TOMALES BAY BULKHEAD VULNERABILITY ASSESSMENT
MARIN COUNTY, CALIFORNIA

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County of Marin Community Development Agency
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1.0 INTRODUCTION

This report summarizes the results of Miller Pacific Engineering Group (MPEG) and Adaptation International's (AI) Bulkhead Vulnerability Assessment for a portion of the eastern shore of Tomales Bay in Marin County, California. Our work has been performed in accordance with our Professional Services Agreement dated August 15, 2021.

1.1 Project Description

The project generally includes evaluating existing bulkheads and related coastal infrastructure throughout an approximately 5-mile section of Tomales Bay's eastern shoreline and assessing their vulnerability to future sea level rise. For the purpose of this study, the term "bulkhead" is used to refer to a variety of engineered structures which alter the natural coastline to protect or accommodate existing or former development. Thus, the term "bulkheads" is utilized in reference to structures including retaining walls, rip-rap buttresses/rock slope protection (RSP), and man-made earth embankments. As shown on Figure 1, the study area extends from Nick's Cove at the north to the Marconi Conference Center at the south, and encompasses the town of Marshall.

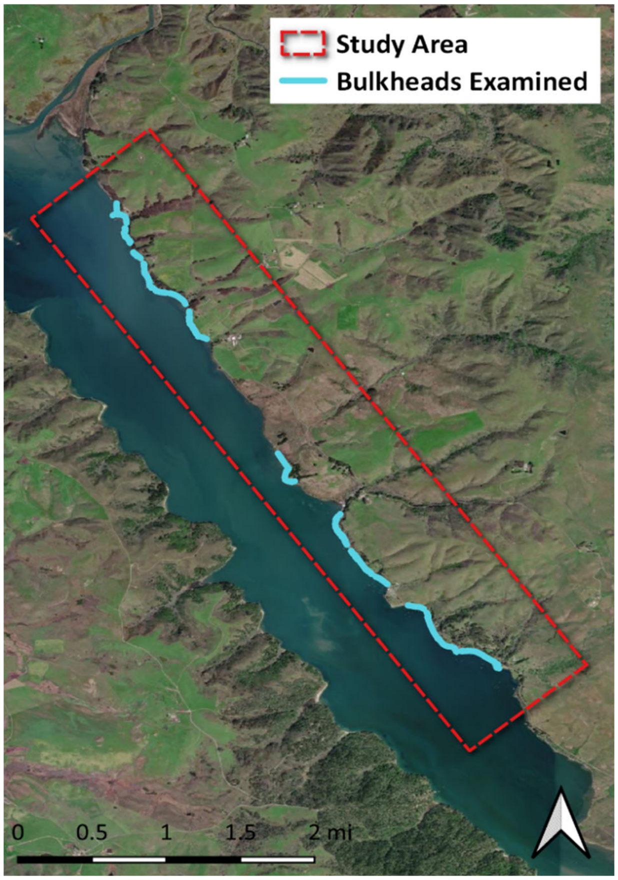

Figure 1 - Tomales Bay East Shore Study Area

1.2 Purpose

The purpose of our evaluation is to better understand the shared risk posed by sea level rise (SLR) and coastal flooding and develop conceptual options for improvement, repair, or replacement of existing bulkheads and related coastal structures that may be vulnerable to the effects of expected future sea level rise. It is understood that the purpose of this report is not to facilitate new development, but to provide local and regional planners with a more detailed understanding of risk and the relative feasibility of conceptual approaches for increasing resilience to SLR as may be needed to maintain existing coastal improvements, infrastructure, natural systems, and environments.

1.3 Scope

The scope of our Assessment is generally described in our proposal letter dated May 7, 2021, and includes the following.

- Review of relevant background information, including available, published regional geologic and topographic mapping, historic air photos, and previous studies by others concerning site conditions, development history, and historic coastal hazard impacts.

- Coordination with project stakeholders, including the Marin County Community Development Agency (CDA), the East Shore Planning Group (ESPG), and Caltrans to compile a database of existing bulkheads and related coastal structures.

- Field reconnaissance to observe and catalog existing bulkhead locations and apparent structural condition.

- Development of a database using Geographic Information Systems (GIS) software and high-resolution topographic information to accurately locate each structure and facilitate evaluation of likely SLR effects under a variety of scenarios.

- Development of professional opinions regarding the ability of existing structures to withstand the potential effects of SLR and the likely consequences where structures are unlikely to perform under different scenarios.

- Development of conceptual options for bulkhead improvement, rehabilitation, or replacement and discussion of related considerations such as probable cost, likely permitting needs, and other planning-level considerations.

2.0 PROJECT BACKGROUND

Marin County's Pacific Coast and Tomales Bay shorelines regularly experience local and regional flooding, erosion, and other effects during king tides, coastal storms, and significant rainstorm events. Sea level rise is expected to exacerbate these hazards. Globally, because of climate change, sea levels are rising due to thermal expansion caused by ocean warming and the melting of land-based ice such as glaciers and polar ice caps. Over the last century, sea levels in the San Francisco Bay area have risen about eight inches, and the observed trend is expected to continue and accelerate throughout this century and into the next (Griggs et al., 2017; OPC, 2018; CCC, 2018). Regionally and locally, sea level rise has the potential to expand the impact of coastal, riverine, and localized nuisance flooding. Over time, these changes may result in permanent inundation, more frequent and longer duration floods, shoreline erosion and overtopping, and elevated groundwater and increased saltwater intrusion. The National Oceanic and Atmospheric Administration (NOAA) predicts that the sea level may rise as much as 1- to 3-feet within the next 30 years.

It is widely understood that global warming and associated sea level rise are a result of greenhouse gas (GHG) emissions related to human activity. Because the precise nature and amount of future greenhouse gas (GHG) emissions cannot be accurately predicted, the exact extents of future warming and sea level rise are impossible to predict. Considering a range of potential future scenarios based on the best available data can be a useful tool for regional and local planning to minimize the potentially significant environmental, social, and economic impacts of sea level rise.

2.1 Geologic Setting

The project site is located within the Coast Ranges geomorphic province of California, which is typified by generally northwest-trending ridges and intervening valleys. These are formed as a result of movement along a group of northwest-trending fault systems, including the San Andreas Fault, which forms the boundary between the North American tectonic plate to the east and the Pacific plate to the west.

Bedrock geology east of the San Andreas is dominated by sedimentary, igneous, and metamorphic rocks of the Jurassic-Cretaceous age Franciscan Complex. Sandstone and shale comprise most Franciscan rock types, while less common rocks include chert, serpentinite, basalt, greenstone, and exotic low- to high-grade metamorphic rocks, including phyllite, schist, and eclogite. West of the fault, Point Reyes and Tomales Point are underlain by granitic rocks known as the Salinian Block, which are of similar age. Salinian Block rocks are locally overlain by a variety of Tertiary and Quaternary sedimentary rocks. Movement within the fault zone, which generally consists of about a one-mile wide deformation zone bounded by prominent, active strike-slip faults on the northeast and southwest sides, has formed the topographic depression now occupied by the waters of Tomales Bay.

As shown on Figure 2, regional geologic mapping indicates that the majority of the study area is underlain by Franciscan "Melange" bedrock. Melange is defined as a tectonic mixture of resistant rock types, primarily sandstone, chert, and altered subaqueous volcanic rocks, embedded in a matrix of pervasively sheared shale. Alluvial deposits, which typically consist of unconsolidated clay, silt, sand, and gravel, are shown occupying the mouth of the unnamed stream just north of Cypress Grove in the southern part of the study area. The broad, gentlysloping area just north of the alluvial deposits and east of Highway One is shown as being underlain by terrace deposits which typically consist of consolidated alluvium that has been uplifted and exposed by fault movement. Each map indicates that, within the study area, the primary, active traces of the San Andreas Fault Zone lie offshore, beneath Tomales Bay.

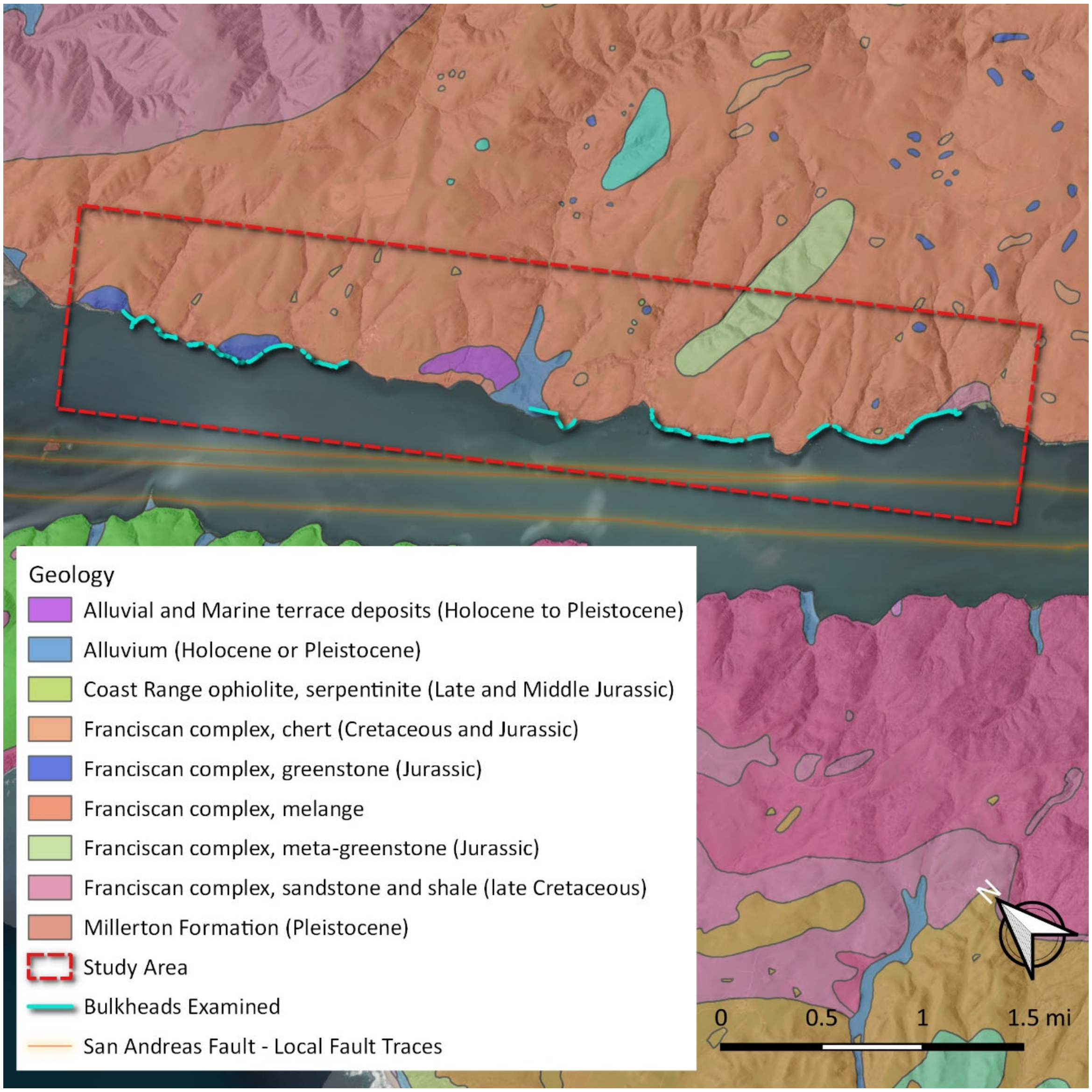

Figure 2- Tomales Bay East Shore Geology (USGS, 2000) and Marin County Open GIS, www.marinmap.org.

2.2 Development History

Settled historically by various Tribes of the Coast Miwok, early development in Tomales Bay was dominated by dairy ranching, which began shortly after the California gold rush with the arrival of the Marshall brothers in the mid-1850's. Construction of the North Pacific Coast Railroad (later the North Shore Railroad and the Northwestern Pacific Railroad) dramatically altered the natural eastern shoreline of Tomales Bay in the late 18th century and early 1900's (Livingston, 2020). Railroad construction included extensive excavation of the natural bluffs and construction of new embankment slopes to form the roadbed, many of which were armored against wave action by placement of rip-rap. The railroad also obliterated the former coastal road, which was moved farther inland in many areas. Locally, new piers and docks were constructed to support railroad timber and seafood freight operations, and a hotel and depot were built in Marshall.

Following abandonment of the railroad and construction of the current alignment of Highway One in the early 1930's, many portions of the former railroad right-of-way were developed with new waterfront homes. Although some of the original maritime infrastructure remains intact, other older wharves, docks, and piers have been abandoned or repurposed as residential or other structures.

2.3 Historic Flooding and Coastal Impacts

The NOAA National Centers for Environmental Information Storm Events Database lists 17 coastal flood events that have affected Marin County since 2005.[1] While these events didn't all affect Tomales bay they did include the following:

- January 1, 2008 - Extreme astronomical high tide
  The extreme tide (7.1 feet above mean sea level) closed State Route One for more than three hours near the intersection with U.S. Highway 101.
- December 3, 2014 – Winter storm and coastal flooding
  A winter storm arrived during an astronomical high tide created coastal flooding, downed trees and powerlines across the region.
- November 15, 2020 – King Tides
  King tides (6.9 feet above sea level) created minor roadway flooding near Sausalito and brought rough seas to the outer coast. One person fell into the surf near Sutro Baths and drowned as rough conditions hampered search and rescue operations.

East shore flooding does happen as demonstrated by the 2006 storm that flooded several buildings in the Audubon Canyon Ranch in Cypress Grove[2].

2.4 Previous Studies

This project incorporates and expands on foundational work recently performed by Marin County, including the Collaboration: Sea Level Marin Adaptation Response Team (C-SMART) Marin Coast Sea Level Rise Vulnerability Assessment (2016) and the Tomales Bay Living Shorelines Feasibility Project Study (2022). Each study considered a range of SLR scenarios from 1.6 ft to 6.6 ft (50 to 200 cm) above mean higher high water (MHHW[3]).

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[1] https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28Z%29+Coastal+Flood&beginDate_mm=01&beginDate_dd=01&beginDate_yyyy=1990&endDate_mm=01&endDate_dd=31&endDate_yyyy=2022&county=MARIN%3A41&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=6%2CCALIFORNIA

[2] https://www.marinij.com/2022/01/29/marin-planners-envision-tomales-bay-sea-level-barriers/

[3] Mean higher high water (MHHW) is the average of the "higher high water height" of each tidal day observed over the National Tidal Datum Epoch. The National Tidal Datum Epoch is the specific 19-year period adopted by the

In order to address the potential impacts of SLR in conjunction with existing flooding risks from storm surge, this study considers the same range of SLR scenarios as well as the 100-year storm event, defined as that storm with a historical one percent (1%) chance of occurring in any given year.[4]

In addition, the Tomales Bay Living Shorelines Feasibility Project based the SLR time horizons on the "medium-high" and "extreme" risk aversion projection curves published by the Ocean Protection Council (OPC, 2018) and as recommended in recent California Coastal Commission guidance documents (CCC, 2018) *(See Section 3.3. – Sea Level Rise Analysis for more information regarding the link between risk aversion and probabilistic projections for sea level rise).* The State Guidance justifies using the "medium-high" risk aversion for projects that are less adaptive and more vulnerable and that will experience "medium to high" consequences as a result of underestimating sea level rise. The same guidance advises using the "extreme" risk aversion for "high" consequence projects with a design life beyond 2050 that have little to no adaptive capacity and would be irreversibly destroyed or significantly costly to relocate/repair should this level of sea level rise occur (OPC 2018). The California Coastal Commission recommends that communities evaluate impacts from sea level rise using the "medium-high" risk aversion as well as understand the worst-case scenario using the "extreme" risk aversion projections (CCC, 2018). The County based the Tomales Bay Feasibility Project sea level rise time horizons on the "medium-high" and "extreme" risk aversion projection curves with the justification that portions of the Tomales Bay shoreline at risk of erosion or flooding include critical infrastructure, such as fire stations, homes, and emergency evacuation routes (Marin County, 2022).

3.0 METHODOLOGY

Investigative field methods utilized for this project generally included a surficial land- and water-based reconnaissance of the study area for preliminary observation and documentation of existing bulkheads. Field data collection was followed by creation of a digital database for spatial and statistical analysis of the expected effects of SLR and coastal flooding in consideration of several different scenarios. Each of these tasks is described in more detail below.

3.1 Site Reconnaissance

We performed a detailed reconnaissance of the study area on December 1 and 2, 2021. Site reconnaissance was performed generally between slack and low tide to allow for viewing of waterfront structures. Our reconnaissance was performed from public lands below Mean Higher High Water (MHHW) under the auspices of the Public Trust Doctrine. Where observation from land areas below MHHW was not possible, observations were made by use of a kayak.

National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for published tidal data.

[4] For context, the 100-year storm has an approximately 26% chance of occurring during the term of a typical 30 year residential mortgage loan.

During our reconnaissance, we collected detailed notes regarding minimum and maximum bulkhead height, apparent bulkhead condition, apparent bulkhead purpose, and notable aspects of each specific bulkhead's contour relative to other coastal features. Structure locations were recorded in the Universal Transverse Mercator (UTM) coordinate system using a handheld Garmin Global Position System (GPS) unit to record geolocated points at each end of each structure. Approximated structure elevations were later determined by transferring GPS coordinates onto a topographic basemap using GIS software as described in Section 3.2.

3.1.1 Existing Bulkhead Inventory

During our reconnaissance, we observed and inventoried a total of 102 individual bulkheads in the project area, covering a total of 12,936 linear feet of shoreline. It should be noted that where contiguous bulkheads span multiple parcels, they were divided such as to reflect the number of affected parcels. As shown on Figure 3, existing bulkheads consist predominantly of concrete retaining walls and rock slope protection (RSP), while other retaining wall types and un-armored earth embankments comprise a small portion of existing infrastructure. The majority of infrastructure is RSP, in terms of total linear feet of structures in the study area, with approximately 8,523 ft. of RSP in the study area, followed by 3,475 ft. of retaining walls, 630 ft. where both retaining walls and RSP are present, and 364 ft. of earthen embankments. However, most parcel-specific structures are retaining walls of various construction composition, despite covering an overall smaller area (see Fig. 3, right).

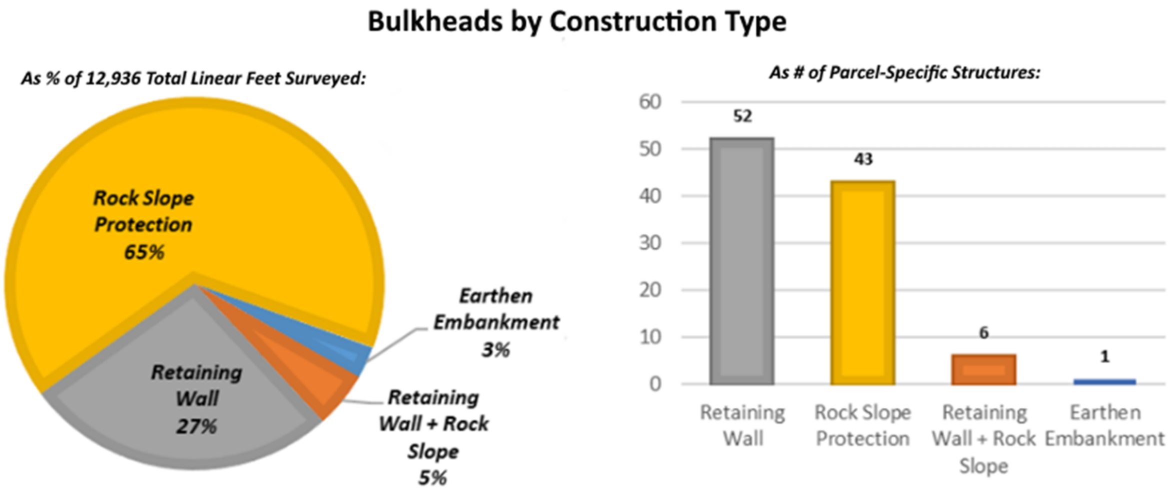

Figure 3- Distribution of bulkhead types as a percentage of total linear feet of structures examined (left) and as the number of structures of each type (right).

3.1.1(A) Retaining Walls

Retaining walls are widespread throughout the project area, and most commonly are used to retain portions of the old railroad embankment or natural shoreline where residential and other structures have been developed along the waterfront. In most of these cases, structures are cantilevered over the water, and are supported by a combination of pilings and the top of the retaining walls themselves. In some cases, retaining walls are effectively integral to the structure itself, in that they both retain fill materials beneath the landward side of the structure and also act as foundations, directly supporting structural framing and other elements. Existing retaining walls typically range from about 4- to 10-feet high. In addition, lower walls are present where more subdued natural shoreline topography exists, mostly where lower-lying portions of the railroad embankment now serve as driveway access to residences and where residences are sited within small coves.

The majority of the retaining walls in the area are of cast-in-place (CIP) concrete construction, however; there are a few Concrete Masonry Unit (CMU) walls, stacked- or grouted-rock walls, and timber post and lagging walls within the study area. Illustrative examples of each are shown in Figures 4 through 7.

Most of the concrete and CMU walls exhibit evidence of shallow footing foundations on the water side of the wall. In many areas, retaining wall footings bear directly on weathered Franciscan bedrock and do not exhibit evidence of significant scour or undermining.

Although relatively sparse, walls bearing on old railroad embankment fill, beach deposits, or particularly sheared or weathered bedrock exhibit local evidence of scour and undermining up to several inches. Many of these walls show evidence of previous stabilization attempts, including steel deadman/tieback cables and anchors, concrete buttresses, and RSP or other revetment along the base of the wall.

Figure 4 - Reinforced concrete wall showing typical distress, including spalling and exposure/corrosion of rebar.

In general, we observed that the majority of the concrete walls in the study area appear to have been constructed concurrent with an associated habitable structure. Thus, most of the walls appear to be several decades old and exhibit evidence of structural distress consistent with age and common construction practices of the early- to mid-1900.These older walls commonly exhibited moderate to extensive concrete cracking and spalling along with extensive exposure of rebar where older walls are internally reinforced. Where rebar is exposed and where steel components are used to connect framing and other elements to the walls, extensive corrosion is common.

Stacked- or grouted-rock walls are relatively sparse in the study area, and typically consist of stacked cobbles, concrete sacks, or concrete rubble (sometimes referred to as "urbanite"), without grout or mortar. Nearly all of these walls exhibit evidence of local distress, including deformation of the wall face, dislodged rocks, and local failure/toppling.

Timber post and lagging walls in the study area were observed to be between about 4- and 6-feet high and typically exhibit evidence of rot, while some exhibit evidence of undermining.

Figure 5- Typical concrete masonry unit (CMU) wall.

Figure 6 - Typical stacked/grouted rock wall.

Figure 7 - Typical timber wall with 4x4 posts and 2x12 lagging showing typical distress due to age and rot.

3.1.1(B) - Rock Slope Protection (RSP)

Figure 8 - Typical rock slope protection (RSP).

Rock slope protection (also known as rip-rap) typically consists of hard rock boulders measuring between about 1- and 3-feet in largest dimension. RSP is present throughout the study area and appears to have been a common means of stabilizing railroad embankment slopes along the coast. RSP typically is placed to form slopes inclined between about 0.5:1 (horizontal:vertical) and 1.5:1, which typically range from about 2- to 8-feet high. In general, where RSP is inclined flatter than about 1:1, these areas appear to have performed well, whereas steeper RSP slopes exhibit evidence of local sloughing and instability, which appears to be primarily the result of scour and wave action along the toe of the RSP.

3.1.1(C) - Earth Embankments

As described previously, much of the natural shoreline has been altered by construction of earth embankments for the old railroad alignment. Where the alignments traverses topographic noses or high points, the embankment appears to have been typically created via excavation on the upslope side and side-casting of excavated material to construct the fill slope on the water side. Where the railroad embankment crosses small coves, inlets, and other topographic lows, it effectively forms a levee created via import of fill from excavations elsewhere along the alignment. Where unaltered by more recent development, embankment slopes are typically 6- to 8-feet high and inclined between about 2:1 and 1:1.

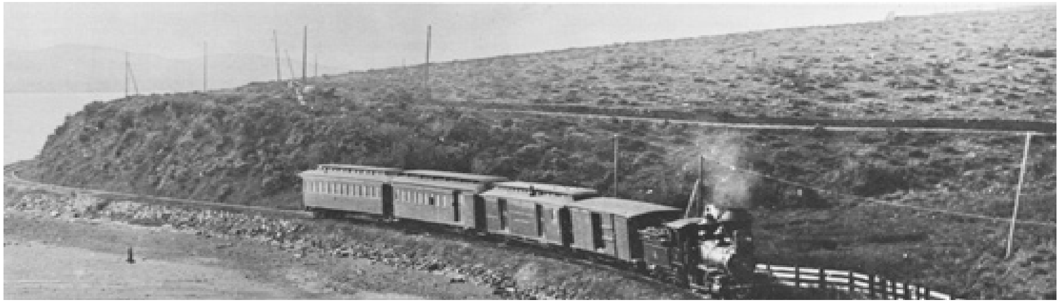

Figure 9 – Typical earth embankment. Southbound train approaching Bivalve (date unknown). Note railroad embankments were typically constructed via excavation on uphill side of tracks and fill placement on downhill side. Note RSP armoring visible on face of embankment along waterfront. (Photo credit - Tomales Bay Regional History Center).

3.1.2 Existing Bulkhead Conditions

Based on our field observations, we categorized each of the inventoried bulkheads as being in “good”, “fair”, or “poor” condition. Bulkheads determined to be in “good” condition generally include structures exhibiting little to no evidence of significant distress and exhibiting apparently “good” historic performance. “Fair” condition bulkheads generally include those which exhibit slight to moderate distress and/or more questionable historic performance, but which could be conceivably improved or retrofitted back to “good” condition. Structures in the “poor” condition category generally include those which have failed or otherwise exhibit severe distress and most likely would need to be replaced entirely to restore “good” performance. For the purpose of this discussion, “performance” should be taken to mean providing protection from wave action, scour, erosion, undermining, and seismic/slope stability hazards.

Overall, bulkhead condition varies throughout the site. As shown in Figure 10, of the 12,936 linear feet of bulkheads evaluated, approximately 23% are in “poor” condition, while bulkheads in “fair” or “good” condition represent 38% and 39% of the total bulkhead frontage, respectively.

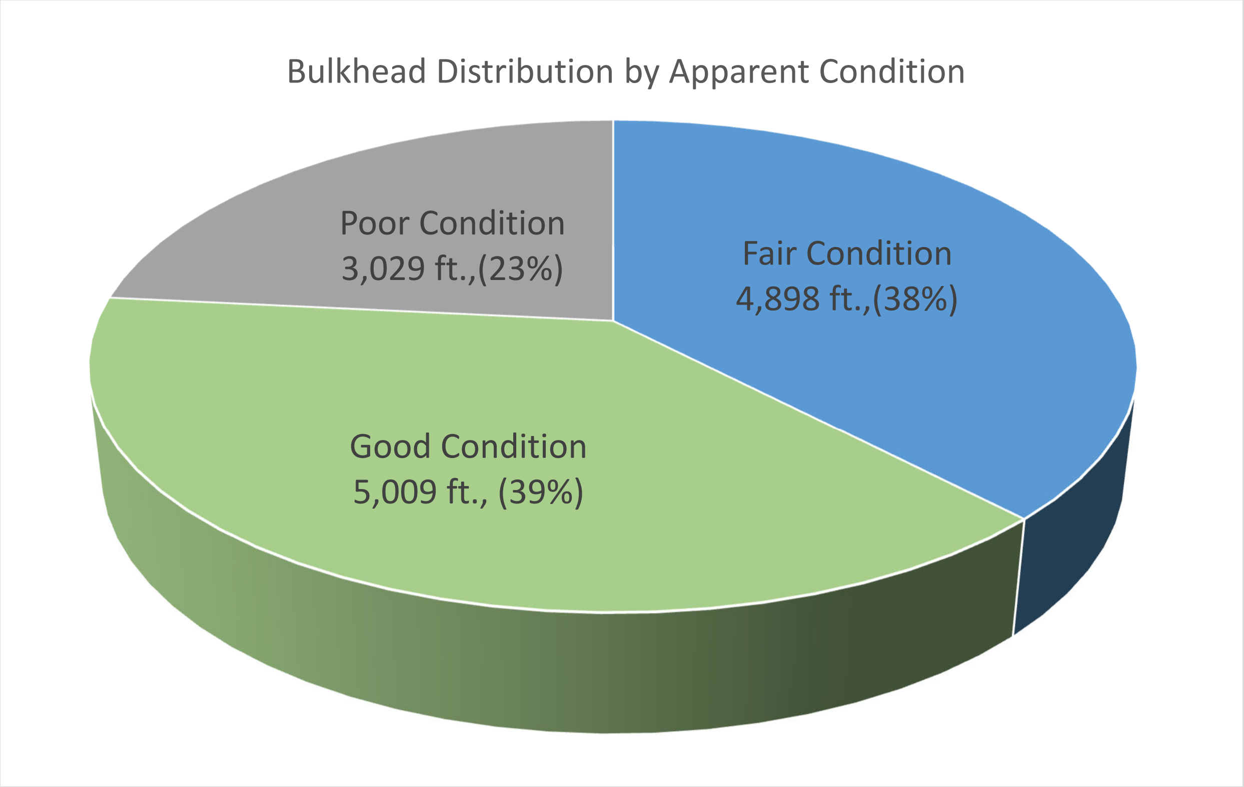

Figure 10 – Bulkhead condition as a proportion of total linear feet examined. As shown, bulkhead conditions are relatively evenly distributed throughout the project site and slightly skewed toward “good” and “fair” condition, with “poor” condition structures representing 23% of the 12,936 linear feet of bulkheads examined.

Our observations indicate a strong relationship between bulkhead condition and performance. As shown in Figure 11, the vast majority of bulkheads noted to be in “good” condition were also observed to be providing “good” performance. Likewise, bulkheads in “poor” condition generally appear to be performing poorly.

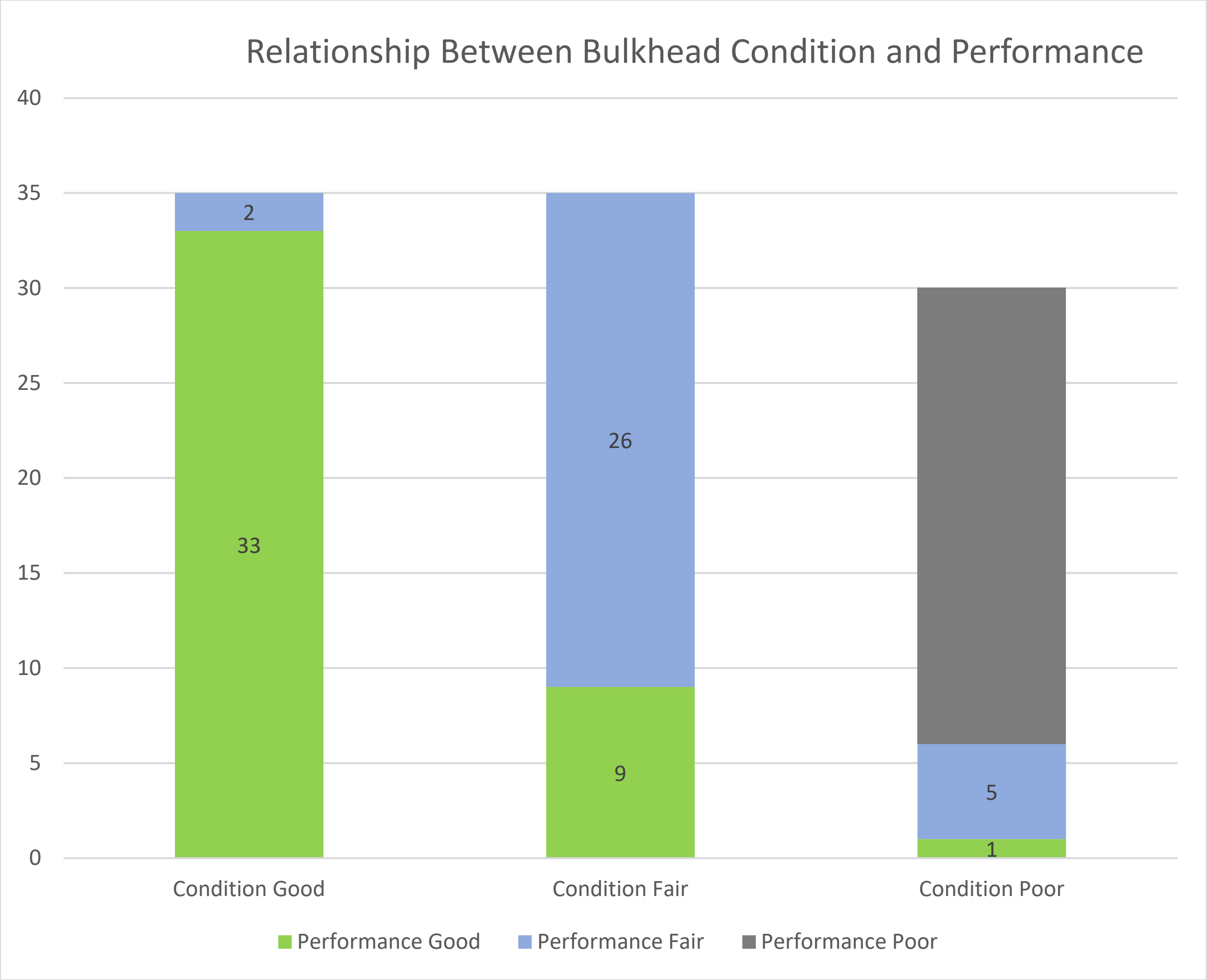

Figure 11 – Relationship between bulkhead condition and performance with the number of bulkheads in each performance category shown by apparent condition. As shown, bulkhead condition commonly has a significant effect on bulkhead performance.

Notably, we did not observe a particular relationship between structure type and either condition or performance. Our observations indicate that, in general, age appears to be the most significant factor controlling structure performance and condition. Regardless of structure type, older structures generally exhibit more advanced distress consistent with age (such as rotting of timber elements and corrosion of steel elements), while newer structures tend to be in better condition, likely as a result of lessened exposure as well as the use of more modern design and construction practices and materials.

3.2 Database Compilation

Following completion of our field reconnaissance, our notes were compiled in Excel format and transferred to Adaptation International staff for incorporation into a spatial database using ESRI ArcGIS software, available satellite imagery (Esri et al. 2022; USDA NAIP 2019), and digital elevation model derived from Marin County LiDAR data (Quantum Spatial, 2019), all of which is projected in the UTM coordinate system and uses the 1988 North American Vertical Datum (NAVD88) as a basis for measuring relative elevations.

To construct the database, each structure location was plotted on the basemap using field GPS coordinates, and was then cross-checked against field notes and aerial photography to ensure positional accuracy. Each structure was then assigned a base and "top of wall" elevation based on its projection against the NAVD88 elevation datum and our field measurements. This resulted a model of the bulkheads across the study region which is meant to provide the best possible approximation of the actual bulkhead position and convolution for the entirety of the roughly 12,936 linear feet of bulkheads within the study area.

Following spatial location of the bulkheads, they were then compared with the LiDAR topography and underlying base elevations. Base elevations were identified for each 1-foot linear segment of bulkhead and then averaged across the entire length of the bulkhead. These averaged elevation values were then added to the bulkhead segment's minimum top-of-wall elevation as measured during our field reconnaissance in order to determine the elevation (relative to NAVD88) which approximates the elevation at which each bulkhead would be actively engaged in resisting wave action, and the elevation at which they would be overtopped.

3.3 Sea Level Rise Analysis

To better understand the shared risk posed to these structures by sea level rise, we employed a combination of primary and secondary coastline datasets. Sea level rise estimates used in this project analysis are from the Our Coast Our Future (OCOF, 2018) tool, which uses USGS's modeling system called Coastal Storm Modeling System (CoSMoS) to evaluate multiple combinations of sea level rise and storm event scenarios.

3.3.1 Probabilistic SLR Time-Horizon Analysis

The speed at which sea levels rise and the magnitude of that rise will depend on multiple factors, including the scale and pace of global greenhouse gas emissions and the global success of actions taken to reduce these emissions. The State of California Sea Level Rise Guidance uses emissions scenarios that are the same as those used by the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC Fifth Assessment (AR5), 2013). Of the multiple emissions scenarios, this study uses projections from the Representative Concentration Pathway 8.5 (RCP 8.5) emissions scenario[5], which represents a suite of socioeconomic

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[5] Representative Concentration Pathways (RCPs) represent different greenhouse gas emission/concentration trajectories.

conditions, policy options, and technological considerations that most closely follow current global emissions trajectories (OPC, 2018). Under this scenario, global average temperatures would rise by nearly nine degrees Fahrenheit by the year 2100.

Current state of the art sea level rise projections are probabilistic, meaning they focus on estimating the probability of different levels of future sea level rise outcomes. These probabilities are determined primarily by process-based modeling of the climate system but also include uncertainty around contributions to sea level rise from future land-based ice melting (Kopp et al. 2014).

While sea level rise projections may change in the future as more data are collected and the factors influencing SLR are better understood, probabilistic projections provide vital information for decision makers. Selection of a particular projection as the basis for future resilience planning is dependent on many factors, including risk aversion.[6] Risk aversion sea level rise projections are associated with various probabilities of sea level rise meeting or exceeding a particular amount. The "medium-high" risk aversion scenario is the 1-in-200 chance (0.5% probability) that sea level rise will meet or exceed a particular amount within a specified timeframe. The "extreme" risk aversion scenario is based on H++ extreme sea level rise scenario (Sweet et al. 2017) that does not have an associated likelihood of occurrence.

In addition to understanding the potential range of sea level rise projections, it is also helpful for decision makers to understand what timeframe a particular sea level is projected to occur. These timeframes can be extrapolated from the various probabilistic projection curves and provide information on the likelihood that a sea level rise will meet or exceed a specific height over various timeframes. As previously mentioned, bulkheads are integral to the protection of individual property and other critical infrastructure, so it makes sense to consider use the "medium-high" and "extreme" risk aversion curve and associated timeframes.

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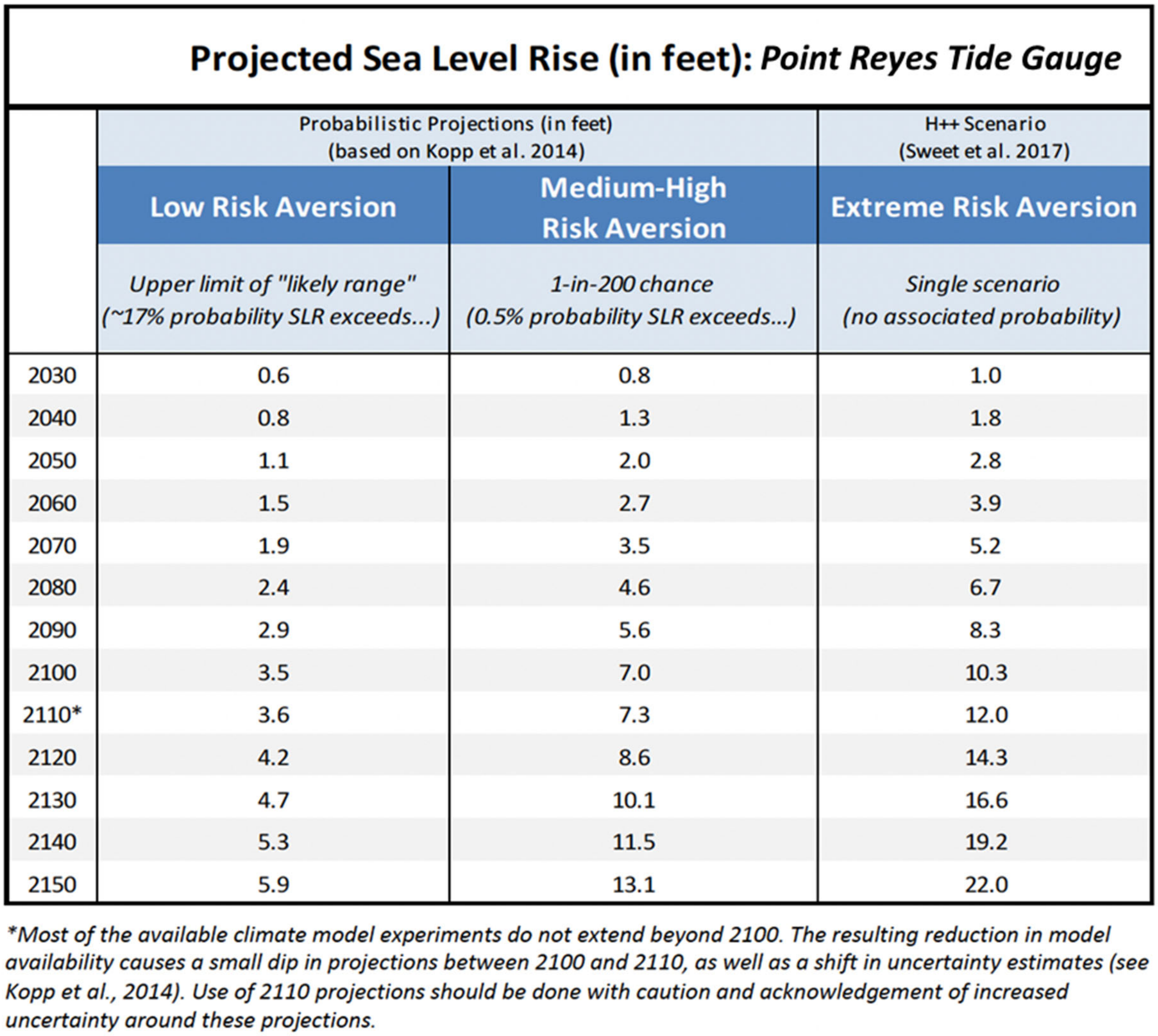
[6] Risk aversion is defined as "the strong inclination to avoid taking risks in the face of uncertainty" (OPC, 2018 pg. 22).

For this study, base water levels and tidal datum information from the National Oceanic and Atmospheric Administration (NOAA) tide gauges at Point Reyes (Station 9415020) and Inverness (Station 9415228) were used to provide baseline tidal elevation levels. Probabilistic SLR projections were then added to this baseline to develop sea level estimates for the time period between 2030 and 2150. As shown in Figure 12, probabilistic sea level rise projections for the Point Reyes tide gauge indicate that in a “medium-high” risk aversion scenario 1.6 feet (50 cm) of sea level rise is estimated to occur between 2040-2050, 3.3 feet (100 cm) by approximately 2065-2075, and 6.6 feet (200 cm) by 2090-2100. In an “extreme” risk aversion scenario, 1.6 feet (50 cm) of sea level rise is estimated to occur between 2030-2040, 3.3 feet (100 cm) by 2050-2060, 6.6 feet (200 cm) between 2075- 2085, and up to 22.0-feet (670 cm) by 2150.



Projected Sea Level Rise (in feet): *Point Reyes Tide Gauge*

	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.6	0.8	1.0
2040	0.8	1.3	1.8
2050	1.1	2.0	2.8
2060	1.5	2.7	3.9
2070	1.9	3.5	5.2
2080	2.4	4.6	6.7
2090	2.9	5.6	8.3
2100	3.5	7.0	10.3
2110*	3.6	7.3	12.0
2120	4.2	8.6	14.3
2130	4.7	10.1	16.6
2140	5.3	11.5	19.2
2150	5.9	13.1	22.0

Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.

Figure 12 - Projected Probabilistic Sea Level Rise for Point Reyes Tide Gauge, CA. This table summarizes sea level rise projections in feet above Mean Higher High Water (MHHW), using baseline data from 2000, for “low”, “medium-high”, and “extreme” risk aversion scenarios. This project focuses on “medium-high” and “extreme” risk aversion timeframes.

Following development of probabilistic projections, “time-rate” curves were plotted to approximate SLR rates under “low”, “medium-high”, and “extreme” risk aversion scenarios. Figure 13 depicts sea level rise risk aversion curves and approximate timeframes for 1.6 feet (50 cm), 3.3 feet (100 cm), and 6.6 feet (200 cm) of sea level rise.

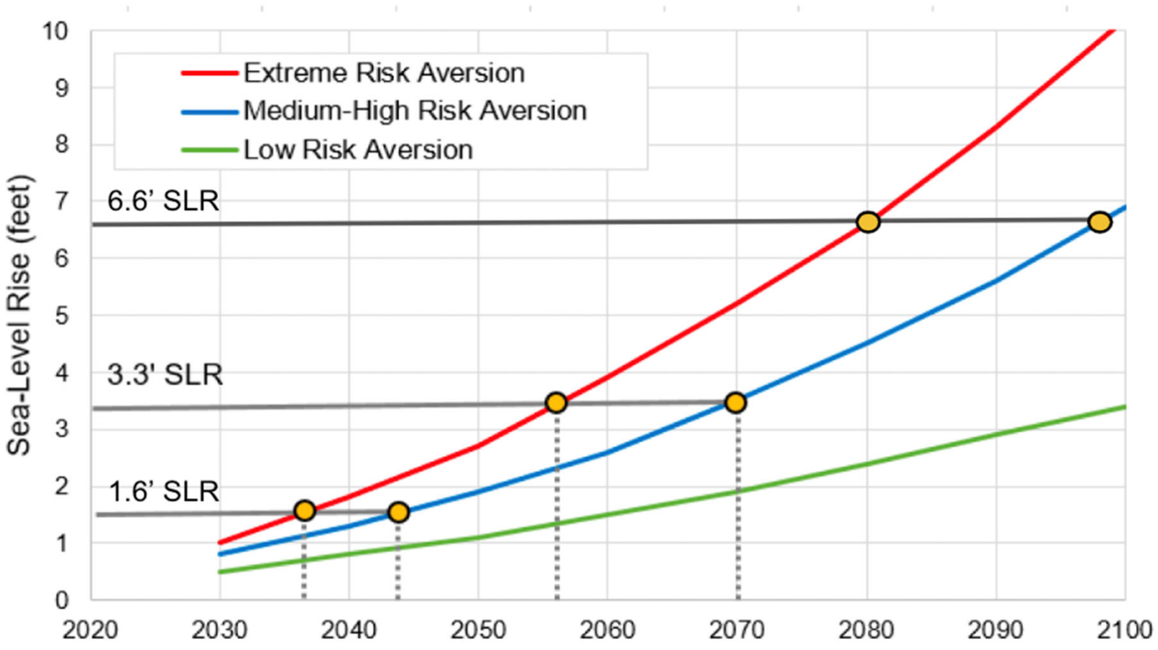


Figure 13 - Sea Level Rise Projections for San Francisco Bay for 2030-2100. Medium-high risk aversion curve is shown in blue, and extreme risk aversion curve is shown in red. Each curve intersects 1.6’, 3.3’, and 6.6’ feet of SLR to provide an approximate timeframe for each projected SLR scenario. (Figure adapted from CCC, 2018 and Marin County, 2021 to include 6.6’ SLR and associated time frames for “medium-high” and “extreme” risk aversion curves.)

3.3.2 SLR and 100-year Storm Events

In order to provide a more complete picture of the current and future impacts to bulkheads from sea level rise, it is important to consider impacts of coastal storm events *in addition to* sea level rise (i.e., the projected future mean-higher high-water level as well as the future 100-year storm water levels) as developed by Barnard et al. (2019). This allows for characterization of the maximum elevation above the NAVD88 datum that water reaches at Mean Higher High Water (MHHW) with associated wave action. In this analysis, storm events (in this context, also called coastal storms) are considered high water-level events that impact outer coasts, embayments, wetlands, and estuaries. The CoSMoS modeling system used in the Our Coast Our Future incorporates:

- Relative sea level rise: localized sea level change relative to a fixed point on land;
- Tides: the regular rise and fall of the sea surface in response to forces exerted by the moon and sun;
- Storm surge: the rise in water levels during storms due to winds pushing water onshore and low atmospheric pressures (measured as the height of the water above the normal predicted tide level);
- Seasonal effects: seasonal variations in sea levels, including El Nino where thermal expansion and changes in ocean circulation that lead to rising coastal water;
- River discharge: freshwater outflow from a river at the river-ocean interface leads to a bulge of water (backflow) and can increase local water levels; and
- Wave runup: total rise in coastal water levels as waves break and rush up the beach, consists of wave setup (increase in water level from breaking waves) and swash runup (how far up the water reaches after the break).

Changes to sea levels from sea level rise alone occur at a much slower pace than changes to water levels from waves and coastal storm events. At the same time, constant wave action has the capacity to raise effective water levels at the shoreline and bulkhead interface well above the average tide level, and process that can be greatly affected by astronomical tidal forces and both local and basin-scale storm events. At present, the 100-year storm event can increase sea levels up to 3.1 feet above mean higher high water and has the potential to cause significant damage to shorelines, coastal infrastructure, and lead to inundation of low-lying areas. Historic storms may not be an accurate predictor of storms under a changing climate, so CoSMoS models future coastal storms (in addition to sea level rise) using the best available climate model projections of environmental conditions. Therefore, we evaluated effects of multiple sea level rise and storm scenarios, as summarized in Figure 14. It should be noted that wave action is also included in calculated maximum water height for all water level scenarios.

Tomales Bay Water Level Scenarios				
Scenario Name	**Scenario Description**	**Increase in Sea Level**	**Water Level** (NAVD88)	**Water Level** (above MHHW)
Current	Current MHHW + Wave Action	0 ft (0 cm)	6.56	0.9
Current Storm	Current MHHW+ 100-yr storm + Wave Action	0 ft (0 cm)	8.76	3.1
1.6' SLR	MHHW + 1.6 ft. SLR + Wave Action	1.6 ft (50 cm)	8.27	2.6
1.6' SLR + Storm	MHHW + 1.6 ft. SLR + 100-yr storm + Wave Action	1.6 ft (50 cm)	10.7	4.1
3.3' SLR	MHHW + 3.3 ft. SLR + Wave Action	3.3 ft (100 cm)	10.1	3.5
3.3' SLR + Storm	MHHW + 3.3 ft. SLR + 100-yr storm + Wave Action	3.3 ft (100 cm)	12.3	6.6
6.6' SLR	MHHW + 6.6 ft. SLR + Wave Action	6.6 ft (200 cm)	13.5	7.8
6.6' SLR + storm	MHHW + 6.6 ft. SLR + 100-yr storm + Wave Action	6.6 ft (200 cm)	15.5	9.8

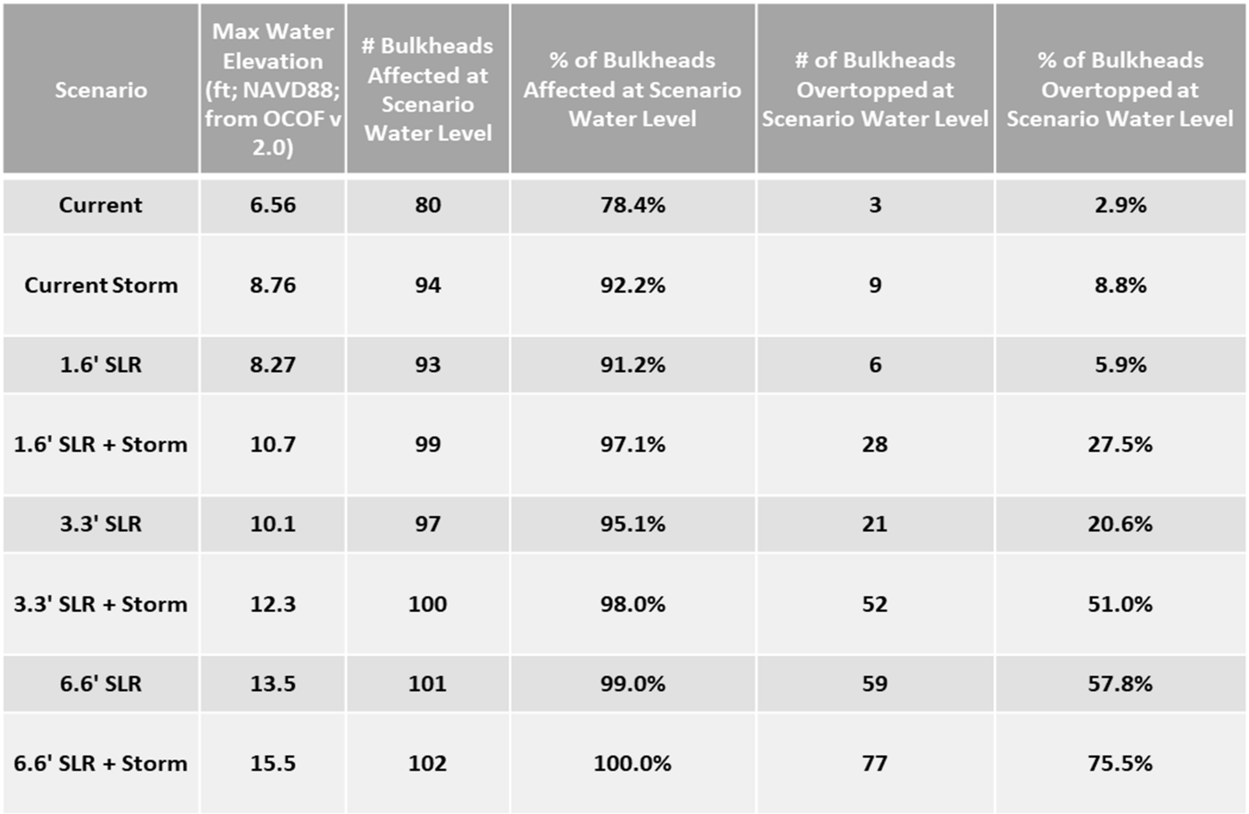
Figure 14 - Tomales Bay Water Level Scenarios. This table describes the different water level scenarios, including the increase in sea level above MHHW, the storm event included, and the water level in NAVD88 and above MHHW.

As shown in Figure 14, wave action associated with a 100-year storm under current (no SLR) conditions results in a maximum water surface elevation of about 8.76-feet. Notably, this elevation is slightly above the predicted "base" water surface elevation (ie, typical, "non-storm" conditions) resulting of 1.6-feet of SLR. In other words, maximum water surface elevations observed during significant storms in the present/near-term may be considered a reasonable approximation of "everyday" conditions following 1.6-feet of SLR. As discussed previously, and as shown in Figure 13, such conditions may be expected to occur by about 2030 to 2045 under either "extreme" or "medium-high" risk aversion scenarios. Accordingly, those bulkheads with maximum elevations *below* about 8.76-feet will likely be overtopped on a consistent basis sometime in the next two decades.

3.3.3 SLR and Storm Impact Analysis

In order to evaluate the potential effects of each SLR and storm scenario on existing bulkheads, we compared our modeled bulkheads to projected localized water elevation values. This resulted in a range of exposure values for each modeled bulkhead's footprint based on its averaged characteristics. The difference in the estimated top of wall elevation and per-scenario water elevation were then utilized to calculate how much of the wall was underwater for a given water elevation and, where applicable, the extent to which a given modeled bulkhead segment was fully inundated or "over-topped" under a specific water elevation scenario.

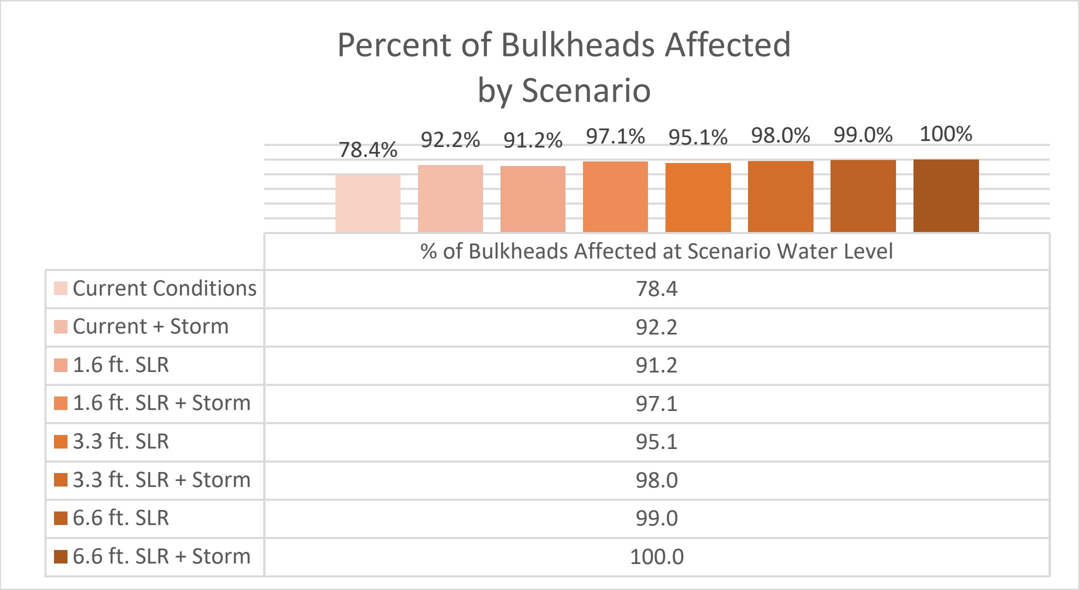
The scenario array examined is defined in Figure 15, and includes both "normal" simulated water elevation values for each incremental increase in sea level over time as well as a modeled increase in water level associated with a 1% annual chance storm (or "100 yr." event) for each scenario. Note that the maximum daily water elevations examined here are slightly above the tidal datum mean higher high water lines, as wave action raises water levels above the averaged MHHW value. The figures and percentages are expressed in terms of number of individual bulkheads as identified in our inventory, as opposed to total linear feet of bulkhead features. Also note that, where contiguous bulkhead features extend across multiple parcels, our inventory reflects an individual structure for each parcel. Therefore, the number of affected bulkheads may be considered to also approximate the number of affected parcels.



Scenario	Max Water Elevation (ft; NAVD88; from OCOF v 2.0)	# Bulkheads Affected at Scenario Water Level	% of Bulkheads Affected at Scenario Water Level	# of Bulkheads Overtopped at Scenario Water Level	% of Bulkheads Overtopped at Scenario Water Level
Current	**6.56**	**80**	**78.4%**	**3**	**2.9%**
Current Storm	**8.76**	**94**	**92.2%**	**9**	**8.8%**
1.6' SLR	**8.27**	**93**	**91.2%**	**6**	**5.9%**
1.6' SLR + Storm	**10.7**	**99**	**97.1%**	**28**	**27.5%**
3.3' SLR	**10.1**	**97**	**95.1%**	**21**	**20.6%**
3.3' SLR + Storm	**12.3**	**100**	**98.0%**	**52**	**51.0%**
6.6' SLR	**13.5**	**101**	**99.0%**	**59**	**57.8%**
6.6' SLR + Storm	**15.5**	**102**	**100.0%**	**77**	**75.5%**

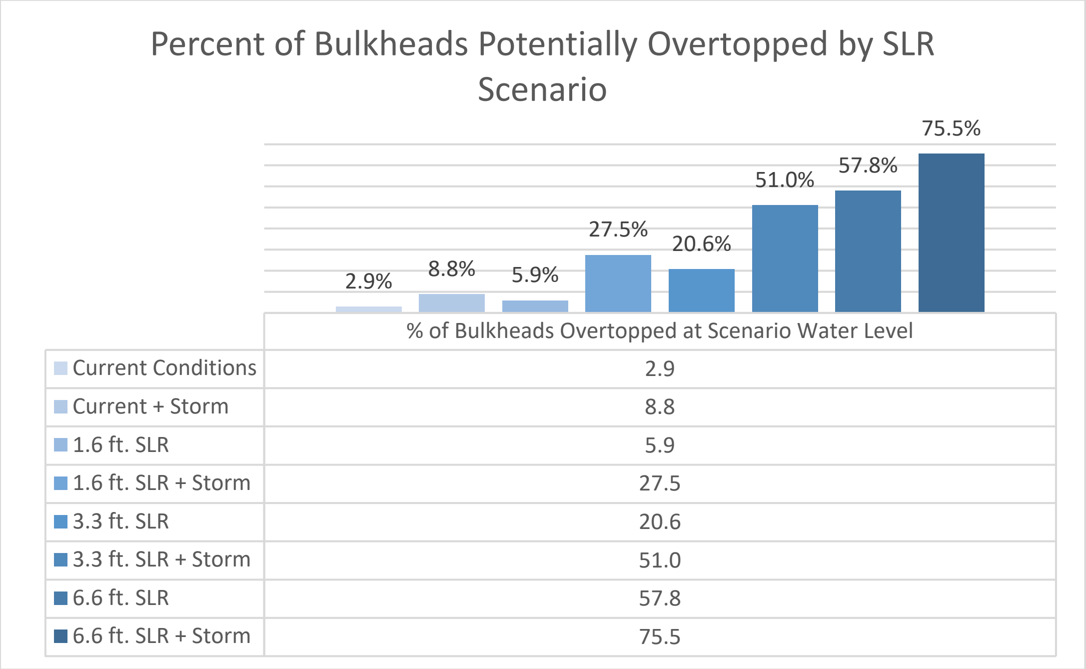
Figure 15 – Summary of bulkhead impacts resulting from modeled SLR scenarios.

As shown in Figures 16 and 17, 78.2 % of bulkheads undergo some sort of interaction with ocean water, with a small number (3 of 102) showing slight overtopping under current (no SLR, "non-storm") conditions. During the 1% annual chance (or "100-year.") storm event, 92% of bulkheads are directly exposed to seawater and wave action, with 9 of 102 potentially overtopped.



	% of Bulkheads Affected at Scenario Water Level
Current Conditions	78.4
Current + Storm	92.2
1.6 ft. SLR	91.2
1.6 ft. SLR + Storm	97.1
3.3 ft. SLR	95.1
3.3 ft. SLR + Storm	98.0
6.6 ft. SLR	99.0
6.6 ft. SLR + Storm	100.0

Figure 16 – Summary of bulkheads affected by each sea level rise and storm scenario.



	% of Bulkheads Overtopped at Scenario Water Level
Current Conditions	2.9
Current + Storm	8.8
1.6 ft. SLR	5.9
1.6 ft. SLR + Storm	27.5
3.3 ft. SLR	20.6
3.3 ft. SLR + Storm	51.0
6.6 ft. SLR	57.8
6.6 ft. SLR + Storm	75.5

Figure 17 – Summary of bulkheads overtopped by each sea level rise and storm scenario.

These values increase incrementally as sea level rises. At 1.6 ft. of sea level rise, 91% of bulkheads are affected, with 5.9% potentially overtopped. With 1.6 ft. and a 1% annual chance storm, 99% of walls are exposed to elevated water levels and wave action, while nearly 28% face potential overtopping.

Under the 3.3 ft. and 3.3 ft. + Storm scenarios, exposure values rise to 97% and 100%, respectively, with an equivalent increase to overtopping risk (21%; 51%). Likewise, at 6.6 ft of SLR and 6.6 ft. of SLR plus a 1% annual chance storm, nearly all bulkheads are put under daily operational demand, with 58% of bulkheads overtopped under normal conditions and 76% overtopped during a 1% annual chance storm.

While the figures above provide a broad view of exposures and risks associated with the different scenarios, it is also useful to understand how the diversity of structures, structure base heights, and wall heights all interact in the model context with the projected water levels for each scenario. To allow for this, the following figures depict each parcel-specific segment of bulkhead structure, ordered from north to south, as a single vertical line, with its base elevation and minimum wall height depicted against each scenario water elevation level, as well as current MHHW, Mean Sea Level (MSL), and Mean Lower Low Water (MLLW) elevations. Given that these figures only represent modeled bulkheads based on the survey work and analysis completed above, these should only be regarded as visual aids, and are not meant to correspond to exact physical conditions at any specific segment of bulkhead structure.

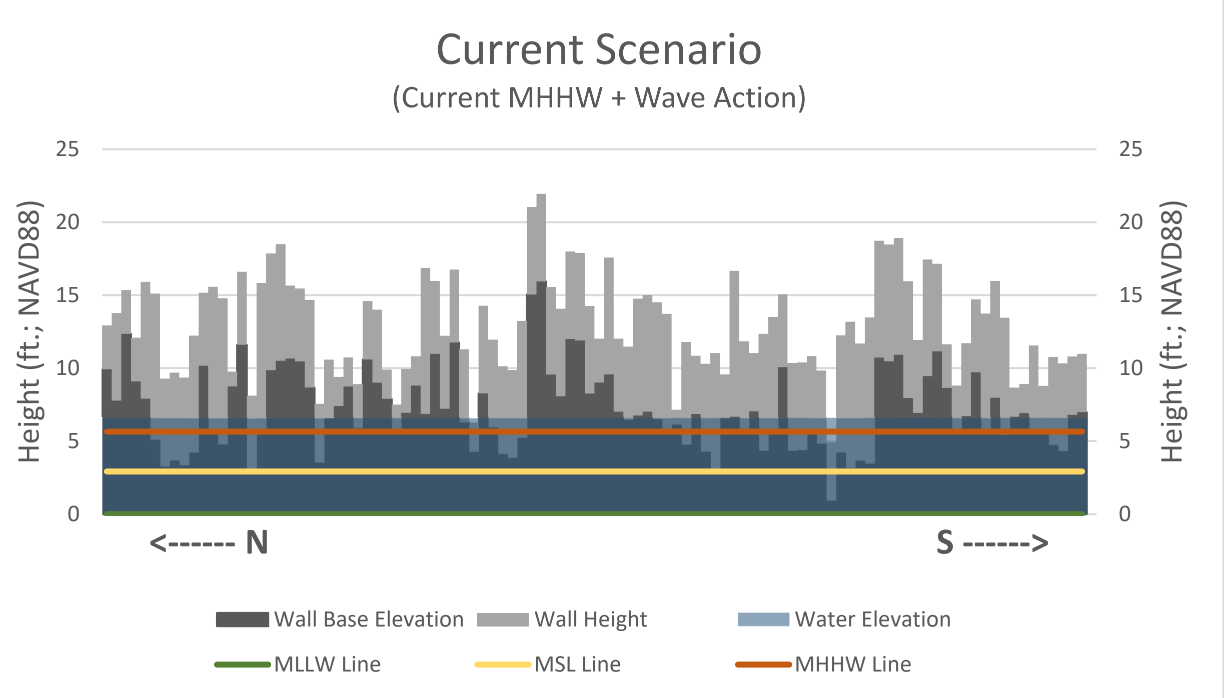


Figure 18 – Summary of exposures for bulkheads along the study areas (from North to South) under averaged current conditions based on tide gauge information.

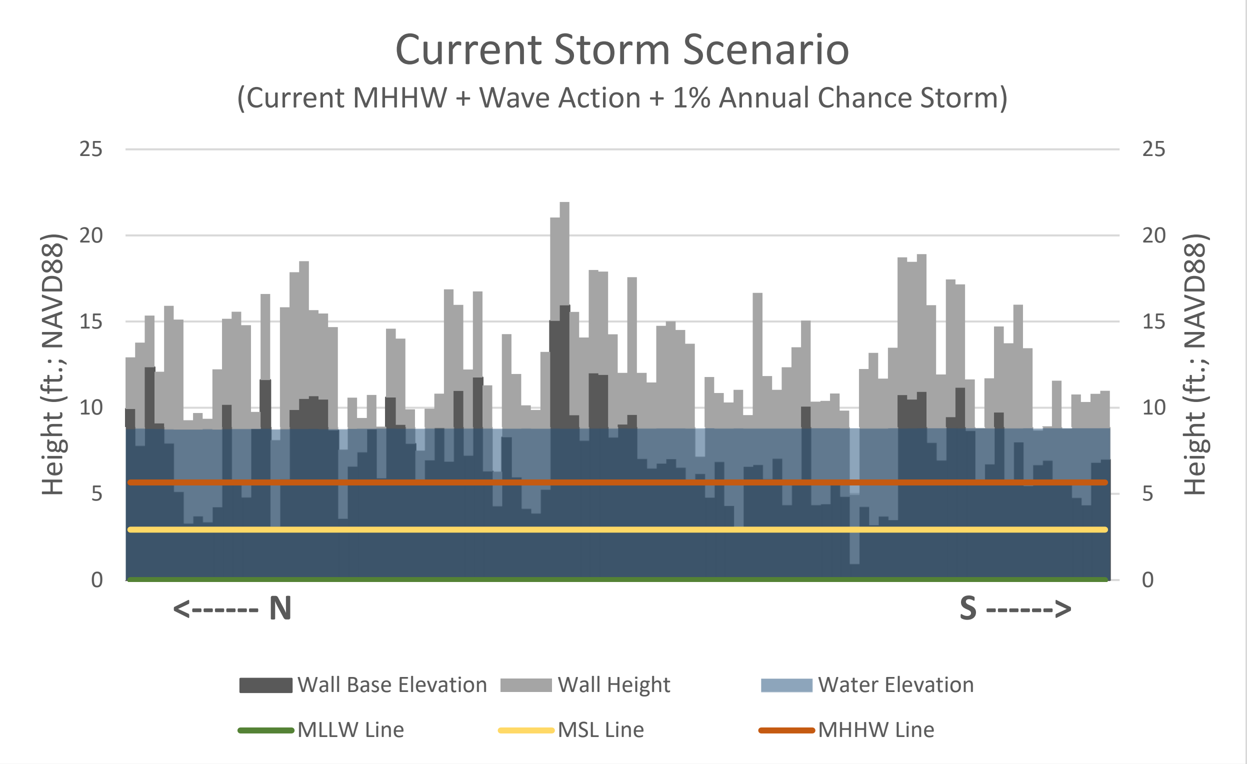


Figure 19 – Summary of exposures for bulkheads along the study areas (from North to South) under averaged existing conditions with an associated 1% annual chance storm.

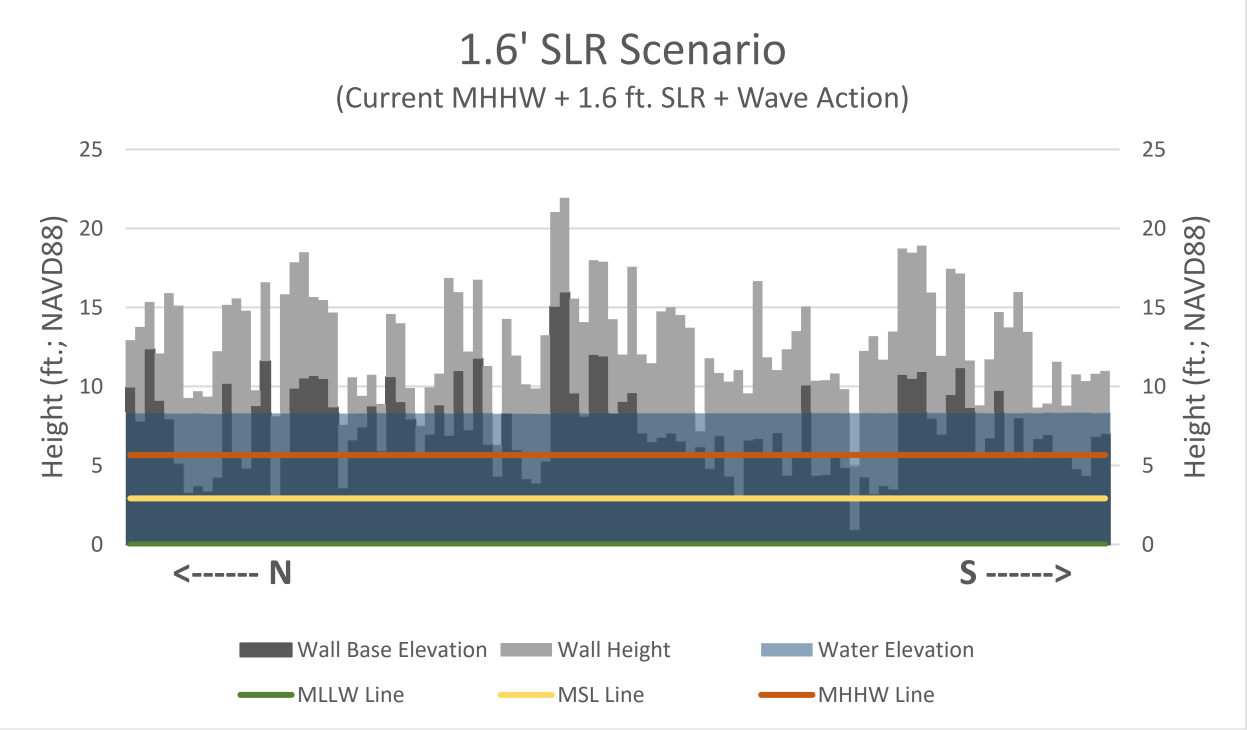


Figure 20 – Summary of exposure for bulkheads along the study areas (from North to South) under a 1.6 ft. SLR scenario.

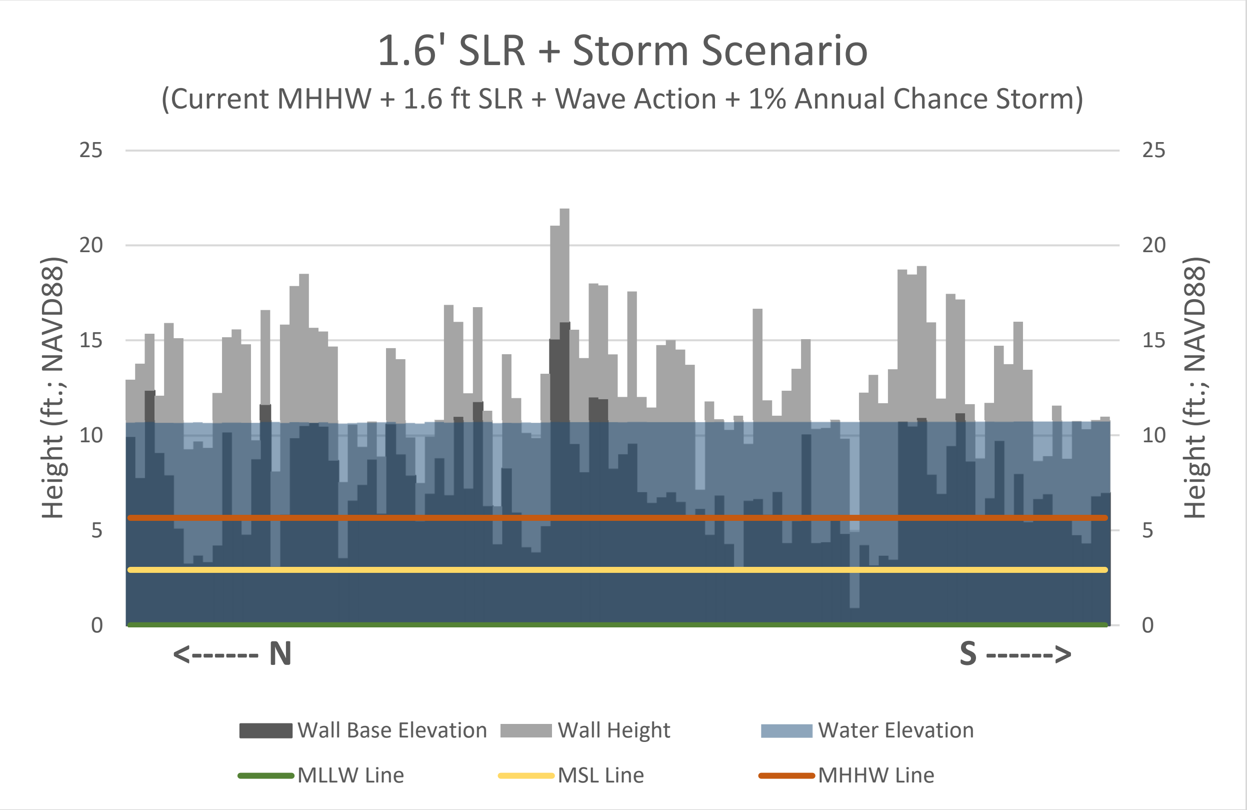


Figure 21 – Summary of exposure for bulkheads along the study areas (from North to South) under a 1.6 ft. SLR with associated 1% annual chance storm scenario.

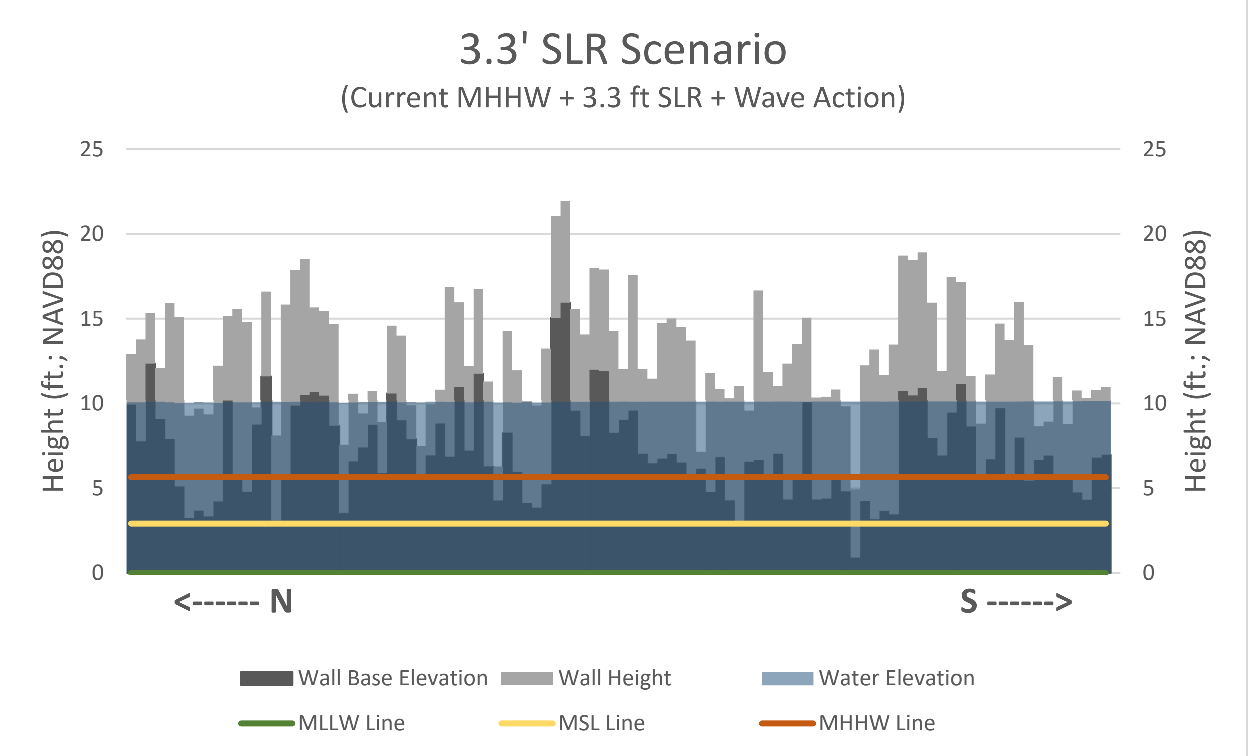


Figure 22 – Summary of exposure for bulkheads along the study areas (from North to South) under a 3.3 ft. SLR scenario.

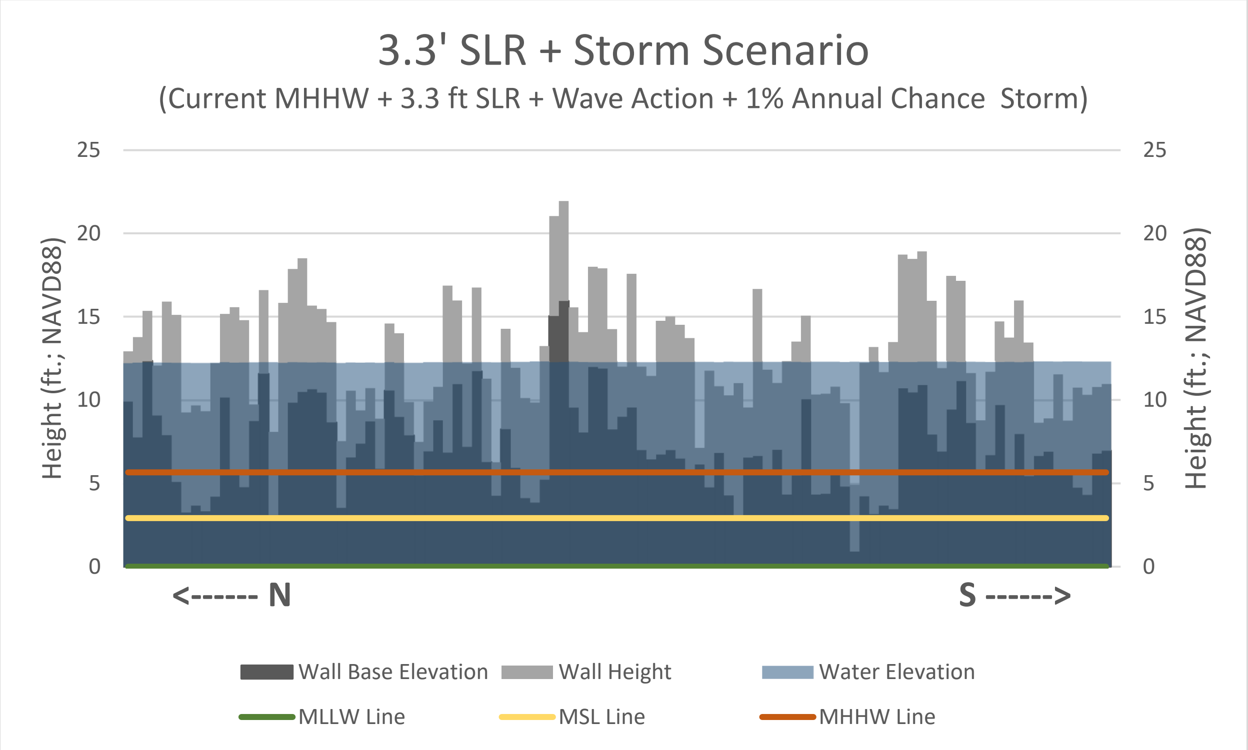


Figure 23 – Summary of exposure for bulkheads along the study areas (from North to South) under a 3.3 ft. SLR and associated 1% annual chance storm scenario.

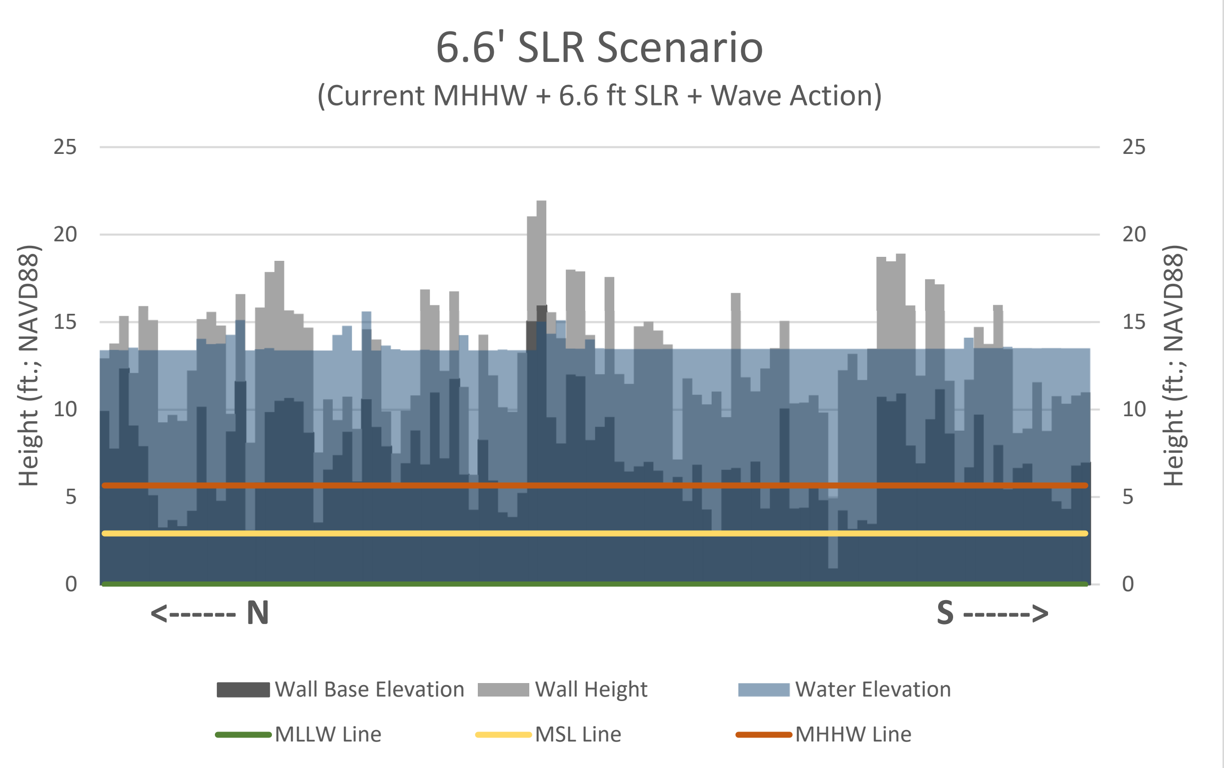


Figure 24 – Summary of exposure for bulkheads along the study areas (from North to South under a 6.6' SLR scenario.

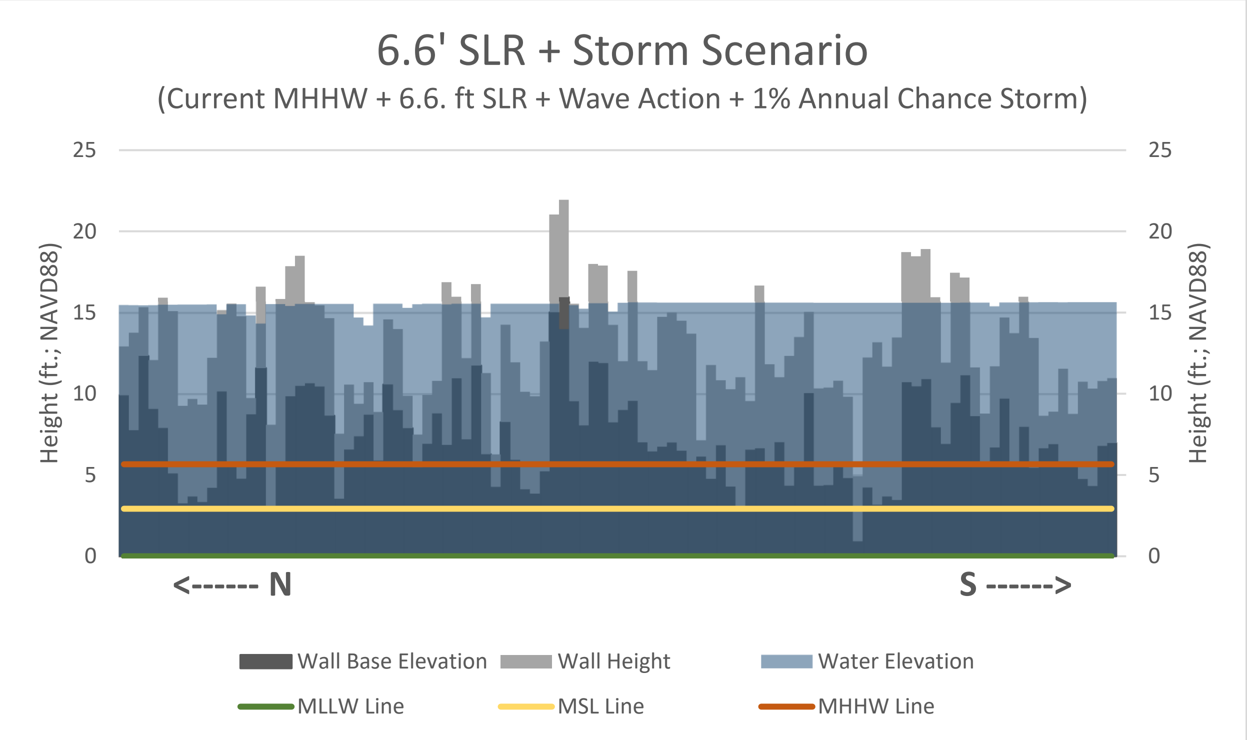


Figure 25 – Summary of exposure for bulkheads along the study areas (from North to South) under a 6.6' SLR and associated 100-year storm scenario.

4.0 CONCLUSIONS

Based on the results of our reconnaissance, research, and analysis, we conclude that, on the whole, existing bulkheads within the East Shore study area may be considered highly vulnerable to the effects of SLR. Approximately two-thirds (2/3) of the inventoried structures are in “fair” or “poor” condition and are effectively nearing the end of their useful structural design life. As described above, nearly all of the bulkheads in the study area are currently exposed to wave impacts during a 100-year storm event, with almost 10% at risk of overtopping. Even under the lowest SLR scenario examined (1.6-feet), virtually all of the bulkheads are exposed to water levels far in excess of current operational demands, while nearly 1 in 3 structures would be at risk of overtopping during a 1% annual chance (100-year) storm.

4.1 Anticipated Effects on Existing Bulkheads

As water levels rise, it is anticipated that local scour/erosion patterns will change and that wave action will be focused higher up on the bulkheads. Where existing bulkheads are already in fair to poor condition, it is expected that rehabilitation or replacement will be needed in the next decade or so as a result of continued structural deterioration, regardless of SLR. Concurrently, we expect that rising water levels will increase the time that all bulkheads are exposed to tidal water and waves, and that changes in precipitation patterns may result in higher-intensity and/or higher-duration storm events. Increased exposure will further exacerbate the rate of concrete spalling/cracking, the rate of corrosion where steel elements exist, and potentially the rate of erosion/scour around the base of the structures. Where structures are overtopped by rising waters, scour and erosion around the back of the bulkheads may result in erosion of backfill materials. Where structures are sited above the bulkheads, this potential erosion/scour of foundation subgrade materials may undermine the structures.

Continued degradation of existing retaining structures that either directly support or are otherwise integral to habitable buildings could jeopardize the structural integrity and life-safety protection of the structures. Where bulkheads support other infrastructure, such as roadways, utilities, and other improvements, future SLR is likely to increase the frequency of maintenance and RSP/earth embankment slope repairs as well as repair or replacement of failed retaining walls.

Where existing drainage facilities, including outfalls for retaining wall drains, foundation drains, and storm drain systems, are at elevations below predicted water levels, backflow of sea water into the drainage systems could result in increased hydrostatic pressure and exacerbate bulkhead failure. Backflow of saltwater into existing drainage systems would also likely accelerate the rate of corrosion and failure of any metallic infrastructure, such as steel culverts.

4.2 Conceptual Adaptation Strategies

In general, and in keeping with the nomenclature and concepts presented in Marin County's Adaptation Land Use Planning (ALUP) guidance document, there are three basic approaches to SLR adaptation and mitigation, including accommodation, protection, and retreat.

4.2.1 Accommodation

Accommodation of predicted SLR would generally entail modifying existing improvements and infrastructure to accommodate increased water elevations, as opposed to modifying the existing shoreline. This may include raising buildings, utilities, roadways, and surrounding grades above projected water elevations using fill soil or other materials. Where existing bulkheads are (or will be) prone to overtopping, raising them to accommodate higher site grades, create a "floodable" crawl space beneath existing structures. Converting buildings into floating structures could also be considered. The feasibility of each approach will need to be assessed on a site-specific basis, and will depend on a combination of factors, including specific site geometry and topography and the age and condition of existing structures and improvements.

4.2.2 Protection

Another approach to mitigating the effects of SLR on a parcel by parcel or more regional basis may be protection. Existing structures and improvements may be protected from risks associated with SLR via engineered works, such as seawalls and revetments, tide gates, pump stations, levees, breakwaters, and other works. Alternatively, "natural" approaches such as nearshore habitat enhancement, bay and beach nourishment, "living shorelines", and other "bio-engineering" approaches could be considered.

4.2.3 Retreat

Managed retreat would involve abandoning improvements threatened by SLR or relocating them to higher elevations.

It is expected that a combination of the above strategies would be considered throughout the study area, and that the selection of one or more "preferred" strategies is likely to be affected by a variety of factors. Regarding the existing bulkheads in the study area, modification or replacement of these bulkheads could be considered either an "accommodation" or a "protective" approach, with the primary difference being how the water is allowed to move and whether or not surrounding grades are raised (to *accommodate* SLR) or not (with only the bulkhead being raised to *protect* improvements from SLR).

Over the entire study area, it will be important to consider the cumulative impact of SLR and potential synergies with developing a shared or collective response. An individual and fragmented parcel by parcel approach may be less efficient and less successful over the longer term. In addition, it can be useful to consider flexible designs. Sea levels are projected to continue rising for not just decades, but for hundreds of years. As evidenced by this study, man-made structures on the shoreline have a finite lifespan and will need to be updated overtime. Flexible approaches and structures that can be updated over time are more likely to continue to be effective as sea levels rise.

4.3 Conceptual Engineered Mitigation Options

Conceptually, we judge that engineered mitigation of both near- and long-term effects of SLR may be feasible. As noted above, such engineered works could be considered elements of an "accommodation" strategy, a "protection" strategy, or both.

However, because of the variable geology, topography, and the number of individual stakeholders, we judge that a "one-size-fits-all" solution likely does not exist, and that providing regional-level mitigation will require integration of several different approaches, each dependent on specific site conditions. It should also be noted that, where existing bulkheads are considered for improvement, rehabilitation, or replacement, site-specific geotechnical and structural investigations will be required to confirm feasibility and develop design criteria for code-compliant design and construction. Additionally, where bulkheads are integral to residential foundation/framing systems, those structures will need to be specifically evaluated by a qualified Structural Engineer.

Selection of the "preferred" mitigation approach(es) is expected to be dependent on a variety of factors, including but not limited to site-specific geologic, geotechnical, and hydrologic conditions, cost, and permitting/ancillary considerations such as construction access, environmental impacts, and other issues as outlined in the following sections.

4.3.1 Site-Specific Considerations

The study area encompasses a variety of geologic and topographic conditions that will need to be further evaluated on a case-by-case basis if and where engineered structures are to be improved, rehabilitated, or replaced. In addition to SLR and associated flood risk, a variety of other geologic hazards must be considered during design of new improvements within the study area, including the potential for strong seismic ground shaking, liquefaction, settlement, erosion/scour, slope instability/landsliding, tsunami/seiche impact, corrosion, and others. The potential for altered or adverse drainage patterns must also be considered since site drainage will generally be integral to long-term bulkhead performance.

4.3.2 Retaining Structures

Many of the existing bulkheads in the study area are retaining structures that are effectively integral to existing residential and commercial buildings. Unless a "retreat" strategy is implemented, these retaining structures will require modification to either accommodate SLR or protect associated improvements from the effects of SLR.

The vast majority of existing retaining structures in the study area are of concrete construction. Although there are likely a few exceptions, it is anticipated that most of these walls are of older (pre-2000 and in many cases pre-1970) construction, and it may be difficult to justify re-using portions of the wall for the purpose of design compliance with the current California Building Code. In particular, the extent of the exposed rebar and corrosion observed in older walls makes it unlikely these elements can be retained with a reasonable expected design life.

Likewise, timber walls in the study area also were noted to commonly exhibit evidence of age, and given timber's susceptibility to rot, these walls typically have a reasonable design life of about 20-years or less. As such, we expect that the timber walls within the study area, regardless of current condition, will likely require replacement in the next 5 to 10 years as a result of timber decay and rot.

Finally, although there are likely a few exceptions, most of the CMU and grouted rock walls in the study area appear un-engineered and likely would require replacement if improvement is required.

Several types of retaining structures could be considered. We judge that, in general, timber retaining elements are undesirable due to their typically limited design life and maintenance needs as compared to appropriately corrosion-protected concrete and steel elements or more natural materials such as earth or RSP. In general, we judge the most feasible and cost-effective optional retaining structures for the study area, which could be utilized either as supplements to or replacements for existing bulkheads, including soil nail and shotcrete walls, cast-in-place concrete walls, or gravity-type retaining walls.

4.3.2(A) – Soil Nails and Shotcrete

Soil nails and shotcrete could be considered for rehabilitation/replacement of many walls within the study area, or for raising existing walls where they are susceptible to overtopping. This approach would entail drilling or coring holes through the face of the existing wall, then installing corrosion-protected rebar soil nails and grouting them in place. The soil nails support the old wall and are connected to the new wall facing with studded bearing plates and nuts. Following soil nail installation, a drainage textile and new layer of rebar is placed in front of the existing wall, and then shotcrete is placed to form the face of the new wall. If needed, a new raised wall stem could also be formed and structurally connected to the existing wall.

In most cases, this approach would avoid the need for demolition/removal of the existing structure – typically, the existing structure is used as a "back-form" for shotcrete placement. Where the existing structure has adequate vertical foundation support and scour protection, this option could potentially avoid work below the base of the bulkhead. As compared to constructing a "typical" new cast-in-place wall, this option may be reasonably cost-effective by virtue of omitting the need for new foundations. Because the new shotcrete face would effectively conform to the shape of the exiting structure, this option is expected to typically have limited, if any, effect on existing hydrologic conditions.

This approach may be undesirable if and where there are potential conflicts between the soil nails and existing structures or property lines behind the bulkhead. Because of the need to perform drilling work and shotcrete placement in front of the wall, this option could require construction best practices or other ancillary mitigation for potential environmental effects of the work.

4.3.2(B) – Cast-in-Place Concrete

This option would generally entail constructing a new, higher reinforced concrete retaining wall where existing bulkhead elevations are too low. Optionally, this new wall could be constructed either in front of the existing wall (to effectively bury it), or behind the existing wall (which would effectively become sacrificial and allowed to overtop). Where bedrock is exposed at or near the ground surface, these walls could typically utilize shallow concrete foundations. Where deeper alluvial soils or marsh deposits exist, deep foundations, such as drilled piers, helical piles, or similar, could be required.

As with the soil nail option, this approach could potentially avoid the need for demolition/removal of the existing structure, provided construction access can be provided in front of or behind the existing wall. In some cases, this could require partial demolition of overlying structures where exterior access below the structure and behind the bulkhead does not exist.

This approach may be undesirable if and where there are potential conflicts between the soil nails and existing structures or property lines behind the bulkhead. This option could require construction best practices or other ancillary mitigation for potential environmental effects of the work, particularly where work in front of (on the water side) of the existing bulkhead is proposed, such as foundation excavation or concrete placement.

4.3.2(C) – Gravity Walls

Gravity-based retaining structures, such as stacked-rock ("Parsons") walls or mechanically-stabilized earth (MSE) walls, could also be considered. These wall types require a large excavation behind the face of the wall, and as such are probably best suited as components of an "accommodation" strategy to support raising site grades through new fill placement, or where existing RSP or earth embankments are too low to accommodate projected SLR. This option is generally not feasible where existing bulkheads support a structure above. These walls typically require excavation of a keyway a few feet below the ground surface at the base of the wall and placement of a foundation leveling course. Block elements are then stacked in successive rows as reinforcing geogrid and fill soils are placed and compacted behind the wall. This option could require construction best practices or other ancillary mitigation for potential environmental effects of the work if and where excavation is required in the water.

4.3.3 Rock Slope Protection

Rock slope protection already exists in many portions of the study area. In many cases, poor condition and performance appear related to lack of maintenance. Where existing RSP elevations are sufficiently above predicted water elevations, relatively minimal maintenance/improvement could be performed, such as localized replacement of loose boulders and/or grouting of RSP where sub-par performance is primarily the result of over-steepened RSP slopes.

If and where existing RSP slopes and/or associated embankments are not high enough to accommodate SLR, they could be raised via placement of additional RSP or compacted soil fill, or new retaining walls (generally either cast-in-place concrete or gravity-type walls) could be constructed at the top of the RSP slope.

We judge that RSP may be a cost-effective option for existing RSP slopes where condition and performance are "fair" to "good" and where local maintenance and improvement would provide reasonable SLR protection/accommodation while imposing little "net" change on shoreline conditions. Where existing earth embankments will be exposed to additional wave action and SLR, RSP could be provided on the face of the embankment to reduce scour/erosion and/or at the top of the embankment to increase its elevation. Although likely to be relatively cost-efficient to construct, RSP may be challenging to permit where ancillary impacts to local hydrology or other environmental issues are expected.

4.3.4 "Bio-Engineering" Considerations

It is anticipated that bulkhead modification/improvement/replacement may be challenging in many instances where "hardened" shoreline structures are not permitted. In general, we expect that a more "holistic" approach incorporating "bio-engineering" or other environmental restoration/mitigation will likely be required. In some cases, we expect that these elements could be designed and constructed as separate structures with a singular purpose (such as a "living shoreline" or restored marshland fronting a raised structure with floodable crawl space). In others, it is possible that these two approaches may be combined into a single structure. For example, cast-in-place concrete or MSE walls could be designed to accommodate plantings or other bio-material on the face of the wall, or RSP or earth embankments could be designed to complement or incorporate habitat improvements.

5.0 LIMITATIONS AND RECOMMENDED SUPPLEMENTAL WORK

- The conclusions and recommendations presented herein have been developed on the basis of relatively limited data, including digitized ground surface and retaining wall elevations determined on the basis of two days' of field work. No detailed, site-specific analysis of individual bulkheads has been performed.
- We recommend exploration of potential collective funding mechanisms, such as grants for infrastructure improvements, creation of a Geologic Hazard Abatement District (GHAD) and associated local tax assessment, or other mechanism.
- We recommend detailed review of California Coastal Commission (CCC) guidelines and requirements, as well as exploratory discussion with CCC and other jurisdictional entities regarding potential regional and local approaches to SLR mitigation.
- We recommend exploration of a streamlined and collaborative approach to permitting repairs through CCC, Caltrans, and other jurisdictional entities and development of criteria the projects would need to meet to be effective and "fast-tracked" for approval.

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