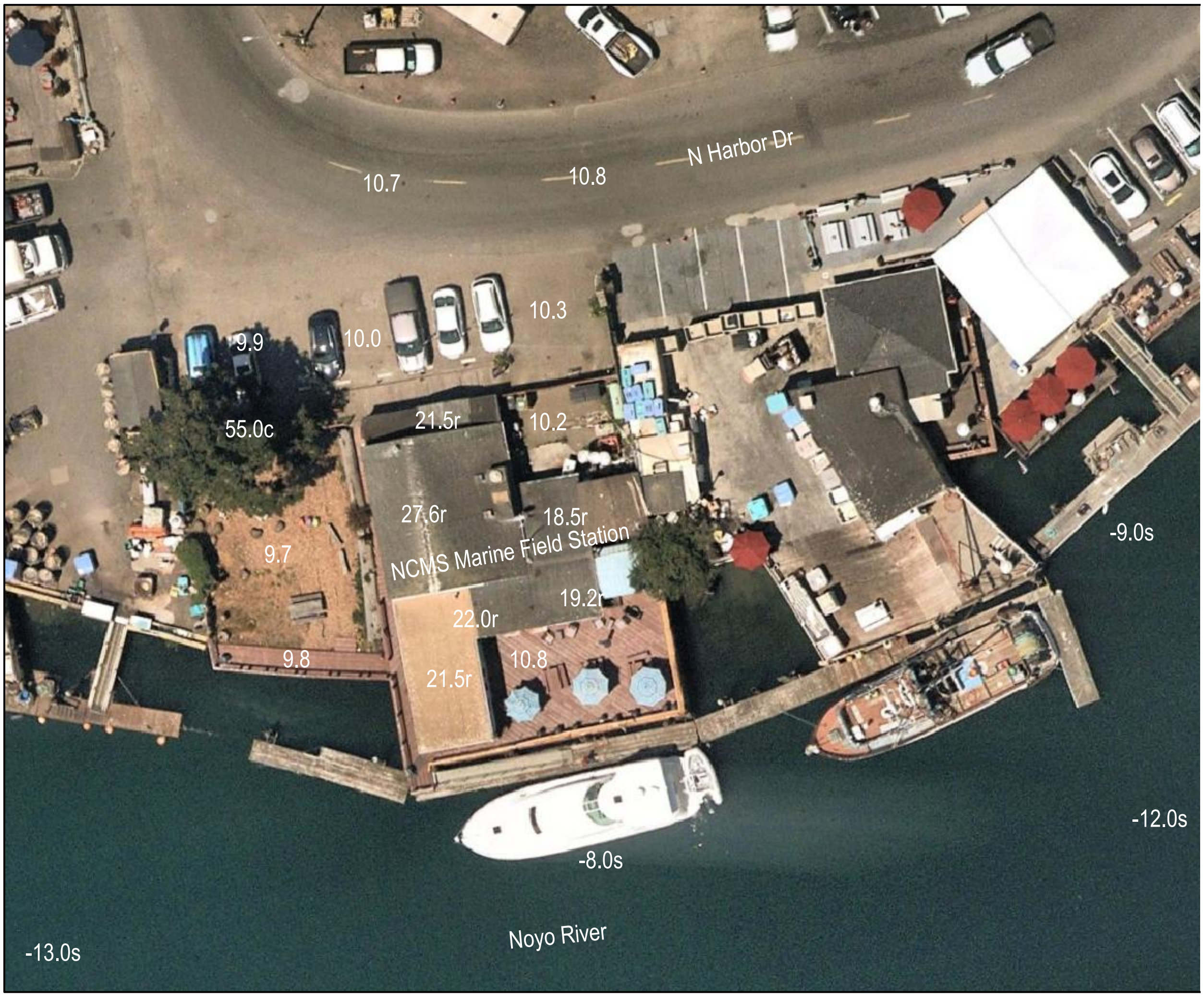
Figure 2-1: Location of NCMS Marine Field Station at Noyo Harbor (circled).

2.2. Horizontal and Vertical Datum

The horizontal datum adopted for the SLR adaptation study is the North American Datum of 1983 (NAD83) horizontal and geometric control datum, California State Plane System, FIPS zone 0402. The vertical datum is the North American Vertical Datum of 1988 (NAVD88).

2.3. Topographic and Bathymetric Data

Figure 2-2 summarizes spot elevations for the Marine Field Station facility and vicinity referenced to NAVD88. Terrain elevations are based on Federal Emergency Management Agency (FEMA) Region 9 LiDAR, NOAA (2017). Building roofline, deck, and tree canopy elevations based on U.S. Geological Services (USGS) source LiDAR, USGS (2016). Channel depths based on U.S. Army Corps of Engineers (USACE) dredge data, USACE (2024).



Terrain elevations (r: roofline, c: canopy, s: riverbed).

Figure 2-2: NCMS Marine Field Station Elevations (feet NAVD88).

2.4. Site Visit and Above-Water Inspection

A site visit and waterfront above-water inspection was conducted on Friday, August 22, 2025. Figure 2-3 provides an overview of the tidal variation per the NOAA (2025) tide prediction for Noyo Harbor, NOAA Station: 9417426. The inspection was conducted by boat, commencing around sunrise at 6:30 am to capture the available low tide window from 5:27 am to 12:01 pm.

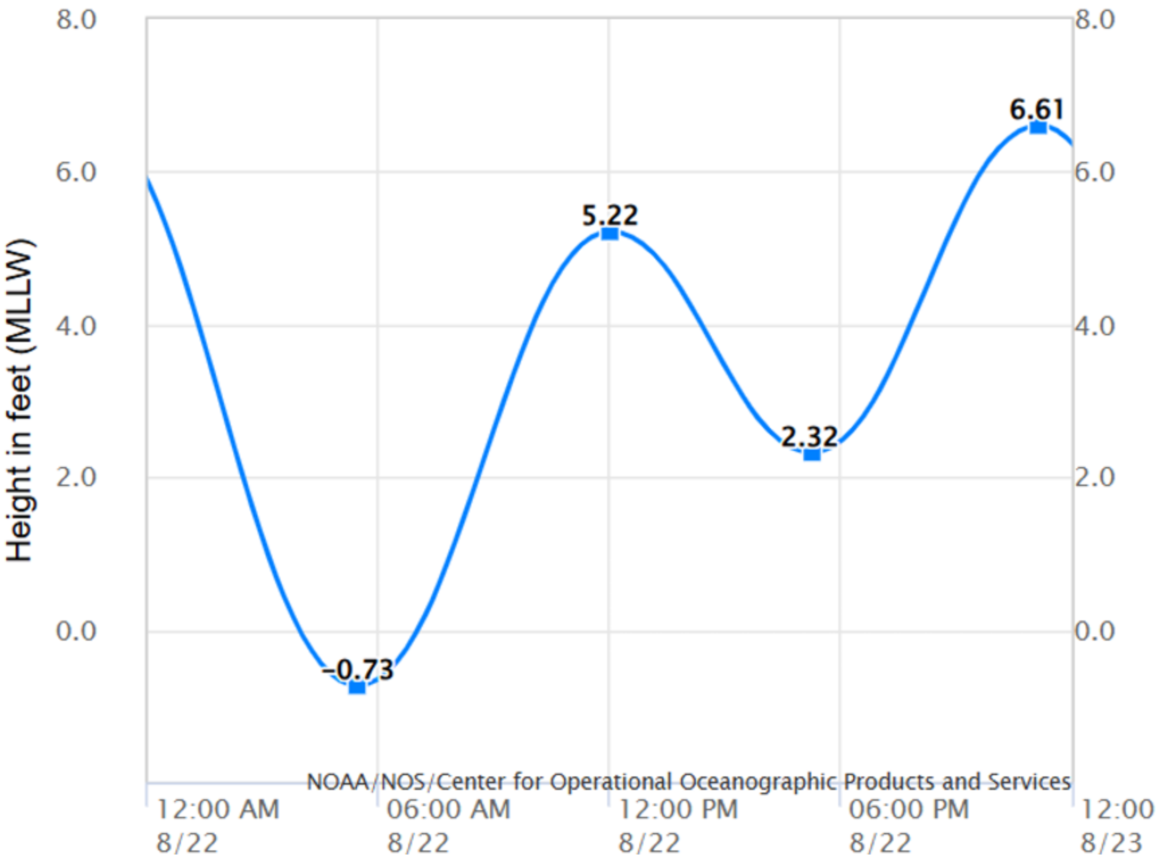


Figure 2-3: Tidal variation on August 22, 2025.

Refer to Appendix A for photos from the site visit. The inspection highlighted the following:

a) Marine pilings supporting the deck structure appear to be in good to moderate condition.

b) Deck structure in good condition.

c) Guide piles are experiencing rot and deterioration at the top and exhibit some reduction in cross-section over the tide range due to abrasion from the hoop pile guide attachments.

d) The boards of the timber (retaining) wall fronting the side yard are softening.

e) The segment of the timber wall under the deck has deteriorated significantly. Note: This part of the wall is not load-bearing, and there is a crawlspace behind the wall in this area.

3. Flood Hazards

The Marine Field Station is located on the Noyo River waterfront and in proximity to Noyo Bay. The Noyo River water level at this location is affected by several influencing factors that can cause the river stage to rise and potentially cause flooding. The flood hazards can be characterized as follows:

1. Fluvial flooding, which is associated with a rise of the river stage due to increased streamflow associated with rainfall within the Noyo River watershed.
2. Coastal flooding, which is caused by storm surge, exacerbated by high tides, El Niño effects, and wave action.
3. Tsunami hazards, associated with seismic, volcanic, and landslide activity in subduction fault zones along the Pacific Ring of Fire.

These hazards were highlighted in the recent Sea Level Rise, Tsunami Hazards, and Erosion Resilience Strategy for Noyo Harbor by ESA/ARUP (2025). The following sections provide an assessment of how these hazards can affect the Marine Field Station present day and with projected sea level rise (SLR).

3.1. Fluvial Flood Hazards

Fluvial flood hazards are attributed to Noyo River streamflow. Fluvial flooding is defined as the condition when the river stage rises and overflows neighboring land and facilities along the riverbank.

Figure 3-1 provides an excerpt from the Effective Flood Insurance Rate Map (FIRM), issued by FEMA. The location of the Marine Field Station is outlined in red. Areas of the map in gray are above the floodplain. Areas shaded in light blue depict the extent of the 1% annual chance floodplain, which has a 1-in-100 chance of occurring in any given year, corresponding to an average recurrence interval of 100 years between flood events of this magnitude. The risk of encountering such a flood event can be quantified via the encounter probability equation, which describes the probability, p, of experiencing a storm event with a given return period RP over a period of N years.

$$p = 1 - \left(1 - \frac{1}{RP}\right)^{N}$$

For a typical mortgage term of 30 years, the probability p of experiencing a 100-year flood event is 26%, which means that there will be about a 1-in-4 chance of flooding at least once.

In the area of the Marine Field Station, the effective FIRM indicates a 100-year river stage at approximately El. +13.3 feet NAVD88, which would flood the outdoor terrace, building space, yard, and North Harbor Drive, which are in the elevation range from approx. +9.7 to +10.8 feet NAVD88, refer to Figure 2-2.

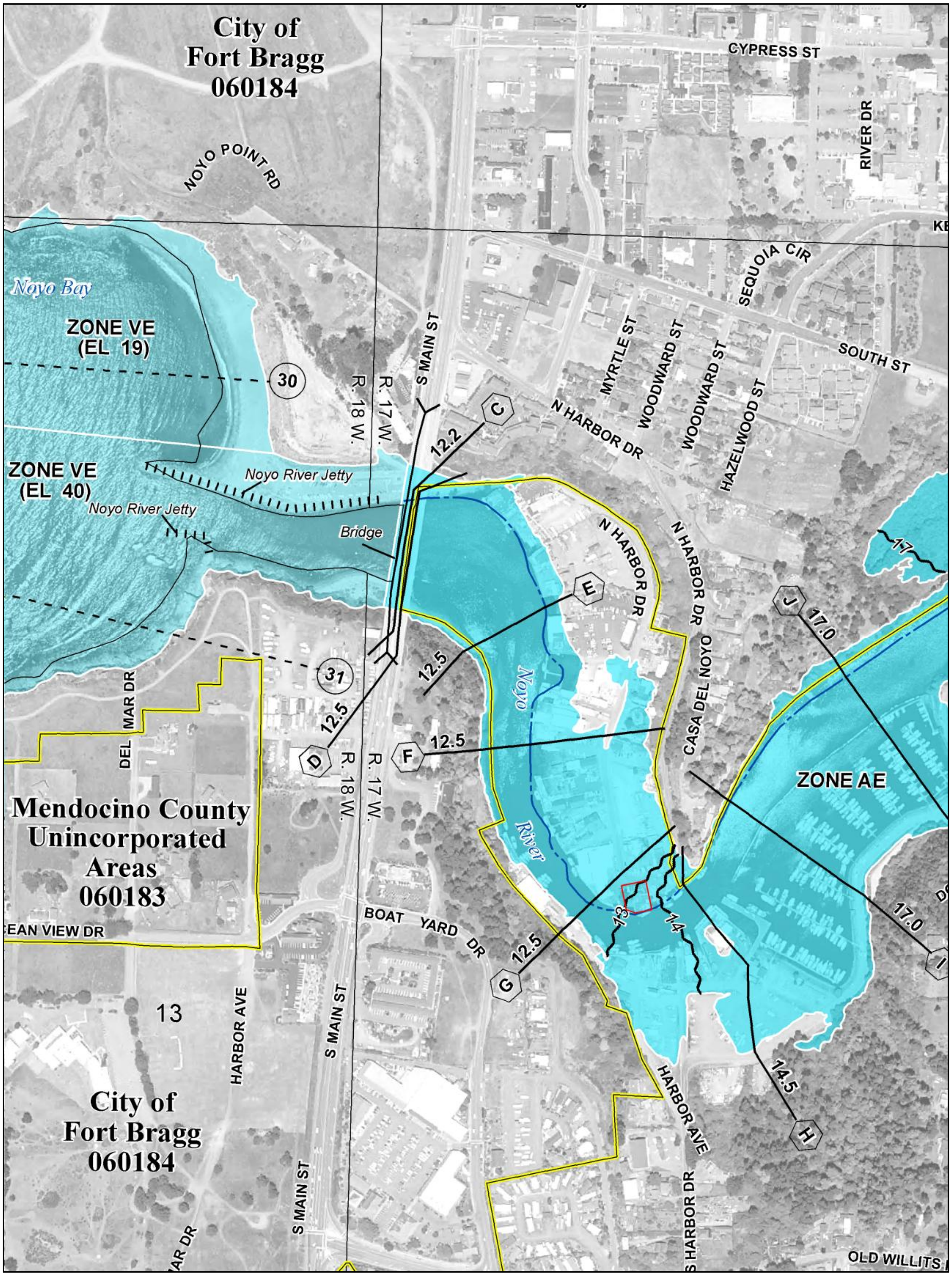


Figure 3-1: Excerpt from Effective FEMA FIRM, FEMA (2017). Marine Field Station outlined in red.

Table 3-1 summarizes information on Noyo River streamflow based on FEMA (2022), with the 100-year recurrence interval representative of a 1% annual chance fluvial flood event. The intermediate recurrence intervals were determined based on interpolation and extrapolation of the scenarios reported in the FEMA Flood Insurance Study (FIS). The resulting river stage and flow velocities were derived from analysis of streamflow data. The 100-year river stage of +13.3 feet NAVD88 corresponds to the Base Flood Elevation (BFE) indicated on the Effective Flood Insurance Rate Map shown in Figure 3-1 from FEMA (2017). The river stage estimates summarized in Table 3-1 are without SLR. Table cells shaded light yellow indicate shallow flooding of the Marine Field Station property experienced when the river stage rises above approximately El. +9.7 feet NAVD88. Cells highlighted in dark yellow indicate more significant flooding that would occur when the river stage rises above the deck elevation at approximately EL. +10.8 feet NAVD88.

Table 3-1: Noyo River Streamflow, River Stage, and Flow Velocity.

Recurrence Interval (years)	Streamflow (cfs)	River Stage (ft NAVD88)	Flow Velocity [c] (fps)
1	5,000	+5.6	1.7
5	13,000	+7.2	4.0
10	17,740	+8.5	5.2
25	25,000	+10.3	6.6
50	31,085	+11.8	7.5
100 [a]	38,000	+13.3 [b]	8.2

a) FEMA 1% Annual Chance Fluvial Flood Event.
b) FEMA 1% Annual Chance Fluvial BFE.
c) Estimated flow velocity along dock.
🟨 Flood impacts to Yard.
🟧 Flood impacts to Marine Field Station Building/Facilities.

The river stages indicated in Table 3-1 are depicted in Figure 3-2 which shows these flood stages in relation to the Marine Field Station. The terrace and building finish floor elevation (FFE) at El. +10.8 ft NAVD88 is indicated by the dashed brown line and callout on the right. The approximate elevation of the yard with finished grade (FG) at El. +9.8 ft NAVD88 along the riverbank is indicated by the dashed brown line and callout on the left. The river stage for a 25-year fluvial flood event is indicated by the yellow line. It can be seen that this event would result in shallow flooding of the yard, but the building and terrace would remain above the flood stage by a small margin. Fluvial flood events with higher recurrence intervals would flood the entirety of the Marine Field Station lot by up to 2.5 to 3.5 feet for the building/yard.

Figure 3-2: Fluvial Flood Hazards with Recurrence Intervals from 1 to 100 years.

3.1.1. Fluvial Flood Hazards with SLR

Table 3-2 provides estimates of the river stage at the Marine Field Station for flood events with recurrence intervals ranging from 1 to 100 years and SLR in increments of one foot up to six feet of SLR. The results show that for annually occurring flood events, the rise in river stage is approximately equal to the rise in ocean level, e.g. a 5.8-ft increase in river stage for 6 ft of SLR for a 1-year storm. However, the data shows that the increase in the river flood stage with SLR is moderate for larger, less frequent storm events. For example, in the case of a 100-year flood event with 6 feet of SLR, the increase in river stage is limited to 1.9 feet. One way of visualizing this trend is that for the case of a mild storm event such as a 1-year storm, the river stage at the Marine Field Station is more strongly governed by the ocean level and tide stage than the streamflow. Conversely, for the case of a 100-year flood event, the river stage at the Marine Field Station is more strongly governed by the streamflow than the ocean and tide level.

Table 3-2: Noyo River Stage change with SLR.

Recurrence Interval (years)	**River Stage (feet NAVD88) for Sea Level Rise (feet) of:**						
	0’	**1’**	**2’**	**3’**	**4’**	**5’**	**6’**
1	+5.6	+6.2	+6.9	+7.7	+8.8	+10.0	+11.4
5	+7.2	+7.7	+8.3	+9.0	+9.8	+10.8	+11.9
10	+8.5	+8.9	+9.4	+9.9	+10.7	+11.5	+12.4
25	+10.3	+10.6	+11.0	+11.4	+12.0	+12.6	+13.3
50	+11.8	+12.1	+12.3	+12.7	+13.1	+13.6	+14.2
100[a]	+13.3[b]	+13.5	+13.7	+14.0	+14.4	+14.7	+15.2

a) FEMA 1% Annual Chance Fluvial Flood Event.
b) FEMA 1% Annual Chance Fluvial BFE.
🟨 Flood impacts to Yard.
🟧 Flood impacts to Marine Field Station Building/Facilities.

The results indicate that a 25-year flood event would produce shallow flooding at the property progressing into North Harbor Drive. With 2 feet of SLR, a 25-year storm would produce flooding above the deck level and more significantly affect the building. Flood events with recurrence intervals above 25 years are estimated to produce flood impacts to the building, which would worsen significantly with SLR. The flood depth would increase with SLR and consequently the level of damage would increase correspondingly.

3.2. Coastal Flood Hazards

Extreme high water levels at Noyo Harbor are a combination of storm surge due to low barometric pressure and wind shear pushing water up against the coast, El Niño effects, astronomical tides, and wave action.

3.2.1. Storm Surge

The storm tracks, magnitude and frequency of winter storm systems vary from year to year. There are two ways that these storm systems can affect the water level at Noyo Harbor. One is due to the barometric low pressure of the storm system, which can pull up the water level. The second effect is wind shear, which can push water up against the downwind shoreline areas.

3.2.2. El Niño Southern Oscillation

El Niño effects (and La Niña) refer to cycles of warming and cooling of the Pacific Ocean, typically lasting 9 to 12 months. These cycles often commence in June or August and reach their peak during December through April and subsequently decay over May through July. Their periodicity is irregular, occurring every 3 to 5 years on average. The warming associated with El Niño produces a rise of the ocean level, which can be on the order of 6 to 18 inches. The period of elevated (or lowered) ocean levels can be on the order of months, while the peak highs and lows occur on a scale of days to weeks.

3.2.3. Tidal Datums

The astronomical tidal variation is governed by the movement of the earth and the moon in relation to the sun. Consequently, tides change daily, seasonally, and interannually. The cycle of tidal variation repeats after a period of 19 years, termed a tidal epoch. The daily tidal variation at Noyo Harbor can be categorized as a mixed semi-diurnal tide, which has two unequal highs and lows each tidal day as depicted in Figure 3-3.

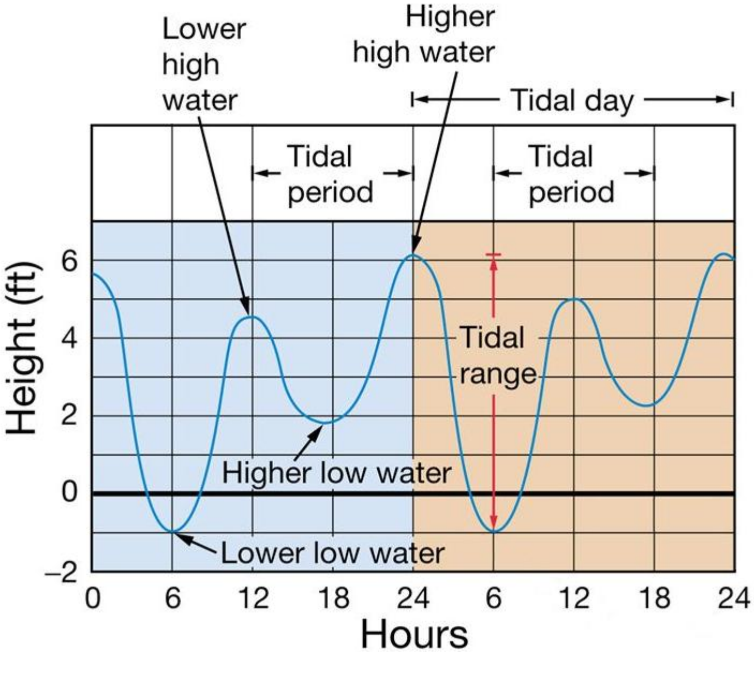


Figure 3-3: Typical Daily Tidal Progression for Mixed Semi-Diurnal Tides.

The higher high tides are referred to as “Higher high water” while the lower high tides are referred to as “Lower high water”. Similarly for the low tides, where the lower low tides are termed “Lower low water” and the higher low tides named “Higher low water”. The tides vary over the cycle of a tidal day, which is approximately 24 hours and 50 minutes. The tidal period is the time between consecutive high tides or low tides. The tidal range is the difference in height between the lowest tide and the highest tide.

The lower part of Table 3-3 summarizes tidal datums associated with normal astronomical tides. The report cover photo presents an example of a condition with King tide, which is highest tide level occurring annually. The upper part of the table summarizes extreme tide levels for Noyo Harbor associated with astronomical tides, storm surge and El Niño effects based on data from NOAA (2025). It can be noted that the 100-year storm surge in Noyo Bay as such would not cause flooding at the Marine Field Station although the water level would rise to within a foot of the top of the riverbank.

Table 3-3: Tidal and Storm Surge Elevations.

Tidal Plane	Feet (NAVD88)
Extreme Tides (with storm surge)	
100-Year RP	+8.9
50-Year RP	+8.8
25-Year RP	+8.6
10-Year RP	+8.5
5-Year RP	+8.1
1-Year RP	+7.2
Normal Astronomical Tides	
King Tide (Approx. Annual Maximum)	+7.7
Mean Higher High Water (MHHW)	+5.9
Mean High Water (MHW)	+5.2
Mean Sea Level (MSL)	+3.1
Mean Low Water (MLW)	+1.0
North American Vertical Datum of 1988	0.0
Mean Lower Low Water (MLLW)	-0.2

The astronomical tide and extreme tidal datums from Table 3-3 are depicted in Figure 3-4 in relation to the Marine Field Station. Astronomical tidal datums are indicated in blue. The elevation of King tides, the highest tides occurring annually, is indicated in green. Extreme tides with storm surge are indicated in purple for recurrence intervals ranging from 1 to 100 years.

The results show that storm surge in itself would not flood the site, although a 100-year flood condition could bring the water level within 0.9 ft of the yard. A small amount of wave action in addition to the flood stage could therefore conceivably contribute to shallow flooding and/or ponding within the yard. The terrace and Marine Field Station building would maintain a clearance of 1.9 feet above the predicted 100-year extreme tide stage. This freeboard can be categorized as a form of SLR allowance.

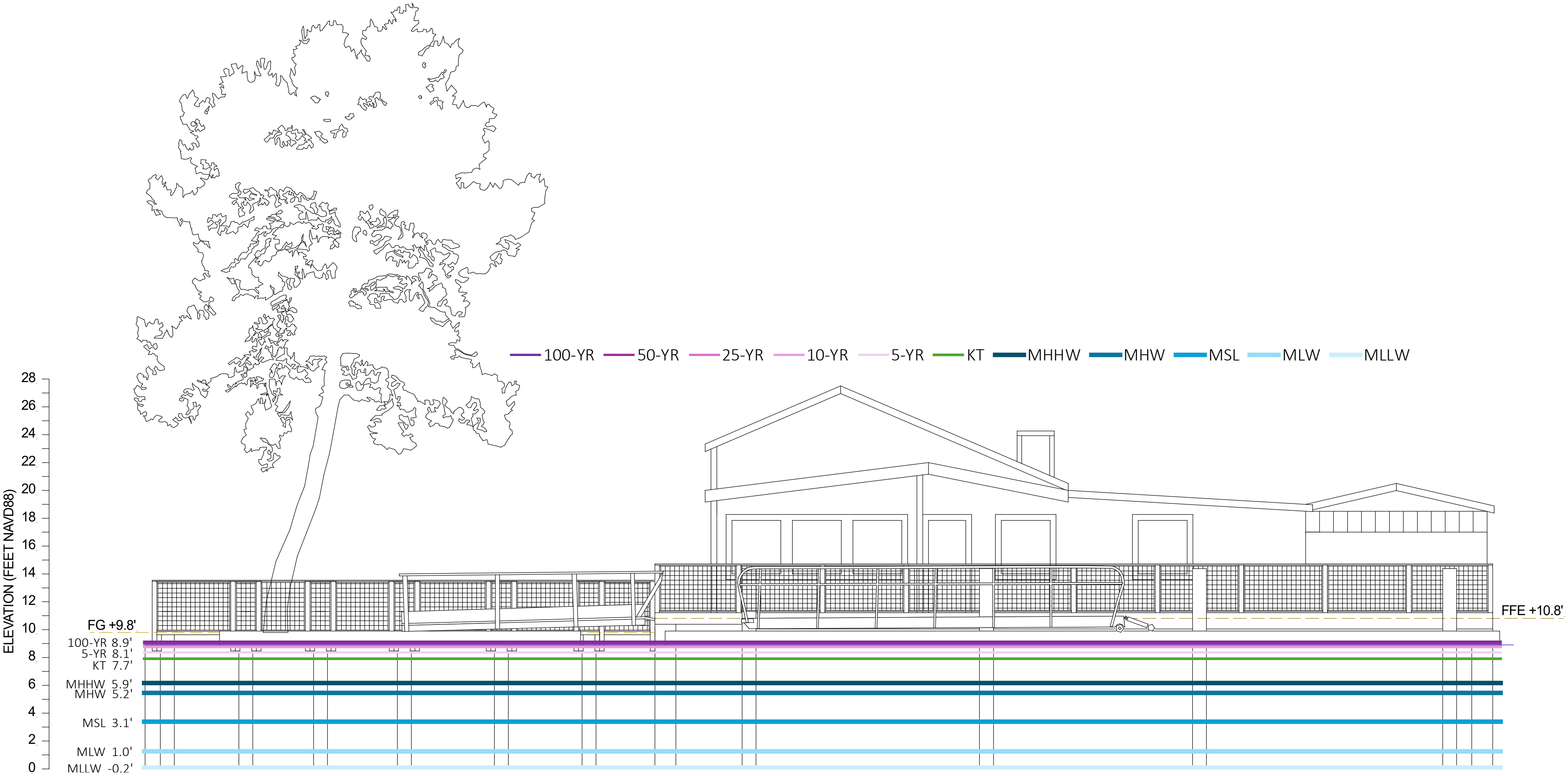


Figure 3-4: Astronomical Tide (Green and Blue) and Extreme Tidal Datums (Purple).

3.2.4. Coastal Flood Hazards with SLR

Table 3-4 summarizes extreme tide elevations with storm surge for recurrence intervals ranging from 1 to 100 years and SLR in increments of one foot up to six feet of SLR. The results show that annually occurring storm events would contribute to flooding at the Marine Field Station with 3 feet of SLR. Storms with recurrence intervals ranging from 5 to 25 years would cause flooding at the Marine Field Station with 2 feet of SLR. Storm events occurring every 50 to 100 years on average would cause shallow flooding at the Marine Field Station (light yellow) with 1 foot of SLR and more significant flooding with 2 feet of SLR (dark yellow).

Table 3-4: Extreme Tide Elevation change with SLR.

Recurrence Interval (years)	Extreme Tide Elevation (feet NAVD88) for Sea Level Rise (feet) of:						
	0’	**1’**	**2’**	**3’**	**4’**	**5’**	**6’**
1	+7.2	+8.2	+9.2	+10.2	+11.2	+12.2	+13.2
5	+8.1	+9.1	+10.1	+11.1	+12.1	+13.1	+14.1
10	+8.5	+9.5	+10.5	+11.5	+12.5	+13.5	+14.5
25	+8.6	+9.6	+10.6	+11.6	+12.6	+13.6	+14.6
50	+8.8	+9.8	+10.8	+11.8	+12.8	+13.8	+14.8
100 [a)]	+8.9	+9.9	+10.9	+11.9	+12.9	+13.9	+14.9

a) FEMA 1% Annual Chance Coastal Flood Event.

🟨 Flood impacts to Yard.

🟧 Flood impacts to Marine Field Station Building/Facilities.

3.2.5. Wave Action

The location of the Marine Field Station on the Noyo River waterfront is generally sheltered from exposure to ocean waves. The local wave climate is dominated by chop associated with wind-waves and boat wake. Consequently, wave action is not a key component of flood hazards at the Marine Field Station.

3.3. Tsunami Hazards

Ports, harbors and waterfront facilities on the west coast of the U.S. are vulnerable to tsunamis originating along the Pacific Ring of Fire. The City of Fort Bragg maintains a tsunami contingency plan for areas within Fort Bragg City limits and portions of Noyo Harbor and the Noyo Jetty. Tsunami threats are monitored via accelerometers capturing seismic activity, and a system of buoys deployed throughout the Pacific. These are maintained by the NOAA Center for Tsunami Research, Pacific Marine Environmental Laboratory (PMEL) for Deep-ocean Assessment and Reporting of Tsunamis (DART). The DART buoys are developed to detect tsunamis in deep water where their height can be limited from just a few inches up to around 3 feet and often not noticeable to vessels at sea.

3.3.1. Noyo Harbor Tsunami History

Table 3-5 provides a summary of written records of tsunami events observed at Noyo Harbor based on information from NOAA (1993). The most severe of these tsunami events produced widespread impacts to ports and harbor facilities along the California coast and incurred millions of dollars in damages. The most impactful tsunami events were the following:

- 1946 Aleutian Islands earthquake and tsunami, which caused over $26 million in damage in 1946 dollars corresponding to about $413 million present day.
- 1960 Great Chilean Earthquake (Valvidia Earthquake) which caused $550 million damage in southern Chile, 1,655 deaths and 3,000 injured, and 2 million people homeless. The tsunami associated with this earthquake produced $75 million damage in Hawaii and $500,000 damage to the west coast of the U.S. in total about $795 million present day.
- 1964 Great Alaska Earthquake and Tsunami, which generated one of the most destructive tsunamis ever observed in North America. The tsunami caused $10 million damage at Noyo Harbor ($101 million present day) and about $311 million in damage in total for impacted areas on the west coast corresponding to $3.1B present day.

Table 3-5: Noyo Harbor Tsunami History.

Date	Origin	Earthquake Magnitude	Wave Height (feet)	Observations
4/1/1946	Aleutian Isl.	8.1	16.0	In a few minutes a surge came in through the mouth of the Noyo River that hit a 5-foot mark. The rise was very swift and boats that were not securely moored broke from their moorings and started drifting upstream.
3/9/1957	Aleutian Isl.	8.6	0.5	The wave was barely noticed at Noyo Harbor.
5/22/1960	Chile	9.5	7.0	At Noyo Harbor almost every dock was damaged, and boats were carried upstream. Virtually every dock suffered loosened or broken pilings. A tier of six boats broke mooring from the south side pilings and still lashed together shot upriver unmanned with a high surge. A lone fisherman in a rowboat caught up to the boats and tied them to a piling. Two of the six broke loose and ended on a mud bank. Half of the fishing fleet had put to sea following a warning.
3/28/1964	Alaska	9.2	12.6	The first wave arrived shortly before midnight. The sheriff had tried to alert boat owners, and some had heard of the threat from radio and television. The Coast Guard Cutter Pt. Ledge cleared the harbor after the first surge. The La Paz, a 42-foot drag boat with three tons of fish in its hold was hit by another boat and shot upstream in full reverse slamming into other boats near Casa del Noyo. The crew tried to tie it up, but another surge sent it upstream another quarter of a mile and aground against the Mary R. Bores proceeded upriver at 35 miles per hour as a series of step-like jumps.
4/25/1992	N. California	7.2	4.8	Recorded on Arena Cove marigram.
10/4/1994	Kuril Isl.	8.4	0.6	Recorded on Arena Cove tide gage.
6/22/2001	Peru	8.4	0.3	Recorded on Arena Cove tide gage.
12/26/2004	Indonesia	9.2	0.9	Recorded on Arena Cove tide gage.
7/15/2005	N. California	7.2	0.2	Recorded on Arena Cove tide gage.
11/15/2006	Kuril Isl.	8.3	1.6	Recorded on Arena Cove tide gage.
1/13/2007	Kuril Isl.	8.1	1.1	Recorded on Arena Cove tide gage.
9/30/2009	Samoa	8.0	1.6	Recorded on Arena Cove tide gage.
3/11/2011	Honshu Isl.	9.0	5.9	Recorded on Arena Cove tide gage.
1/15/2022	Tonga	8.4	5.5	Recorded on Arena Cove tide gage.
7/30/2025	Kamchatka Peninsula	8.8	2.4	Recorded on Arena Cove tide gage.

Figure 3-5 provides an overview of tsunami hazard mapping issued by the California Department of Conservation (DOC). This tsunami hazard mapping is primarily intended to assist cities and counties in identifying tsunami hazards for local jurisdictional and coastal emergency response planning. The tsunami hazard area map was compiled with the best available scientific information and represents the area that could be exposed to tsunami hazards during a tsunami event. It is based on inundation limits corresponding to a 975-year return period tsunami event. The 975-year recurrence interval corresponds to a 5% or 1-in-20 chance of experiencing a tsunami event of this magnitude over a 50-year time frame. Areas potentially affected by tsunami inundation are indicated in yellow. These areas represent the maximum considered tsunami runup from several extreme, infrequent, and realistic tsunami sources. Areas unaffected by tsunami hazards are indicated in green. The location of the Marine Field Station is outlined in red and is within the area of potential tsunami hazard.

Tsunamis are rare events and there is a sparsity of known occurrences in the historical record. Consequently, there is a limited basis for estimating the likelihood of any tsunami affecting an area within a specific time period. Agencies such as the California Office of Emergency Services (Cal OES) and American Society of Civil Engineers (ASCE) operate with varying levels of tsunami hazard exposure for emergency planning purposes and building codes for structures, summarized in Table 3-6.

Table 3-6: Overview of Tsunami Hazard Scenarios adopted by Regulatory Agencies.

Agency	Recurrence Interval (years)	Time Frame (years)	Probability of Occurrence	Description
Cal OES	525	50	9%	Typical full-rupture earthquakes
Cal OES	975	50	5%	Severe full-rupture earthquakes
Cal OES	2,475	50	2%	Worst case full-rupture earthquakes
ASCE	2,475	50	2%	Maximum Credible Tsunami

Extreme-value analysis (EVA) was applied to the Table 3-5 historical tsunami information to estimate tsunami events with smaller recurrence intervals (more frequent events). The results are presented in Figure 3-6 and summarized in Table 3-7.

Table 3-7: Tsunami Hazard Scenarios for 10 to 100-Year Events.

Basis	Recurrence Interval (years)	Time Frame (years)	Probability of Occurrence	Description
EVA	100	50	39%	Magnitude 7.0 or larger partial, full-rupture, and megathrust earthquakes.
EVA	50	50	64%	
EVA	25	50	87%	
EVA	10	50	99%	

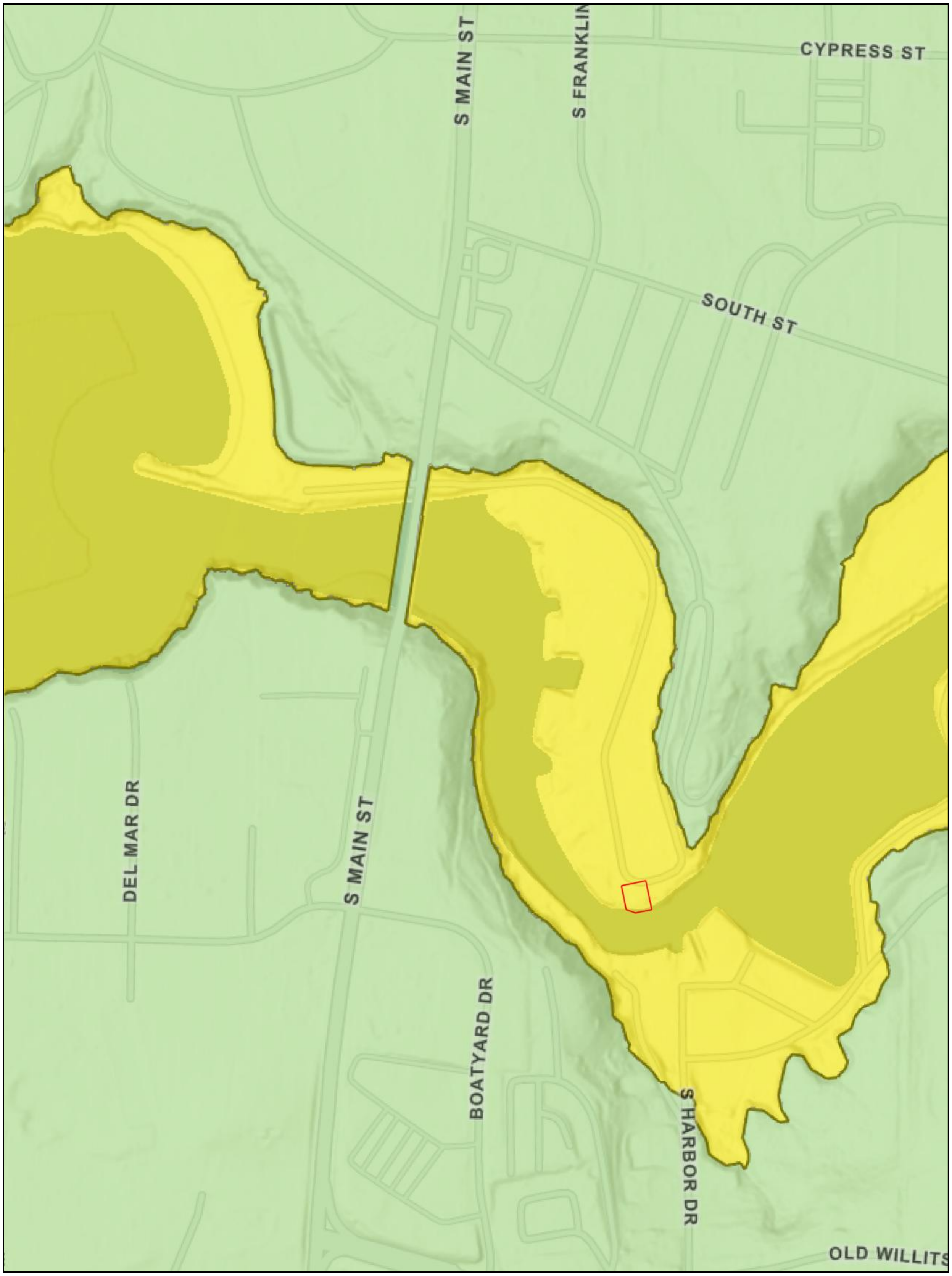


Figure 3-5: Excerpt from Tsunami Hazard Map, DOC (2021).

It can be noted in Figure 3-6 that there are no tsunami events with recurrence intervals below 5 years. This is because the tsunami wave height of such events is within a few inches in height and therefore mostly goes unnoticed.

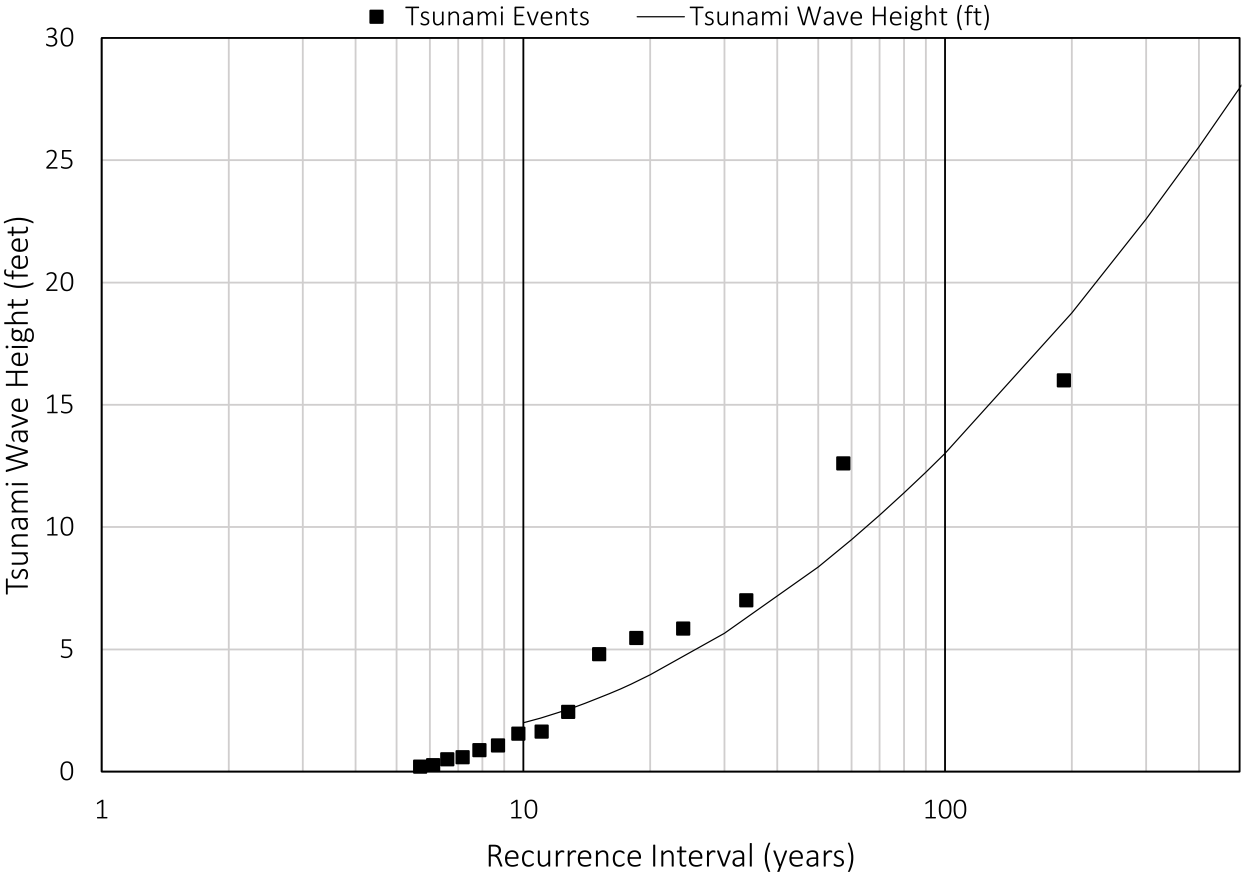


Figure 3-6: Tsunami Wave Height Exceedance based on Observations from 1946 to 2025.

Tsunami inundation levels for the Table 3-7 tsunami hazard recurrence intervals are shown in Figure 3-7 in relation to the Marine Field Station. The results indicate that the peak water level associated with a 25-year tsunami event would remain below the elevation of the Marine Field Station and facilities. However, the indication is that a 50-year tsunami event could have the potential to cause shallow flooding over the terrace and Marine Field Station finish floor elevation. A tsunami event with a recurrence interval of 100 years would produce more significant flooding, estimated to 3.1 feet flow depth over terrace and around the Marine Field Station, and approximately 4.1 feet of depth over the yard. It should be noted, however, that the extent of flooding associated with tsunami events is highly dependent on the tide level, which rises and falls independently of tsunami activity. Based on Table 3-3 the mean tide range from MLW to MHW is 4.2 feet. The tsunami water levels indicated in Table 3-7 are based on a MHW tide level, assuming that a tsunami event could occur over a high tide. Depending on the actual tide level, the peak water levels could therefore be slightly higher or somewhat lower and the associated tsunami flood hazards range from severe to limited. While these uncertainties exist in relation to tide and tsunami peak water levels, tsunamis commonly produce conditions of high flow in inlets and waterways due to the significant exchange of water. Overland flow velocities are also projected to manifest as very fast-moving water which can be on the order of 10 feet per second or higher.

Figure 3-7: Present-Day Tsunami Hazard.

3.3.2. Tsunami Hazards with SLR

Table 3-8 summarizes tsunami inundation results for the Cal OES 975-year tsunami event with SLR in 1 foot increments in terms of peak water level, flow depth, and peak flow velocity. Peak values taken as the highest value occurring during the tsunami exposure. The results show that the level of tsunami inundation rises approximately with SLR.

Table 3-8: Tsunami Inundation with SLR.

Tsunami Parameter	**Tsunami Impacts for Sea Level Rise (feet) of:**						
	0’	**1’**	**2’**	**3’**	**4’**	**5’**	**6’**
Peak Water Level (ft NAVD88)	+25.5	+26.5	+27.5	+28.4	+29.3	+30.4	+31.0
Flow Depth (ft)	15.2	15.2	15.2	15.1	15.0	15.1	14.7
Peak Flow Velocity (fps)	21.4	22.4	23.4	24.9	26.0	28.8	27.7

Table 3-9 summarizes estimated tsunami inundation levels for tsunami events with recurrence intervals ranging from 10 to 100 years.

Table 3-9: Tsunami Peak Water Level with SLR.

Recurrence Interval (years)	**Peak Water Level (ft NAVD88) for Sea Level Rise (feet) of:**						
	0’	**1’**	**2’**	**3’**	**4’**	**5’**	**6’**
10	+5.9	+6.9	+8.2	+9.2	+10.2	+11.6	+12.6
25	+7.9	+8.9	+10.8	+11.9	+12.8	+13.8	+14.8
50	+11.1	+12.1	+13.1	+14.1	+15.1	+16.2	+17.2
100	+13.9	+14.9	+16.0	+17.1	+18.2	+19.2	+20.3

🟨 Potential flood impacts to Yard.
🟧 Potential flood impacts to Marine Field Station Building/Facilities.

4. Sea Level Rise Projections

4.1. Sea Level Rise Trend

Figure 4-1 presents the SLR trend at Arena Cove, the closest NOAA station to Noyo Harbor. Water level data has been recorded at this station since 1978.

The relative sea level trend is 1.11 millimeters/year with a 95% confidence interval of +/- 0.80 mm/year, which is equivalent to a change of 0.5 feet in 100 years. The blue curve in the figure depicts the monthly mean sea level variation without regular seasonal fluctuations from coastal ocean temperatures, salinity, wind, atmospheric pressure, and ocean currents. The relative sea level trend (red line) is shown with 95% confidence bands (black lines).

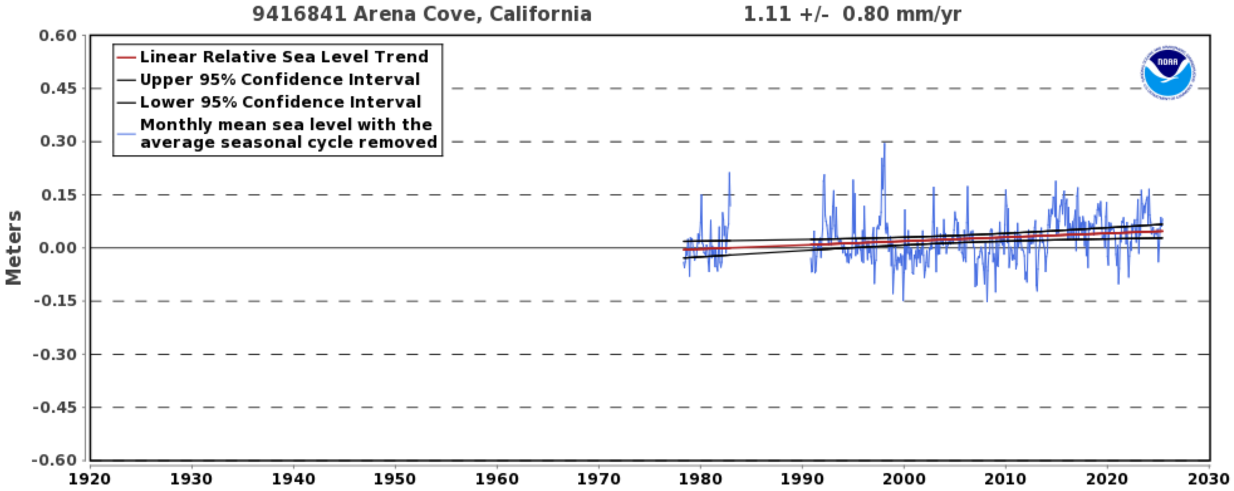


Figure 4-1: SLR trend observed at Arena Cove, NOAA (2025).

The data presented in the figure shows that the variation of the monthly mean sea level can be up to 1.5 feet (0.45 m). In addition, the daily tide range can vary from about 4.2 feet for Mean High Water (MHW) tides to 7.9 feet for annually occurring King tides (KT), refer to Table 3-3. SLR projections generally assumed zero starting in 2000 and since that time, the estimated SLR in the vicinity of Arena Cove and Noyo Harbor has been on the order of 1.85 inches. These estimates illustrate the difficulty of capturing the SLR trend when the day-to-day water level variation is about 100 times greater. So, despite the fact that more than two decades have passed since 2000, the data that the trend is based on is in fact quite irregular. The data presented in Figure 4-1 is therefore mostly focused on presenting the historical data, and does not offer much in terms of predicting future SLR, i.e. the underlying data is too irregular to tell whether the linear trend is the best estimate or whether SLR has begun to accelerate.

4.2. Sea Level Rise Scenarios

The best available science and most recent guidance on sea level rise from OPC (2024) is summarized in Figure 4-2, which presents five sea level scenarios for the Arena Cove region labeled:

Low, Intermediate-Low, Intermediate, Intermediate-High, and High. The sea level scenarios can be characterized as follows:

- **Low.** Linear trend based on the current rate of sea level rise continuing into the future. This scenario is on the lower bounding edge of plausibility given current warming and sea level trajectories.
- **Intermediate-Low.** This scenario provides a reasonable estimate of the lower bound for the most likely sea level rise by 2100.
- **Intermediate.** This scenario is driven predominantly by high emissions scenarios and provides a reasonable upper bound for the most likely range of sea level rise by 2100.
- **Intermediate-High.** This scenario reflects rapid ice sheet loss contributing to sea level rise and is representative of a plausible high-end projection.
- **High.** This scenario assumes high future emissions and high warming with large potential contributions from rapid ice sheet loss, and representative of a worst-case scenario.

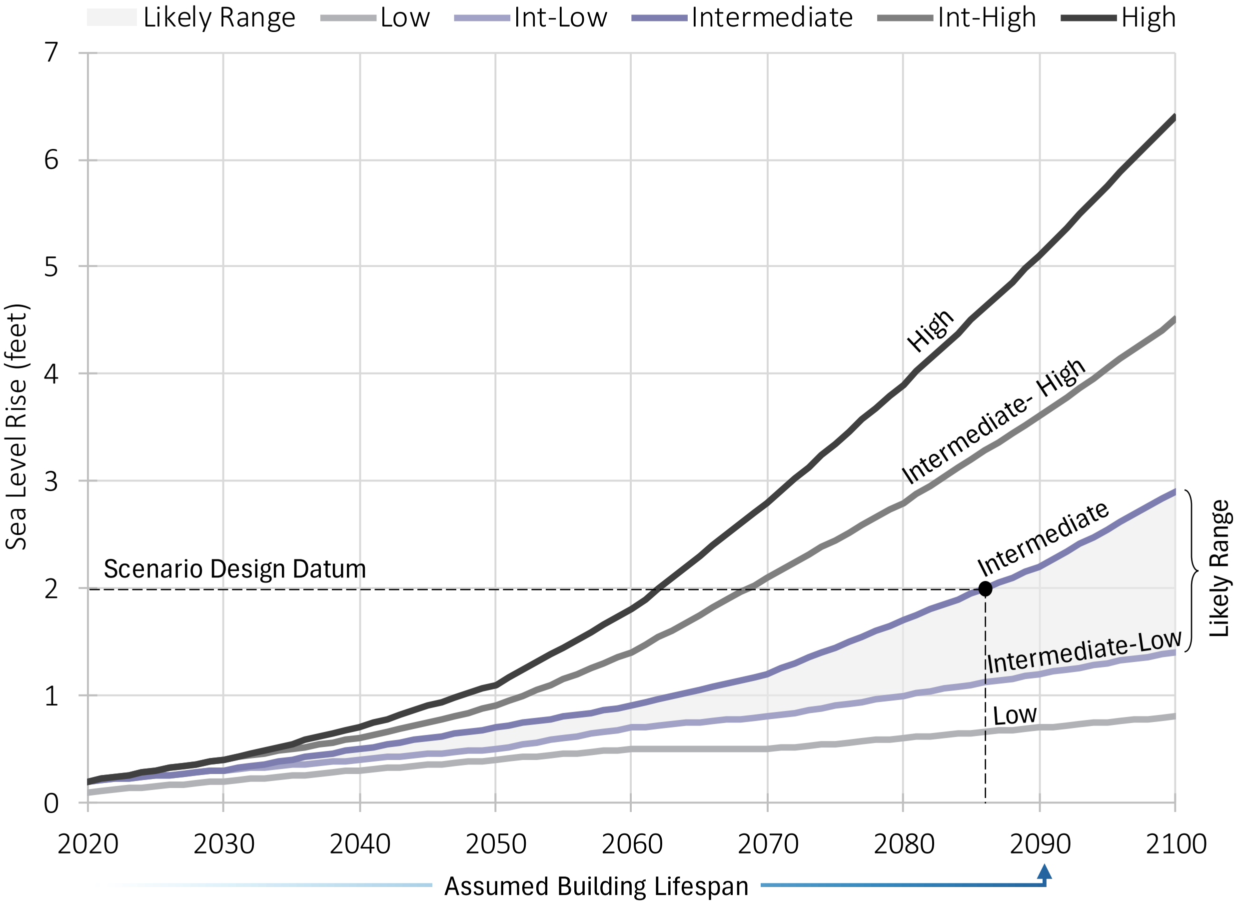


Figure 4-2: Arena Cove, CA SLR Scenarios, OPC (2024).

The likely range of SLR is projected to fall between the Intermediate-Low and Intermediate Scenario. The Intermediate Scenario is representative of continued high emissions and provides a reasonable upper bound for the most likely range of SLR by 2100. The Scenario Design Datum adopted for the project is 2 feet of SLR, aiming to address SLR projected over an assumed building lifespan out to approximately 2090. Flood hazards, tidal datums, and tsunami hazards at the Scenario Design Datum of 2 feet of SLR are presented in Figure 4-3, Figure 4-4, and Figure 4-5.

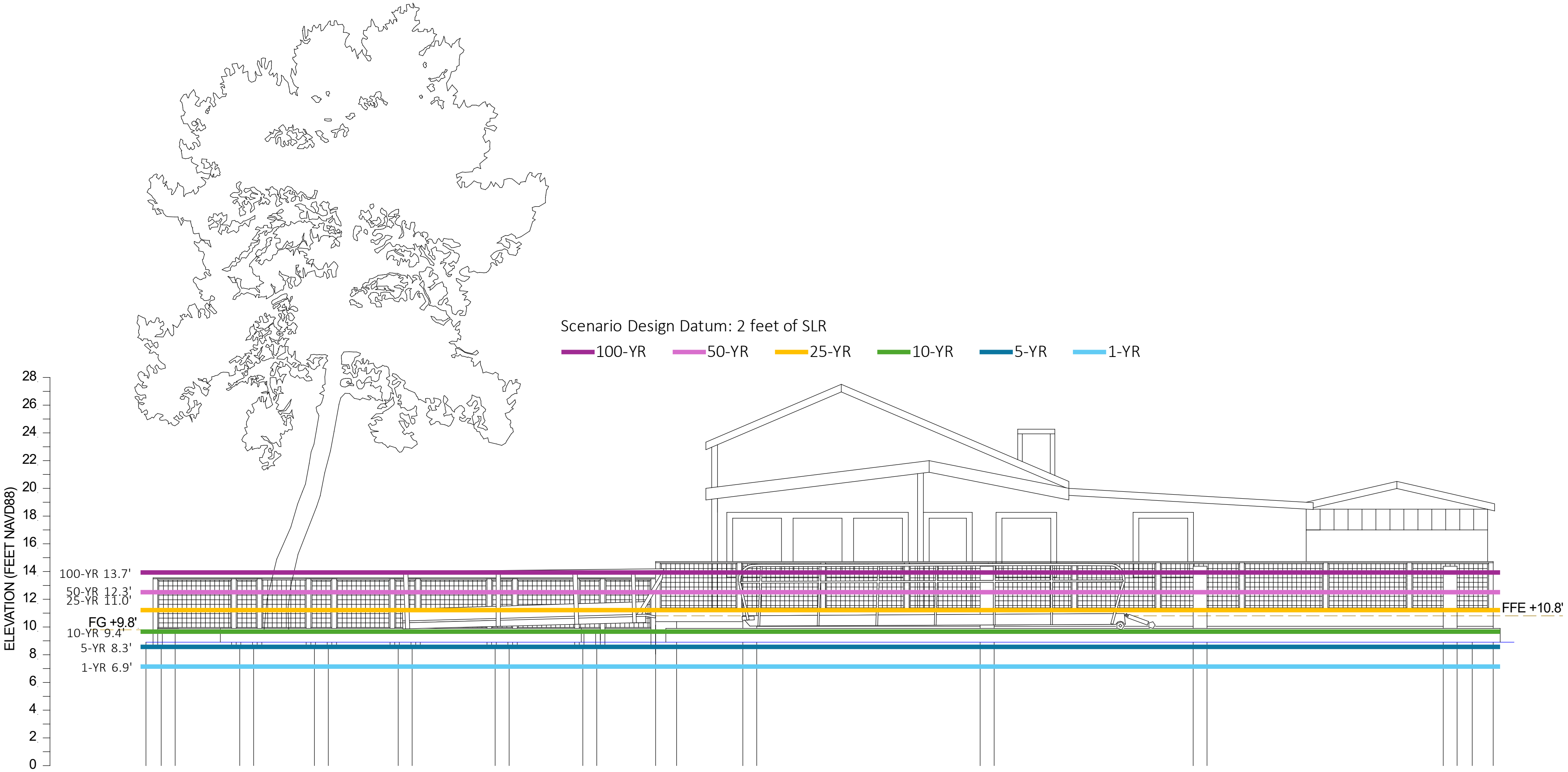


Figure 4-3: Fluvial Flood Hazards, 1 to 100-year recurrence. Scenario Design Datum: 2 feet of SLR.

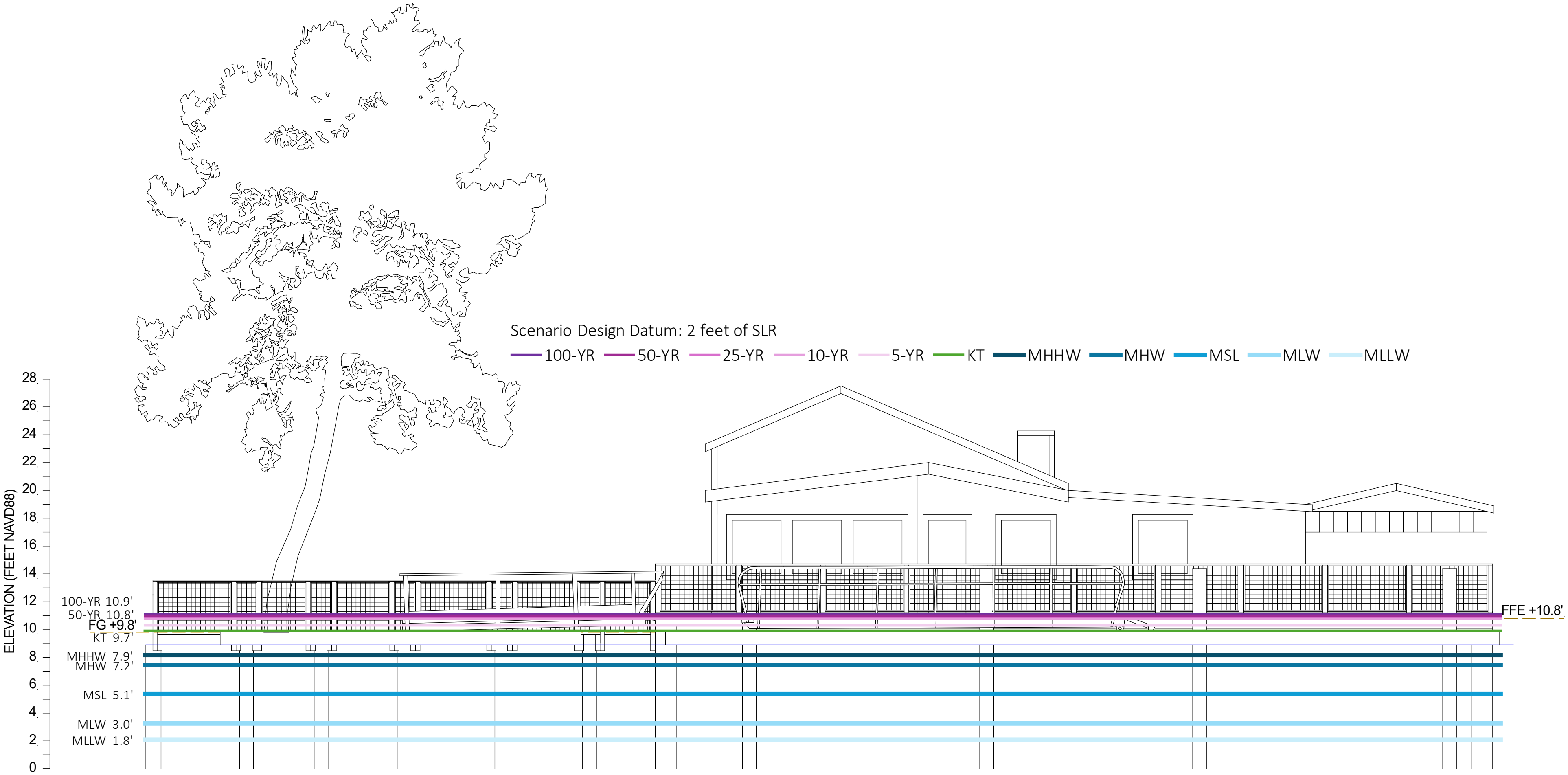


Figure 4-4: Astronomical Tide and Extreme Tidal Datums. Scenario Design Datum: 2 feet of SLR.

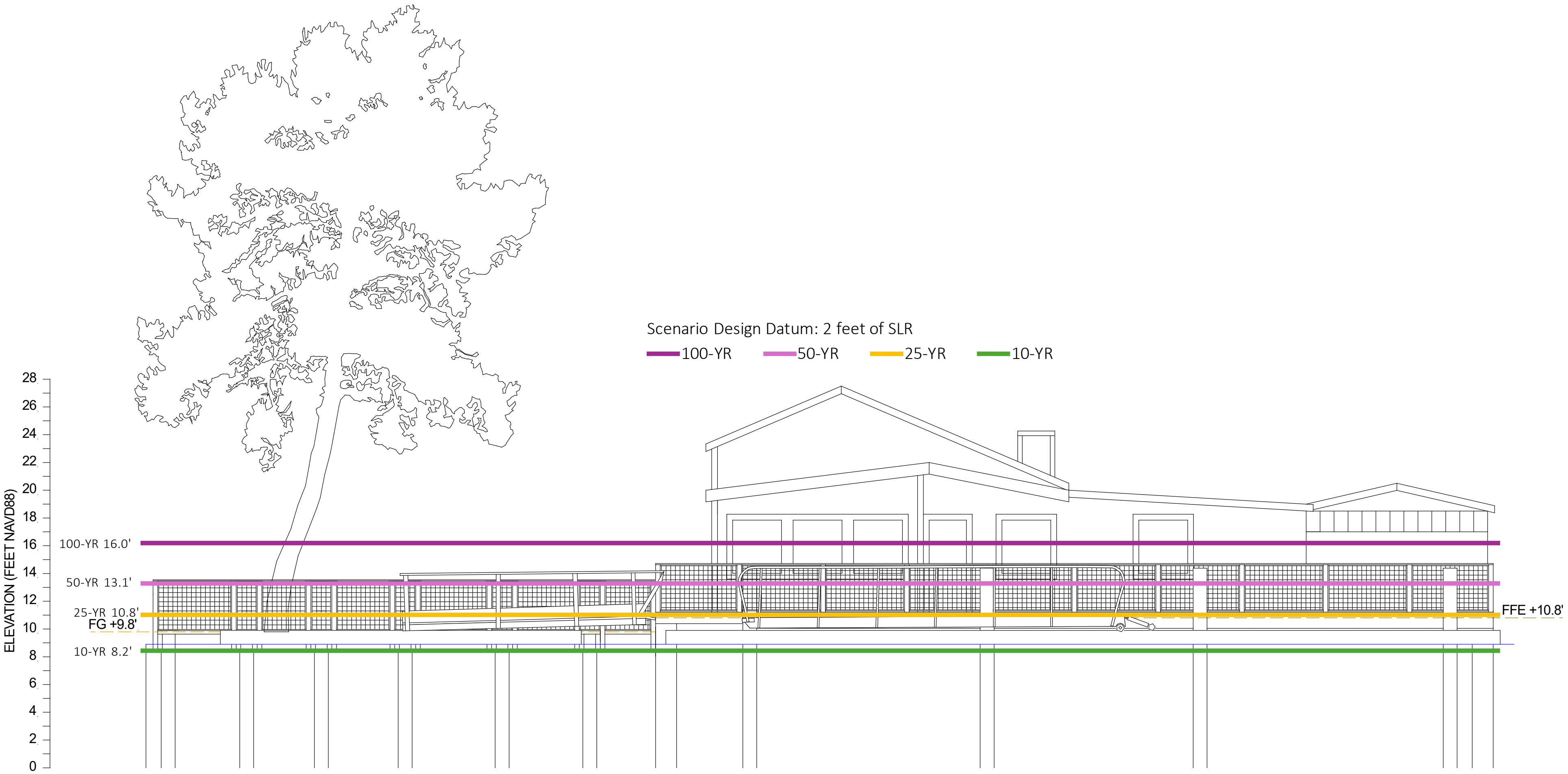


Figure 4-5: Tsunami Hazard. Scenario Design Datum: 2 feet of SLR.

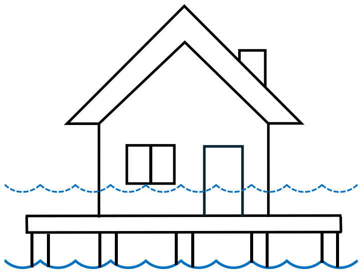
5. Sea Level Rise Adaptation

The following SLR adaptation strategies are considered:

1. No Action.
2. Protect.
3. Elevate.
4. Accommodate.
5. Retreat.

These are described in the following.

5.1. No Action



A no action approach would leave the Marine Field Station vulnerable to present day flood hazards, inclusive of fluvial flood hazards, coastal flood hazards, and tsunami hazards. These hazards are projected to increase with SLR. Additionally, climate change may further exacerbate these hazards. Global warming and associated warming of the Pacific is projected to result in stronger and more frequent El Niño episodes. The temporary rise in ocean level associated with El Niño would in effect increase the risk of coastal flood hazards and the frequency of these. Increased rainfall with climate change is projected to increase the magnitude and frequency of fluvial flood hazards and broaden the seasonal window where these fluvial flood hazards have a potential to occur. With respect to tsunami hazards, the primary increase in risk is due to SLR contributing to higher elevations of tsunami wave runup. Figure 5-1 provides example damage curves for a one-story building without basement and content as a function of the flood depth.

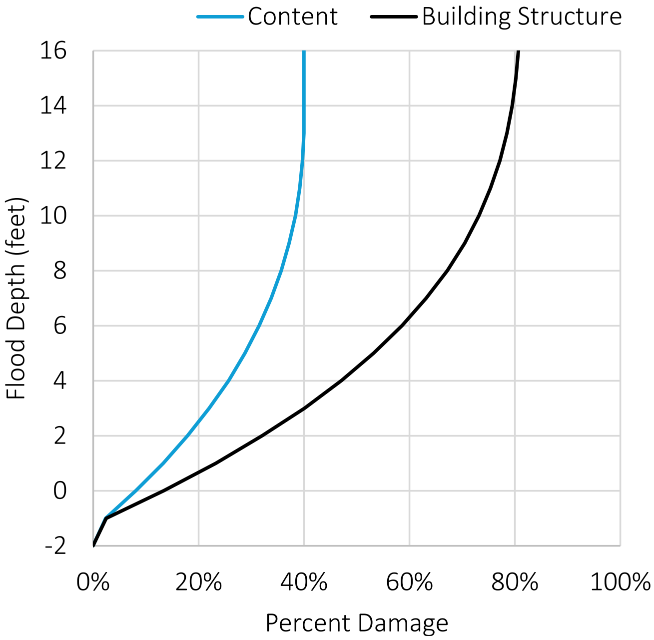
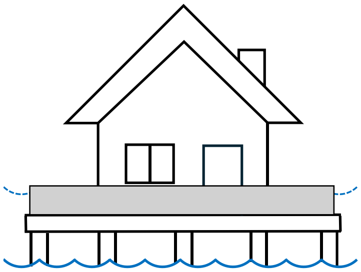


Figure 5-1: Flood Depth-Damage for One-Story Building, USACE (2000).

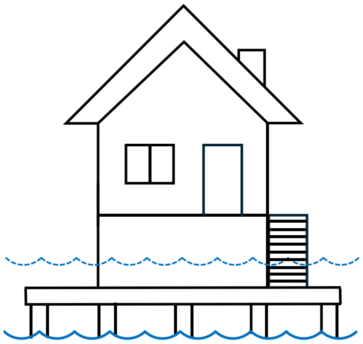
5.2. Protect



An adaptation strategy to protect NCMS facilities against flood hazards and SLR would focus on incorporation of a perimeter floodwall around the building. The height of the floodwall would be set to address the pertinent level of flood hazards and projected SLR. The floodwall or parts of it could consist of concrete, steel, or glass. In addition to a watertight perimeter floodwall, the Marine Field Station would need to be outfitted with a watertight floor sufficiently anchored to resist uplift if immersed up to the height of the floodwall. A pump system would be needed to evacuate stormwater resulting from rainfall.

Figure 5-2: Example Flood Protection with Glass Floodwall.

5.3. Elevate



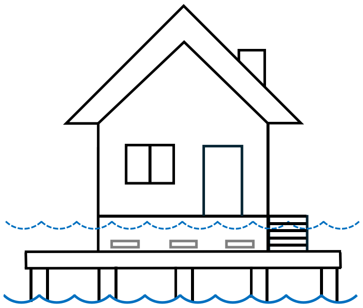
A strategy to elevate NCMS facilities would aim to locate the building above the projected floodplain with an allowance for SLR. This approach could significantly reduce flood hazards at the Marine Field Station. However, ramps and stairways would need to be integrated to facilitate access to the building. Areas of the facility remaining in the floodplain could be utilized for temporary storage, parking, open space, and facility elements that are less sensitive to flood hazards.

Figure 5-3: Example of Building Elevated on Piles.

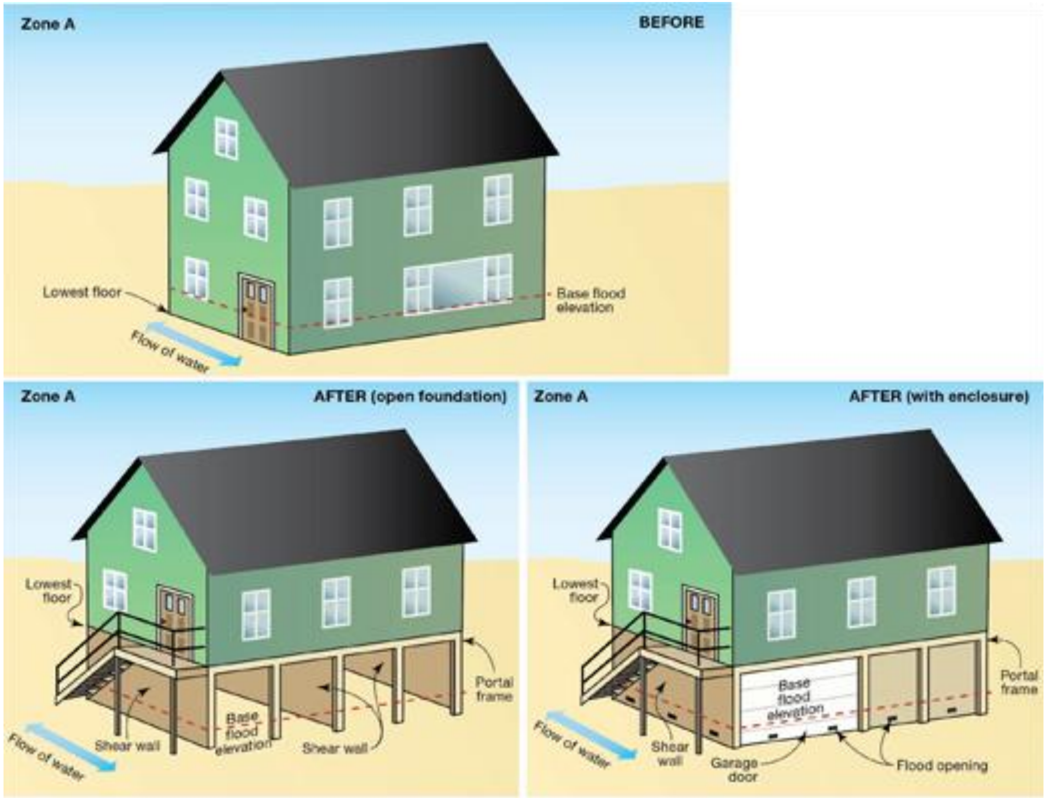
5.4. Accommodate

A strategy to accommodate flood hazards would aim to let floodwater pass around or through the building foundation. This can be achieved via wet or dry floodproofing as described in the following.

5.4.1. Wet Floodproofing



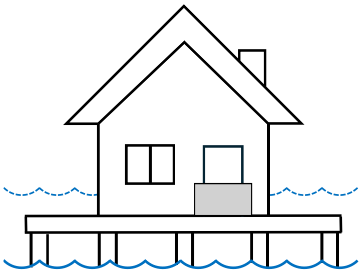
Wet floodproofing is a ‘flow-through’ strategy that allows floodwaters to enter and exit the facility through dedicated openings that work to equalize internal and external water pressure and minimize structural damage. Having a flow-through foundation can help prevent floodwaters from piling up against the side of the building and thereby reduce the water pressure on the building walls. Building elements that can serve as flow-through structures commonly include a crawlspace or raised foundation constructed using flood-resistant materials. Vulnerable facility assets that would be damaged by floodwater are located on elevated platforms, piles, or moved to a higher floor of the building.



Note: Drawing is not to scale. The number of flood openings shown is for illustration purposes only; the total number of openings depends on the square footage of the enclosure and the type and design of the opening.

Figure 5-4: Example Building Conversion to Wet Floodproofing with Open/Closed Foundation.

5.4.2. Dry Floodproofing

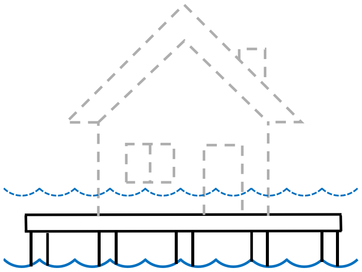


The aim of dry floodproofing is to make the building watertight and keep floodwaters out by outfitting walls with coatings, membranes, and specialized barriers and sealing cracks and openings. Drains need to be outfitted with backflow preventers to keep floodwaters from entering the building through these outlets. Doors and windows would need to be outfitted with flood gates and shields.

There is a wide range of temporary and permanent dry floodproofing solutions on the market, ranging from deployable barriers to structural elements such as flashboards and watertight doors. A potential risk of this strategy is that flood hazard reduction relies entirely on the facility being watertight. Structural upgrades are commonly needed to enable the building to withstand water flow and pressure on the building walls, and for this reason dry floodproofing is typically more suitable for shallow, low-velocity flood conditions. The method can still be applicable in conditions with higher flow if e.g. a structure or landscape feature is installed that can serve as a breakwater.

Figure 5-5: Example Barrier Utilized for Building Dry Floodproofing.

5.5. Relocate



A relocation SLR adaptation strategy would involve planned, permanent relocation of NCMS facilities to safer, higher ground. A key benefit to this strategy is that the vulnerability of the existing development, staff, and infrastructure is thereby removed. In practical terms, relocation of the Marine Field Station to higher ground could mean that the facility would need to move away from the riverbank and would consequently forego waterside access. An intermediate step could be taken if the possibility exists for the Marine Field Station to relocate to another facility location along the riverbank with reduced flood exposure and/or better flood hazard mitigation. Alternatively, a solution may be found through expansion whereby key NCMS facility assets are relocated to a safer location and the existing parcel retained for waterside access and Marine Field Station assets that are not sensitive to flooding.

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Appendix A:
Site Inspection Log

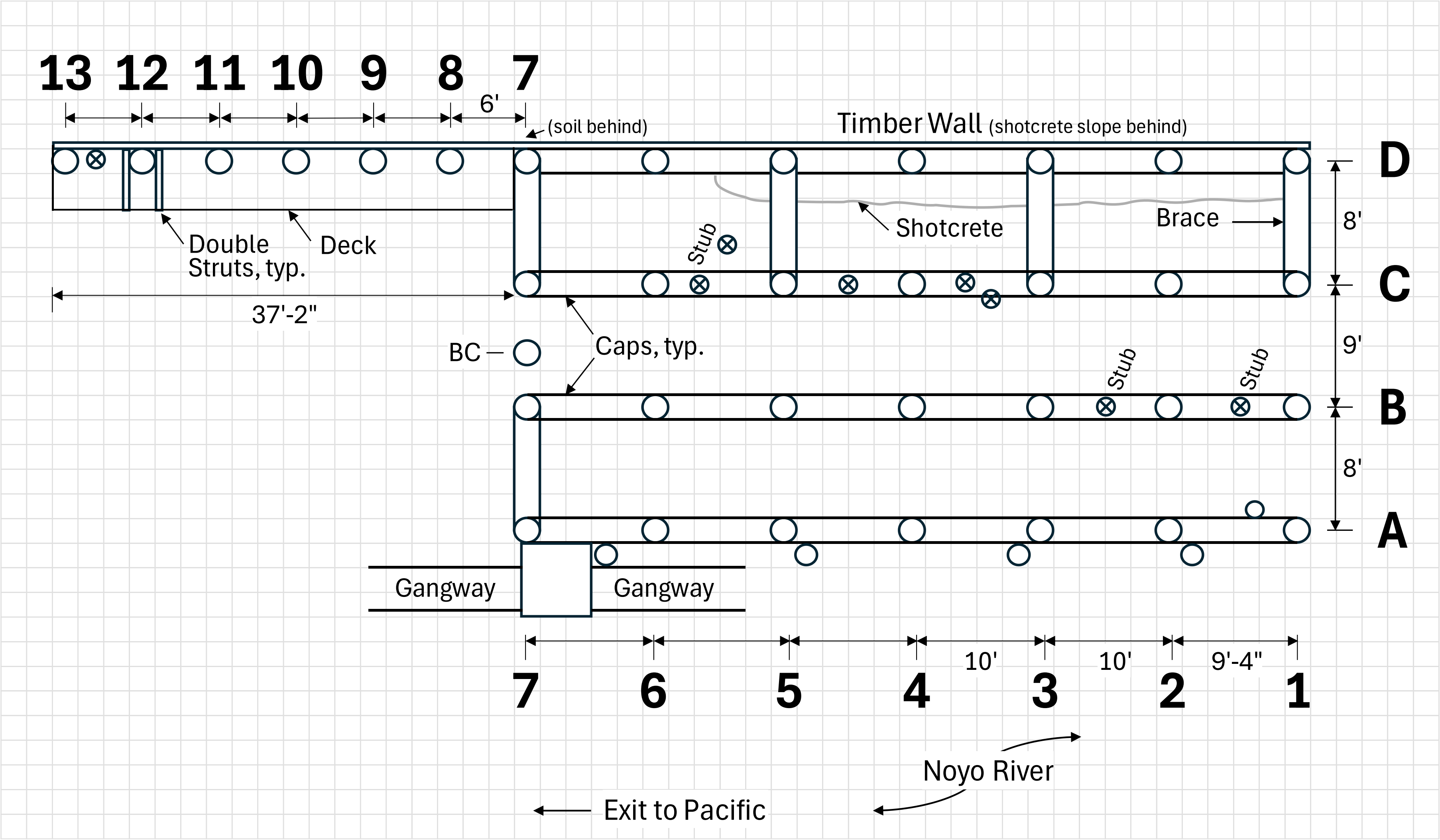


Figure A-1: Wharf Structure Inspection Plan.

Table A-1: Wharf Inspection Log.

Pile	Rating	Comment
D-1	No damage	3.5’ stick
C-1	Minor	
B-1	Minor	
B-2	Minor	~14’stick. small bolt holes
B-3	Moderate	~14’stick
B-4	Moderate	~14’stick
B-5	Moderate	~16’stick
B-6	Major	~16’stick. Cracks/check ½” deep, extend down from soffit. Hollow sound. ~50% remain.
BC-7	Minor	~17’ stick
B-7	Major	~17’ stick. long check
C-7	Moderate	~10’ stick. Hollow sounding slots 4’ from soffit.
CD-7 brace	Moderate	Poor bearing at C-7. Ineffective
D-7	Moderate	~7’ stick. ~25% loss
C-6	Minor	~10’ stick.
D-6	Minor	~7’ stick. Smaller dia. pile ≃10”
C-5	Minor	~9’ stick. Small hole
CD-5 brace	Moderate	Some softness in intertidal zone
D-5	Moderate	6.5’ stick. 10° batter in bent axis. ~25% loss
C-4	Severe	~10’ stick. checks extend 5’ from soffit 60% section loss 4’ from soffit down 1 ft
D-4	Major	8’ stick. Hollow. Backside missing. ~40% loss
C-3	Minor	8’ stick
CD-3 brace	Minor	Fully bearing, a little softness at MHW
D-3	Minor	6’ stick. crack gouge < ½”
D-2.75	Minor	6’ stick. ~16” Ø butt, some softness at surface
C-2	Minor	8’ stick. small holes/gouges
D-2	Minor	6’ stick. ~16” Ø butt, a few surface level gouges
C-1	Minor	10’ stick. ¼” check wide oozing creosote
CD-1 brace	Moderate	Small checks ≃ 1” deep
D-1	Minor	4’ stick. 16” butt
A-7	Moderate	14.5’ stick. Some surface softness at intertidal
A-6.5 fender	Top severe Major remaining	14.5’ stick. guide pile/fender pile small amount of wear due to collar Hollowed at top down 32”
A-6	Minor	14.5’ stick. ~1” deep checks at top ⅛” opening

Pile	Rating	Comment
A-5	Minor	13.6’ stick. small check at top
A-4.75	Moderate	13.5’ stick. checks ≃ ½” wide. Guide pile / fender pile, wear at face from float
A-4	Minor	13.25’ stick. Surface level gouges. Small checks at top
A-3.25	Minor to Major	13.75’ stick, ⅜” wide checks. Guide pile / fender core eroded at top 19” down
A-3	Moderate	13.75’ stick. Gouge 2” deep × 6” wide
A-2	Minor	13.5’ stick. No load transfer from cap (can move it with foot) Pile in minor condition
A-1.25	Major to severe	13.75’ stick. Fender pile/guide checks > 0.5”. Hollow at WL ~ 40-50% section loss
A-1.1	Moderate	13.75’ stick, ~7” of bearing. 3” Ø gouge ½” deep at waler ½” wide check extends to center
A-1	Minor	13.75’ stick. ~18” Ø butt, bearing and guide pile.
D-8	Moderate	8.5’ stick
D-9	Moderate	
D-10	Moderate	
D-11	Moderate	Smaller Ø than others

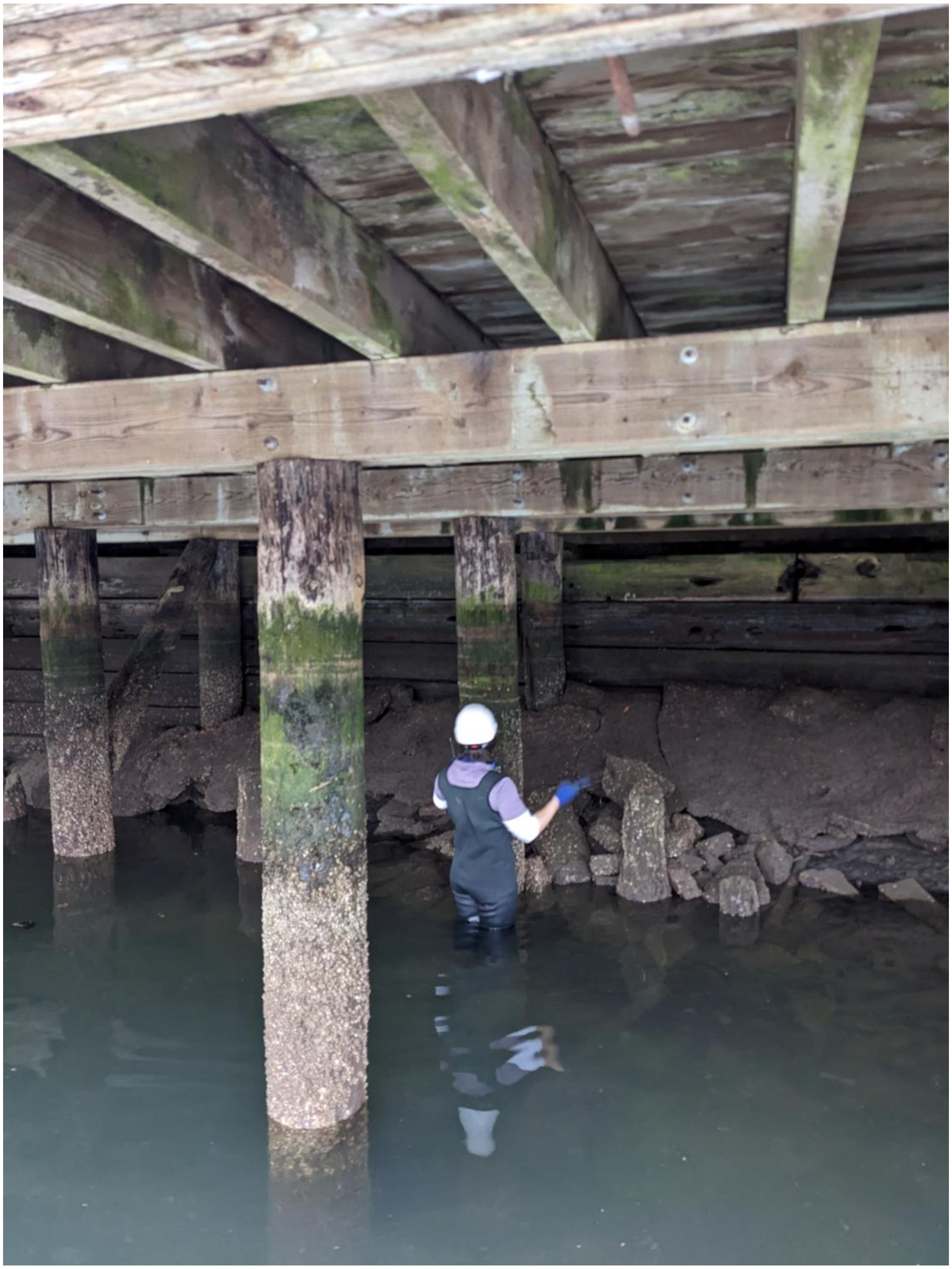
Appendix B:
Site Inspection Photos

Timber wall and deck along yard looking northwest.

Timber wall and deck along yard looking northeast.

View of pile-supported and deck gangway looking east.

Waterside view of Marine Field Station looking north.



View under deck, shotcrete over riprap above waterline.