Richardson Bay Shoreline Study

Evaluation of Sea Level Rise Impacts and Adaptation Alternatives

*****PUBLIC REVIEW DRAFT*****

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CONTENTS

TABLES

Figures

Appendices

1.0 INTRODUCTION

The Richardson Bay shoreline is one of the most vulnerable locations around San Francisco Bay to sea level rise (SLR). Annual high tides currently flood large areas of roadway, parking and infrastructure even without storms. When storms occur at high tides, flooding significantly increases. Under any likely future scenario of sea level rise, much larger urbanized areas will be impacted by deeper and more damaging coastal flooding. As such, the Department of Public Works (DPW) has undertaken this study to begin planning for this eventuality and to support planning efforts by others especially those of the Marin County Community Development Agency (CDA) and the City of Mill Valley. To aid in these planning efforts, this study evaluates both impacts and costs for a range of potential adaptation options to address direct coastal flooding along the Richardson Bay shoreline under three potential scenarios of sea level rise conditions. This study is also intended to educate the general public on the impacts of SLR and possible solutions.

This study focuses on the engineering basis for future community and County planning efforts. Options and associated order of magnitude costs are developed for a series of potential adaptation alternatives that could provide coastal flood protection for built areas and infrastructure in their existing locations along the shoreline. Costs range from tens of millions to hundreds of millions of dollars depending on the selected scenario of sea level rise and adaptation alignment option. Alternatives that involved retreating and/or relocating buildings or existing infrastructure are not specifically developed but are always an option to the in-place barrier options developed within this study. One goal of this study is to provide estimates for these adaptation costs to stimulate future planning discussions about how to best protect people and the natural environment of the shoreline.

Ultimately, planning for sea level rise adaptation will have to come from the community working with the cities and County as well as with the permitting agencies and other stakeholders.

The major sections of this report include:

1. **Background and Scope.** Part I presents the background information needed to understand shoreline flooding. We included the location of critical infrastructure in the lower watershed whenever possible to develop a first-cut vulnerability assessment for existing infrastructure and how it would be impacted.

2. **Assessment of Impacts of Direct flooding from Richardson Bay**. This analysis includes an initial assessment of the geographic area that will be flooded.

3. **Toolbox of Flood Barrier Alternatives.** An overview evaluation and discussion of the various adaptation options for addressing direct coastal flooding along the shoreline.

4. **Shoreline Inundation Under Current and Future Sea Level Rise Scenarios.** Presents maps of areas by reach of shoreline that currently flood or are anticipated to flood as sea level rises.

5. **Direct Coastal Flooding Reduction Alignments Under Sea level Rise Scenarios.** Presents a series of possible alignment barrier alternatives for direct coastal flooding. Also includes conceptual cost estimates (including right of way acquisition, permitting, and design) for construction for an engineered barrier system.

6. **Perspective on the Future of Flooding and Flood Protection Along the Shoreline**

2.0 BACKGROUND AND SCOPE

This report evaluates impacts and a range of possible engineering measures to address direct tidal flooding of the existing urban edge along the Richardson Bay shoreline within the boundaries of Zones 3 and 4 of the Marin County Flood Control and Water Conservation District ("the District") extending from Marin City into the southwestern edge of the Tiburon Peninsula of Marin County (Figure 1). A number of locations along the Richardson Bay shoreline flood during the semi-annual, high king tides (technically known as the "perigean spring tides"). Roadways, trails, and parking lots flood, even without any storm-driven flows (which only worsen flooding). Direct bay coastal flooding and watershed flooding are expected to significantly worsen as the climate changes, bay tides rise, and rainfall patterns change. As discussed in detail in this study, higher bay tide levels also increase wave heights and associated shoreline erosion.

The low-lying areas bordering Richardson Bay have flooded periodically for decades. Zones 3 and 4 were formed in response to flooding in the late 1950s; since then, numerous facilities and channels have been built to address creek flooding, including eight stormwater pump stations, an earthen and concrete levee system, and many storm drainage improvement projects. Much of the historic flood protection engineering in the Zones involved improving the stormwater drainage system to bring stormwater flows from the upper watershed down to the low-lying areas along the bay shoreline to be pumped or drained by gravity into the bay. With sea level rise, gravity drainage systems will become less effective: the pumping system may need to be expanded or other approaches taken to control backwater flooding. A rising bay tide level also makes direct coastal flooding more difficult and costly to manage, ultimately requiring longer and higher coastal barriers and associated stormwater drainage systems such as pump stations behind the barriers.

The physical nature of the shoreline itself, with its low elevation areas adjacent to steep hills, exacerbates the impacts of coastal flooding and limits the space available to implement solutions. Many of the low-lying areas along the Richardson Bay shoreline were historic tidal marsh. Later they were filled for development and are now densely urbanized, with residential and commercial shopping areas, along with infrastructure such as sewer, water, and electrical utilities that may be impacted as sea level rises. These areas and infrastructure will need to be protected or relocated. Flood protection design and facilities should account for the next 30 to 100 years, due to the scale of the problem and the existing and projected future costs associated with maintaining flood protection in this watershed.

The Richardson Bay shoreline represents an opportunity for climate change adaptation planning. The make-up of the shoreline, with its mix of residential and commercial properties, businesses, parks, wetlands, trails, and utilities and infrastructure, make it an ideal laboratory and potential model for sea level rise adaptation strategies for the rest of the San Francisco Bay Area. The Richardson Bay area also has an engaged community and local political leadership—a vitally important part of any adaptation planning process.

The primary purpose of this study is to assess the impacts of sea level rise along parts of the Richardson Bay shoreline within the study area and to present and discuss a range of potential engineering and planning alternatives to increase the level of flood protection under selected scenarios of sea level rise. The pros and cons and considerations of various adaptation options (the "toolkit") are presented and discussed to promote understanding of their advantages and disadvantages. It is important to note that this study looks at direct coastal flooding only.

Adaptation options include a number of possible alignment alternatives for barrier type structures along the shoreline edge. In each case, we developed alternatives to inhibit direct coastal flooding and protect the built infrastructure along the urbanized shoreline edge. Therefore, we did not develop any alternatives that involved retreating and/or relocating buildings or existing infrastructure. For our various alignment alternatives, we then developed low to high ranges of potential order-of-magnitude cost estimates for protecting infrastructure (in its current location) using engineered, barrier type solutions (primarily walls and levees). Although we did not evaluate retreat/relocation, the costs we developed for protection in-place can be used as a baseline to compare against other adaptation approaches, such as planned retreat and removal of structures/utilities and use of larger, landscape-scale, natural approaches. We have included several nature-based solutions (horizontal levees and engineered beaches) where they fit in the landscape, but we did not develop costs for retreat and establishment of new wetlands in currently built areas even though these types of solutions may be more cost-effective in the long term. We purposely did not develop alternatives involving removal of private properties, as these alternatives should be developed (if at all) as part of a broader community process in future phases involving property owners.

This report is a study of impacts and adaptation alternatives at the concept level. It is not a formal vulnerability assessment that carefully analyzes each asset for its vulnerability, sensitivity, and adaptability to climate change. Neither is it a design report specifying exact solutions and costs, for it is too early in the process to design a specific set of engineering adaptation measures for future sea level rise impacts. This report is a general evaluation of vulnerability to sea level rise along the shoreline with the purpose of educating the community about the impacts and magnitude of potential costs of adaptation measures. Additional funding will be needed to refine aspects of this study to develop a more specific adaptation plan. The County has also recently begun a larger vulnerability assessment (VA) of the entire eastern Marin shoreline known as the Bay Waterfront Adaptation Vulnerability Evaluation (BayWAVE) project. BayWAVE will identify and evaluate impacted assets as well as the sensitivity and adaptability for critical assets to SLR along the eastern Marin shoreline but will not address adaptation in its first phase. It is anticipated that the first phase of BayWAVE will be completed by mid-2017.

Ultimately, planning for sea level rise adaptation will have to come from the community working with the cities and County as well as with the permitting agencies and other stakeholders. To refine adaptation measures presented in this report, planners will need to consider direct coastal flooding as well as how sea level rise may exacerbate riverine flooding, including creeks overtopping levees and backwater flooding from storm drains, as well as how potential changes in rainfall patterns and intensity may worsen riverine flooding.

2.1 Goals of the Study

- Provide a first cut assessment of potential impacts from direct bay coastal flooding on the Richardson Bay shoreline community, habitats, and infrastructure as sea level rises due to climate change.
- Present a “toolbox” of potential adaptation options for the Richardson Bay shoreline, with a discussion of advantages and disadvantages.
- Develop a set of potential alignment options and associated order-of-magnitude costs for design, permitting and construction, and monitoring and maintenance. These alignment options and cost estimates are intended to assist planners and community members to better understand options and possible costs for protecting the built infrastructure in its current location.

This report is intended to provide information to help the community and elected officials decide where and how to spend valuable resources. It is just one part of a larger planning process regarding shoreline adaptation; we expect that additional community-based planning and adaptation studies will be needed before any final recommendations can be developed or accepted. Adaptation to climate change (especially sea level rise) is a multi-jurisdictional issue that crosses political boundaries and involves numerous interests; it is not solely an engineering or technical issue. Many other disciplines and County departments (especially the

Marin County Community Development Agency) have played, and will continue to play, a key role in refining the potential solutions in this report.

This report evaluates the general impacts of direct bay coastal flooding and presents a general discussion of potential solutions under existing conditions and three sea level rise scenarios. However, flooding within the watershed is more complicated than just direct coastal flooding. Many creeks will flood their banks from large, high intensity long duration storms and/or even smaller storms when bay tide levels are high. In addition, backwater (e.g., street and building flooding) may occur when storm drains are unable to drain against the higher creek water levels.

Furthermore, upstream urbanization increases both the speed and quantity of floodwaters that flow downstream to the lower elevation areas where the flooding tends to occur. Within the active landslide prone areas of the Southern Marin watershed, other factors such as hillslope erosion and downstream sediment deposition in channel and culverts can exacerbate flooding.

This report focuses on direct bay coastal flooding because flooding due to riverine and stormdrain backwater flooding will be addressed in other technical studies by Marin Flood Control.

2.2 Richardson Bay

This section provides background information on Richardson Bay within the study area. The information in this section is not meant to be a complete summary of all of the information available about the watershed or shoreline. A bibliography of available reports and information is posted on the Marinwatersheds.org website.

PHYSICAL SETTING

Richardson Bay lies along the southeastern Marin shoreline as a sheltered shallow embayment adjacent to the deep waters of Raccoon Straights in San Francisco Bay. The bay has a broad, flat, gently sloping bottom extending from the head to the mouth between Sausalito Point and Belvedere Island.

The bay can be divided roughly into an inner and outer bay by the Highway 101 Bridge. The depths and shoreline of the inner and outer bay reflect a balance between sediment supply derived from a combination of local watershed and open San Francisco Bay sources, and the forces of waves and tides that move and redistribute these sediments. Studies of Bothin

Marsh have indicated a relatively low supply of suspended bay sediments which could limit the ability of the remaining tidal marshes to maintain their elevations as sea level rises.

Several watersheds in Mill Valley, Belvedere, Marin City, Sausalito, the Town of Tiburon, Tamalpais Valley, and Strawberry Point areas of unincorporated Marin drain into Richardson Bay.

GEOLOGY

Richardson Bay is a shallow five-mile long tidal estuarine basin off the central basin of San Francisco Bay formed from the progressive burial of a drowned river valley by up to 150 feet of soft estuarine sediments. Although the valley probably began to form two to three million years ago, the past half million years have been marked by multiple interglacial and glacial periods. During interglacial periods characterized by relatively high sea level, clays, silts, and some sand and gravel were deposited in estuarine environments. During the glacial periods characterized by relatively low sea level (because vast quantities of ocean water were stored in continental glaciers), the Bay floor became a valley and experienced erosion and downcutting. Sea level changes resulted in different strata within San Francisco Bay, most notably the Older Bay Mud and Younger Bay Mud. Human activities can affect deposition—close to half of the Young Bay Mud was placed in the period 1855-1865 as a result of placer mining in the Sierra Nevada foothills.

Much of the built Richardson Bay shoreline consists of artificial fill placed on top of historic marsh and mudflats. Over time, dewatering and consolidation of the underlying bay mud sediments has resulted in land subsidence and numerous issues associated with settlement, including cracking of buildings and roadways.

Sea level in San Francisco Bay has gone up and down in accordance with the various ice ages. At points during past periods of ice age glaciation, the bay's sea level was over 200 feet lower than it is today; during other periods of warming it has been much higher. During past periods of sea level rise, habitats, plants, animals, and any people who were affected adapted by relocating upslope. The difference today is that we have built major infrastructure along the bay's edge that warrants protection, rebuilding, or relocation as sea levels rise.

BIOLOGICAL RESOURCES

Richardson Bay is a biologically rich wildlife preserve and considered one of the most pristine estuaries on the Pacific Coast in spite of its urbanized edge. The bay is recognized as an Important Bird Area (IBA) and is located on the Pacific Flyway, an important migratory bird corridor. During the winter months, the bay supports hundreds of thousands of waterbirds, shorebirds, and waterfowl. The watershed supports a number of special-status plants and animals. Of particular interest are some species found in coastal marsh in the lower watershed, including the Ridgeway Rail, black rail, San Pablo Song Sparrow, Salt Marsh Harvest Mouse, and Point Reyes Bird's Beak.

Due to the steep topography of the land next to the bay, tidal marshes have always been limited along the shoreline (Habitat Goals Project 1999). Historic tidal areas were lost to development and channel realignment. Today, only a few tidal marshes remain in the watershed. The largest is the Bothin Marsh Open Space Preserve, a large salt marsh at the north end of Richardson Bay. Arroyo Corte Madera del Presidio enters this marsh near Camino Alto between Sycamore and Miller Avenues. Full of cordgrass and pickleweed, Bothin Marsh supports the California Ridgeway Rail and Salt Marsh Harvest Mouse, both endangered species, and a variety of shorebirds and waterfowl.

The tidal marshes also provide shelter and habitat for many invertebrates and shorebirds. Much of the marine and estuarine life in Richardson Bay directly depends on these marshes. Bothin Marsh contains several locations of Salt Marsh Bird’s Beak (*Cordylanthus maritimus*), a rare and endangered annual plant. High marsh and uplands habitat also provide a buffer area for wildlife, particularly shorebirds and migratory waterfowl, insulating the water areas from upland urban activity. The upland areas in the marsh also provide shelter and a foraging area for wildlife, particularly shorebirds, during periods of very high tides. Moreover, uplands provide opportunities for the public to visit and observe the marsh and open water areas.

Coarse-grained beaches or rocky shorelines are a historic feature of outer Richardson Bay and can provide habitat for a number of invertebrates that use this habitat type.

Richardson Bay is an area of high value for fish that spend part of their life in the ocean and part in the bay estuary, as well as a refuge for seabirds and migratory waterfowl during winter storms. Because of the shallowness of the bay's water, many acres of mudflats are exposed at low tide, providing important feeding areas for shorebirds and habitat for small crustaceans. Approximately 55 fish species inhabit Richardson Bay all year or for part of their life cycle. Richardson Bay is particularly important for fish spawning and as habitat for fish in their early lives. Pacific Herring, a valuable commercial fish, spawn in the shallow waters and eelgrass beds of Richardson Bay from December through February. The herring and herring eggs are also very important sources of food for birds that inhabit the bay during winter. Anadromous fish, including salmon, steelhead trout, striped bass, sturgeon, and shad, migrate through the marine environment of Richardson Bay upstream through the Delta to fresh water to spawn. These fishes, particularly the young, also venture into the shallower waters of Richardson Bay to rest and feed. The primary migration period for these fishes is in the spring (generally April through June); however, salmon and steelhead also migrate in the fall (late August through November), and some salmon migrate in the winter (December and January). Pelagic bait and forage fishes in Richardson Bay, including the Pacific Herring, Northern Anchovy, Jacksmelt, and Topsmelt, are important food sources for larger fishes and some mammals, such as the Harbor Seal, and birds such as gulls, terns, grebes, pelicans, cormorants, ducks, and kingfishers.

Harbor Seals, found in only a few areas in San Francisco Bay, have historically inhabited Richardson Bay and have hauled out on Aramburu Island near Strawberry Spit, although not in recent years. In addition, some seals haul out on floating booms and jetties along the Sausalito waterfront.

Richardson Bay's sheltered, open water areas are extensively used by migratory waterfowl, particularly during the winter months. The mudflats and tidal marshes are heavily used by shorebirds. These birds feed in the bay muds and subtidal channels and basins and seek shelter in the tidal marshes.

The Richardson Bay Audubon Center and Sanctuary manages 900 acres of submerged baylands. They also manage an 11-acre upland parcel directly adjacent to the bay, which includes beach, bluffs, grasslands, oak woodland, coastal scrub, and riparian woodland. The Center and Sanctuary operates a Monitoring Avian Productivity and Survivorship (MAPS) bird-banding station during the breeding season. The state Mount Tamalpais Game Refuge and the Audubon Society's Richardson Bay Wildlife Sanctuary help protect Richardson Bay wildlife. Boating is not allowed within the 900-acre Audubon Society Sanctuary during the winter months to avoid disturbing migratory waterfowl.

LAND USE

Existing land uses along Richardson Bay are varied and comprise residential, commercial, light industrial, parks and open space, community facilities, and various utilities and infrastructure. In particular, the low-lying areas along the Richardson Bay shoreline from Marin City through Mill Valley connect commercial centers throughout the watershed, and Marin County with San Francisco.

BOATING AND RECREATIONAL USES

The western shore of Richardson Bay, all of Belvedere Cove, and the eastern shore of Corinthian Island are active small boat harbors because of their sheltered positions and proximity to deep navigable water and the Golden Gate. The channel to the former U.S. Army Corps of Engineers' Operations Base and turning basin had been dredged to between -27 and -30 feet MLLW and was the only actively maintained navigation channel in Richardson Bay. The channel is not a Congressionally authorized project, but in the past has been considered part of the maintenance expense of the Corps' Operations Base. Private homeowners along the Strawberry Peninsula pay for dredging operations to maintain boat access.

Probably the most widely enjoyed recreational "use" of the Bay is simply viewing it from the shoreline, the water, and the hills overlooking the bay. The dramatic landscape-scale views of Richardson Bay are an important community asset and also enhance property values. A bay view can add substantially to the value of a home, office, or apartment building. In addition, the waters of Richardson Bay are a major tourist attraction. The Mill Valley-Sausalito multi-purpose pathway along the alignment of the old railway is a very popular public facility.

WATER QUALITY

On July 9, 2008 a Basin Plan Amendment was adopted that established a Total Maximum Daily Load (TMDL) and implementation plan for pathogens in Richardson Bay.

3.0 ASSESSING IMPACTS OF DIRECT SHORELINE FLOODING FROM RICHARDSON BAY

This section assesses the impacts of direct bay coastal flooding along the Richardson Bay shoreline along the study reach. This is the first phase of any vulnerability assessment to identify potentially impacted infrastructure and then assess its resiliency to sea level rise. To assist in the impacts evaluation, we have divided the shoreline into seven segments (or reaches) for further evaluation of impacts and evaluation of current and future flooding issues and engineering adaptation possibilities. Within each reach, we have identified and tabulated the major infrastructure facilities and infrastructure impacted under the evaluation assumptions as a first cut guide to impacts.

3.1 Major Existing Shoreline Infrastructure

The primary categories of built infrastructure potentially impacted by sea level rise evaluated ion this study are described below.

RESIDENTIAL/COMMERCIAL AREAS

Large areas of residential and commercial development extend along the Richardson Bay shoreline from Marin City all the way to and around Mill Valley and along the Strawberry and Tiburon peninsulas. The commercial and business developments tend to be smaller scale retail and light industrial commercial. There are commercial shopping centers at Marin City and Tam Junction, both of which flood under current conditions. The shopping and retail centers are highly used and important for the economic life of the area. In this engineering focused study, we have not separately evaluated existing areas of low income or disadvantaged communities. These communities could be further evaluated during subsequent phases of the work. For this study, we evaluated the building and development categories defined in the County MarinMap GIS database.

ROADWAYS AND TRANSPORTATION

The major road that runs along the Richardson Bay shoreline is Highway 101, a regional transportation system connecting San Francisco to Marin and the northern Bay Area counties. While Highway 101 is generally elevated, the interchanges and frontage roads from Marin City to Coyote Creek, Shoreline Highway, and Almonte and Miller Avenues are at low elevations and subject to frequent flooding. Roadway flooding is a significant issue along the Richardson Bay shoreline and a focus of this study.

STORMWATER DRAINAGE SYSTEM

The Marin County Flood Control and Water Conservation District (District), Marin County Department of Public Works, and the City of Mill Valley maintain numerous stormwater drainage facilities along the shoreline. All stormwater eventually flows to the shoreline, the topographic low point in the watershed, where it gravity drains through culverts or is pumped into the bay by one of several pump stations. Higher levels of SLR will impact the ability of these systems to meet performance standards. In many locations, the stormdrain system is privately built and maintained as part of the development and not maintained by the County.

OTHER PUBLIC UTILITIES AND INFRASTRCTURE

Numerous public utilities are located along the Richardson Bay shoreline and are described in more detail below. These utilities include the typical urban support infrastructure such as water, power, telephone, and sanitary system conveyance.

MARSHES AND ECOLOGICAL RESOURCES

As described above, there are significant ecological resources especially within the existing Bothin Marsh complex along the shoreline. Sea level rise threatens these marshes through increased inundation depths and erosion. Existing data from previous studies in Bothin Marsh indicates that the existing suspended sediment in Richardson Bay is relatively low and would therefore inhibit the ability of the marsh to maintain its elevation as sea level rises.

3.2 Richardson Bay Shoreline Reaches

The Richardson Bay shoreline is over 12 miles long. To aid in the analysis and discussion of the shoreline, we divided the shoreline into seven smaller reaches (Figure 1) based on their physical characteristics and, in some locations, political boundaries.

This study focuses primarily on the first three reaches, which are publically owned for the most part, with major public infrastructure from Marin City along the western edge of Inner Richardson Bay to the City of Mill Valley shoreline. The final four reaches along the Strawberry Peninsula and Tiburon comprise privately owned residences with some public parks and natural areas. Adaptation solutions here will likely be developed by the private property owners themselves or potentially under a future agreement with Public Works. However, many of the possible responses (that would also be relevant to privately-owned areas) are covered in the discussion of the first three shoreline reaches.

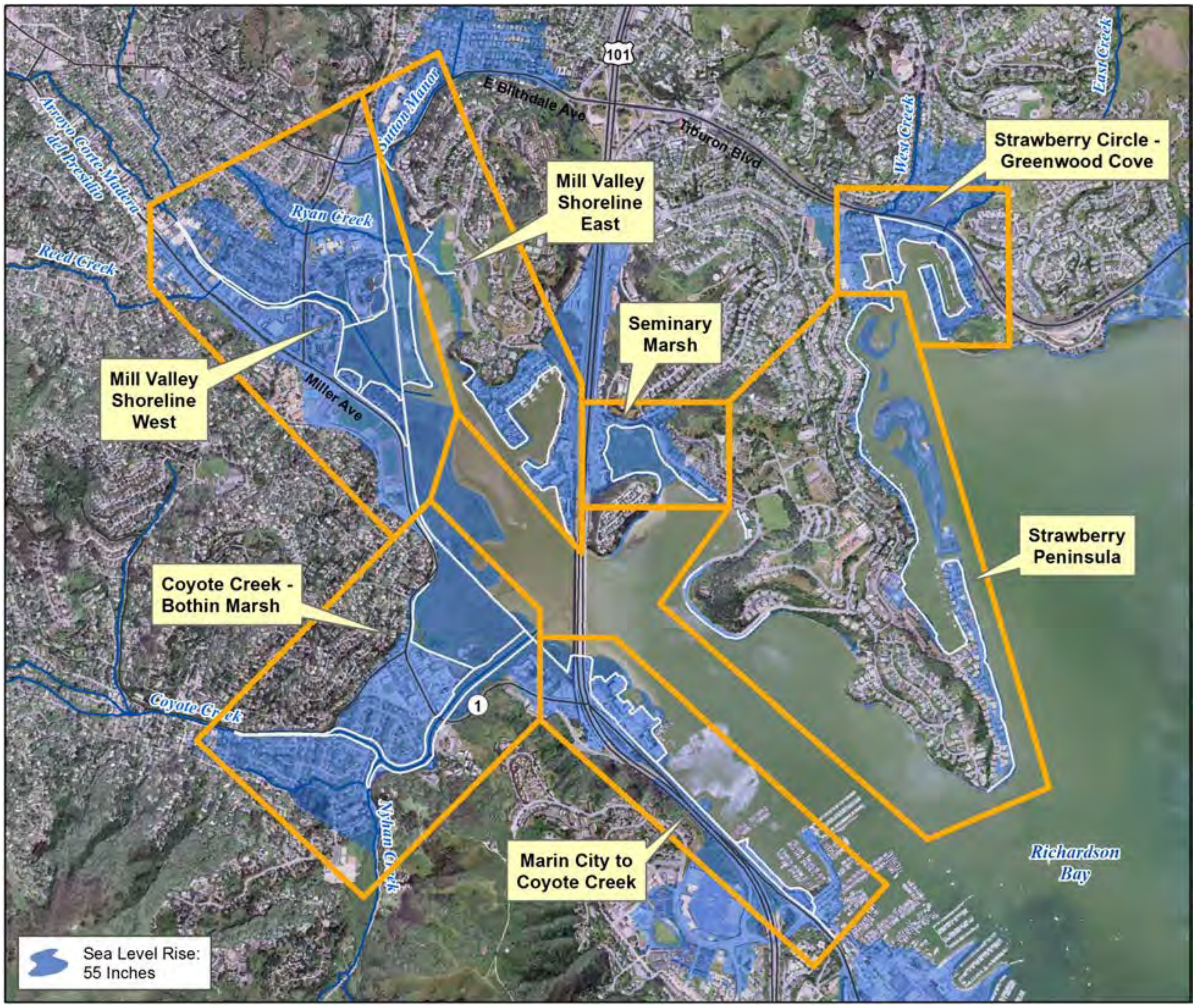

Figure 1: Richardson Bay Reach Delineation Map.

REACH 1 - MARIN CITY TO COYOTE CREEK

Reach 1 comprises the shoreline from Marin City to the south end of Coyote Creek. It includes the Caltrans Manzanita Park and Ride lots, where some of the most significant tidal flooding along the San Francisco Bay shoreline occurs. This reach is generally narrow, consisting primarily of Highway 101 separating the steep hills from the bay and the Marin City shopping center.

REACH 2 - COYOTE CREEK AND BOTHIN MARSH COMPLEX

This reach of the bay extends from the south end of Coyote Creek north to the southern end of the Bothin Marsh complex. It includes Coyote Creek and the residential/commercial areas behind the Coyote Creek levees that are vulnerable to flooding and within the Federal Emergency Management Agency (FEMA) designated Special Hazard Flooding Area. It also includes the south Bothin Marsh wetlands complex, through which the Mill Valley-Sausalito bike and pedestrian trail runs.

REACH 3 - MILL VALLEY SHORELINE WEST

Figure 1 shows the reach of the Richardson Bay shoreline that extends from the north side of the Bothin Marsh complex through the City of Mill Valley and up around the east side of the Mill Valley arm of the channel.

REACH 4 – MILL VALLEY SHORELINE EAST

The eastern edge of the mill valley shoreline includes several public facilities such as sports fields as well as tidal marsh areas vulnerable to sea level rise impacts.

REACH 5 – SEMINARY MARSH

Seminary Marsh is privately owned and maintained and abuts several privately held residential developments.

REACH 6 - UNINCORPORATED MARIN COUNTY AT STRAWBERRY PENINSULA

The Strawberry Peninsula tends to be steep and many of the homes and infrastructure are located above the anticipated area of sea level rise. It does contain shoreline areas and residences vulnerable to sea level rise along both sides of the Peninsula. It is predominantly privately owned, with the exception of a couple of parks owned by Marin County Parks and lands owned by the Strawberry Recreation District.

REACH 7 – STRAWBERRY CIRCLE/GREENWOOD COVE

The final reach is the portion of the Tiburon Peninsula that falls within Flood Control Zone 4. This includes the eastern side of the Strawberry Peninsula, Strawberry Elementary School, and the southwest areas of the Tiburon Peninsula.

3.3 Major Issues Associated with Sea Level Rise and Climate Change

This section summarizes the issues associated with flooding and sea level rise along the inner Richardson Bay shoreline. It is not a complete description of all natural disasters (earthquakes, for example), but focuses on the hazards most directly associated with increased flooding and sea level rise. For a more complete description of natural disasters and emergency response plans for Marin County, see the Emergency Preparedness Guide prepared by the Office of Emergency Response (OES 2012).

DIRECT BAY COASTAL INUNDATION

Direct bay coastal inundation is potentially the most damaging impact to the shoreline from a rising bay tide level. As sea levels rise, the current infrequent king tides will become more frequent, larger in inundation extent and duration, and deeper. The increased tidal depth will also increase duration impacts and wave heights under storm surge conditions. Direct coastal inundation will increase both damages and impacts to the built infrastructure, including roads and utilities. Direct inundation impacts the integrity of structures as salt water corrodes concrete and asphalt, and prolonged inundation degrades most building materials. Functional uses are lost as well: for example, infiltration of bay water into pipelines impacts pipe performance, and roadway flooding impacts road usage. Future study phases of the shoreline may include a more formal vulnerability assessment that would specifically evaluate the impacts, sensitivity, and adaptability of various assets to sea level rise.

Coastal shoreline erosion is another direct outcome from higher bay water levels and associated increased wave heights and frequency. Erosion is a significant problem along the Richardson Bay shoreline and will continue to undermine the shoreline edge, reducing marsh habitat, and contributing sediment into the bay, possibly impacting water quality.

In addition to the clear threats inundation poses to the built environment, inundation is also predicted to impact natural systems in several key ways. High marsh that is only flooded during extreme high tides may downshift to mid and low marsh by mid-century and convert to mudflat before the end of century as sea level rise rates accelerate (http://www.pointblue.org/priorities/climate-smart-conservation/coastal-adaptation/). Low sediment supply in the Bay constrains marshes' ability to build up, and the lack of broad transition zone habitat due to adjacent development or steep hillslopes as exists on much of the Richardson Bay shoreline constrains their ability to migrate landward. Increasing marsh edge erosion due to increasing wind-wave action in deeper water will also narrow these marshes over time. Ultimately, existing marshes in the project area are predicted to drown without restoration and enhancement.

RIVERINE FLOODING

Two significant streams flow down the east-facing side of Mount Tamalpais into Richardson Bay: Coyote Creek and its tributaries and Arroyo Corte Madera del Presidio (ACMdP) and its tributaries that flow through the City of Mill Valley. Smaller creeks in other watersheds also drain to Richardson Bay.

Riverine flooding refers to direct overbank flooding from these creeks onto the floodplain and built landscape, a process that often results in property damages. Both Coyote Creek and ACMdP are subject to overbank flooding under less than the so-called 100-year flood conditions—the storm event that has a 1 percent chance of occurring in any given year (note that this calculates to almost a 30 percent probability of this storm event occurring within 100 years). A higher downstream tide can also exacerbate riverine flooding by increasing water levels in the upstream channel.

Depending on the storm event, there may be some correlation between high tides coinciding with storm-driven riverine flows. Barometric pressure, winds, and rains during storm events can influence both tidal flooding and watershed riverine flooding. This coincident flooding risk can be evaluated under future design studies.

STORM DRAIN BACKWATER FLOODING

Most of the urbanized areas of the Richardson Bay shoreline are drained by a network of storm drain pipes and catch basins. In many locations, this drainage system depends on being able to drain by gravity to the creek or bay through an outfall. With higher bay tide levels, the ability of this system to drain will be further impaired. In addition, higher bay tide levels can increase sedimentation in pipes and outfalls, which can also significantly reduce the system's performance. All of these factors can result in backwater flooding of urbanized areas when the system is unable to drain effectively. Note that a common cause of storm drain flooding is localized blockage of the inlets due to leaves or trash, and bay water entering the system through backwater flooding from a higher bay tide level.

CHANGING RAINFALL PATTERNS

In general, climate change is expected to result in more intense rainfall events but less total annual rainfall overall. Both of these patterns can accelerate erosion and sedimentation and increase flooding. Increased drought weakens hillslope vegetation and raises fire risk, which can greatly increase landslides and erosion, the sediment from which can clog storm drains and creeks. Shorter, more intense storms can both overwhelm storm drain inlets and pipes as well as increase creek flooding, exacerbating overall flooding. While there is less scientific consensus around rainfall patterns and climate change, these trends are generally expected to happen and should be included in adaptation planning. This report addresses direct bay coastal flooding and not specific impacts from rainfall runoff. The District has recently remodeled the hydrology and runoff for southern Marin watersheds and can use these models to simulate future impacts from changing rainfall patterns once these patterns become clearer.

ELEVATED GROUNDWATER LEVELS

Higher bay tides will also result in elevated groundwater levels and more saline groundwater as the higher tides push the fresher groundwater landward. While most Marin residents get their drinking water from the Marin Municipal Water District water supply system and not from groundwater, higher groundwater and saline levels will cause a number of impacts to underground utilities and foundations by corroding pipes and pump metals and concrete, which tend to degrade in saline environments. These impacts could significantly increase maintenance and replacement costs for these utilities and impact operational efficiency.

SEDIMENT EROSION AND DEPOSITION

Suspended sediment can be deposited in culverts and outfalls by bay tides and watershed runoff. It can then block storm drains, impeding drainage and causing flooding. Some predictions for changes in rainfall patterns associated with climate change indicate greater rainfall intensity, which may result in more landslides and hillslope erosion, and therefore, more sediment deposition and clogging of storm drains.

SHORELINE EROSION AND LOSS OF OPEN SPACE

Higher water levels due to SLR increase the wind-wave erosive energy on the shoreline further threatening infrastructure and loss of open space areas. Most barrier type solutions require foundations especially in areas of soft soils that will need to be protected from direct shoreline erosion which will increase adaptation costs.

WATER QUALITY

Richardson Bay is listed by the San Francisco Bay Regional Water Quality Control Board as impaired by pathogens from houseboats and vessels, sewer overflows and leaks, and stormwater runoff. In general, current water quality has improved over previous years, but the shallowness of the bay means that its flushing ability is somewhat limited and thus may be more vulnerable to water quality impacts then other parts of the Marin shoreline.

PUBLIC SAFETY

Flooding is one of the leading causes of natural damages in Marin County. Flooding of roads will directly impact the ability of emergency responders and residents to use public roads for transportation. Increased creek flooding endangers adjacent communities.

INFRASTRUCTURE MAINTENANCE COSTS

Deeper and more prolonged tidal and backwater flooding degrades infrastructure and increases maintenance and replacement costs substantially. This is particularly true with underground utilities such as water supply, sewer, and other pipelines. Budgets for maintaining infrastructure even to current levels will need to be increased.

3.4 Rates of Sea Level Rise in San Francisco Bay

The bay tide level has been continuously measured for the last 150 years at NOAA's tide gage at the Presidio in San Francisco, one of the oldest continuously recording tide gages in the country. During this period, tide levels in San Francisco Bay rose approximately 2 cm/decade (equal to approximately 2 mm/year or approximately 7 inches in the past 100 years). This rate is reportedly equal to global measurements of sea level changes. Most climate scientists anticipate that water levels in San Francisco Bay will increase by at least this rate moving forward, and likely even accelerate mid-century due to a variety of local and global factors.

PROJECTED RATES OF SEA LEVEL RISE

In general, most climate change simulations project a substantial rate of global sea level rise over the next century due to thermal expansion as the oceans warm and runoff from melting land-based snow and ice accelerates. There are numerous projections of sea level rise due to the number and variation of the factors that influence future climate conditions. These factors include uncertainties in the computer modeling and model inputs and, perhaps, most importantly, the choice of future emissions scenarios. In addition, the science is changing rapidly. New data increases our understanding of model processes and inputs, which also affects results.

While there is much uncertainty, it is generally expected that the rate of sea level rise for San Francisco Bay will increase sometime mid-century or beyond to 4 to 6 mm/year, a significant increase over the historic rate of rise of 2 to 3 mm/year. Details of all of the various sea level rise projections and their basis is beyond the scope of this memo, but they are well described in the 2012 National Research Council (NRC) report (see References). Different rates of sea level rise are reflected in the various projections based upon different emissions assumptions. Figure 2 shows the range of sea level rise projections from the 2012 NRC report. See also http://data.prbo.org/cadc/tools/sealevelrise/compare/

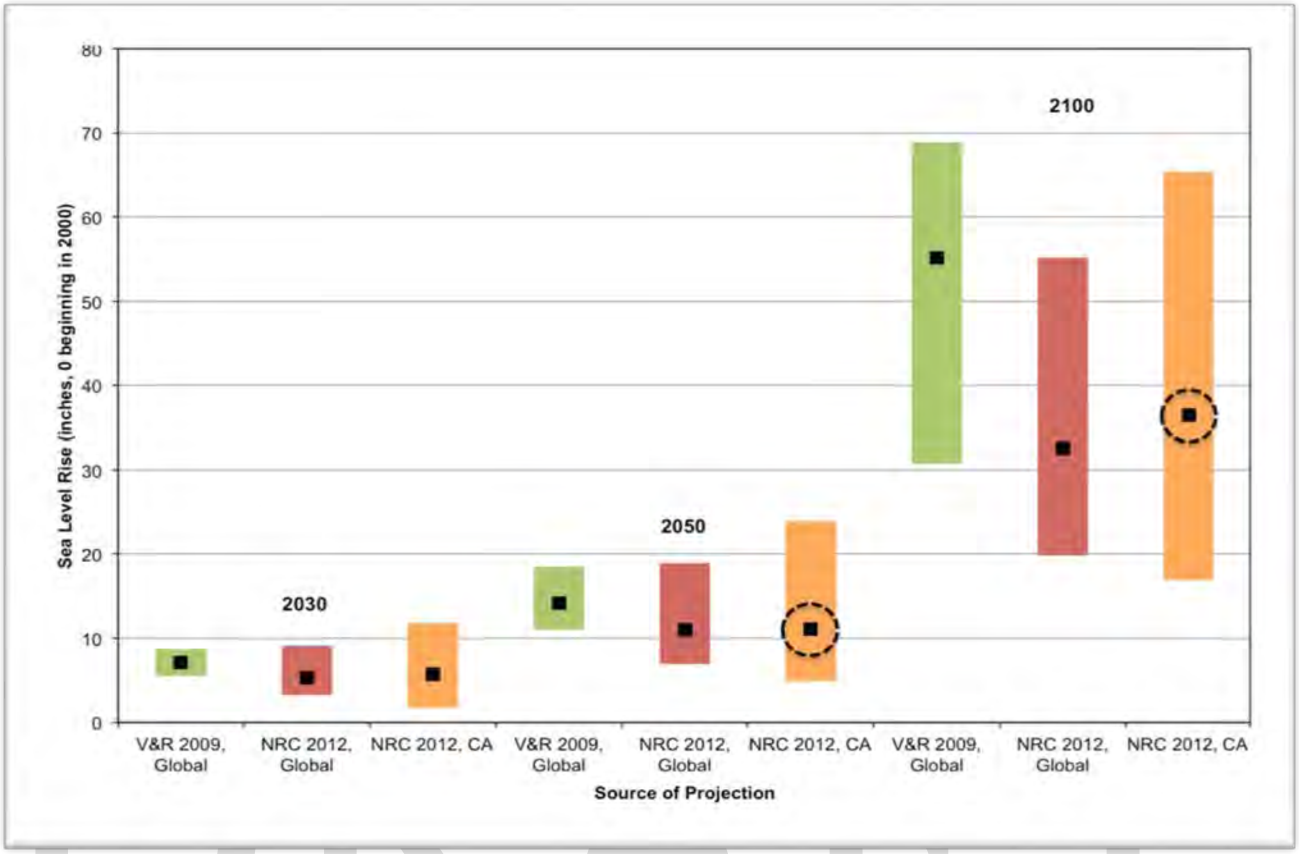

Figure 2: Projected Range of Sea Level Rise by Year for Various Studies (From NRC 2012).

3.5 Development of Sea Level Rise Scenarios for Study Analysis

While bay tides are likely to increase, the exact values and time frames are not known. Different reports use different emissions scenarios to produce wildly different estimates of sea level rise at different time frames. Estimates for the end of the century are very uncertain.

In addition, predictions about the impacts of sea level rise on tidal marshes also depend on assumptions about suspended sediment concentrations and accumulation of organic matter (i.e., vegetation), which help maintain marsh elevations over time. Suspended sediment concentrations and organic matter accumulation tend to be low in Richardson Bay, meaning that its marshes are unlikely to be able to maintain their elevations as sea level rises.

At the time this study was prepared, there appeared to be two general approaches to developing sea level rise values for impacts assessments.

The first approach is to use predicted values that are tied to specific future dates. The most current source is the 2012 NRC report, which contains mean, low, and high values (see Table 1 below, tied to Figure 2 above) for sea level rise tied to the specific years of 2030, 2050 and 2100. As noted, the range of values for 2100 is very large.

Table 1. Values of Projected Sea Level Rise and Standard Deviation (From NRC 2012).

	from NRC 2012			
Year	*Mean (in)*	*Range low (in)*	*Range high (in)*	*One standard deviation (+- in)*
2030	5.7	1.7	11.7	+- 2.0
2050	11.0	4.8	23.9	+- 3.6
2100	36.1	16.7	65.5	+- 10

The other approach taken by NOAA in their online sea level rise viewer is to show sea level rise inundation in one-foot increments, but not tie these values to any specific dates. Both approaches are equally valid, and there is no officially approved or correct approach. Communities and planners often use both methods, knowing that successful adaptation will require understanding thresholds of change not only in shoreline flooding, but in policy, funding, and political opportunity.

For the sea level rise impact projections in this study, we primarily used the first approach and values in Table 1 that are roughly tied to specific year projections. We believe that planning on a 30 to 100 year time frame is appropriate for major sea level rise adaptation strategies given the potential expenditure of funds and the lifecycle of most infrastructure improvements. Note that any dates are subject to significant uncertainty and should only be read as a very approximate guide to the future to allow for long-term planning horizons. Depending on emissions scenarios and the melting of glaciers, the rates of sea level rise at any future dates could vary significantly from this table. The goal of this study is not to plan to specific dates, but to pick three scenarios of water level rise that cover a range of impacts, promoting discussion of a range of solutions.

The three scenarios used for this study are as follows:

1. **Scenario 1 – 12 inches of sea level rise**. As shown in Table 1 above, the 2012 NRC report lists a low, mean, and high values for 2030. For this scenario we have used the high value (rounded up to 12 inches) to evaluate potential impacts. This 12 inch rise in sea level roughly corresponds to the current king tide events at an elevation of approximately 7 feet NAVD88, which can be seen impacting the landscape today, twice a year. Under this scenario, the flooding that now occurs twice a year would occur daily.
2. **Scenario 2 – 36 inches of sea level rise.** In this projection we used 36 inches of sea level rise, which roughly corresponds to a value above the two high values for 2030. It is thus closer to a high value for the year 2070 and also corresponds to the mean or expected value of sea level rise for the year 2100.
3. **Scenario 3 – 60 inches of sea level rise.** Sixty inches of sea level rise roughly corresponds to a high-end value for the year 2100 in the NRC 2012 estimate. Sixty inches of sea level rise would be the upper end and most conservative estimate in planning for sea level rise adaptation for an approximate 75-year time frame.

Table 2. Proposed Sea Level Rise (SLR) Projection Scenarios for Inundation Assessments.

SLR Scenario and year (NRC 2012)	*Rise in bay water level (added onto current MHHW)*	*New MHHW Tide Elevation (feet NAVD88) (North American Vertical Datum)*	*Possible Interpretations of New Water Levels*[1]
Scenario 1 – year 2030 – high estimate	12 inches	6.9	Simulates the approximate current king tide elevation as the new MHHW condition (occurs daily)
Scenario 2 – year 2070 high value or the year 2100 mean value	36 inches	8.9	Simulates the previous FEMA estimate of the 1% still water elevation (SWEL) in the bay as new daily MHHW tide (Note: in 2014 FEMA updated the 1% SWEL to 9.7 feet NAVD)
Scenario 3 – year 2100 – high value	60 inches	10.9	Upper end of NRC 2012 prediction for 2100 – might be expected to approximate the MHHW tide under this condition or the 1% tide condition under 36 inches of SLR: as such it approximates what future FEMA coastal flood insurance rate maps at 36 inches SLR might look like.

Numerous scenarios of sea level rise could be evaluated, but we selected three scenarios that cover a range of useful planning horizons for assessing

[1] This is one of many possible interpretations.

vulnerabilities and adaptation options. We believe that these three proposed values cover a useful range of inundation extent and depths for planning purposes, without needlessly complicating the discussion with a myriad of other inundation scenarios.

CAVEATS AND ASSUMPTIONS

Note that the values in Tables 1 and 2 were used to prepare a series of inundation maps (Figures 13 to 16) to assess the potential aerial extents and associated depths of direct coastal flooding for the new daily MHHW tides under sea level rise. This provides a first-cut vulnerability assessment of flooded areas using a "bath-tub" type flooding model (i.e., assuming a single static water surface elevation overlaid onto the County's ground elevation model) as described in Section 3.6 below.

These maps are subject to the following limitations:

- For the inundation maps, we added sea level rise values on top of the current MHHW tide elevation (5.9 feet NAVD (North American Vertical Datum) 88) in order to assess areas of chronic, daily, coastal flooding in the future but not necessarily storm driven flooding. Therefore, it is important to then note that these figures do not map the greater potential inundation from the highest tides (i.e., king tides), nor do they show flooding caused by storm-driven wave runup. The extent and magnitude of storm-driven tides are subject to many factors such as wind speed and direction, water temperature, depth, and atmospheric pressure and as such may exceed the inundation extents of these maps. The OCOF study does contain various scenarios of tides and storms, but we found that it was not as reliable for evaluating sea level rise in the detailed area of Richardson Bay due to issues with the underlying model topography.
    - To map the extent of storm driven flooding, a first approximation would be to use the more conservative starting elevation of approximately 9.7 feet NAVD (=the current FEMA 1% [100-year] stillwater elevation (SWEL) in Richardson Bay) instead of MHHW as the starting elevation since this is approximately three feet higher and thus may better approximate storm driven flooding extents.
- These inundation maps do not account for riverine or backwater stormdrain flooding (i.e. interior drainage flooding). The extent of riverine flooding as well as storm drain flooding is subject to many factors including rainfall patterns and the downstream tide levels during storm flows. A combined

analysis of riverine and coastal flooding is beyond the scope of this study. In areas where riverine flooding exceeds coastal flooding, the FEMA flood insurance maps provide a guide to the extent of the 100-year storm event flooding from direct riverine flooding and these areas could be added to inundation maps. Analysis and development of flood control projects to address riverine or stormdrain flooding would need to be conducted on a watershed-by-watershed basis. As such, there will additional facilities and infrastructure not shown on these maps of direct coastal flooding that will likely be impacted during storm events.

3.6 Approaches to Mapping Impacts of Sea Level Rise

There are several technical analysis approaches used to evaluate the impacts of sea level rise on the shoreline and each has its own pros and cons.

"BATHTUB" MODELING

One commonly used approach is to project a static water level uniformly from the bay to where it intersects at that same elevation with land, and color the area as flooded. This is the called the "bathtub" model because it assumes a single water surface elevation across the landscape. This is the simple approach used for this study. It is appropriate for this level of analysis since the uncertainties over magnitude of sea level rise are unknown. As described in Table 2, storm driven runup can be approximated by using the higher assumed level of sea level rise without having to model storm runup.

For assessing impacts, another commonly used value is the statistically derived 1% annual exceedance probability (AEP) bay water elevation (the so-called 100-year tide elevation) developed by FEMA for their flood mapping work and includes storm driven tides. For evaluation of storm driven runup on critical structures, we have used this 100-year tide elevation as the starting point for sea level rise mapping as shown in Table 3.

1D WAVE TRANSECT RUNUP MODELING

Another important factor to consider in sea level rise impact evaluations is flooding from wave runup onto the shoreline and wave erosion. As waves break at the shore they transform their energy into momentum and flow upslope and onto the shoreline at higher elevations than simple bath tub modeling would predict. The higher wave heights can also significantly increase shoreline erosion. Richardson Bay is a relatively protected embayment, and currently, wave heights are in the 1-

2 foot range. However, wave heights increase with water depth, and wave height and erosive power are expected to increase significantly as sea level rises. The most common approach FEMA uses in developing their flood maps is 1D wave runup transect modeling.

2D COASTAL WAVE MODELS

Another type of model is a two-dimensional coastal model that produces spatial results across a subject area. These models can simulate water levels, wave heights, and associated flooding over a larger scale for specific storm events and give more detailed results along a wide swath of the shoreline. However, 2D modeling can be very complex and expensive and require significant data collection for model inputs as well as advanced modeling expertise (beyond the scope of this assessment study). As described in 4.5.2 above, the USGS has just released wave runup projections under the Our Coast, Our Future (OCOF) project, which provide wave runup inundation estimates in 25 cm increments for a variety of storm and tides scenarios. We compared the outputs of the OCOF project with the modeling performed in this study and found the results to be in reasonable agreement. Any differences likely reflect the relatively large grid spacing of the OCOF modeling work since the OCOF study covers the entire San Francisco Bay so is gridded at a larger scale then the smaller study area. We have not used the OCOF model results for this study and recommend that if they are to be used, additional work be performed by OCOF or others to refine their model results for Richardson Bay.

The OCOF website is http://data.prbo.org/apps/ocof/index.php/

We used the first two modeling tools to perform a first level assessment of the impacts of sea level rise on the Richardson Bay shoreline. Models such as OCOF are potentially more accurate and may have value as a specific planning tool in subsequent phases of the project.

4.0 TOOLBOX OF ADAPTATION ALTERNATIVES

This section presents brief descriptions of several flood control alternatives that could potentially be implemented as part of a long-term flood risk reduction strategy (or range of strategies). The pros and cons, and discussion of impacts and approximate unit costs for each alternative are described in this section. These alternatives could be considered a "toolbox" of potentially useful and effective adaptation approaches to consider for the shoreline.

This study doesn't make a recommendation for a preferred alternative or suite of alternatives. Planning for sea level rise is a difficult and complicated process because it involves long-term planning across multiple sites with both public and private property owners. Ultimately, planning for sea level rise will require cooperation between numerous parties to achieve a shared vision of goals and objectives and the ground steps needed to achieve them.

4.1 What is a "Reasonable and Potentially Effective" Flood Protection Alternative?

"Reasonable and potentially effective" is meant to include the following:

- A broad range of alternatives that includes both "inside" and a little "outside the box" type thinking. Adaptation to a rising sea level is new, and it is likely that the range of solutions and how they will be applied will also need to be innovative.
- Alternatives that are difficult to permit, expensive, or even undesirable are included as long as they (or pieces thereof) might be implemented in a way that achieves some of the project goals and meets critical constraints.
- Unproven technologies are not included. This report is not intended to present research and development. While some of our considered alternatives (i.e., floating cities) may not be easily implemented or cost-effective, the basic concepts are certainly within the range of what is technologically feasible under current conditions.

The regulatory climate is subject to change as situations change. It is possible that potential alternatives that would be difficult to obtain permits for now could be permitted under changed future conditions. Our goal is to identify and discuss reasonable and effective alternatives.

4.2 Permitting and Regulatory Issues

This section discusses permitting and regulatory issues associated with constructing and permitting projects around San Francisco—and Richardson Bay's—edge. Proposals for building in wetlands or other natural areas are subject to regulatory review by a number of agencies. Permit conditions depend on the project's potential impacts to the bay and its habitats and whether threatened and endangered species or species of concern are present. Projects proposed to be built in non-aquatic areas or that have limited to no foreseeable ecological impacts may only require permits from local agencies such as planning or building departments.

Numerous agencies are involved in permitting projects around San Francisco Bay. The primary agencies are the San Francisco Bay Regional Water Quality Control Board, the San Francisco Bay Conservation and Development Commission (BCDC), the US Army Corps of Engineers, and the California Department of Fish and Wildlife. When projects are proposed for sites that are inhabited by threatened and endangered species, the Army Corps will also consult with the (federal) US Fish and Wildlife Service, whose concurrence will be required for the project to proceed.

Flooding alternatives that involve placing fill in wetlands (standard levees, walls, horizontal ecotone levees, tide gates, fill to raise grades) require a permit from several agencies and are regulated as "fill" in the bay. Non-fill projects that could have indirect impacts to aquatic areas by modifying flows (i.e., muting tides through high tide gates) or water quality also require permits.

In general, it has been very difficult to permit fill projects since the 1980s in response to a long history of fill around the bay's edges that reduced tidal wetlands by 90 percent (in some estimates) from historic conditions and greatly impacted the use and experience of the bay. In response, the regulatory agencies have been very reluctant to approve projects that further degrade bay habitat and water quality. There are also FEMA regulations limiting "fill" within the FEMA regulatory floodway. Projects proposing fill such as barriers or tide gates will need to demonstrate a "no net rise" in the water surface elevation.

Projects that impact habitat or threatened or endangered species typically require mitigation. Project proponents are usually required to restore the amount of lost wetlands because of the project, sometimes more. Mitigation is required to be done on site whenever possible.

In recent years, regulators have begun to realize that with sea level rise, San Francisco Bay is actually getting larger and threatening to flood urbanized areas. The regulatory agencies are currently reevaluating their policies in light of sea level rise.

In this study, mitigation costs are not estimated, but they are likely to be significant depending on the alternative implemented. It is unclear whether construction of levees with ecotone slopes (“horizontal levees”) will trigger mitigation requirements, or how much mitigation will be required. The costs of creating and restoring wetlands can be significant.

4.3 Flood Reduction Tools for Direct Bay Coastal (Tidal) Flooding

A number of tools are available for adaptation planning. These are described in some detail below along with their pros and cons and approximate costs. Note that the tools evaluated in this study involve engineering adaptation and do not include carbon reduction or sequestration options, which, while valuable, do not provide direct flood protection benefits. Retreat and relocation of assets is an important strategy not developed in this study, however, is always available as an alternative, possibly cost-effective approach.

There are many ways to categorize the various adaptation options. In this study, we have broken them down into Protection Options. Adaptation planning tools that have been deemed applicable to Richardson Bay have been divided into three categories: hard engineering; soft engineering; and infrastructure and lifestyle adaptation. There are likely options that have not been included below but may be useful for the shoreline.

CATEGORY 1. “HARD” ENGINEERING ADAPTATION TOOLS

These alternatives include the more standard, traditional, “hard” engineering alternatives, including the following:

- Flood/seawalls
- Levees and dikes
- Pump stations
- Rock rip-rap
- Tidal gates

CATEGORY 2. "SOFT" ENGINEERING ADAPTATION TOOLS

These alternatives attempt to work with natural processes and use natural systems to achieve engineering goals while also providing other benefits such as habitat for species. Wetlands systems have been proven to provide important flood control benefits by serving as natural buffers that attenuate wave heights and energies. Wetlands serve as a prime example of natural capital that should be available for use in any planning study. Examples of "soft" adaptation tools include:

- Wetlands enhancement/conversion
- Wetlands creation/enhancement
- Levees with wetlands transition zones
- Shoreline erosion protection

CATEGORY 3. INFRASTRUCTURE AND LIFESTYLE ADAPTATION

Category three alternatives involve modifying existing and proposed infrastructure to adapt to a rising tide level. These alternatives are considered with the recognition that it may not be possible (or affordable) to stop the tides under all conditions. Therefore, one important range of adaptation tools includes modifying the infrastructure itself. We have also included zoning and ordinance changes in this category since they impact lifestyles, but they could be put into a separate category since they are mainly planning and permitting tools.

Specific examples of infrastructure and lifestyle adaptation include:

- Structures elevated above future tides
- Ground elevations and associated infrastructure raised above sea level rise conditions
- Floodable and floatable developments (floating house boats, Dutch "polders")
- Planned retreat (allowing lands to become fully or partially inundated)
- Infrastructure removed, relocated, or rebuilt at a higher location
- Local zoning and permitting changes

Many of these approaches are not mutually exclusive and can work together. Developing a plan will involve finding the best combination of tools and approaches that work together to meet objectives.

CATEGORY 1. "HARD" ENGINEERING ADAPTATION TOOLS

The top-of-structure elevation of any barrier is always a question that comes up in the planning and design process. How high to build a barrier depends on several factors including the level of protection desired, costs, impacts of overtopping, and the critical importance of the asset or area being protected. Table 3 below shows possible barrier top elevations given different sea level rise scenarios: (1) the minimum elevation to achieve FEMA certification for structures behind the barrier, and (2) the top elevation needed to inhibit annual king tide flooding, and thus, allow for storm flow overtopping. As shown in Table 3, the difference in barrier elevations is significant, on the order of three to four feet, which can translate to large costs differences. Therefore, future design phases of this project will need to focus on the design elevation requirements for any barrier.

Note that construction of a barrier to achieve FEMA certification requires a more complex analysis than in this report. The elevations below should be considered the minimum required (two feet above 100-year SWEL). Also note that sea level rise will not stop in 2050 or 2100. Barrier design should include approaches that allow for raising the top elevation into the future so that this work can be done when/if sea level rise exceeds design values. Also important to note is that from an engineering design safety standpoint, overtopping of structures is potentially a very bad idea and could result in total failure of the structure. Typically, walls and levees are designed to prevent overtopping or, alternatively, have overtopping control points designed into them. Therefore, especially under the projected higher levels of sea level rise (36 and 60 inch scenarios), all barrier type options should be designed to prevent overtopping where failure could result in loss of life or property.

Table 3. Barrier Top Design Elevation Alternatives.

SLR Scenario	Minimum Design Elevation to contain annual king tide under SLR conditions (peak annual tidal flooding) [2]	Minimum design elevation to achieve FEMA certification based on current 1% (100-yr) SWEL elevation + 2 feet (minimum FEMA standard)
12 inch SLR	9 - 10 feet NAVD88	13 feet NAVD 88
36 inch SLR	11 - 12 feet NAVD88	15 feet NAVD88
60 inch SLR	13 - 14 feet NAVD88	17 feet NAVD88

All barrier type solutions have been established and people expect this level of flood protection, it will be difficult to stop maintaining it and increasing its height and days of closure as sea level rises. This reliance is also known as "moral hazard," and the same concern applies to all barriers, such as walls and levees.

Flood/Seawalls

Flood and/or seawalls are engineered walls that hold back flood or tide waters to prevent inland areas from being inundated. Walls can be constructed on the ground or on top of existing levees or dikes. Flood/seawalls are typically designed not to be overtopped. In this study, we assume that walls will be built to provide freeboard without overtopping.

[2] Based on static water elevation, wind waves can increase water levels above this elevation.

Figure 3: Concrete Floodwall.

Figure 4: Sheet Pile Wall.

Figure 5: Sheet Pile Wall in San Rafael.

Pros:

- Can be built in a narrow right of way where other solutions may not fit—a key benefit.
- Effective when built and maintained properly.
- Specialty floodwalls can be manually or automatically raised during floods.

Cons:

- May be expensive. When floodwalls are built in soft bay muds or soils with less strength (as is typical of soils in former marsh areas reclaimed for development), costs can be very high because the wall has to be embedded deeper into the ground to be stable.
- Aesthetic Impacts. Sea and floodwalls tend to be built out of metal, concrete or vinyl. They are unsightly, and, depending on the design elevation, may impact views and even public access to the shoreline. These design considerations may be mitigated to a point, but any large-scale wall will have landscape-scale impacts.

- Additional bolstering needed. The edges and footings of the walls require protection from direct shoreline erosion and loss of structural support. This is typically provided by ensuring sufficient land waterside of the wall or by adding rock rip-rap or wetlands to reduce wave impacts on the waterside edge of the wall.
- Need for a contiguous structure. Any barrier structure (walls and levees) is only as strong as its weakest link. To be effective, barrier structures need to have a continuous boundary and be tied into higher ground at both ends to avoid flooding behind the barrier.
- Barriers may isolate shoreline habitat from uplands.
- Barriers do not address continued erosion at the shoreline that could undermine the barrier's foundation.
- All barrier solutions (walls, gates, levees) have the potential for catastrophic failure if engineering factors of structural safety are exceeded during actual storm events.
- As sea level continues to rise, walls may need to be raised. Depending on the design height and construction method, at some point, the wall's foundation may become inadequate and need to be rebuilt or reinforced to remain effective.
- Specialty walls tend to be expensive and better suited for protecting buildings, not long stretches of shoreline, given their costs. With the extent of shoreline in Richardson Bay, specialty floodwalls are probably not a viable option. Critical buildings that need to be protected with automatic walls (for example, across a driveway); can be included at an associated higher cost.

Costs:

- Costs for sea and floodwalls can vary greatly. Costs depend primarily on wall height and depth and structural requirements for the foundation. In the Arroyo Corte Madera del Presidio (ACMdP) riverine study, small floodwalls less than five feet high were estimated at $150/linear foot (lf). This cost is lower than the costs published for floodwalls in several other sources, especially for those built on soft, bay mud soils. As described below, the costs of sea/floodwalls used in this study are further developed and presented.
- There are additional design costs for barrier walls. Typically, a geotechnical investigation will need to determine the quality of the soils and hence the costs for the wall. We included rough estimates of these costs, along with other design and permitting costs for private property, as part of the design costs. Other costs, such as right of way acquisition for private properties, are also estimated separately.

Levees and Dikes

Levees and dikes are earthen structures built to hold back flood waters coming from rivers or the bay. They can be built to any desired height but require more space then flood or seawalls. A typical levee can require at least 80 feet at the base and additional right of way space.

Figure 6: Levees along Coyote Creek.

Pros:

- Levee tops can be used for roads/trails when properly designed and can provide views of the bay from the levee top.
- Depending on the location of the borrow source (soil for fill placement) and right of way acquisition (ROW) costs, costs will typically be somewhat less for levees than for floodwalls, and levees are usually less likely to catastrophically fail since they typically erode from the top rather than fail completely. However, if borrow and/or ROW costs are high, then levees become potentially more costly then floodwalls.

Cons:

- Require a larger right of way for construction. The exact width of the right of way depends on the starting and ending elevations, levee top elevation, and side slopes. A minimum footprint area of 60 to 80 feet is required for a flood control levee, and depending on various factors, the actual right of way required may be much greater. The right of way requirement depends on existing ground slope and condition, but typical right of way requirements are larger than the minimum footprint, usually in the range of 80 to 100 feet from toe to toe. Levees may not be possible in areas where the right of way is too narrow. The top width of the levee needs to be wide enough so the levee can be raised at a later date if sea level rise rates increase.
- Like most any other elevated, linear barrier structure, levees can block views from the land side, depending on the elevation of the adjacent ground. Depending on location, some vegetation can be planted to soften views provided levee integrity is not compromised.
- The edge of a steep levee may require protection from direct shoreline erosion and loss of structural support. This is typically provided by ensuring that there is sufficient land waterside of the wall or by bolstering the levee with rock rip-rap. An alternative approach is to enhance or create wetlands on the water side to reduce wave impacts naturally (horizontal levee approach), or to build an experimental, engineered bay beach to inhibit erosion.
- Like flood/seawalls, levees require regular inspection and maintenance to maintain their flood protection benefits.

Costs:

- A typical new levee costs in the range of $300 to $400/linear foot. Levee costs can range from $200 to $1,000 or more per linear foot. Actual costs depend greatly on the amount of fill required and, most importantly, on the proximity of the fill borrow area and the degree of soil conditioning required for placement.

Pump stations

Pump stations are centralized locations where one or more large capacity pumps pump stormwater from behind a levee or wall to the bay or creek. A common secondary impact of coastal barriers such as levees and seawalls is that they impede gravity drainage of flood flows from the land. Therefore, stormwater pumping facilities are needed to move stormwater over or through the barriers to prevent flooding. Marin County currently operates several pump stations along the eastern edge of Richardson Bay. Pump stations tend to be expensive to design, build, and maintain. In critical drainage areas, an on-site power generator may be needed to maintain pumping ability in the event of electrical power outages.

Figure 7: Novato Creek Pump System.

Pros:

- Effective when working and designed properly.

Cons:

- Very expensive—one of the highest costs per unit of -per-gallon alternatives.
- Subject to power outages and complete loss of pumping capability.
- Higher maintenance costs, especially in more saline environments.

Costs:

- Costs for stormwater pumping stations can vary greatly depending on the size of the pump station and generator. Typical costs for design and construction for pump stations can vary greatly but would start at $500,000 to $1MD for smaller pump stations up to several million (for this study we used up to $4M for larger pump stations). The annual costs for electricity to run pumps (depending on usage) and pump maintenance and repair can be upwards of $50,000 per year (again, highly variable).

Rock rip-rap

Rock rip-rap is designed to inhibit loss of shoreline caused by the erosive effects of direct wave action. It is typically applied to steeper shorelines and consists of a filter blanket or filter layer of smaller rock with larger rocks on top to combat wind-wave erosion.

Figure 8: Rip-Rap along the San Rafael Shoreline.

Pros:

- Cost–effective, proven technique when properly design, constructed, and maintained.

Cons:

- Aesthetic and habitat impacts (rock can harbor rats) as well as maintenance costs. Generally, unattractive with single benefit. Increasingly difficult to permit.
- Limited protection from rising tides. Vulnerable to overtopping and failure from rising tides.

Costs:

- Costs for rock rip-rap can vary greatly depending on rock sizes and extent. Costs have been estimated at $80 to $100/linear foot of rock rip-rap installed.

High tide-limiting gate structures (structures across waterways that control the impact of high tides)

High tide gates are used more frequently in other countries. These floating or controllable tide gate structures are usually built across creeks, rivers, and major waterways to limit the impact of high tides by closing during high tide events. Various types of gate structures are available. The costs are highly variable and depend on the size and complexity of the structure. For this study, three types of high tide gates have been included:

- Smaller gate structure across small creeks, drainage ditches, and culvert outfalls. These structures are assumed to be smaller and have less impacts and permitting issues.
- Mid-size tide gates that span creek mouths. We have estimated this size of tide gate for alignments across Coyote Creek and ACMdP Creek, both channels that drain significant, upstream watershed areas and provide important flood protection capabilities.
- Large, Bay-Scale Tide Gates. As described in more detail in Section 2.2, there are at least two proposals for large tide gates in the water at the entrance to Richardson Bay or at the Highway 101 bridge foundation.

Figure 9: Fish Friendly Tide Gates.

Pros:

- Can be effective when properly designed, built, and maintained.
- Tide gates can potentially protect a significant length of upstream shoreline relative to the length of the tide gate. May be the only viable solution where right of way for other solutions cannot be obtained.
- A properly designed tide gate can provide protection without major levees and seawall costs and right of way acquisitions.

Cons:

- Very expensive to build and maintain, especially on the soft soils that likely exist at the creek crossings at Richardson Bay's edge. On soft soils, expensive pile support structures could need to be built to prevent settling. Gate systems that rise and fall with tides require sophisticated control systems and large maintenance budgets.
- As the bay tide elevation increases, the gates will have to be closed more often to be effective, which could cause water quality issues.
- As the gates close more frequently, tidal marsh habitat will be impacted as the frequency and depth of inundation increases, especially where marshes are blocked from transgressing landward. Several threatened and

- endangered species would likely be affected as well as fish populations in the bay.
- In the event that the barrier is breached, catastrophic failure could occur if floods exceed the gate design criteria. Redundancy in the gate structures would help mitigate this risk.

Costs:

- Costs for flood gates vary greatly by type, extent, and size. Small tide gates may cost tens of thousands of dollars, and larger gates can cost in the millions of dollars. A cost of $1M to $2M per structure for the mid-size tide gates for the two main creeks draining into Richardson Bay is a likely minimum cost. This does not account for any mitigation requested by the regulatory agencies.
- For the very large gates proposed for Richardson Bay, it is even more difficult to estimate cost since there are no construction costs for gates of this size in the Bay. The NOAA Adaptation cost report provides a construction cost range of $0.7M to $3.5M per meter of length for a surge barrier, which may apply to very large and complex gate structures in deeper waters. Using these NOAA cost numbers, the potential cost of a large tidal barrier across Richardson Bay (discussed in more detail below) could range from $218,000 to $1,094,000 per linear foot. The smaller of the two barriers proposed—approximately 1,700 linear feet—could cost hundreds of millions depending on the design and system control requirements, plus an estimated five to ten percent for the capital costs of annual maintenance. Large structures of this type are highly dependent on local design considerations; perhaps the shallow depths of Richardson Bay or using the Caltrans 101 bridge structure supports could significantly reduce construction costs for a Richardson Bay barrier. These details would have to be evaluated during preliminary design. Note that the proponent of one proposed large tidal gate (RBBTB) believes it can be attached to the footings of the existing Highway 101 Bridge and built to a lower elevation and thus believes that its cost will be in the tens of millions rather than the higher costs using the NOAA guidelines. To our knowledge, no cost estimates and discussions with CalTrans have been conducted to confirm these assumptions.

CATEGORY 2. "SOFT" ENGINEERING ADAPTATION TOOLS

These alternatives attempt to work with natural processes and systems to achieve engineering goals while also providing other benefits such as habitat. Wetlands have been proven to provide important flood control benefits by serving as natural buffers that attenuate wave heights and energies. Wetlands serve as a prime example of natural capital that should be considered for use in any planning study.

Wetlands enhancement/conversion through fill placement

This adaptation alternative involves placing fill in a manner that enhances wetlands but may result in a conversion of wetlands type (i.e., from subtidal to mudflats or mudflats to tidal marsh). In general, wetlands enhancement/conversion is an acceptable and sometime preferable permitting option for regulatory agencies. Wetlands constructed to a higher elevation provide wave attenuation benefits while still providing habitat and ecological benefits. This option includes engineered fill placement through dredge sediment or mechanical fill placement with trucks. So-called "horizontal levees" are discussed separately although they potentially involve fill placement in wetlands also. There are passive approaches such as off-shore marsh recharge mounds but these have not been permitted to our knowledge.

Pros:

- Can provide both flood protection and ecological benefits.
- Can potentially reuse dredged sediment from local creeks to raise wetlands, while reducing ongoing creek sediment dredging costs.
- Meets ecological goals for integrating wetlands into a multi-objective project (i.e., horizontal levee approach).

Cons:

- It is difficult to obtain permits to fill the bay even to create wetlands.
- Wetlands projects are complex to design and permit since they must accommodate habitat and flood protection needs.
- The effectiveness of wetland solutions will diminish with higher levels of sea level rise unless grades are raised as the wave dampening ability of tidal wetlands diminishes with increased water depth.

Costs:

- Costs for wetlands enhancement vary greatly by scale and quantity/location of fill source.

New wetlands creation/enhancement through excavation (removal) of fill

Another approach to creating wetlands (usually preferred by permitting agencies) is to excavate soils from existing vacant uplands down to the appropriate grades to allow for either/both tidal or seasonal wetlands to form.

Pros:

- Newly created wetlands could be used as potential mitigation (i.e., offset areas) for other shoreline impacts likely to occur under other alternative strategies.

Cons:

- Reduces existing uplands along the shoreline. Given the limited space available along Richardson Bay shoreline, retreating from the uplands edge may be difficult in some areas. Relocating existing land uses and structures may require negotiations and payments.
- Locations along the shoreline where fill can be removed to create wetlands (without retreat of built areas) are very limited. In this study, the only such locations considered are the parks along the Mill Valley shoreline.

Costs:

- Costs for wetlands excavation can be estimated per acre. Typical costs are $10,000 to $60,000 per acre, but the range can be highly variable.

Construct levees with wetlands transition zones through fill placement (“horizontal levee”)

“Horizontal levees” are earthen levees with flatter side slopes towards the water’s edge and use the wave attenuation benefits of expanded wetlands in front of the levee to reportedly reduce the top of levee crest elevation and thus levee height and costs. The full horizontal levee also involves use of treated wastewater to infiltrate through permeable layers to enhance wetlands vegetation and recreate natural processes.

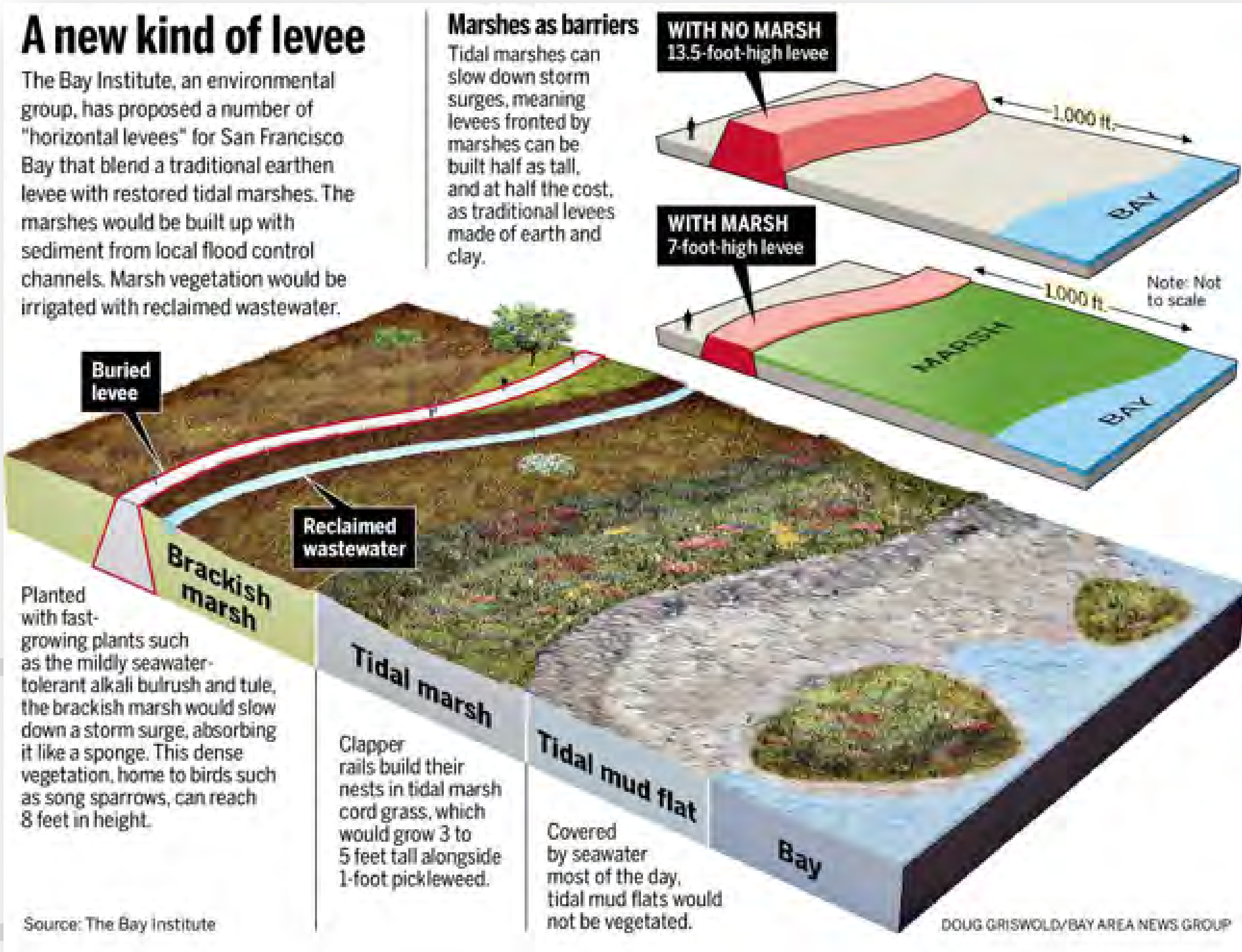

Figure 10: Horizontal Levee Figure (From Bay Institute 2013).

Pros:

- Horizontal levee projects combine flood protection benefits with habitat benefits by maintaining or enhancing wetlands along the water side of the levee.

Cons:

- Significant wave attenuation across a tidal marsh requires a minimum width of several hundred feet. In many locations of Richardson Bay, finding enough space to create more tidal marsh will be problematic. If enough marsh cannot be created, the final levee crest elevation may not be significantly lowered and the cost benefits achieved. However, the ecological and wave attenuation benefits of horizontal levees combined with the benefits of expanded wetlands should be considered an important adaptation approach when developing a comprehensive plan for sea level rise. The District is evaluating a modified approach to the horizontal levee concept that achieves wave attenuation goals within the more confined marsh space available in Bothin Marsh.

Costs:

- Costs for importing and placing fill vary significantly depending on the location and quality of the borrow source of sediment. Horizontal levee construction costs may be approximately the same as described for more traditional levees above. The Bay Institute Report (Bay Institute 2013) assumed a cost of $25/cy for engineered fill and $15/cy for placing non-engineered fill to create wetlands on the water side of the proposed levee. In this study, we developed approximate costs for horizontal levee protection for different levels of sea level rise using similar unit costs.

Shoreline erosion "scarp" (small cliff) protection through engineered beach construction (minimizes direct shoreline erosion through coarse-grained gravel placement)

A relatively new technique pioneered in Marin County uses elements of natural bay beaches as design analogues for a nature-based approach to inhibiting wind-wave erosion of the shoreline edge. Currently, many parts of the inner Richardson Bay shoreline are losing their shoreline edge and associated habitat from wave erosion. Using this approach could inhibit erosive loss at relatively low cost while providing some habitat values.

Figure 11: Aramburu Island Beach Restoration Project.

Pros:

- Relatively inexpensive when proper sediment sizes are available. This approach has minimal environmental impacts and significant environmental benefits when properly designed. Even if this approach were to fail, the coarse-grained sediments would simply fall into the bay within minimal impacts.
- Habitat benefits for several bird species have resulted from the Aramburu Island Beach Restoration Project in Richardson Bay.
- Promotes nature-based solutions as alternatives to more traditional engineering approaches.

Cons:

- Relatively new technique that has proven successful at one location in outer Richardson Bay (Aramburu Island) but has not yet been demonstrated to be

effective at halting shoreline erosion at a variety of locations. Given the relatively low wave environment and shallow depths of Inner Richardson Bay, however, it is likely to be very successful at the locations proposed in this report.
- Likely effective over a limited range of sea level rise to at least mid-century. Maintaining the beach system may require periodic replenishment of differently sized sediments.

Costs:

- Costs for a small cross-section of engineered beach are estimated at $80 to $150/linear foot based on the Aramburu project costs.

CATEGORY 3. REBUILDING AND INFRASTRUCTURE ADAPTATION

It may not be possible, desirable, or affordable to use engineering approaches to stop direct coastal flooding under all conditions and at all locations. One set of adaptation tools involves modifying the infrastructure itself by raising or relocating it out of the flooding areas.

Specific examples of rebuilding and infrastructure adaptation include:

Elevate structures above future tides

An important adaptation approach is to elevate structures above coastal flooding elevations. This measure is consistent with FEMA guidelines. Note that unlike storm event flooding, sea level rise entails consistently recurring flooding that worsens over time as water levels rise. Elevating structures is only one aspect of this approach: associated utilities such as roadways, power, sewer, water, and electrical connections also need to be raised, or waterproofed, to some extent to avoid damage. These costs should also be considered.

Pros:

- Can be effective if done properly and associated utilities are also raised above future tidal flooding levels.

Cons:

- Depending on the sea level rise scenario used, the possible elevation change can be significant. Redesigning and rebuilding structures and relocating utilities and infrastructure can be very expensive.

- Not all slab on-grade homes can be raised and might have to be demolished and rebuilt.
- Any structure and infrastructure not elevated would not be protected and still be subject to flooding.

Costs:

- Costs for raising structures will have to be determined based on the type and number of structures. A recent study estimated a typical cost for raising a single family house at approximately $50,000 (Stetson 2013). Larger homes and commercial structures will cost significantly more to elevate. However, sea level rise, as opposed to riverine flooding, is a more permanent type of flooding and therefore, it would not be enough just to raise structures; the associated utilities and infrastructure, such as roads, would also have to be raised. These costs will depend on many factors and will be very significant; they have not been estimated for this study.

Raise grades (add fill to raise the ground elevation)

This alternative adds fill to raise the land surface above flooding elevations. This alternative requires large amounts of imported fill to raise site grades and thus would also require the subsequent rebuilding of the communities at the new higher elevations (i.e. buildings and all associated infrastructure). This alternative is a large engineering undertaking that to our understanding has been implemented in parts of Japan (also known as “super levees”).

Pros:

- Once completed, raising the land surface would be a very effective and relatively low maintenance solution.
- Views from the new elevated land areas might be enhanced.
- Might allow for more modern design approaches for floodable developments with greenways and design approaches that combine natural with urban systems.

Cons:

- Would take a large amount of fill as well as significant costs to rebuild the entire community at higher elevations.
- People in areas not elevated would have their views blocked by elevated areas.

- Would require complete agreement across all public entities and private homeowners and businesses. While super levees have been built in some areas of Europe/Japan, through consensus or eminent domain, the level of consensus needed to build them in the USA is more difficult to achieve. This approach may be more applicable as a longer-term planning goal if sea level rise cannot be managed using other approaches.
- This approach is potentially costly and how well it could be implemented is unknown. Also, associated levees would need to be stabilized; either with a natural sloping edge or perhaps an engineered structure such as a bulkhead or hardened levee face (see Category 1 engineered structures above).
- Added fill may be more vulnerable to seismic issues.

Costs:

- Costs would be substantial. Structures within areas to be raised would have to be removed and abandoned or rebuilt at higher elevations. New infrastructure would have to be built, at substantial cost.
- Fill costs are always very difficult to estimate since they depend greatly on the borrow source location and fill quality. In this case, the quantity of fill needed may be very large, and no local sources of fill have been identified.

Floodable and floatable development (floating house boats, Dutch "polders")

This approach involves rebuilding structures and associated infrastructure (the entire development) to adapt to sea level rise. Designs for creative floodable housing structures and communities that can withstand and accommodate flooding are being proposed for many locations around the world. Floodable development is a relatively new type of urban design for zones (or tiers) of areas and buildings where more or less flooding is allowed. The lower tiers would be designed for areas such as wetlands, parks, and open spaces that can handle more consistent flooding, moving up to areas and structures at higher elevations that are not designed to be flooded

Figure 12: Example of Dutch Floodable Development (Polder).

Pros:

- As housing is rebuilt, there will be more opportunities to rebuild the housing stock in a way that adapts to sea level rise. Given the magnitude of sea level rise projections, floatable housing—house boats or floating communities—may be a viable solution for inhabiting low-lying areas adjacent to the bay that are subject to direct coastal flooding.

Cons:

- Costs for redevelopment including utilities if not borne by private developers are high. Ultimately, this approach may require rethinking the shoreline planning and density limitations and require community consensus as private development would likely result in increased development density.

Costs:

- Costs for this approach depend on the scale of the adaptation effort and construction requirements; costs are uncertain and cannot be estimated without knowing redevelopment costs. Commonly, redevelopment costs are financed by private developers in exchange for market-based property income.

Planned retreat (allowing lands to become inundated)

In this approach, areas would be allowed to be flooded and possibly converted to occasionally flooded parklands/uplands and transition zone habitat, and, ultimately, as sea level rises, to wetlands. These areas could potentially be used as mitigation for impacts to wetland areas. Structures and facilities in the planned retreat areas would be removed and potentially relocated. A subset of this approach is known as "design for disassembly," meaning that structures are designed and permitted to be relocated as sea level rises. Or structures can be demolished and rebuilt upslope. To our knowledge, these types of innovative approaches have not yet been implemented locally, but represent some of the newer ideas in planning adaptation. It has been reported that in other areas, such as Louisiana, some residences within coastal areas have retreated due to the high cost of flood insurance and rebuilding.

Pros:

- Ultimately provides reduced costs for flood protection.

Cons:

- Potential loss of properties, businesses, and housing as well as park and public use areas.
- Likely requires relocation of utilities for servicing built areas or remaining or rebuilt areas.
- While costs for retreat may be relatively low, costs for buying out property owners or for rebuilding structures and infrastructure elsewhere can be significant. Very limited—if any—space for rebuilding upslope exists in Richardson Bay watersheds, so this approach is probably less of an option than in other communities where there is more space available.

Costs:

- Costs for retreat from coastally flooded areas are typically lower then engineered protection, and if the retreated areas can be used as mitigation, they may also be useful in reducing costs for other alternatives. However, costs for buy-outs or rebuilding may be significant. The loss of some areas that have a lot of community usage may have impacts. This alternative may be useful when it is deemed that protecting these areas is beyond the likely means of the local community.

- Costs for retreat are variable and depend on the costs for removal of existing structures if any, as well as any requirements for compensation and/or for relocation. As such, retreat from parklands would be less expensive than retreat from urbanized areas. Costs would also depend on the degree of environmental clean-up that would be required to return these lands to the tides or habitat areas.

CATEGORY 4–ZONING AND PERMITTING ADAPTATION

Local zoning and permitting changes

Changes in zoning and permitting to adapt to climate change can be implemented in conjunction with any and all alternatives. One zoning tool that has been implemented in some locations is the "rolling easement," which prevents hard structures and armoring of the shoreline but does not prohibit the land from being used while the property is still useful. This type of easement "rolls" or moves inland as sea level rises, maintaining areas of public tidal lands and allowing for shoreline habitat to migrate inland. Structures may be moved elsewhere on the property, or elevated to allow for water flow, but the shoreline cannot be further armored. A property owner's right to access can be grandfathered in to such an easement, if rebuilding after disasters is allowable.

Pros:

- Zoning is a key part of any long-term planning effort and provides certainty and vision for the local community.
- Fits well within the planning horizon for sea level rise. Since this is a relatively slow moving disaster, we have an opportunity to implement these types of changes in time to inhibit the major impacts of sea level rise.
- Rolling easements allow owners to use their property while flooding is still manageable, but restrict the ability of the owner to add protection from coastal flooding; recognizing that the property will ultimately degrade and becomes part of the bay system.

Cons:

- Zoning and ordinance changes are likely to face political opposition.

Costs:

- Costs for making changes in zoning and local ordinances are minimal and a normal part of government. Innovative ordinance changes such as rolling easements require specific planning expertise.

SAMPLE EVALUATION CRITERIA

All approaches have pros and cons that can vary across criteria. Some of the criteria that could be used in subsequent phases of work to evaluate potential elements and project alternatives include:

- *Flood protection benefits* – A primary goal of this study is to maximize flood protection benefits for communities as sea levels rise. This criterion evaluates projects on their ability to meet this goal during a specified planning horizon.
- *Project cost* – Project cost is always an important evaluation and ranking criterion. Costs can be broken down into initial capital costs and annual maintenance and reporting costs as well as costs for right of way acquisition.
- *Ease of permitting* – The anticipated ease of and costs for receiving permits from all levels of government: local, state, and federal. Working in wetlands can trigger a number of permit requirements. Projects that create new wetlands and do not impact existing wetlands are easier to permit, with less mitigation costs.
- *Visual impacts* - Given that most adaptation measures along the shoreline will have visual impacts, it is useful to evaluate and rank this criterion separately. A prime use of Richardson Bay is for viewing wildlife and scenery.
- *Habitat/wildlife benefits* - The existing habitat values of Richardson Bay are important to its residents and a prime reason why many people choose to live here. Preserving wildlife and preserving and enhancing habitat values are key criteria to evaluate in any adaptation scenario.
- *Public access/recreational values* – Access to the beautiful Richardson Bay shoreline is important to residents who use it for recreation of many kinds, walking dogs, enjoying views of the bay, and viewing birds and wildlife, etc. These criteria would score the public usage aspects of the project.
- *Water quality* – Benefits to water quality in the Bay is an important criterion for evaluation of alternatives.
- *Emergency response access* – The ability for emergency responders to access home and residences is an important criterion for the evaluation of alternatives.

5.0 SHORELINE FLOODING INUNDATION UNDER CURRENT AND FUTURE SEA LEVEL RISE SCENARIOS

This section evaluates the extent and impacts of flooding under selected scenarios of sea level rise conditions. We mapped three scenarios of sea level rise (12, 36, and 60 inches) onto the shoreline to identify locations of potential impact. We show both the lateral landward aerial extent of sea level rise inundation on the landscape (as done previously in the BCDC, USGS, and NOAA maps), but we also prepared maps of water depth under various scenarios to show what future depths could potentially be realized. Depths are a good way to differentiate nuisance flooding, which is short-term or can be avoided, from deeper and longer flooding that may pose a greater risk to property and public safety. Some areas may only experience a few inches of inundation, which may be manageable, while other areas may experience depths on the order of feet, which is much more serious. Depths are shown at selected critical focus locations.

Note that these maps only show static (bathtub) type modeling results for the various scenarios. Storms that drive wind-wave events could result in greater inundation extents then shown on these figures.

This section is not a formal in-depth vulnerability assessment conducted BCDC Adapting to Rising Tides (ART) project. The more formal approach to conducting a vulnerabilities study is to assess and categorize each major infrastructure asset including its vulnerability, sensitivity, resilience, and importance for protection future sea level rise impacts. Our understanding is that a more complete vulnerabilities assessment will be conducted by the County under a separate effort. The approach taken for this study to identify the major infrastructure threatened by sea level rise and to identify and provide a first-cut order of magnitude cost for hard engineering barrier structures along adaptation that can provide protection a rising sea level.

5.1 Sea Level Rise Scenario Results - Inundation Extent and Depth

Figures 13 through 16 show the large scale, overview maps for sea level rise inundation for each of the shoreline segments under three sea level rise scenarios. Smaller scale figures (17 through 52) focusing on critical flooding locations are contained under each scenario description.

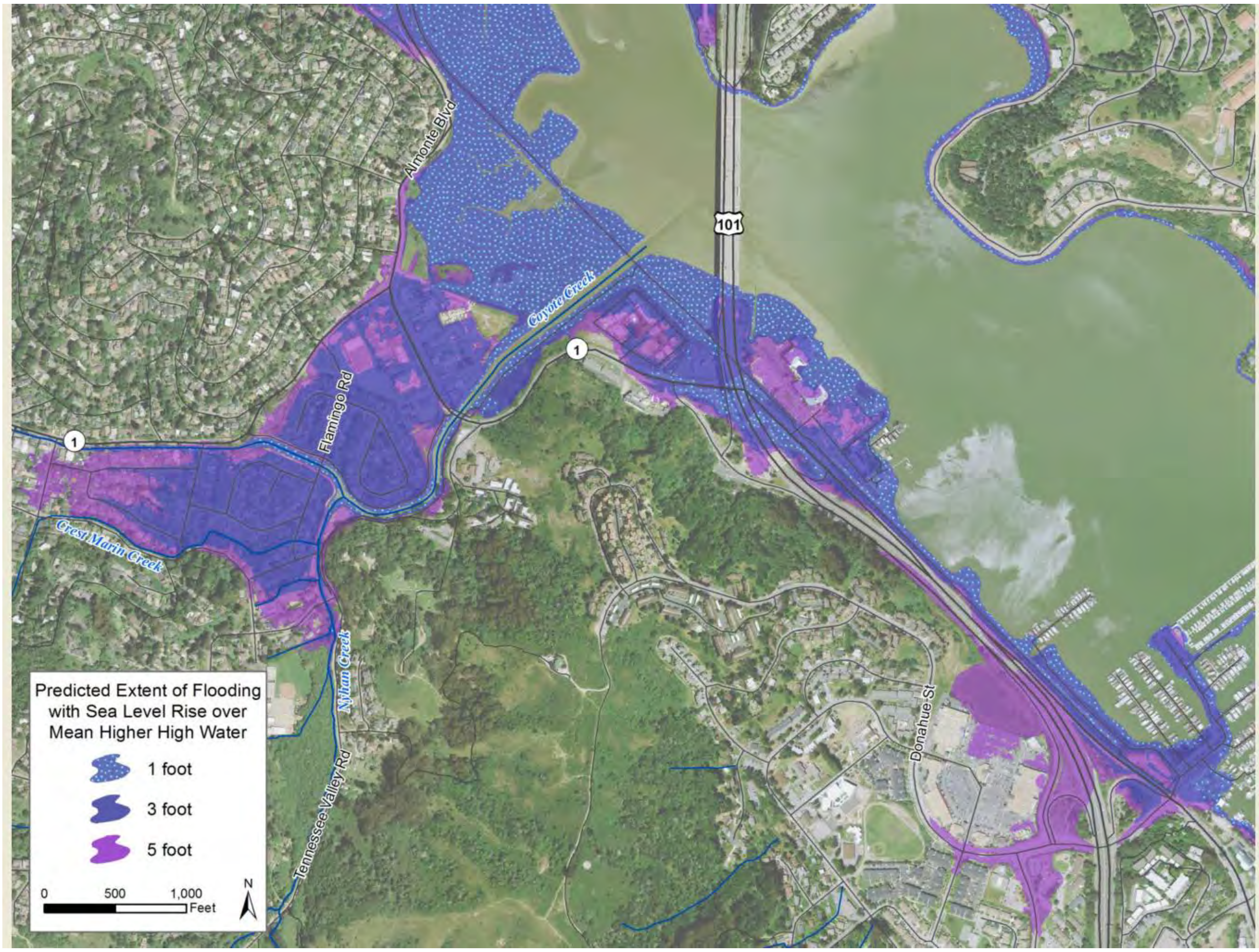

Figure 13: Reach 1 and 2 Inundation Extents for Three Sea Level Rise Scenarios (12, 36, and 60 Inches).

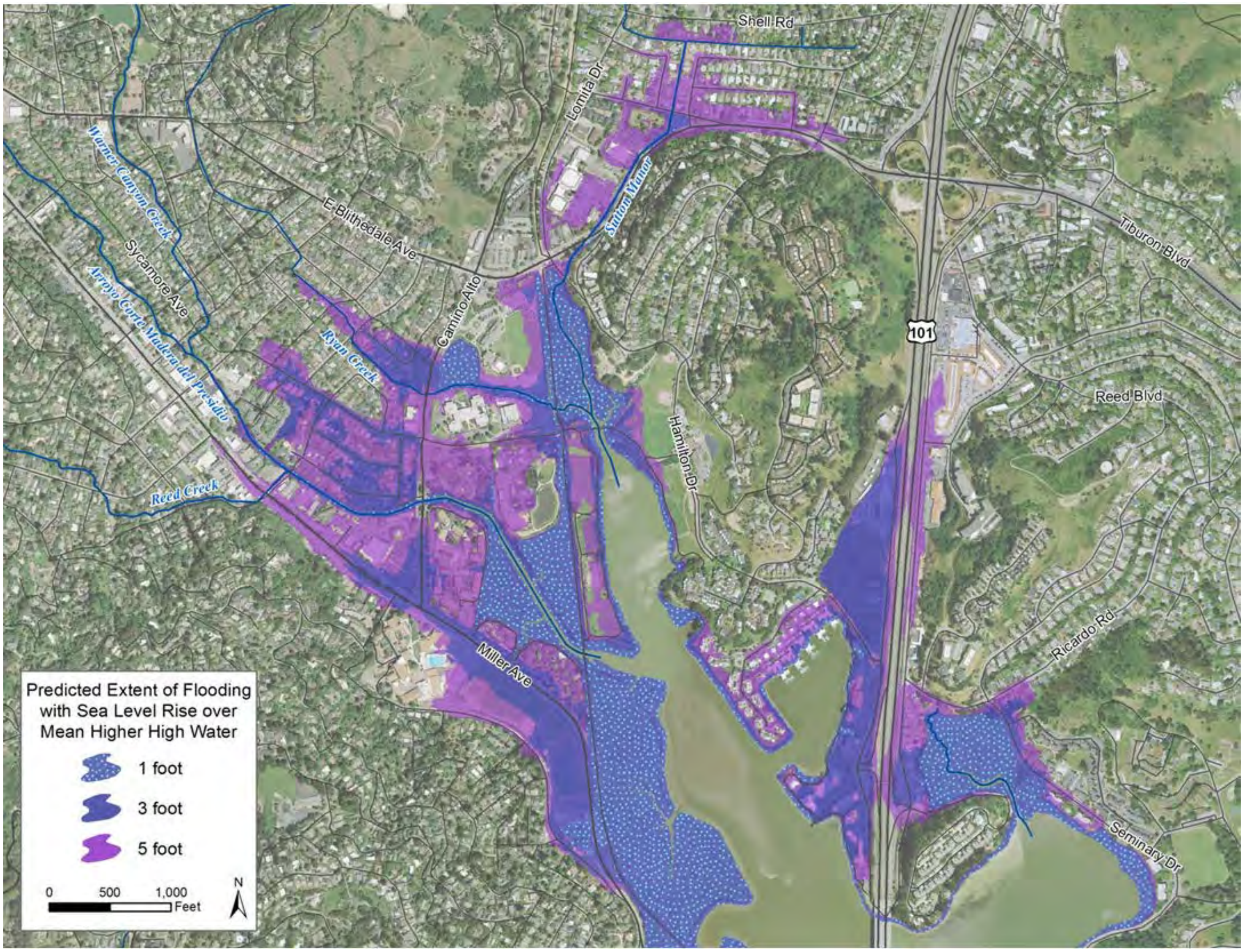

Figure 14: Sea Level Rise Inundation Extents for Reaches 3 and 4.

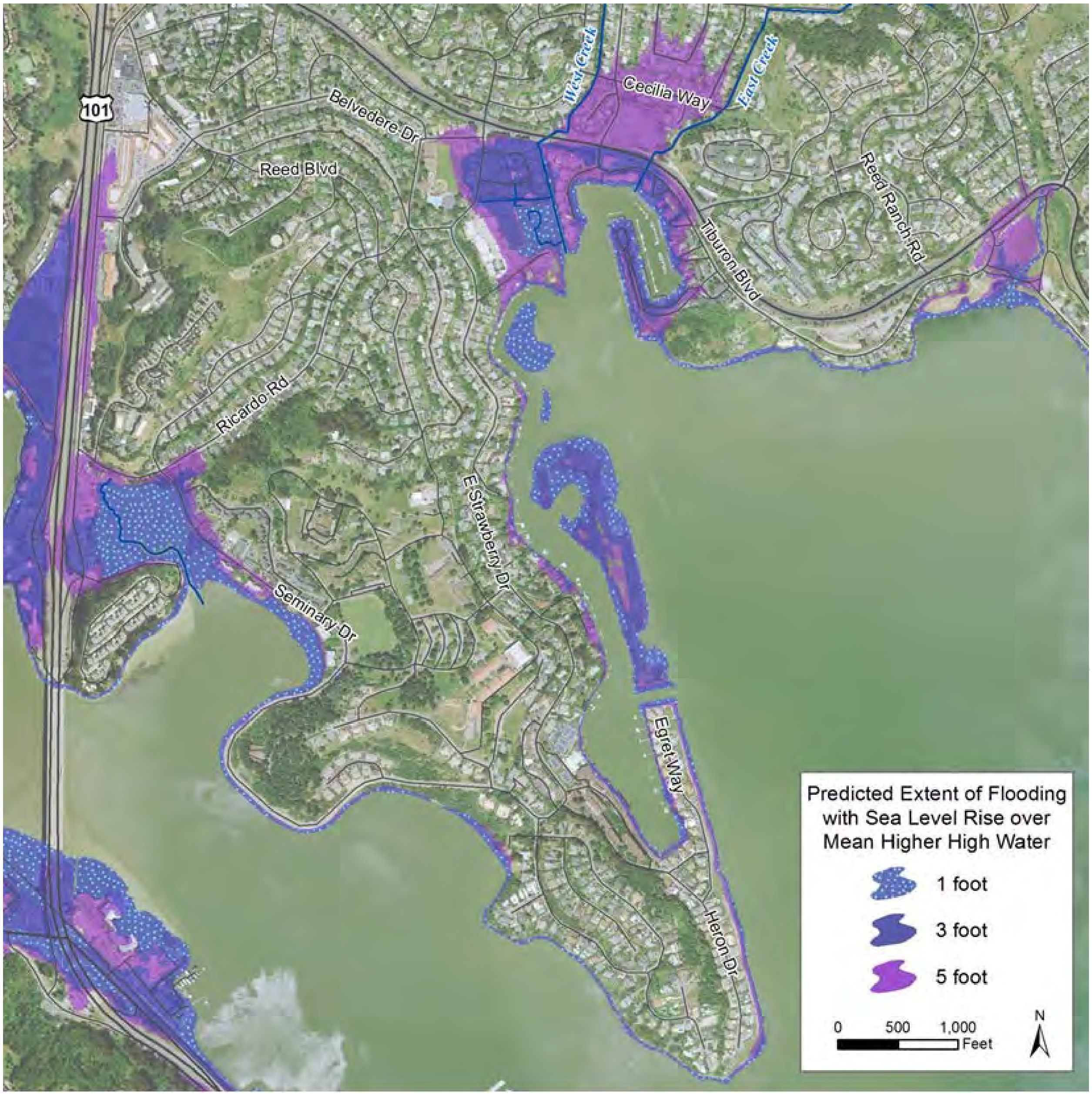

Figure 15: Sea Level Rise Inundation Extents for Reaches 5 through 7.

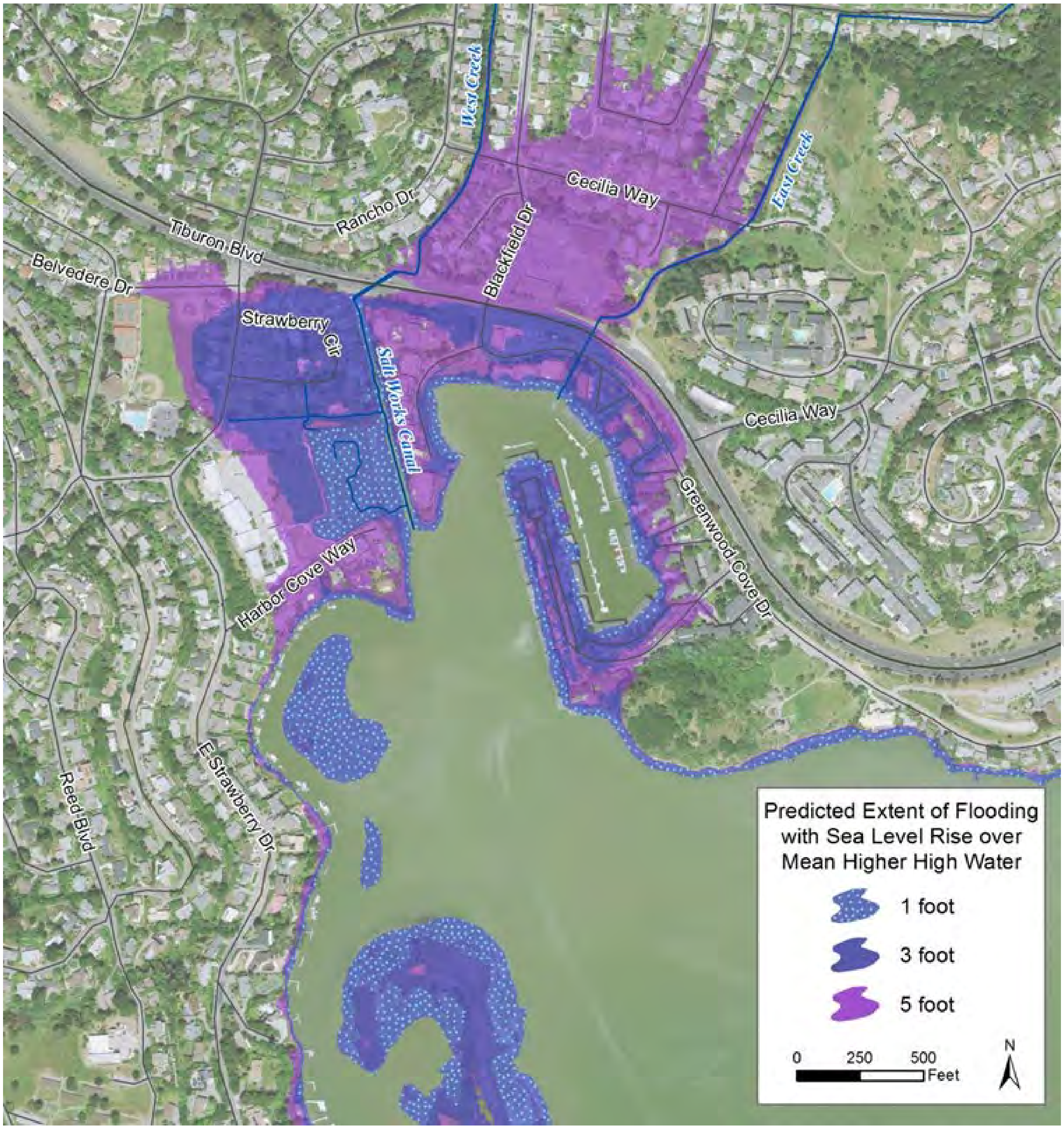

Figure 16: Sea Level Rise Inundation Scenario Extents for Reaches 6 and 7.

IMPACTS UNDER THE 12 INCH SEA LEVEL RISE SCENARIO

This scenario shows the current king tide flooding, which corresponds approximately to the year 2030 scenario of 12 inches of sea level rise. Under a 12 inch rise in bay tide levels, the king tide (which now occurs twice a year and can be partially managed through temporary road closures and by driving through flooded streets) would become the daily MHHW tide elevation. What is now an occasional, twice-a-year inconvenience would become a daily nuisance. Prolonged inundation of infrastructure such as storm drain pipes, roadways and trails and shoreline erosion would be increased, probably necessitating more frequent repairs and replacement, and increasing costs. The probability of combined riverine and coastal flooding would be greatly increased, and thus flood damages during storm events. Note that king tide flooding is also variable in magnitude by several inches depending on a variety of factors (water temperature, barometric pressure, winds, etc.); therefore, different tide events will result in different levels of flooding.

Under 12 inches of sea level rise, low elevation areas along the shoreline extending from the Caltrans Manzanita parking lot and all along Miller/Almonte Avenue and the Mill Valley-Sausalito Pathway to the north end of the Mill Valley shoreline would be inundated. Figure 17 shows a blowup of the Manzanita Parking area at the shoreline highway exits off of Highway 101 at the mouth of Coyote Creek. This figure shows the depths of flooding as well as impacted infrastructure.

Note that these maps only show directly connected overbank flooding. In some areas, notably Miller Avenue and the Manzanita Parking area, flood waters may back up through storm drains and onto the land surface, and therefore, there will be additional flooded areas at perhaps greater depths than shown on the attached figures. Also, flooding shown across Highway101 is actually flooding below the roadway since the roadway elevations are not in the digital elevation land surface model.

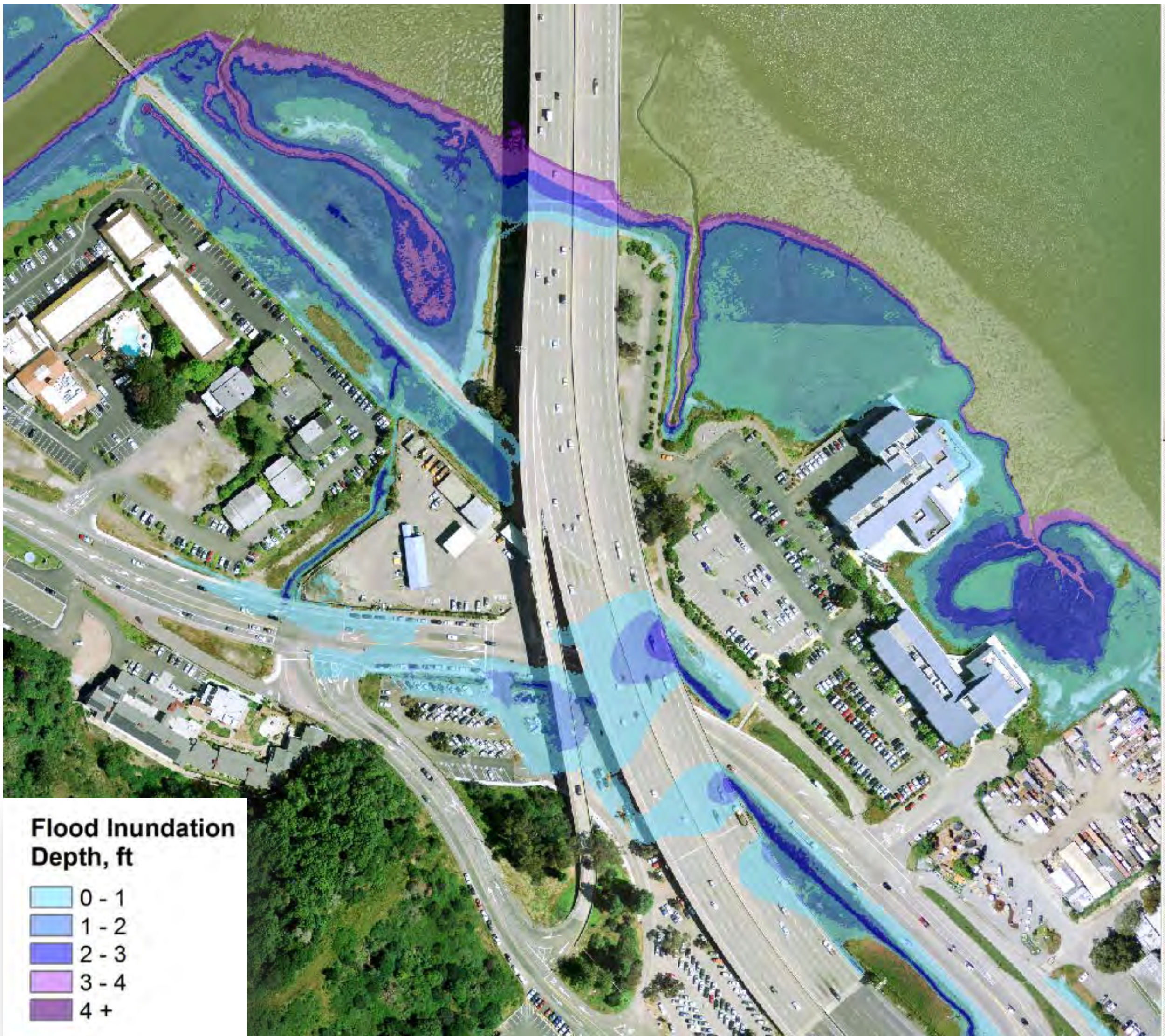

Figure 17. Critical Area Inundation Focus Map Showing Flooding Depths with 12 Inches of Sea Level Rise at Shoreline Highway and Manzanita Parking Area South of Coyote Creek.

Note: The flooding shown on the elevated section of Highway 101 is actually *__beneath__* *the roadway.*

IMPACTS UNDER 36 INCH AND 60 INCH SEA LEVEL RISE SCENARIOS

Under these scenarios of even greater sea level rise expected to occur in the second half of this century, impacts include much deeper and more prolonged tidal flooding then in the previous 2030 scenario. Flooding extends farther inland into populated areas and significantly impacts roadways and infrastructure along the shoreline. Under these scenarios, what had previously been a nuisance is now a regular and serious flooding problem that requires mitigation or retreat and restoration to avoid major impacts to structures and roadways.

Costs are now much higher due to the size and height of any barrier structures and associated right of way acquisition.

The 60 inch rise scenario, which is the upper end of the year 2100 NRC projections for sea level rise, is approximately equal to the previous 36 inch scenario in lateral landward extent of flooding but now occurs at a higher elevation with a greater depth of flooding. The inundation depths under this scenario would result in the loss of use of these facilities. Extensive engineering would be needed to maintain infrastructure or facility services in place or to relocate them.

FACILITIES IMPACTED BY SEA LEVEL RISE

The following table summarizes the results of each scenario for potentially flooded areas, number of buildings, and miles of roads and trails.

Table 4. Summary of Flooded Areas by Sea Level Rise (SLR) Scenario Assuming No Adaptation/Mitigation Measures.[3]

Impact	12 Inches SLR	36 Inches SLR	60 Inches SLR
Total Flooded Areas (acres)[4]	168	371	597
Flooded Park and Open Space Areas (acres)[5]	27	83	120
Linear Feet of All Flooded Roads and Trails (feet and miles)	12,070 feet (2.3 miles)	68,500 feet (13 miles)	118,200 feet (22 miles)

[3] All values calculated through GIS.

[4] Includes all flooded areas above elevation three feet NAVD, assuming no barriers.

[5] Includes areas designated as parks and open space on MarinMap.

On the following focus flood map figures, critical structures and utilities (except for water supply lines (for which data is not publically available) are shown according to the following legend:

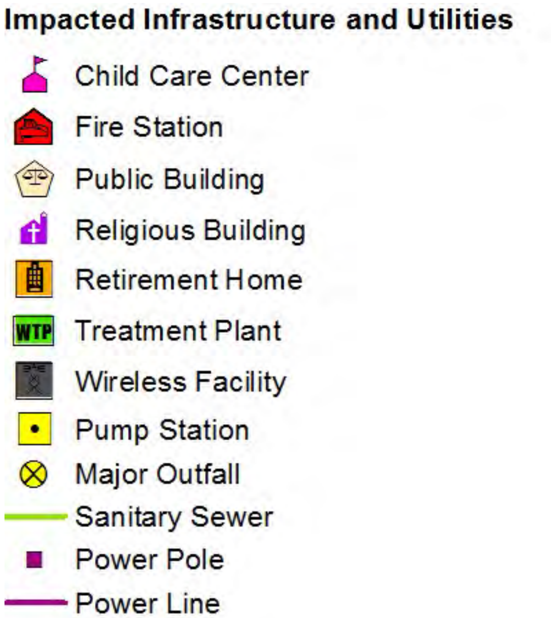

Figure 18: Figure Legend of Critical Facilities and Utilities Impacted by Flooding.

Table 5 shows a summary of facilities flooded by different scenarios of sea level rise based on an evaluation of available GIS data in MarinMap.

Table 5. Facilities Potentially Flooded Under Different Levels of Sea Level Rise (SLR), Assuming No Adaptation.[6]

Facility Type	12 Inches	36 Inches	60 Inches
Building	83	691	1284
Bus Stop	3	17	34
Child Care Center	1	1	3
Community Center	0	0	1
County Facility	0	1	1
District Office	0	0	3
Electrical Pole	6	35	67
Outfall	27	41	44
Park And Ride Lot	1	3	3
Pump Station	1	7	7
Religious Facility	0	0	1
Wireless Facility	1	3	5

(1) Flooded building properties are based on LiDAR ground elevations and not finished floor elevations. Therefore a property was counted as flooded if the water level exceeded the parcel ground elevation.

Table 6 presents the available Marin County tax assessor value of properties that could be impacted under the three sea level rise scenarios. This data does not include values for properties not subject to taxes, including public buildings such as schools, government offices, and religious buildings. Therefore, the values in the table below are low.

[6] Based on available GIS data.

Table 6. Estimated Value of Properties and Buildings Impacted Under Different Levels of Sea Level Rise Based on Tax Assessor Values.

SLR Scenario	Count	Land Value	Improved Value	Total Value[7]
Parcels intersecting 1 foot SLR	394	$187,592,105	$211,296,297	$398,888,402
Parcels intersecting 3 feet SLR	889	$371,298,461	$366,134,667	$737,433,128
Parcels intersecting 5 feet SLR	1545	$649,217,099	$636,736,662	$1,285,953,761

5.2 Impacts Assessment by Shoreline Reach

This section provides more detail about the impacts to specific reaches of shoreline under various sea level rise scenarios.

REACH 1 - MARIN CITY TO COYOTE CREEK

This reach of the study area extends from Marin City to the south end of Coyote Creek. It includes the Caltrans Manzanita parking areas that have experienced the most significant sea level rise flooding along the San Francisco Bay shoreline to date. This reach is generally narrow, consisting primarily of Highway 101 separating the bay from the steeper hills and the Marin City shopping center.

The primary land use in this area is Highway 101 and the frontage roadways. At the south end, a community dock and boating facilities reflect the water-related history of the area. There are areas of light industrial and office buildings along with a seaplane business. Across Highway 101, the shopping center is an important commercial center for Marin City.

[7] Only for properties and buildings contained within assessor tax lists; does not include non-taxable buildings and parcels. Total value should be considered as a low-end estimate.

LOCATIONS OF KNOWN FLOODING

Areas known to flood along the shoreline reaches within Department of Public Works Flood Control District's jurisdiction are listed below. This list is not intended to be complete but to summarize the locations where flooding is most common. Note that the sources of flooding vary and are not all the result of direct bay coastal inundation.

- The off-ramps in both directions from Highway 101.
- The parking areas of the shopping center and Donahue Street (which also experience localized flooding from the shopping center storm drain system). Unclear how much, if at all, backwater flooding from the bay impacts present day flooding in this location, but it likely will add to overall flooding as sea level rises.
- Some of the low-lying ground and frontage roadway edges east of Highway 101 along the edge of the bay (direct coastal flooding).
- The Caltrans parking lot at Manzanita and Shoreline Highway frontage road under Highway 101 (significant direct coastal flooding).

VULNERABLE INFRASTRUCTURE

Highway 101 arguably represents the most critical local and regional infrastructure along this reach. Highway 101 connects Marin County to San Francisco and all destinations north. It is a heavily used roadway and a vital transportation link in the Bay Area roadway system. Several utilities and commercial businesses east of Highway 101 will be vulnerable to a rise in bay tide level and impacted by direct coastal flooding.

A wetland and pond just west of 101 receive storm drain flows from the adjacent shopping center. Siltation of the pond has reduced its effectiveness in detaining flood flows prior to discharge to the bay. As sea level rises, the pond's outfall to the bay will experience increased backwater flooding and deposition of fine-grained sediment from the bay tides.

Scenario 1 – 12 Inches Sea Level Rise

The primary impact under this scenario is more wind-wave erosion of the shoreline and pathways. As shown in Figure 17, along Highway 101 at the southern end of the reach, the static water level is right up to the edge of the shoreline. While not overtopping the edge yet, this water level will result in increased shoreline erosion and may overtop during storm events with increased wind-wave runup.

Figure 19 presents the water depth key for all following figures. Depths are important as an indicator of the severity of flooding. Flood depths of less than 12 inches may only cause nuisance flooding. Greater flooding depths may not only cause greater facility damage, this may also be too deep to allow for emergency vehicles to access flooded areas.

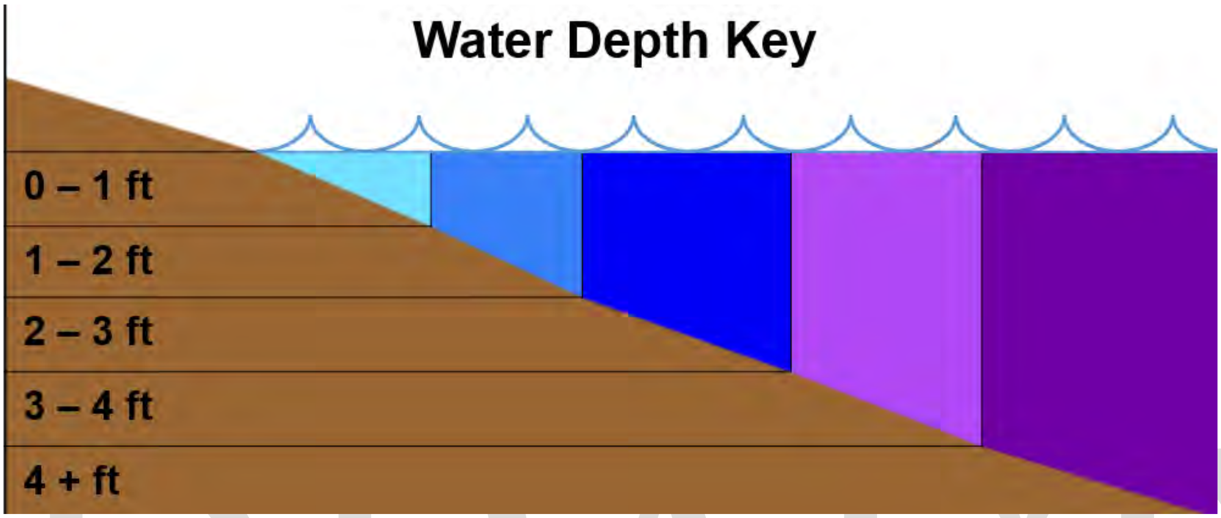

Figure 19: Color Key for Inundation Maps Showing Water Depths.

Figure 20: Flood Focus, Marin City Shoreline Area. 12 Inch Sea Level Rise.

Within the Marin City area, the stormwater lagoon and associated storm drain system will experience increased backwater flooding when storm flows cannot drain against the higher bay tide level. If tide gates are not well maintained, more suspended sediment from the bay could be deposited in the culverts. In general, flooding due to backwater impacts will increase.

At the north end of the reach, the flooding that now occurs during the annual king tides at the Caltrans Manzanita parking lot area, as well as along Shoreline Highway, will become a daily event. These areas will require flood protection actions as discussed below. Figure 20 above shows the anticipated flooding extent and depths with 12 inches of sea level rise.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

These scenarios involve extensive flooding of roadways, trails, and structures along Reach 1 (Marin City to Coyote Creek). The depth of flooding is now significantly deeper (Figures 21 and 22), on the order of two to three feet static water depth (darker blues and purples) with 36 inches of sea level rise, becoming mostly purple (> three feet flooding depth) with 60 inches of sea level rise. This level of flooding obviously becomes a major public safety issue and would significantly impact property values as it would occur on a daily basis if not addressed.

The increased water depths and inundation will now cause significant shoreline erosion, for which adaptation measures will be needed. In Marin City, the stormwater lagoon and associated storm drain system will need to be redesigned, either by elevating gravity drainage systems or converting to pump systems so that stormwater flows can drain against a higher bay tide level and over any floodwalls or levee barriers.

The north end of the reach, including Shoreline Highway and the Caltrans Manzanita parking lot, will experience flooding three to four feet deep, which will endanger public safety and therefore require protection measures, including floodwalls with new stormwater pumping systems as discussed below. Given the narrow available right-of-way in this reach, levees are likely impractical.

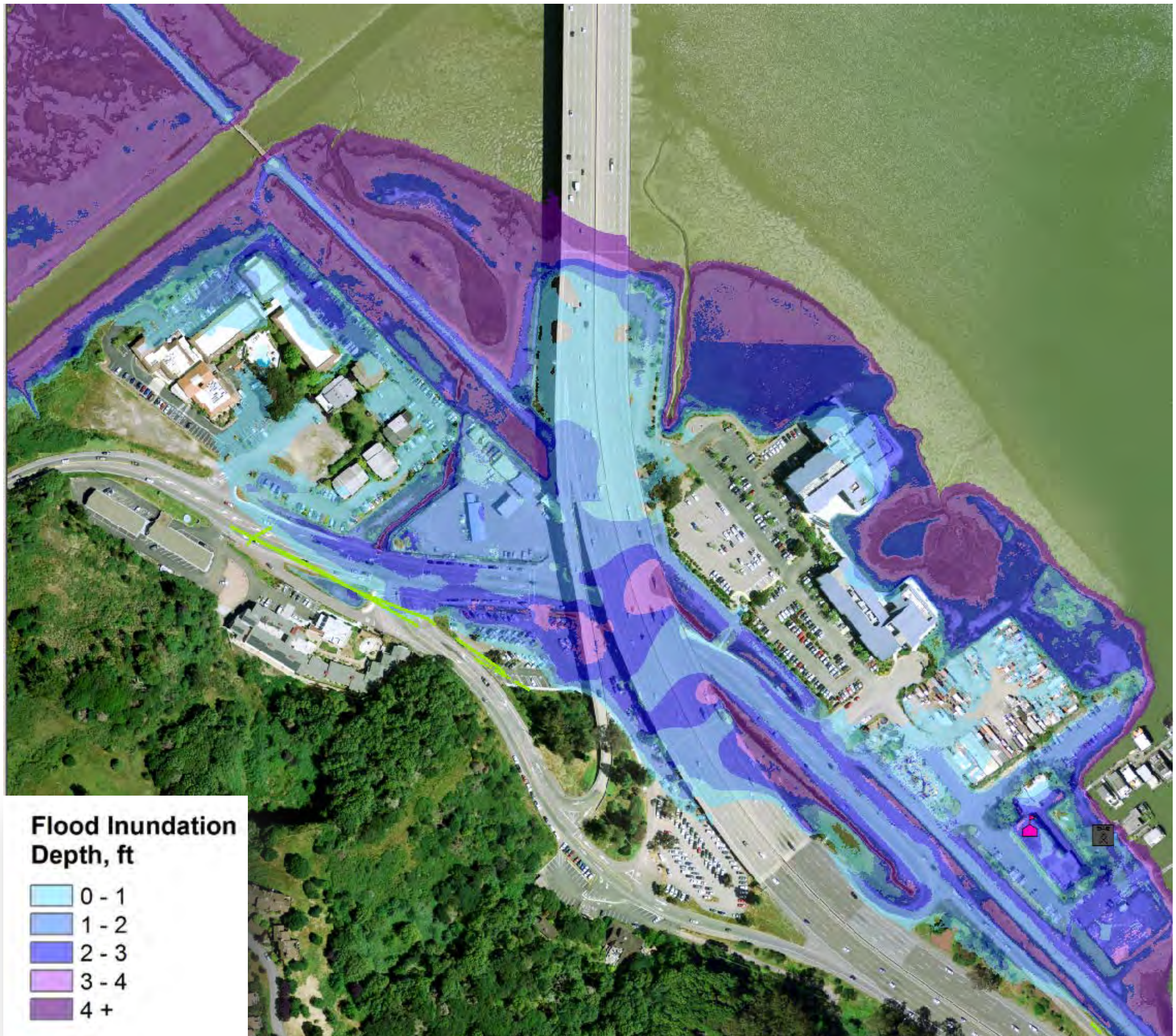

Figure 21: Flood Focus, Manzanita Parking Area. 36 Inch Sea Level Rise.

Note: The flooding shown on the elevated section of Highway 101 is actually beneath the roadway.

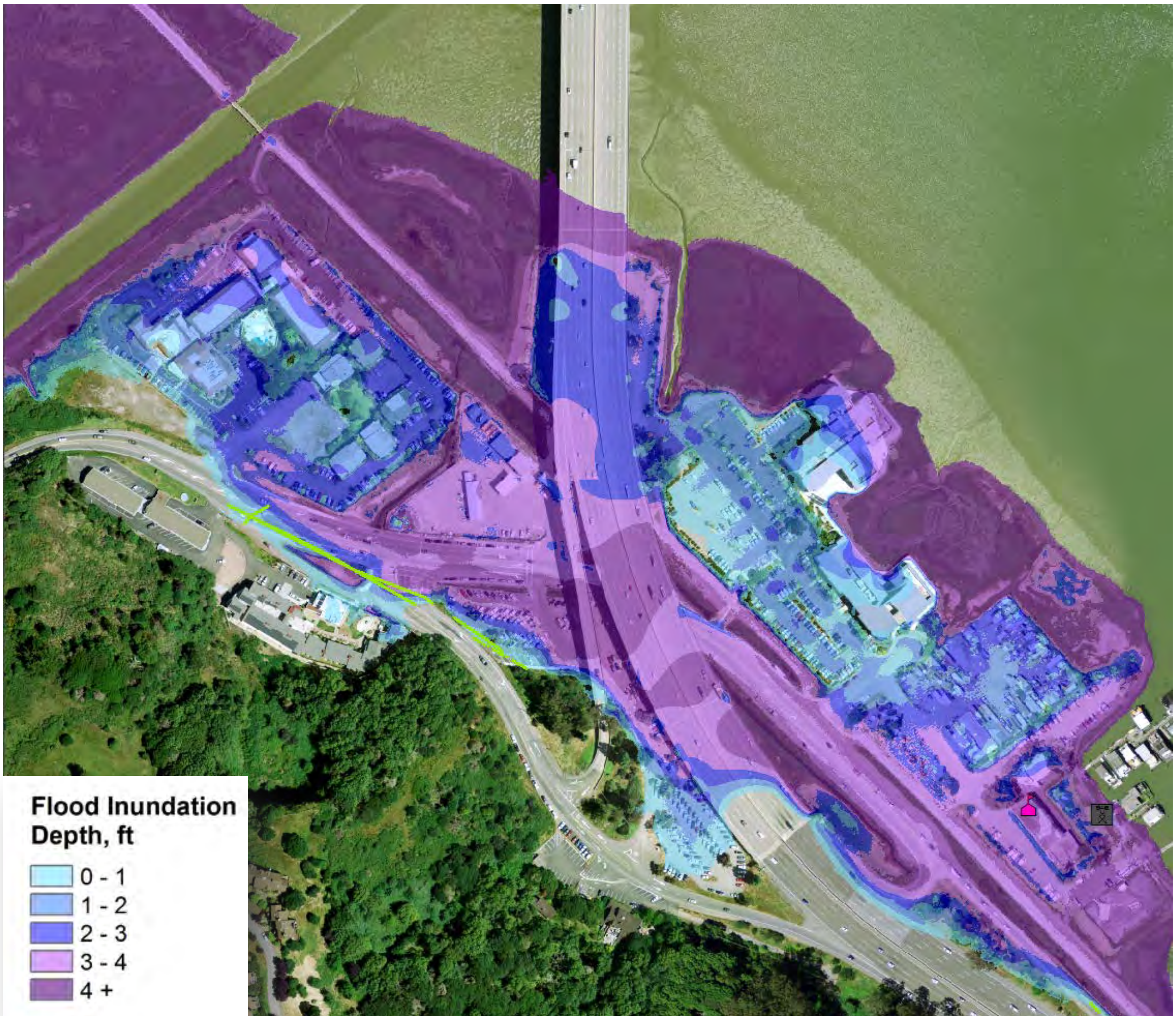

Figure 22: Flood Focus, Manzanita Parking Area. 60 Inch Sea Level Rise.

Note: The flooding shown on the elevated section of Highway 101 is actually beneath the roadway.

REACH 2 - COYOTE CREEK AND BOTHIN MARSH COMPLEX

Reach 2 stretches from the south end of Coyote Creek north to the southern end of the Bothin Marsh complex. It includes Coyote Creek and residential/commercial areas behind the Coyote Creek levees that are vulnerable to flooding and within the FEMA SHFA maps. It also includes the south Bothin Marsh wetlands complex through which the Mill Valley-Sausalito bike and pedestrian trail runs. This reach and Reach 3 contain the most residences impacted by sea level rise.

The primary land uses are wetlands and open space, with significant residential areas and the commercial area of Tam Junction behind Coyote Creek's U.S. Army Corps of Engineers (USACE) flood protection levees. Note that these levees provide an approximate 20-year level of flood protection based on the original Corps flow estimates.

LOCATIONS OF KNOWN FLOODING

The lower reaches of Coyote Creek and the built-up areas of Tam Junction and the Birdland street areas are prone to flooding, especially when the tide is high and rain is falling. The existing levee system was designed to the 20-year flow event at a lower MHHW tide elevation then the current one. Figure 23 shows the primary known location of overbank flooding during this combination of high tide and storm events. Many localized floods occur, especially in Tam Junction, due to storm drain inlet clogging, or backwater flooding from a high water level in the creek, which impedes gravity drainage.

VULNERABLE INFRASTRUCTURE

This reach contains critical and vulnerable infrastructure, including all of the primary utilities feeding the residential and commercial areas of Tam Junction as well as the residential properties within Tam Junction proper. These utilities include roads, electrical, telephone, water, wastewater, and transportation links.

Scenario 1 – 12 Inches Sea Level Rise

A one-foot rise in tide level causes only some limited pathway flooding along the lower ends of Coyote Creek. The creek banks will experience increased tide levels and associated bank erosion. In general, relatively small berms will be needed to inhibit direct coastal flooding. However, there will be increased backwater flooding as the stormwater drainage system behind the levees is no longer able to gravity drain effectively against the higher tide condition downstream.

Bothin Marsh will experience more flooding and inundation, which may impact habitats unless the available suspended sediment in Richardson Bay (which is currently fairly low) is able to maintain marsh grades. Places of refuge for wildlife during high tides and prolonged tidal flooding will be insufficient. The District is evaluating reuse of dredged sediments from the Coyote Creek channel to maintain grades and increase the amount of high tide refugia in Bothin Marsh as well as to build up the transition zone to lessen sea level rise impacts over time.

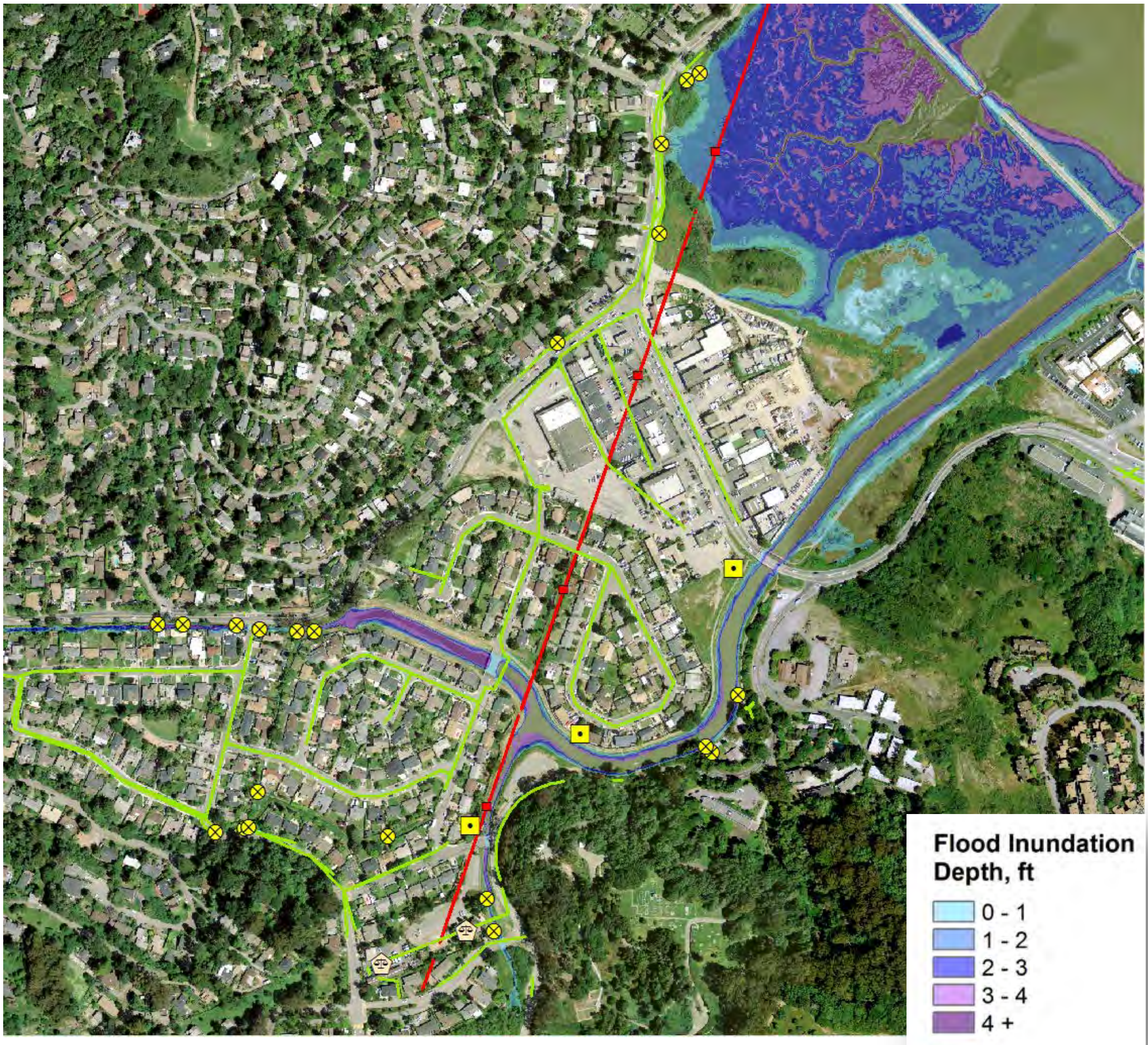

Figure 23: Flood Focus, Coyote Creek Area. 12 Inch Sea Level Rise.

See Figure 18 for figure legend of impacted facilities.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

These scenarios result in extensive roadway flooding of Shoreline Highway and the Manzanita parking area as well as overtopping of the existing Coyote Creek flood control channel. Note that high tides will exacerbate flooding during storms that will occur during what will be more common higher tide levels. Figures 24 and 25 show only direct coastal flooding depths and not the combined flooding storms at higher tides, which will worsen these conditions and potentially increase water depths in these figures.

Within Tam Junction, the residential and shopping areas would experience water depths of two to three feet from direct overtopping of tides in the channel and up to four feet in some locations under the 60 inch scenario.

Without mitigation, Bothin Marsh would lose tidal marsh habitat as it converts to mudflat and subtidal habitat, and also lose endangered tidal marsh species such as the Point Reyes Bird's Beak or the California Ridgway Rail currently found at the site. The marsh would lose habitat complexity and values as it converts to mudflat. Adding fill to maintain marsh grades would be essential to prevent loss of tidal marsh habitats. The District is evaluating reuse of dredged sediments from the Coyote Creek channel to maintain marsh grades as a buffer to sea level rise in Bothin Marsh.

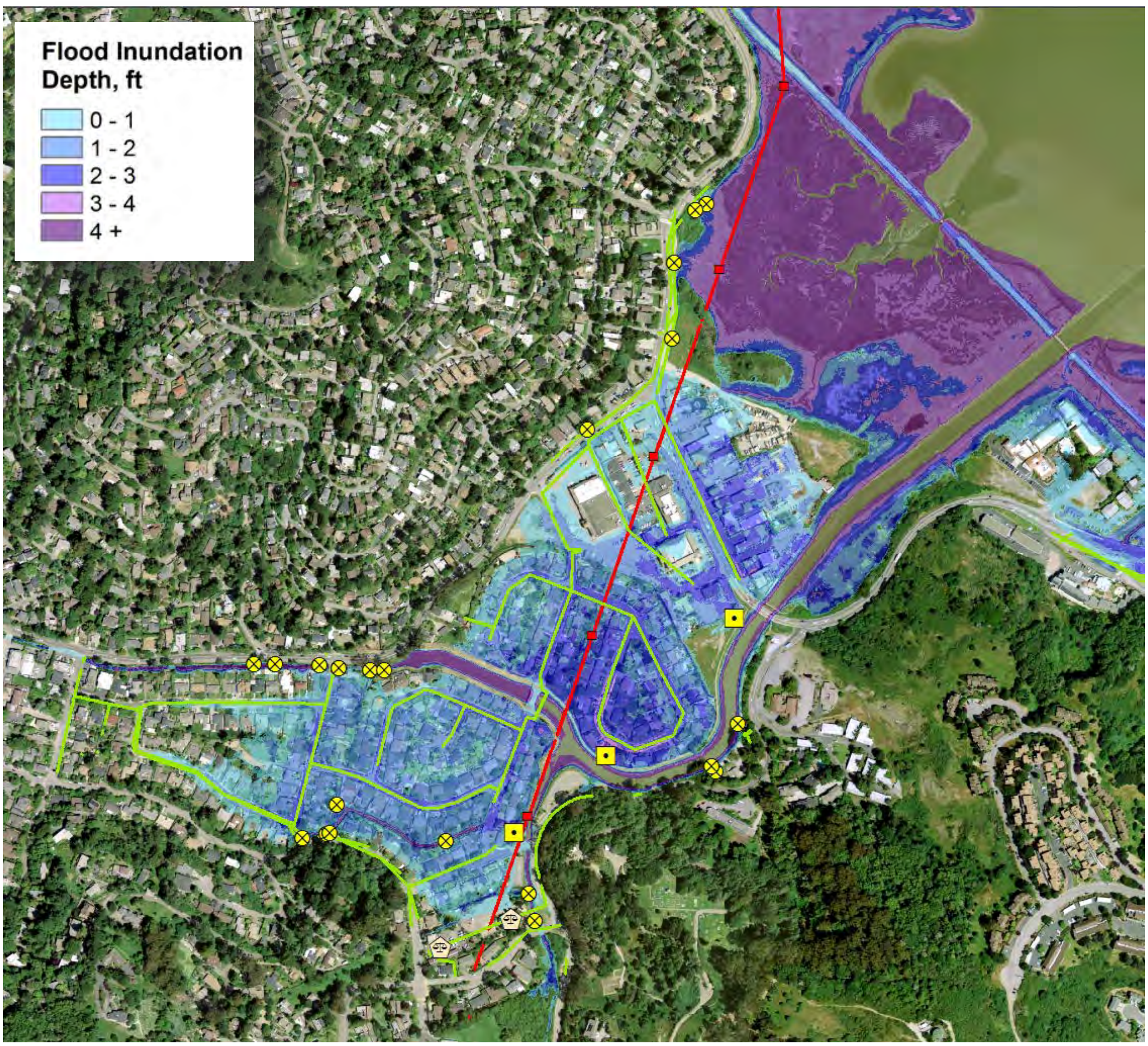

Figure 24: Flood Focus, Coyote Creek Area. 36 Inch Sea Level Rise.

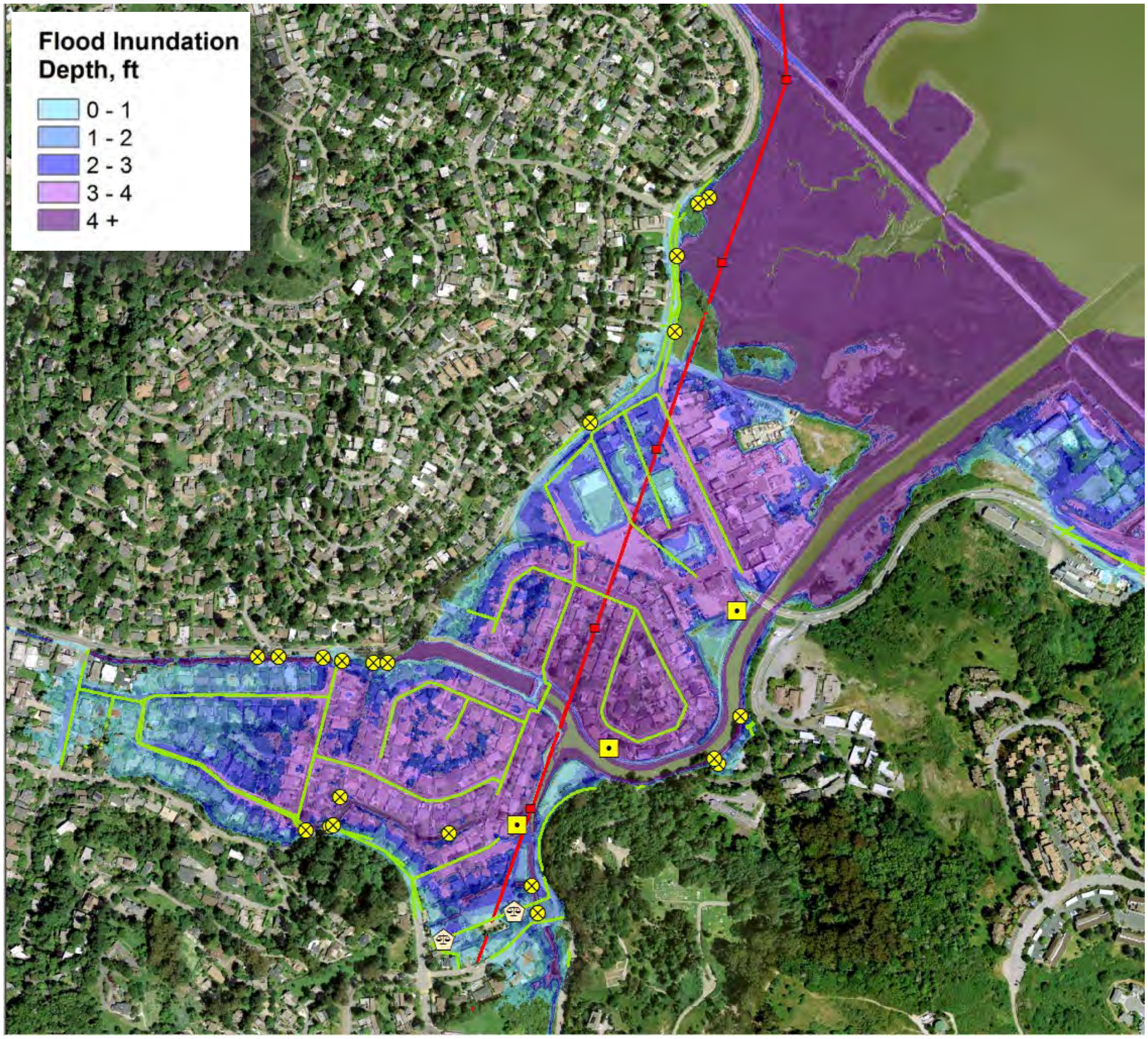

Figure 25: Flood Focus, Coyote Creek Area. 60 Inch Sea Level Rise.

REACH 3 - MILL VALLEY SHORELINE WEST

This reach of the Richardson Bay shoreline extends from the north side of the Bothin Marsh complex through the City of Mill Valley and up around the east side of the Mill Valley arm of the channel.

This area is primarily a mix of parks, wetlands, and open space. There is some residential development, notably the Redwood Shores retirement community and condo developments located on the back side of the marsh. The Mill Valley sewage treatment plant (SASM) is located in this reach, along with a mix of other utilities and infrastructure.

LOCATIONS OF KNOWN FLOODING

Redwood Shores is a concern, especially during high tide flooding events and emergencies, given the limited mobility of many of the residents. Under future scenarios of sea level rise, flooding is expected to worsen significantly. There are numerous locations of flooding in Mill Valley, including Miller Avenue and the Mill Valley Sausalito Pathway. The Mill Valley shoreline is currently showing evidence of active erosion especially of the marsh edge, which can be expected to worsen under sea level rise.

VULNERABLE INFRASTRUCTURE

Practically all infrastructure in this area is subject to the impacts of a rising bay tide level. SASM plant managers are preparing a separate plan to protect the wastewater plant from the impacts of sea level rise.

Scenario 1 – 12 Inches Sea Level Rise

Portions of Miller Avenue in this reach along and south of the Tamalpais High School currently flood on king tide events. As previously discussed, these floods will occur on a daily basis under 12 inches of sea level rise, which means that localized measures, including floodwalls and pump stations, will be needed. Figure 26 show the areas that modeling indicates will flood at each high tide, and therefore, require flood mitigation in the near-term. There may be increased backwater flooding from the constructed wetlands due to impacts to gravity drainage. The light blue color indicates a fairly shallow depth of overtopping flows, likely still in the range of nuisance flooding. Note that water temperature and wind effects can substantially increase the tide elevation above the predicted range.

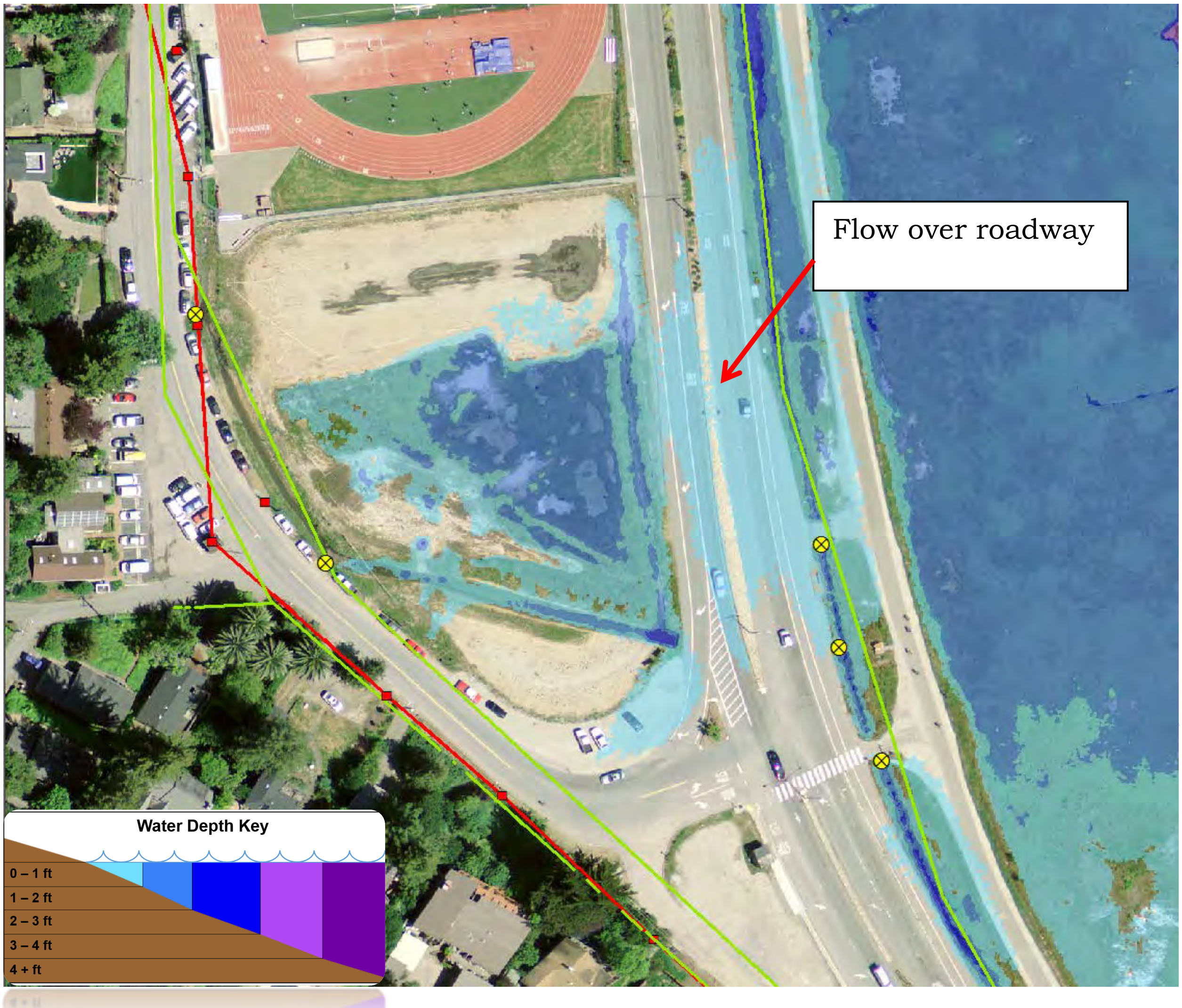

Figure 26: Flood Focus Figure Miller Avenue at Tam High. 12 Inch Sea Level Rise.

Elsewhere along Miller Avenue, the modeled water surface comes up right next to the roadway. Taking into account any additional wave runup, we anticipate that some type of grading or barrier construction will be needed to keep the daily tides from impacting traffic and road conditions. Note that the existing Mill Valley-Sausalito bike path/trail will be significantly impacted under this scenario. As discussed under the alternatives section below, keeping the bikeway in its current location will involve relocation or protection.

Farther up the Mill Valley shoreline, there are some locations where the water level overtops pathways close to Redwood Shores. Dog parks and playing fields along the pathway will also be flooded.

Figure 27: Flood Focus Figure Mill Valley Shoreline. 12 Inches Sea Level Rise.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

Almost the entire extent of Miller Avenue from Blithedale south to the high ground around Almonte Blvd. will experience significant flooding under these two scenarios. Flood barriers and pump stations will be needed. Figures 28 and 29 below show the flooding along much of Miller Avenue that occurs under these scenarios. The darker blue color indicates flood depths of one to three feet.

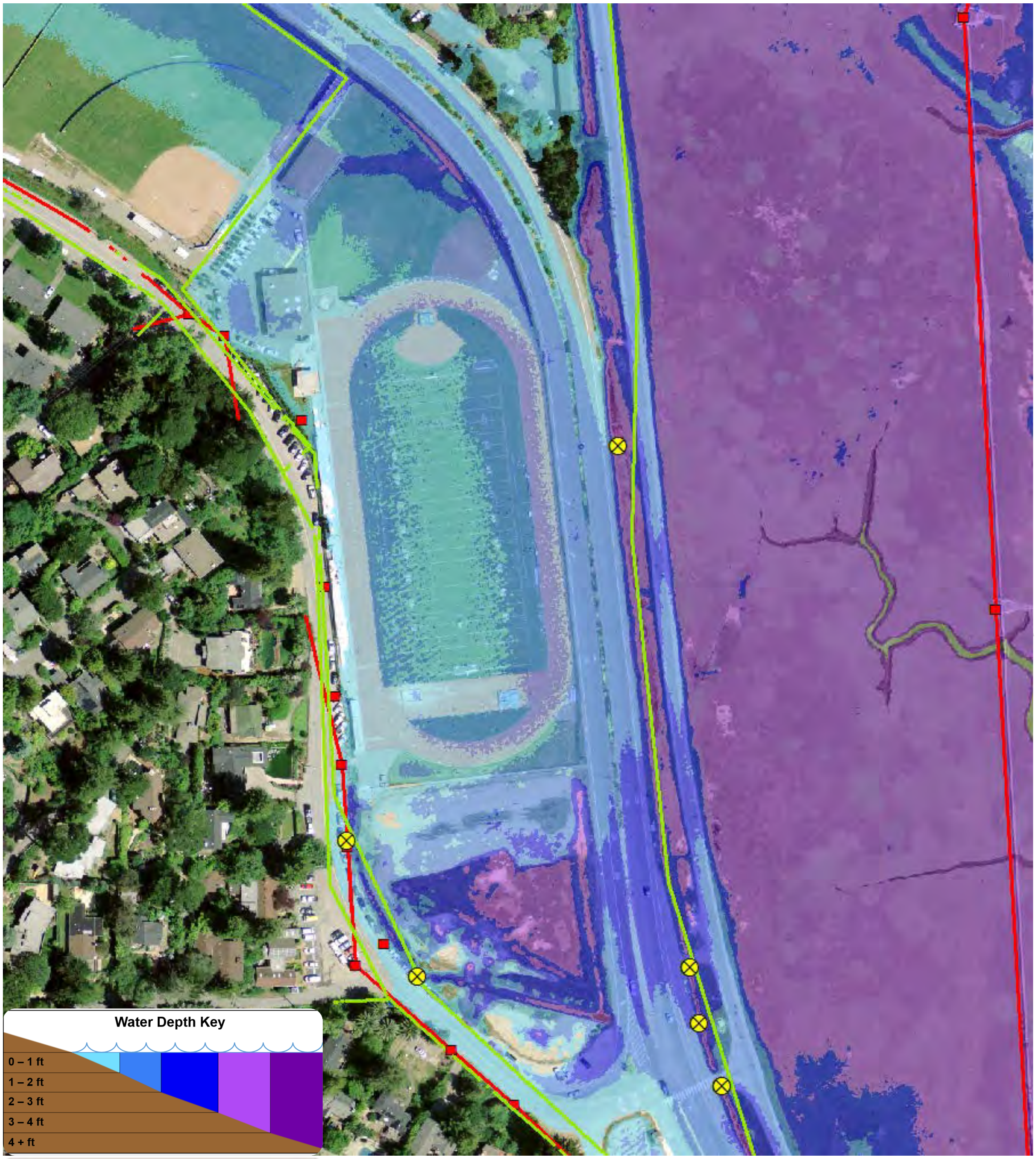

Figure 28: Flooding Across Miller Avenue. 36 Inch Sea Level Rise Assuming No Mitigation Measures; Flooding Depths on the Order of 1 to 2 Feet Across Roadway.

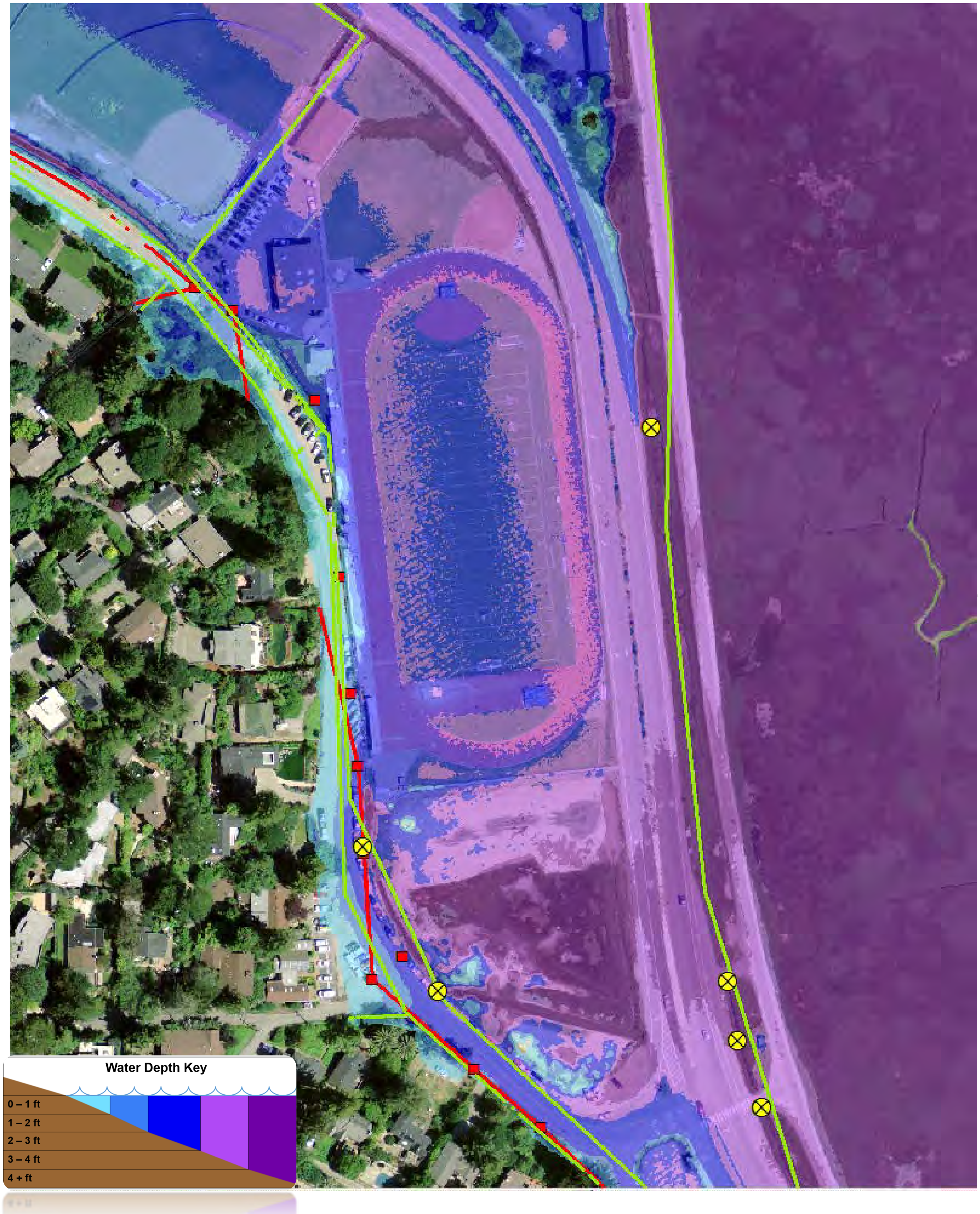

Figure 29: Flooding Across Miller Avenue. 60 Inch Sea Level Rise Assuming No Mitigation Measures; Flooding Depths on the Order of 3 to 4 Feet Across Roadway.

The increased water depths and velocities accelerate shoreline erosion all along Miller Avenue, and along the bike path, ball fields, and parks. Numerous utilities, such as sanitary sewer and storm drain pipes will flood and need to be relocated and raised to allow for gravity drainage.

Redwood Shores will experience increased flooding and loss of access for emergency vehicles during storm events, which will require mitigation.

SASM plant managers have evaluated sea level rise to this depth and determined that with minor grading improvements the plant could withstand this level of rise. This work was included in a study by Carrollo Engineers (Carrollo 2014) that determined that the treatment plant could be protected by building berms and levees. It is our understanding that this study did not look at impacts to the sanitary sewer collection system in terms of increased maintenance or possible increased inflow and infiltration impacts to the system.

REACH 4 – MILL VALLEY SHORELINE EAST

The eastern edge of the Mill Valley shoreline is vulnerable to sea level rise. Both impacts and possible adaption solutions are similar to what is described for Reaches 1 through 3.

This reach is a mixture of public lands with ball fields and fringing tidal marsh shows evidence of shoreline erosion and slump block failures. Several private developments with residential housing condominium complexes are located on the waterfront.

LOCATIONS OF KNOWN FLOODING

The only areas known to flood now are along the undeveloped edges of the fields during very high tide events. We are unaware of flooding to the built infrastructure along the shoreline.

VULNERABLE INFRASTRUCTURE

The infrastructure most critical to protect will be the homes and roadways potentially inundated by direct sea level rise. In particular, an increase in wave impacts under a rising tide could have a significant impact on the docks and homes along the shoreline. Some gravity outfalls may also be backwatered more often, resulting in increased upstream storm drain and street flooding. Turf on the ball and play fields may become more difficult and expensive to maintain, as groundwater becomes more saline and more saline tides impact the fields.

Scenario 1 – 12 Inches Sea Level Rise

The main impact appears to be increased shoreline erosion along the pathways and walking trails. Some private residential structures within Shelter Bay may also be impacted by prolonged flooding, erosion, and impaired gravity drainage.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

The roads and trails adjacent to the bay will flood and the shoreline will erode. Some private residential structures within Shelter Bay will likely flood on a more frequent basis.

The roads and commercial areas adjacent to Shelter Cove will experience direct coastal flooding one to two foot deep.

REACH 5 – SEMINARY MARSH

Seminary Marsh is owned by Marin County Parks and abuts several privately held residential developments. The developed areas of this reach are mostly privately owned and include de Silva Island, a privately-owned development on the bay.

The predominant land use is private residential, public roadways, and commercial facilities located along Seminary Avenue.

LOCATIONS OF KNOWN FLOODING

The primary area in this reach that floods now is Seminary Drive and associated businesses. DPW installed a new pump station in 2012 to help relieve storm drain flooding of local businesses from the roadway off-ramp, but the facility was not designed to pump direct bay flood waters.

VULNERABLE INFRASTRUCTURE

The most vulnerable infrastructure is the businesses along the frontage roadway and 101 off-ramps (particularly Seminary Drive) that will be inundated by direct sea level rise. Some gravity outfalls may also be backwatered more often, resulting in increased upstream storm drain and street flooding.

Scenario 1 – 12 Inches Sea Level Rise

Seminary Marsh will be more consistently and deeply inundated under this scenario. Depending on the available sediment supply, existing marsh habitat may be impacted. For example, deeper and more prolonged inundation could impact certain species that use the low tides to forage for food, but need marsh habitat as a refuge during high tides.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

The roads and commercial areas adjacent to Seminary Avenue will experience extensive direct coastal flooding from the marsh, which will overwhelm existing pumping station capacity. The habitat within the marsh will be impacted, resulting in more erosion and loss of habitat.

REACH 6 - UNINCORPORATED MARIN COUNTY AT STRAWBERRY PENINSULA

Strawberry Peninsula contains bay shoreline along both sides of the peninsula. It is mostly privately owned, with the exception of a couple of parks owned by the Marin County Parks. Much of the Peninsula is at higher elevations, with roadway access at higher elevations, which means that many impacts will be felt only by low-laying property owners.

LOCATIONS OF KNOWN FLOODING

The primary locations of known flooding are the back side of the existing marshes, especially the marsh behind Seminary Avenue. High tides in this area can flood the streets, as well as exacerbate upstream storm drain flooding.

VULNERABLE INFRASTRUCTURE

Many homes and roadways are vulnerable to inundation by direct bay coastal flooding as sea level rises. The increase in wave energy under a higher bay tide elevation would have a significant impact on the docks and homes along the shoreline. Some gravity outfalls may also be backwatered, resulting in increased upstream storm drain and street flooding. Although most homes are elevated above the sea level rise scenario conditions, there are still many parcels that will be directly impacted by direct coastal flooding.

Scenario 1 – 12 Inches Sea Level Rise

Numerous private residences will likely experience impacts to their shoreline properties and boat dock facilities. Some pathways may be difficult to access during high tides. A property-by-property analysis would be needed to assess specific impacts, but in general, nuisance flooding and accelerated shoreline erosion during larger storms from the south would be the most significant impacts.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

Many private residents will experience impacts to their shoreline properties as well as their boat dock facilities. Many of the pathways will be flooded during the daily high tides.

REACH 7 – STRAWBERRY CIRCLE/GREENWOOD COVE

The final reach along the shoreline is the portion of the Tiburon Peninsula that falls within Flood Zone 4. This includes the eastern side of the Strawberry Peninsula, Strawberry Point Elementary School, and the southwest areas of the Tiburon Peninsula.

Much of this reach is private residential, including numerous houses along the edge of the inner Richardson Bay marsh. Strawberry Point Elementary School and its marsh lie within this reach.

VULNERABLE INFRASTRUCTURE

The homes below Tiburon Blvd. are probably the most vulnerable to direct coastal flooding under sea level rise. Wave energies from a rising sea level will also increase flooding and coastal erosion along this reach.

LOCATIONS OF KNOWN FLOODING

The main locations of known flooding are the areas and residences located below Tiburon Blvd. within the current FEMA bay coastal inundation maps. Flooding upstream of Tiburon Blvd. has been reported but is likely due to local riverine conditions and is not the subject of this study.

Scenario 1 – 12 Inches Sea Level Rise

Similar to Reach 6, numerous private residential structures may experience shoreline impacts and increased nuisance flooding. The existing marsh at Strawberry Point Elementary School may experience increased erosion and drowning of current marsh habitats since the levee slopes are steep (approximately 2:1 horizontal to vertical side slopes), with no room for habitat transgression.

Scenarios 2 and 3 – 36 Inches and 60 Inches Sea Level Rise

Similar to Reach 6, numerous private residential structures may experience shoreline impacts and increased nuisance flooding. The existing marsh at Strawberry Point Elementary School will likely experience increased erosion and loss of habitat.

6.0 DIRECT COASTAL FLOOD REDUCTION ALIGNMENTS UNDER SEA LEVEL RISE SCENARIOS

Adaptation planning requires a set of guiding principles and goals and objectives for moving forward. The following are a set of possible starting goals and objectives for the Richardson Bay shoreline that can be used and refined during the planning process:

- Develop a planning process in close coordination with the community and with significant input from the cities and Marin County. To the extent possible, a broad cross-section of community interests should be represented.
- Develop multi-benefit projects that protect both the built and natural environments while also providing for other benefits such as views and recreation.
- Any adaptation plan should be closely aligned with the local topography in order to reduce earthwork and construction costs. Coastal protection is something of a chain and thus is only as strong as its weakest link. To be effective, any direct coastal flooding barrier would have to be continuous across the reach of flooded area and not allow flows around the barrier.
- Evaluate phased adaptation approaches that recognize the time frame of various sea level rise scenarios, adaptation strategies, regulatory frameworks, and financing mechanisms.
- The plan with the highest likelihood of success will be comprehensive and evaluate Richardson Bay as a whole along with the tradeoffs involved in large-scale planning.

6.1 Decide Where to "Limit the Tides" – The Limit of Direct Coastal Flooding (LDCF) Alignment

Planning for sea level rise across multiple jurisdictions and timeframes is complex. While there are multiple approaches for adaptation planning, in this study, we propose that the community and County define a limit line or zone in which direct coastal inundation would be allowed. This could establish a "limit of direct coastal inundation" (LDCF) alignment, or location along the shoreline where the community wants to "hold the line" against direct coastal flooding. Up to this line or zone, the tides and waves would be allowed to ebb and flow unimpeded by human structures. Measures would be implemented to preserve or protect the built environment beyond this zone.

This LDCF limit is a planning tool and can be moved as sea level rises to reflect changes in priorities. It can allow for flooding to occur in one location until a certain rise in sea level occurs and then can be relocated at a higher elevation. In some areas in the figures below, we show several different alignment possibilities.

The set of preliminary alignments shown in the figures on the following pages, and used for developing cost estimates are intended to protect all existing built areas. These costs can then form the basis for adaptation discussions and planning. However, given these costs, the community may decide that it is too expensive to protect some areas and that planned retreat would be the best option. Then, new LDCF lines could be designated farther inland and costs reevaluated.

6.2 Evaluate Adaptation Options

Once a limit line or zone of direct coastal inundation has been developed, various adaptation alternatives can be considered in the context of all the evaluation criteria. In the sections below, we develop a conceptual representation of possible adaptation scenarios. Although we present these scenarios by shoreline segment, the goal of holistic planning is to identify tradeoffs that can agreed-to by the community and then negotiated with the regulatory agencies responsible for protecting the environment. In holistic planning efforts, all parties achieve some—but not all—of their goals. Holistic planning includes a wider range of cost-effective solutions, not just the most reactive solution.

The following section describes the work performed to date to address direct bay coastal flooding and then evaluates potential adaptation scenarios at the broad-brush level to further discussion.

This study looks at examples of alternatives that address direct bay coastal flooding. We have addressed only direct bay coastal flooding and have not included riverine flooding and storm flows from the watersheds; although we have estimated the costs of new pump stations behind barrier type solutions. For this order-of-magnitude estimate, we focus on protect-in-place engineering solutions along with soft engineering approaches such as beaches and horizontal levees in certain locations where they are deemed appropriate.

While this study focuses on developing engineering alternatives to estimate costs, this does not mean that we consider the other categories of adaptation options in the toolbox (i.e., wetlands, planned retreat, structure rebuilding) to be less valid or unsuitable for Richardson Bay. Quite to the contrary, we expect that the costs developed in this study can be used in subsequent cost-benefit assessments of hard engineering protection versus planned phased retreat or rebuilding of the shoreline. Through the community planning process, the costs and impacts for various alternatives would be assessed and a comprehensive plan developed that maximizes benefits at manageable cost.

LDCF ALIGNMENT ASSUMPTIONS

We lay out multiple alignments within several of the reaches as examples of possible locations where a barrier could be built and examine the various cost implications and tradeoffs. The alternatives developed are just examples; many other LDCF alignments could be drawn and evaluated. The final selection of any barrier location should be developed as part of a larger community planning process. That said, we believe it is helpful to outline possible alignments so that community members can respond to options to evaluate trade-offs in terms of protection of vulnerable urbanized areas against factors such as costs, habitat values, aesthetic impacts etc. (see criteria above). The costs for various alignments vary and may be large, so analysis of evaluation of trade-offs are going to be an important part of long-term planning for adaptation around the shoreline. Developing a holistic shoreline plan allows for trade-offs in terms of protection of some areas and perhaps retreat and creation of new wetland habitats in others. It is not our intent to suggest who would be responsible for paying for any particular alignment but rather to lay out some options to stimulate discussion of pros and cons and trade-offs.

6.3 Conceptual Cost Estimate Assumptions

12 INCH RISE IN SEA LEVEL (2030-HIGH ESTIMATE) COASTAL FLOOD BARRIER SCENARIO

A 12 inch rise in sea level would equate to the present day (2015) king tide event, but would occur daily as the new mean higher high water (MHHW) condition. Nuisance flooding would increase significantly as the regular tides equal or exceed the MHHW elevation at least once per day. This higher year 2030 MHHW tidal elevation would result in daily roadway and backwater storm drain flooding, as well as increased shoreline erosion.

We present estimates for a selection of additional adaptation design elements, such as pump stations and wetlands enhancements, that will likely be included—and probably required by regulatory agencies—as part of any final design effort. These additional elements are included in the cost estimates below and are not meant to be complete or comprehensive.

Since this alternative addresses only a one-foot rise in water level, in general, any direct flood barrier would need to be just a few feet high—although the exact height will depend on existing ground elevation. We anticipate that the top barrier elevation designed to block the higher storm tides would be built to a minimum of +10 feet NAVD88 and in some locations up to +11 feet NAVD in order to account for some wind-wave runup (see Table 3).

LIMIT OF DIRECT COASTAL BARRIER ALTERNATIVES FOR 12 INCH SEA LEVEL RISE SCENARIO

REACH 1 - MARIN CITY TO COYOTE CREEK

Reach 1, from Marin City to the south end of Coyote Creek, includes the Caltrans Manzanita parking areas that have been subjected to some of the most consistent and significant existing sea level rise flooding along the San Francisco Bay shoreline. This reach is very narrow, consisting of only the roadway separating the bay from the steeper hills except in the area of the shopping center.

Under this scenario, we have shown the following two alignments (Figures 30 and 31):

- Alignment 1 winds around the built edge of the shoreline and extends to include many of the properties farther out into Richardson Bay. This alignment protects private property along the boat docks and commercial areas that are currently above water.
- Alignment 2 generally follows the public right of way along the shoreline frontage road and does not protect the private businesses along the boat docks and commercial buildings. But, as shown in Table 7, it is located primarily in the public right of way so can likely be built more easily, without acquisition costs.

Additional Flood Protection Elements

In addition to the proposed barrier, we include costs for the following flood protection elements:

- Two new stormwater pumping stations located in the Caltrans Manzanita parking area. Only relatively small pumps are needed for this flooding situation. We deemed costs for backup power generators unnecessary since only roads and parking areas will be flooded. These assumptions are subject to change under future analysis.
- A small stormwater pump station has been shown at the south end of the reach between the interchange and the bay. This location is not shown as impacted by direct coastal flooding since it has already been identified as an area that floods from backwaters.
- We assumed that two new tide gates with headwalls would be installed at the outlet of the drainage culvert from the Marin City pond and drainage pipes into the bay for Alignment 1, and that three would be installed under Alignment 2.
- Some costs were included under the "other" category for a gate or for raising grades along the bike path. No costs were included for raising or altering the existing bridge but may need to be added during future design steps. The "other" category is intended to capture some miscellaneous known costs but is not a comprehensive listing of all potential "other" costs.

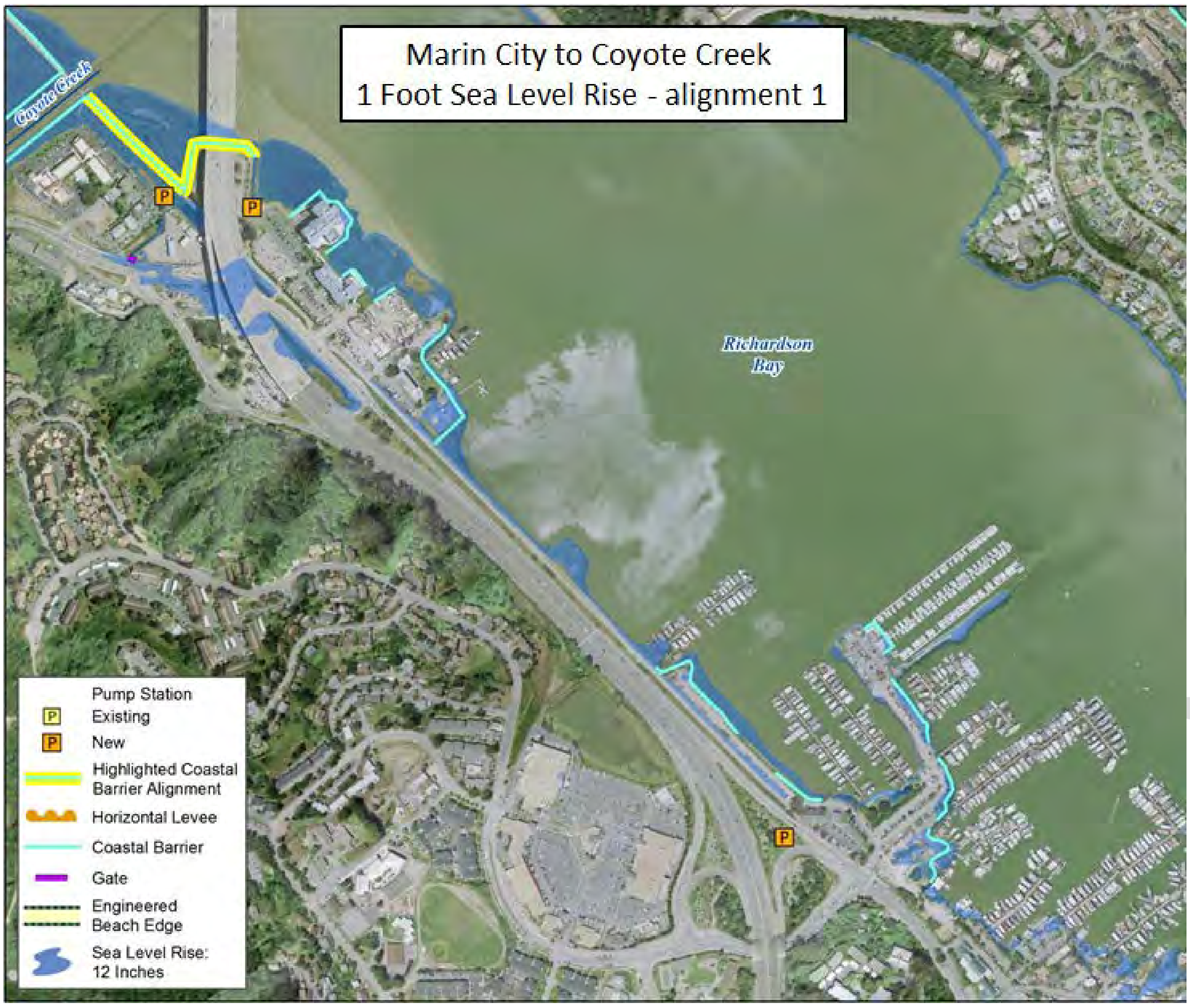

Figure 30: Reach 1, Alignment 1. Extent of Direct Coastal Flooding Barrier 12 Inch Sea Level Rise Scenario.

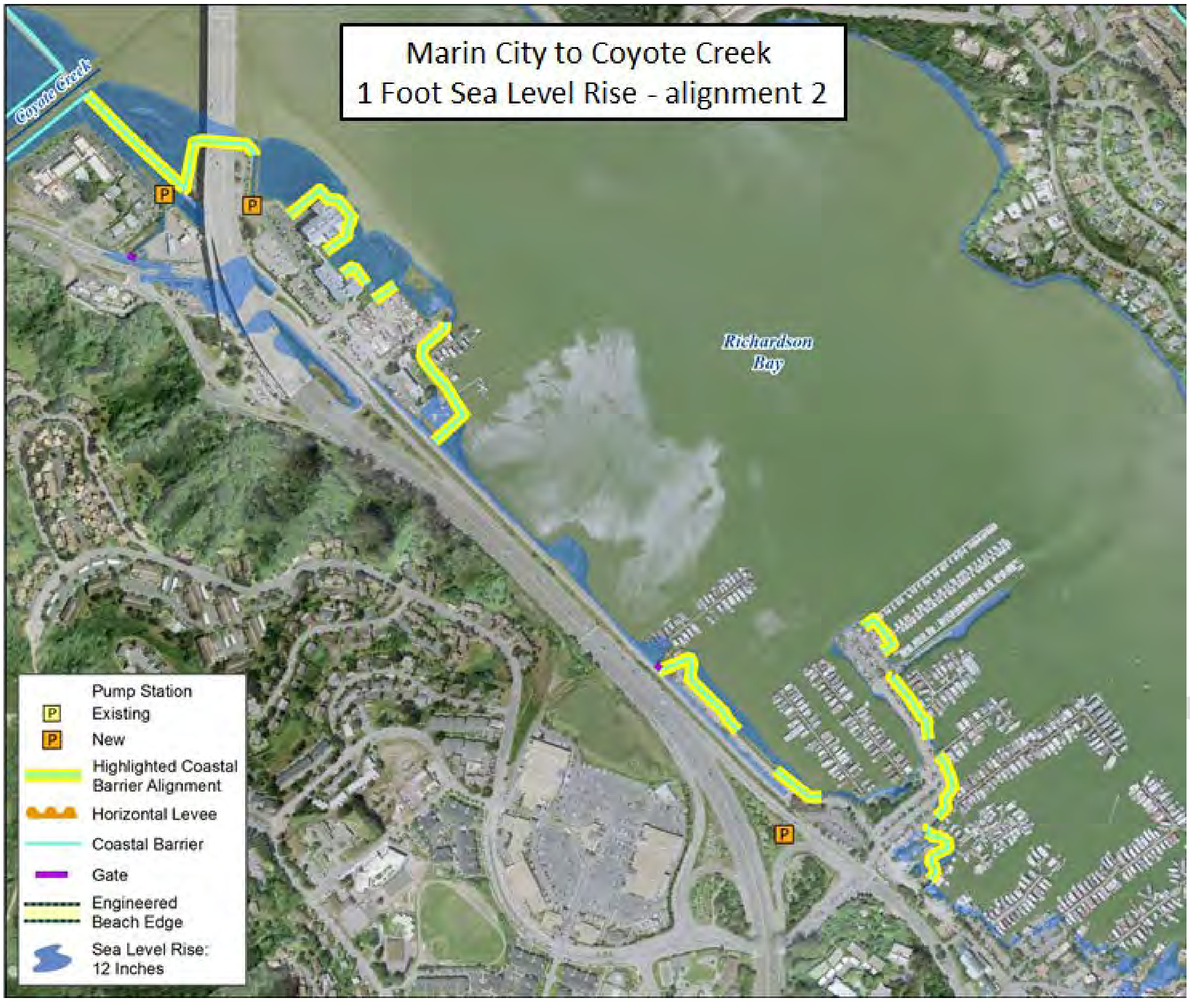

Figure 31: Reach 1, Alignment 2. Potential Limit of Direct Coastal Flooding Barrier Alignment.

Note that the modeled water level comes up to the edge of the trail/roadway in several locations: this area may or may not need a barrier. Given that these modeled water levels are static and do not account for wind-wave runup, we developed both a minimum and maximum barrier length for these areas to protect some pathway/roadway areas that may be overtopped. This minimum to maximum estimate is reflected in the alignment lengths with a low to high range.

Table 7. Reach 1 Alignment Lengths.

Reach 1	Public ROW (feet)	Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	1,863	---	1,863	0
Alignment 2	3,007	---	3,007	1 (high tide gate at bike path bridge into Bothin Marsh)

REACH 2 - COYOTE CREEK AND BOTHIN MARSH COMPLEX

We developed the following two potential LDCF barrier alignments for this reach:

- Alignment 1 is drawn along the edge of built areas, including pathways that show inundation under this scenario.
- Alignment 2 includes potential additional length of barrier to include the popular Mill Valley Sausalito bike/pedestrian pathway. Again, the type of barrier solution is not specified with any alignment, and could include raising the pathway, relocating (rerouting) the pathway landward (westward), or building a barrier such as a wall or levee in front. All of these solutions would be developed as part of the planning process.
    - A new high tide muting gate structure would need to be built at the existing bridge into Bothin Marsh. Over time, it would mute the tides in the marsh and impact habitat.
- For both alignments we include costs for enhancing Bothin Marsh grades by placing sediment in the marsh to maintain marsh elevations. This added sediment will help bolster the marsh against additional wave attenuation and prepare its back side to be raised to combat future sea level rise.

Additional Flood Protection Elements

In addition to the proposed barrier, we include costs for the following flood protection elements:

- We assumed a 1,000-to-1,500 foot long, low horizontal levee would be needed along the back side of Bothin Marsh, as shown. For this scenario, the horizontal levee would be low but built wide enough at the base to allow for raising over time as (or if) the bay tides rise.
- We included a small reach of engineered bay beach along the actively eroding Bothin Marsh.
- We assumed that approximately 1,000 linear feet of rock rip-rap will be needed along the creek's right bank near its mouth (not shown).

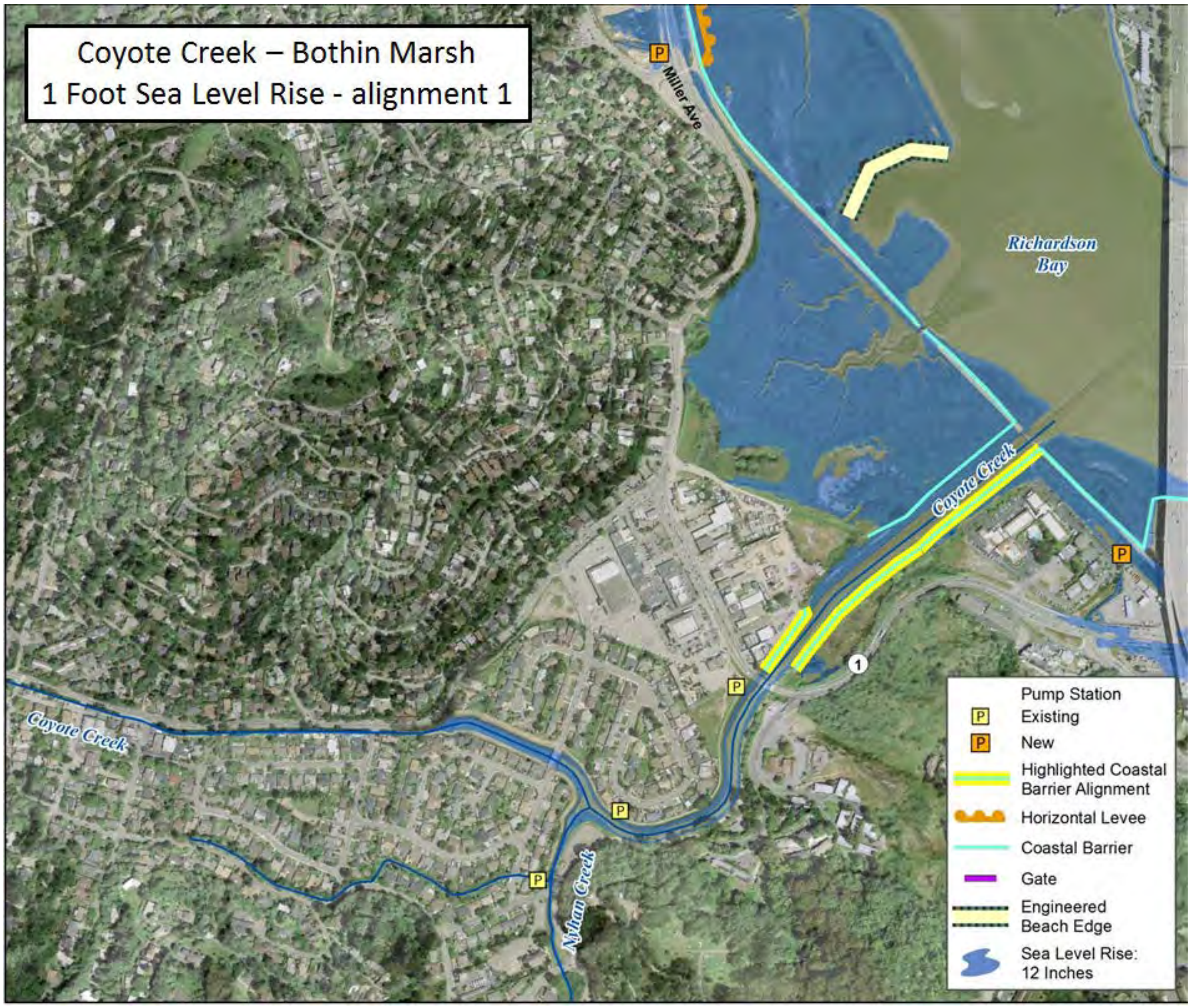

Figure 32: Reach 2, Alignment 1. Possible Limit of Direct Coastal Flooding Barrier Alignment.

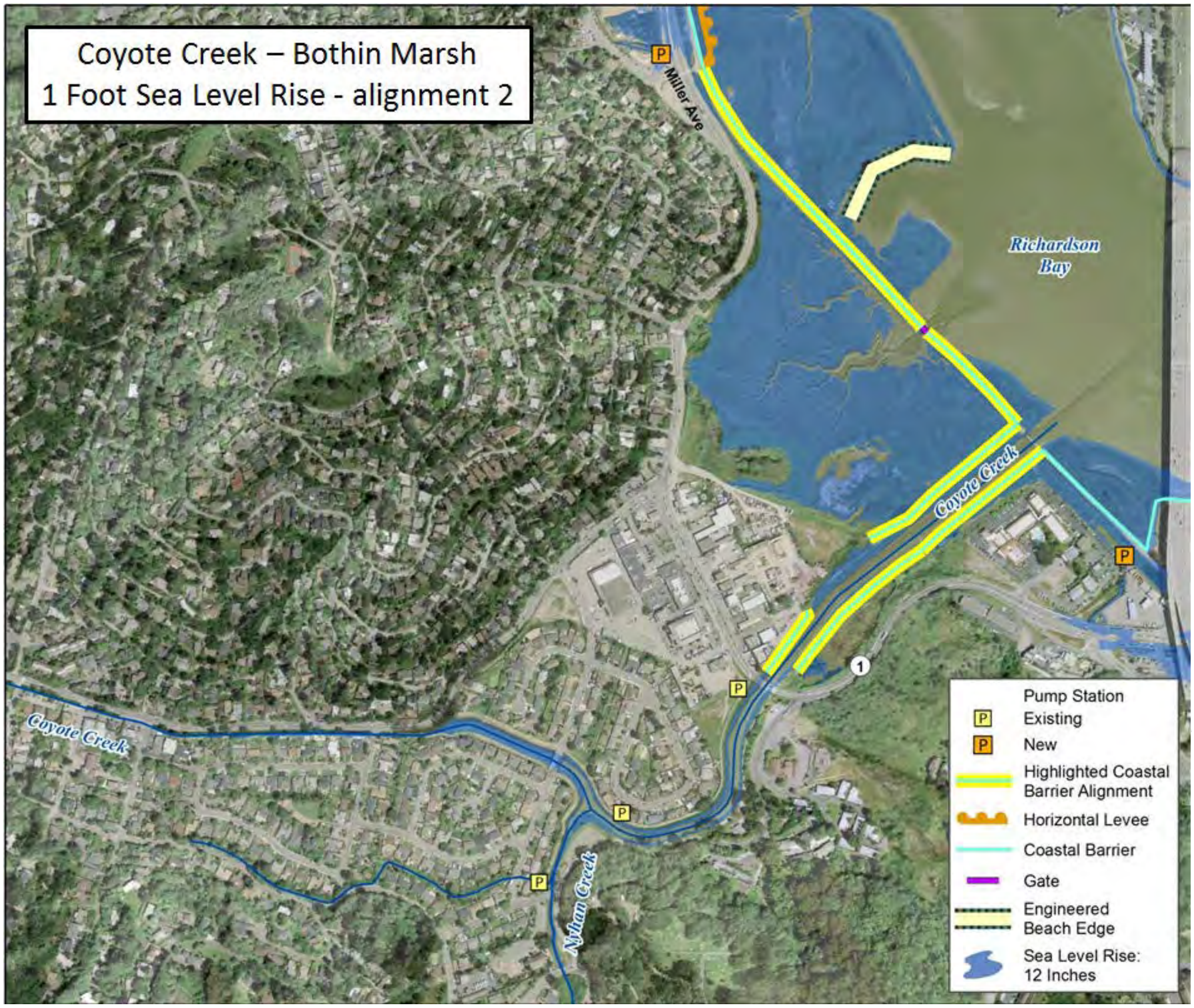

Figure 33: Reach 2, Alignment 2. Possible LDCF Barrier Alignment.

Table 8. Reach 2 Alignment Lengths.

Reach 2	Public ROW (feet)	Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	1,863	---	1,863	0
Alignment 2	3,007	---	3,007	1 (high tide gate at bike path bridge into Bothin Marsh)

REACH 3 - MILL VALLEY SHORELINE WEST

For this reach, we developed two potential barrier alignments to address areas of the built environment shown as flooded during high tides.

- This reach requires a low barrier along the edge of Miller Avenue to inhibit flooding of this important transportation route, which is currently flooded during king tides. In most areas, this barrier would be relatively low and could likely be built with earthen berms and grading modifications or with a low floodwall. Maintaining wetlands at high marsh elevations or constructing higher elevation transition zone habitat would enhance the flood protection benefits of the wetlands and reduce any wall height requirements.
- The difference between the minimum and maximum alignment length reflects some additional length that would address high tide flooding at the dog park. This protection is optional since structures are not flooded. However, this is a heavily used walking trail, so some level of protection is advisable and has been included.
    - Alignment 1 minimum value is drawn along the edge of built areas.
    - Alignment 1 maximum value adds more length of high tide barrier to protect public areas of the trail along the Mill Valley dog park that show inundation at high tides.

Other Flood Protection Enhancements

- Two small pump stations with headwalls and tide gates have been included at Miller and Almonte and at Miller and Camino Alto to reduce flooded areas along Miller Avenue. These pump stations were identified in the Winzler & Kelly 2007 study. We advise leaving enough space around each pump station to allow for expansion as sea levels rise.
- We include costs for enhancing tidal marsh by adding fill to raise marsh elevation (setting the stage for the full "horizontal levee") and for building coarse-grained beaches along the edge of the marsh to inhibit wind-wave erosion. This work will also prepare areas along Miller Avenue for being raised to protect the roadway in its current location. Again, retreat was not explicitly considered for this study, but the costs developed can be used to evaluate the economics of protect-in-place versus relocation and retreat of critical infrastructure.
- We included a length of engineered, coarse-grained bay beach treatment at known locations of shoreline erosion to provide for wind-wave protection under these levels of sea level rise.

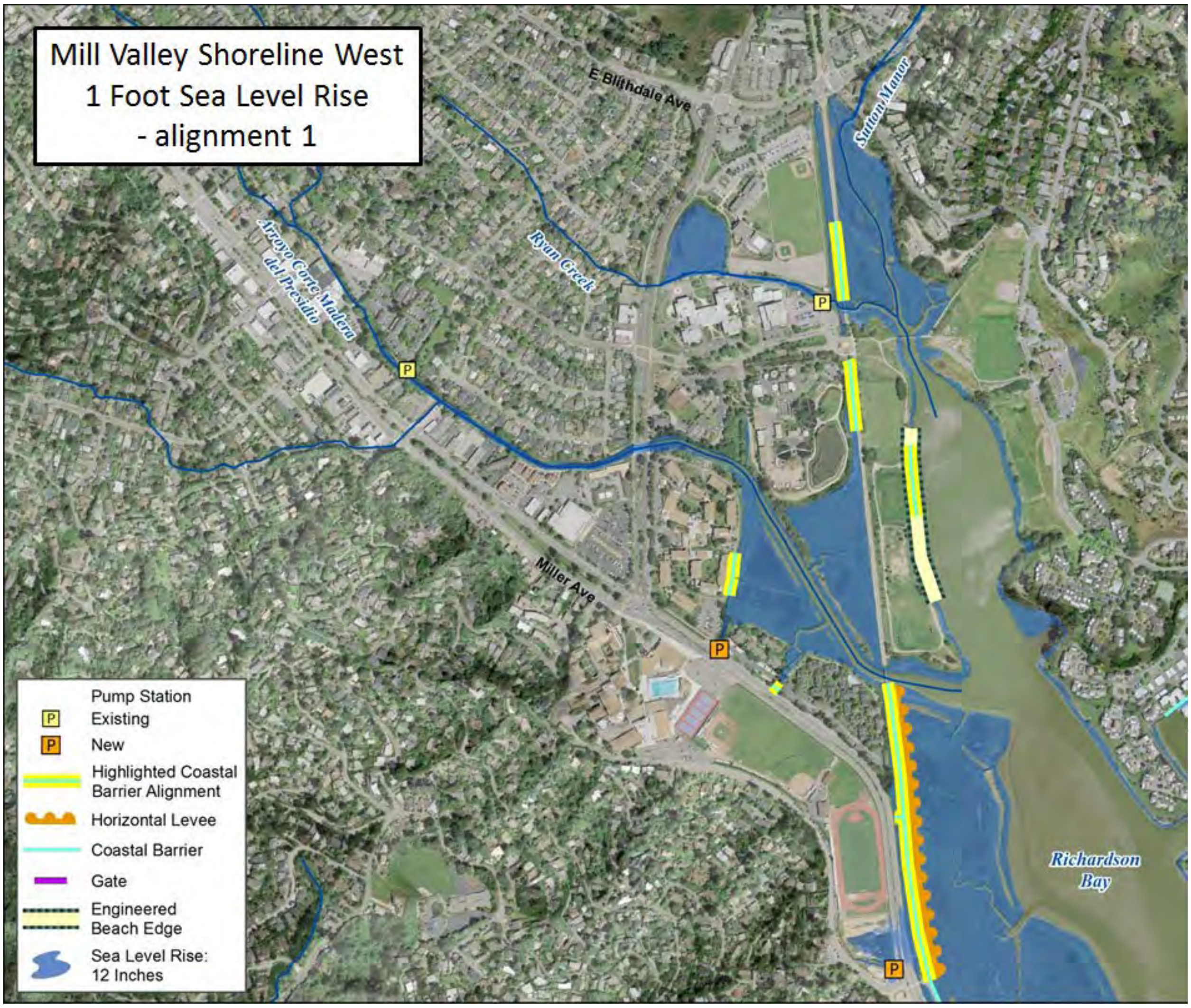

Figure 34: Reach 3, Alignment 1. Possible LDCF Barrier Alignment.

Table 9. Reach 3 Alignment Lengths.

Reach 3	Public ROW (feet) min to max	Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	2,660 to 3,045	386	3,046 to 3,431	2

REACH 4 – MILL VALLEY SHORELINE EAST

One foot of sea level rise could cause trails and shoreline in this reach to erode, potentially impacting some of the private residential development in Shelter Bay. Most of the modeled areas impacted under this scenario are on private property.

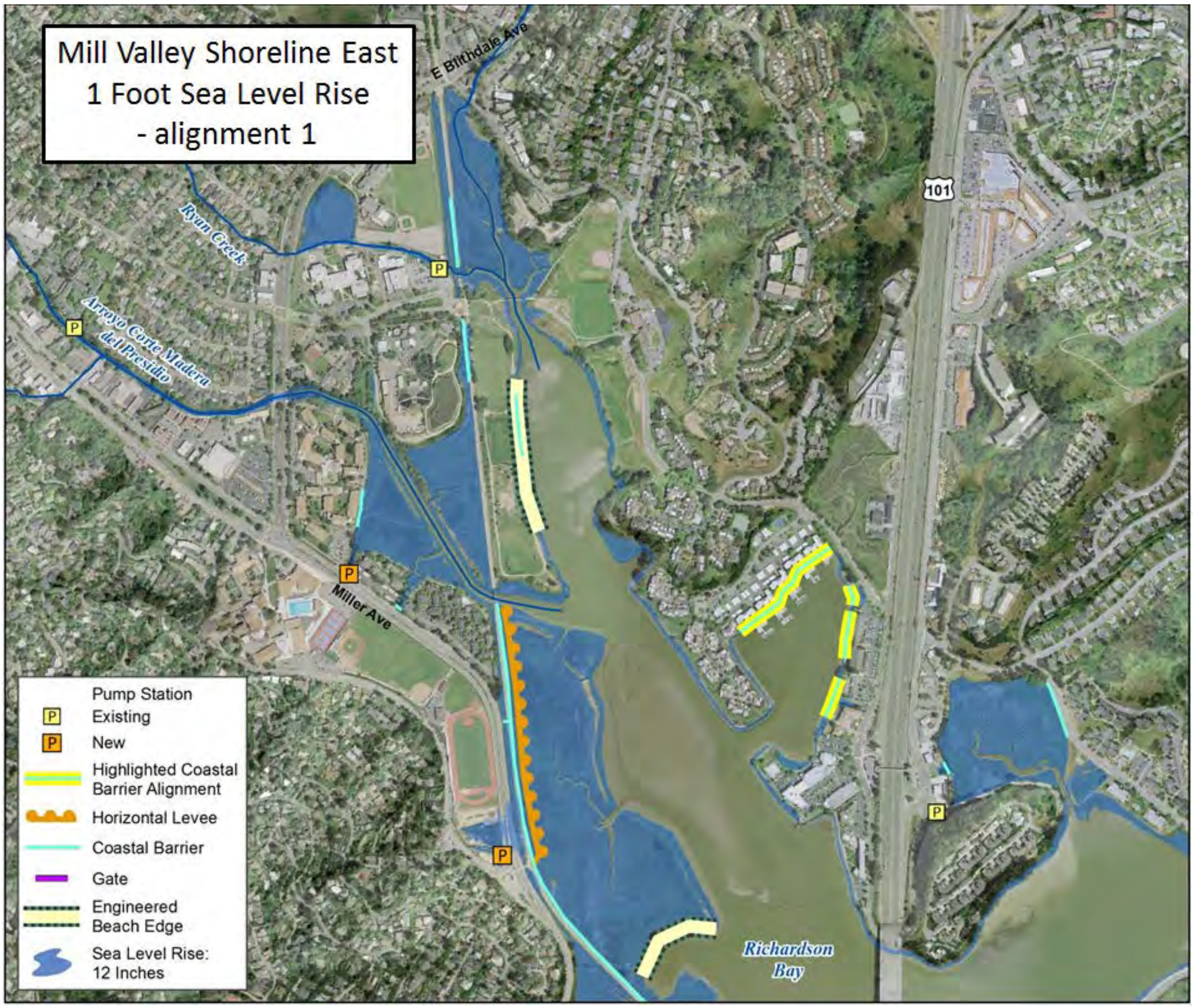

Figure 35: Reach 4, Alignment 1. Possible LDCF Barrier Alignment.

Table 10. Reach 4 Barrier Lengths.

Reach 4	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	---	1,468	1,468	0

REACH 5 – SEMINARY MARSH

One foot of sea level rise could cause nuisance flooding of commercial areas and roadways. All of the impacted areas are on private property.

Figure 36: Reach 5, Alignment 1. Possible LDCF Barrier Alignment.

Table 11. Reach 5 Barrier Lengths.

Reach 5	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of New Hydraulic Gate Structures
Alignment 1	---	362	362	0

REACH 6 - UNINCORPORATED MARIN COUNTY AT STRAWBERRY PENINSULA

One foot of sea level rise could cause trails and shoreline to erode, potentially impacting private residential properties along the Strawberry Peninsula. All of the impacted areas are on private property.

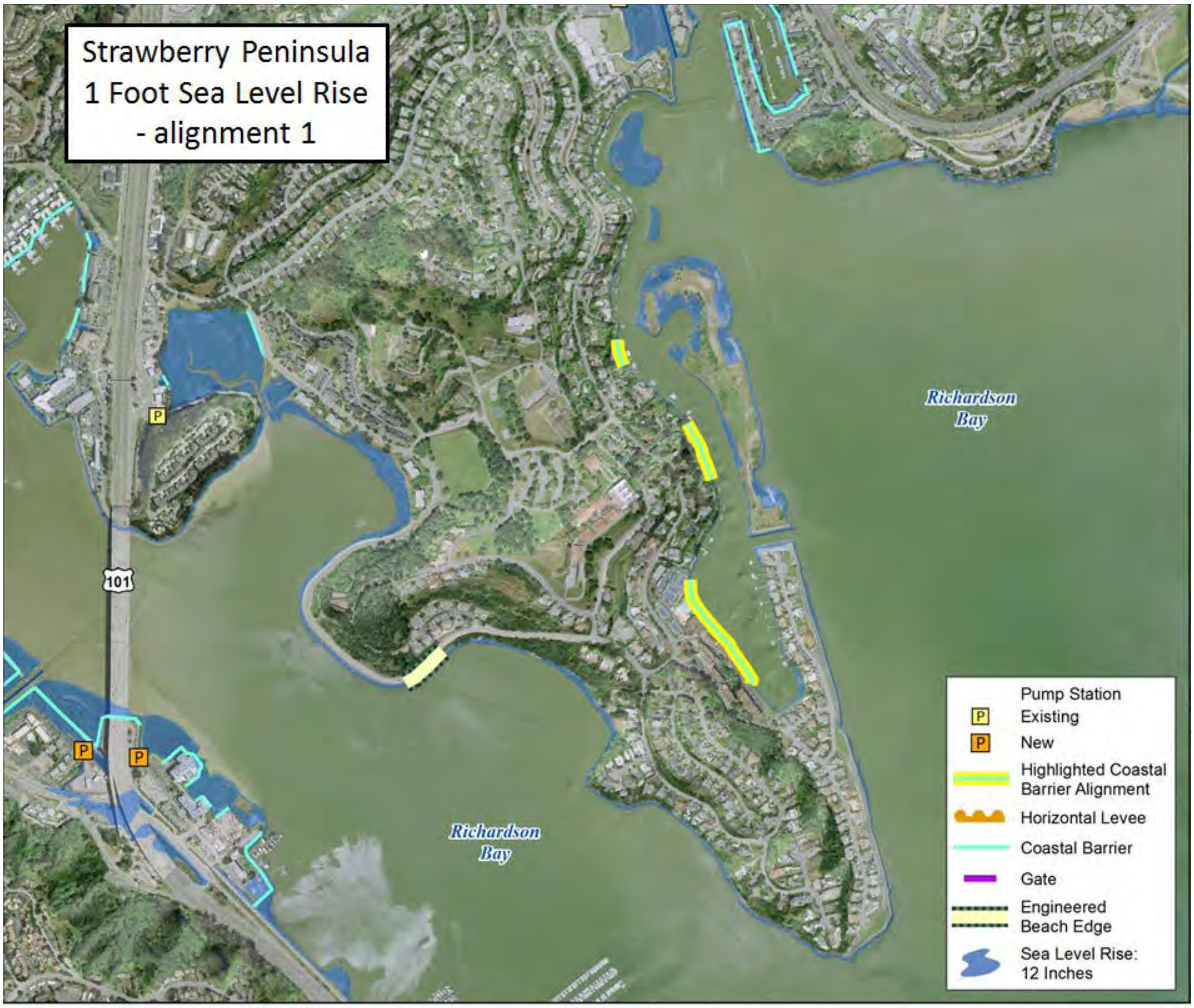

Figure 37: Reach 6. Possible LDCF Barrier Alignment.

Table 12. Reach 6 Barrier Lengths.

Reach 6	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	---	1,638	1,638	0

REACH 7 – STRAWBERRY CIRCLE/GREENWOOD COVE

We developed a single alignment where the model showed flooding of roads or properties. All of the impacted areas are on private property. We did not study impacts to specific properties since they are beyond the scope of this study. For developing the approximate cost estimate, we assumed that the soils would be adequate for wall construction, but actual soil condition is unknown.

Figure 38: Reach 7. Possible LDCF Barrier Alignment.

IMPACTS TO UPSTREAM FLOODING

The barrier layouts for this reach are not as continuous along the shoreline as in other alignments, so it is likely that the upstream stormwater drainage system can be reconfigured to provide gravity drainage. Those details were not developed in this study.

36 INCH AND 60 INCH RISE IN SEA LEVEL COASTAL FLOOD BARRIER SCENARIOS

The alignments for the different reaches presented in this section correspond to 36 and 60 inches of sea level rise. These scenarios of sea level rise represent a serious increase in flood risk and will require mitigation to avoid impacts to the shoreline and built infrastructure. We selected these values of sea level rise as a reasonable estimate to use for assessing impacts and planning for mid- to late- century adaptation.

Thirty-six inches of sea level rise will result in extensive flooding of built areas and roadways. This level of sea level rise will require adaptation, consisting of barriers and/or relocation and retreat of critical utilities and infrastructure from flooded areas.

A 60 inch increase in bay tide level increases the depth of flooding and results in more flooded areas of shoreline and infrastructure. Given the geography of the bay, the aerial extent of barrier options is approximately the same as the 36 inch inundation results although in some areas the length of barrier is increased. However, the elevation, impacts, and costs for any flood barrier would be significantly increased. It is likely that substantial fill will be needed to maintain wetland and transition zone elevations to grades that can help provide flood protection. This level of sea level rise increase is very substantial, and the potential impacts and costs are approximate at this stage, but they will be great. We emphasize that only barrier option costs were developed and other potential solutions, such as raising properties or managed retreat, were not developed. However, they should be considered when developing any final plan for the area.

This section looks at two different alternatives for addressing impacts to the shoreline from higher levels of sea level rise in the bay. Alternative 1 evaluates the idea of a large tidal barrier across the mouth of the bay, which has been proposed by at least two different proponents. Alternative 2 continues the previous approach of land-based alternatives along the shoreline.

ALTERNATIVE 1 –RICHARDSON BAY TIDE BARRIER(S)

Two concepts have been proposed for a high tide barrier across Richardson Bay. Both concepts are at the early concept-level phase of planning and to our knowledge neither proposal has undergone design engineering or cost estimating. The first proposal by Mill Valley Council member Gary Lions would install a high tide barrier anchored to the Caltrans Highway 101 bridge foundation to mute the higher tides within inner Richardson Bay and is called the Richardson Bay Bridge Tidal Barrier (RBBTB). The design concept has not been fully developed but could consist of inflatable dams, a sheet pile lock and gate system, or some other unspecified type of tide barrier. The system would include a modern gate opening and closure control system. The RBBTB is based on known marine design principles. The second proposal is by a local architect Liz Ranieri (Kuth-Ranieri Associates) and called “Folding Waters” and would construct a high tide barrier structure farther out into Richardson Bay (Figure 39). That structure concept design would be supported by a foundation installed in bay muds, and would include a new screw-type gate control system along with a lock for boat passage. Very few engineering design details are provided but FoldingWaters is proposing to use new and relatively unproven barrier system and as such is harder to evaluate.

We assumed that a flood barrier of this size and cost would only be required for the 36 inch and 60 inch scenarios, so they are discussed here and not under the 12 inch scenario alternative above. However, the same approximate costs apply to any scenario, so this alternative could be developed further at any time.

Both proposals are in the concept stage, and no preliminary cost estimates have yet been developed by the proponents. Since a barrier of this type would reduce the need for land based shoreline adaptation measures, the costs for these two proposals are shown separately as “water-based” adaptation solutions. However, as shown on Figure 39, the RBBTB concept plan would “protect” a smaller length of shoreline reach and thus does also require land based adaptation structures in addition to protect areas outside of the gate. However, the RBBTB is proposing to use the existing footings of the CalTrans Highway 101 Bridge to anchor the gate and thereby, if feasible, would greatly reduce its construction costs. In concept, another benefit of the RBBTB would that it may allow for storage of riverine floodwaters in the drained area behind the barrier, potentially reducing upstream riverine flooding, however, no volume calculations have been performed to quantify the extent of the benefit. The FoldingWaters gate would have to be self- anchored in the muds of Richardson Bay and would therefore, likely require a deeper and more expensive foundation.

Permitting these large barriers will require extensive analysis and modeling and will likely be very difficult under the current regulatory framework. Such barriers are likely to impact fish passage and water quality in the portion of Richardson Bay behind the structure as water levels rise and the gates close more and more frequently to avoid high tide flooding. Note that solutions of this type set up a New Orleans levee type-situation where people behind a barrier come to rely on its level of protection and thus public agencies are then legally required to maintain this level of protection (known as “moral hazard”). Therefore, cities and counties would be obligated to improve and maintain the barrier under all future levels of sea level rise. It would be very difficult legally to declare that at a certain point in the future, the barrier would be abandoned and large protected areas would be allowed to flood. So it is important to note that building such large tidal barriers is a course of action that would not be easily reversed in the future.

The top of barrier elevation is a critical design parameter. This elevation sets the barrier height, level of flood protection, cost, and potential consequences in the event of failure. Neither barrier design has been finalized to this level of detail as far as we know. It is possible that barriers of this type would have to be built to the 100-year tide flood level plus freeboard—otherwise it would be overtopped during storm events with plunging flows and potential scour impacts to the foundation, however, the design and permitting requirements of this type of barrier are unknown. If the barrier is intended to meet FEMA certification, its elevation would have to be in accordance with Table 3, or to a minimum elevation +15 feet NAVD and +17 feet NAVD for 36 and 60 inches of SLR, respectively. Since sea level rise won't end in 2100, it is likely that the regulatory agencies would require a plan or design for sea level rise values for barriers of this type for beyond the 2100 time frame of this study.

In informal discussions, the proponent for one of proposed barriers (RBBTB) initially proposes to build their barrier to an elevation of approximately 14 ft. NAVD88 to contain the MHHW tide plus an allowance for sea level rise and some freeboard. There would be the potential for some high storm flows to overtop the barrier under future sea level rise conditions. We do not know if this design approach of allowing for high flood flow overtopping is acceptable to either design engineers or the permitting agencies as the design is in its early stages.

Figure 39: Locations of Two Proposed High Tide Barriers at the Entrance to Richardson Bay.

Note: All land-based adaptation barriers required to complete shoreline protection outboard of tide barriers not shown.

Table 13. Richardson Bay Entrance Tide Barrier Lengths.

Tidal Barrier	Approximate Total Length (linear feet)	Proponent Concept Description
Richardson Bay Bridge Tidal Barrier	2,000 plus land based land based floodwall/levee connections to high ground Also requires land based floodwalls/levees for reaches outside of barrier	Initial concept is for a dam that would be inflated at higher tides although the design is flexible to incorporate whatever type of device can work. The gate foundation would be tied to the Caltrans 101 bridge structure, which would need Caltrans approval. Barrier protects vulnerable areas within the 101 bridge structure area but not the outer areas of Richardson Bay. Proponent plans to protect against new MHHW tides plus some level of SLR and may allow for overtopping during storm events. However, the design is flexible.
"Folding Waters" Barrier	2,300 plus land based connection to high ground	Concept is for a mechanical screw gate mechanism that engages at higher tides—intended to generate its own power. Requires its own foundation. Includes a lock for boat access. New and unproven technology.

Estimating costs for barrier so this size is difficult and depends on many factors, especially the depth and type of foundation. One approach is to use estimated costs for these tidal barriers using guidelines from NOAA and the costs of similar, albeit smaller, tidal barriers installed in Europe. The European barrier costs are summarized below. They were taken from Wikipedia and responses from a sea level rise adaptation internet group and are not meant to be a comprehensive or in-depth evaluation of these structures. We have also included the cost estimate for tide barriers from NOAA's report (NOAA Eastern Research Group 2013). Note that the NOAA and European barrier costs are very high and may reflect increased costs for their local conditions of potentially deeper water and in flowing rivers. We have also included very rough costs for a barrier that would be constructed with sheet piles walls and with tainter gate (adjustable) structures to allow for water inflow and outflow. Given the complexity of these structures, improved cost estimates will require additional design work by qualified marine engineering consultants.

Note that the RBBTB proponents believe the costs will be less than estimated using the NOAA or European gate analogues (Table 15 below) for several reasons: the proposed tide gate structure will be more of a wall then the highly controllable European gates; foundation costs will be greatly reduced by anchoring the gate into existing Highway 101 bridge supports or because the depth of Richardson Bay is relatively shallow; and this gate is proposed to contain only the new MHHW tides (not storm flood driven tides), so the top elevation is lower (of course, this means the barrier will be overtopped at storm tides which may cause structural issues). As such, the project proponent believes the costs for RBBTB will be in the tens of millions of dollars and not hundreds of millions estimated using the above parameters. However, since there is no current design or cost estimate and it is unclear if CalTrans will even consider allowing a high tide structure to be anchored to their bridge footings, we have shown these reference costs in Table 35. But it should be noted that these cost are very approximate since there are many unknowns.

Table 14. Reference Costs for Large Tidal Barriers.

Barrier	*Length (feet)*	*Capital Cost ($ and Year)*	*Maintenance Costs (estimate)*	*Notes*
Thames	~1,700	$2.24BD (2001 costs)	Unknown – but large	High maintenance cost and issues
Maeslantkering	~1,300	~$780MD (2001 costs)	Unknown – but large	High maintenance cost and issues
NOAA Cost Guidelines	~2,000	$0.2MD to $1.1MD per LINEAR FOOT	Used 2% and 5% of capital costs – half of what NOAA report	Costs from NOAA report are in line with actual costs from European

			suggests using	barriers.
Sheet Pile Wall with Tainter Gate Flow Structures	~2,000	Estimated at $60MD to $100MD	unknown	Estimated costs for sheet pile walls assuming a relatively shallow depth of embedment into the underlying bay muds

ALTERNATIVE 2- LAND BASED ADAPTATION ALTERNATIVES

In this section we evaluate land-based alternatives to adapt to 36 and 60 inches of sea level rise. The flood protection design elements such as pump stations and wetlands enhancement features developed under the 12 inch sea level rise scenario have been incorporated into these alternatives and expanded and upsized to handle the additional flows and water surface elevations anticipated under these higher tide conditions. Some additional and expanded pump stations are included in the cost estimates, but are by no means complete. There will certainly be miscellaneous design costs that are not considered at this stage of the project; for example, connecting an engineered barrier to existing roads and bridges may require reconstructing and raising grades at barrier crossing locations.

REACH 1 - MARIN CITY TO COYOTE CREEK

With 36 inches of sea level rise, much of this reach is continuously flooded, including significant flooding at the Caltrans parking lot and shoreline highway roadway at Highway 101 at Manzanita.

Similar to the previous scenario, we have shown the following two alignments (Figures 40 and 41):

- Alignment 1 winds around the built edge of the shoreline and extends to include many of the properties that extend farther into Richardson Bay to protect private property along the boat docks and commercial areas that are currently above water.
- Alignment 2 generally follows the public right of way along the shoreline frontage road and does not provide protection for the private businesses along the boat docks and commercial buildings. But as shown in Figure 41,

this barrier is located mostly in the public right of way, so it can probably be built more easily, without acquisition costs.

Overall, any barrier would have to be built to at least an elevation of approximately 9 feet NAVD88, just to block MHHW, which would still allow higher tides to overtop. To provide a consistent level of protection, the barrier would have to be built to elevation +10 or +11. To protect the community from storm-driven tides, a barrier of at least +12 feet NAVD or higher would be necessary.

Additional Elements:

For these alternatives, we assumed new and larger pump stations in the same locations as in the 12 inch sea level rise scenario, plus an additional pump station in the Marin Pond location. At locations we identified as most appropriate, we included horizontal ecotone levees built to a higher elevation than the previous scenario.

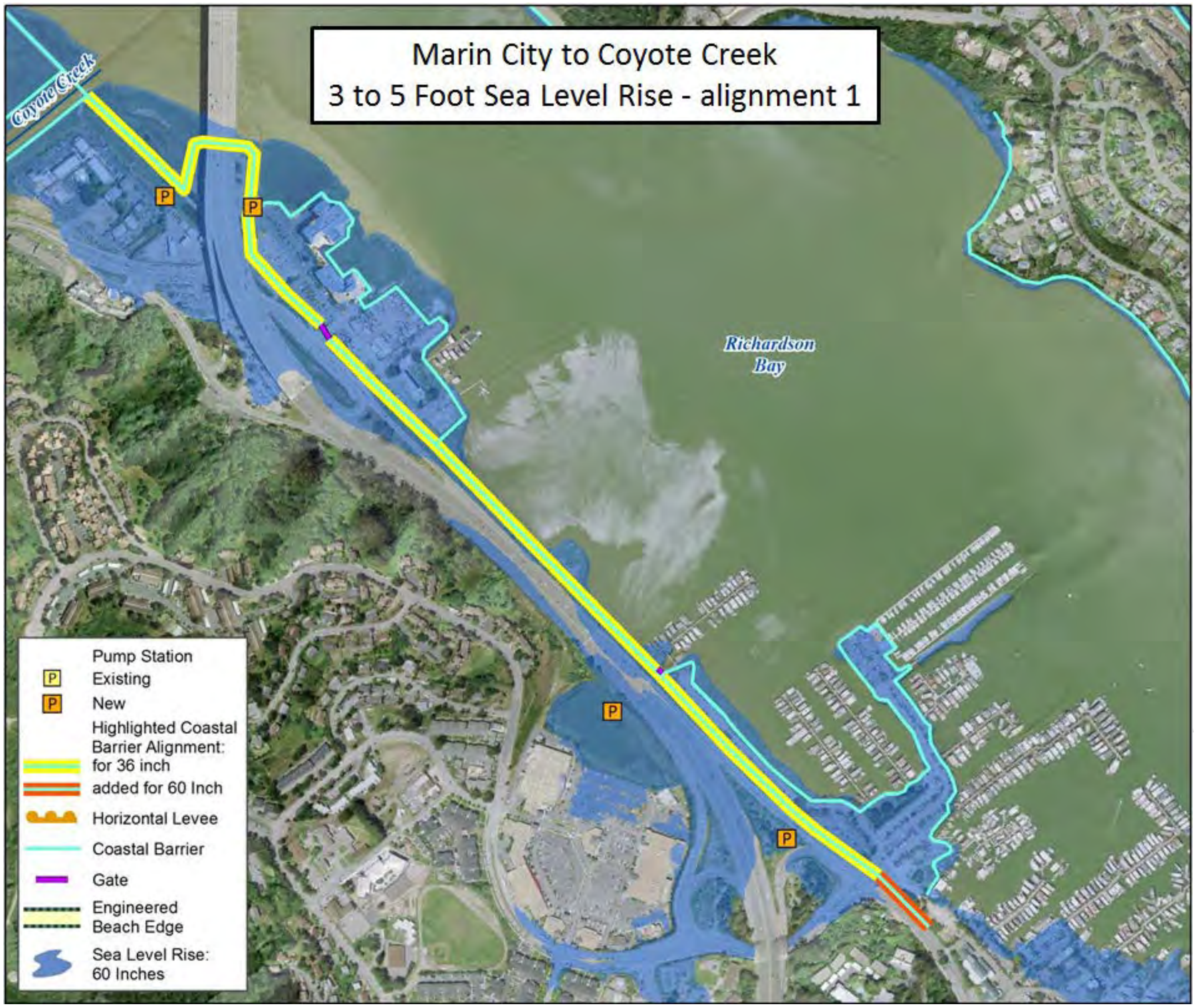

Figure 40: Reach 1, Alignment 1. 36 and 60 Inch Sea Level Rise LDCF Alignment (60 Inch Sea Level Rise Extensions In Red).

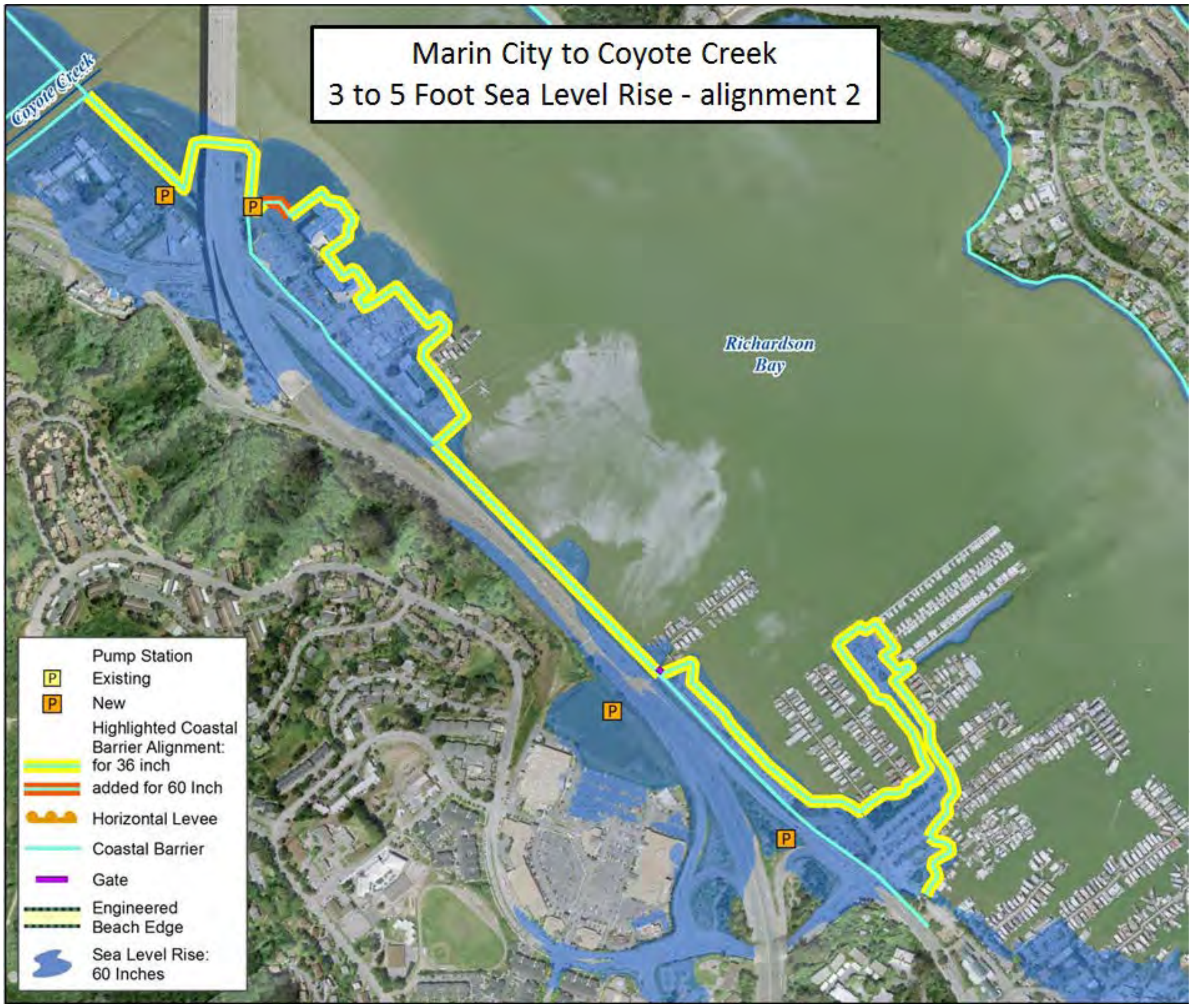

Figure 41: Reach 1, Alignment 2. 36 and 60 Inch Sea Level Rise LDCF Alignments.

Table 15. Reach 1 Barrier Lengths.

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Estimated Number of Hydraulic Gate Structures
Alignment 1 – all in public ROW	5,837	0	5,837	3
Alignment 2 – extends barrier into the private, built areas along the shoreline	3,690	6,252	9,942	3

60 inch Scenario

At 60 inches of sea level rise, widespread and deep flooding would occur across all of these areas, and potentially flood Highway 101. Extensive backwater flooding of the storm drain and sewer systems would occur within Marin City and elsewhere. Figure 41 shows the additional length of barrier required for this scenario.

Extensive flooding would also occur at the Caltrans parking lot and shoreline highway roadway at Highway 101 at Manzanita.

Overall, any barrier height should be built to an elevation of 15 feet NAVD88 to provide flood protection from the future 1 percent annual exceedance probability (AEP), or the so-called “100-year” tide elevation, under this scenario of sea level rise Designing for waves due to storm events and freeboard to meet future FEMA certification would potentially require higher elevations. In some locations, the barrier heights could exceed seven feet in crest height—a significant structure. At lower elevations, larger storm events would crash over the wall, which could raise concerns about both the safety and structure of the barrier foundation. In our experience, the general engineering practice is not to allow for the unengineered overtopping of high water barrier structures due to these concerns. At these heights and costs, planned retreat to higher ground would be a very viable alternative.

Table 16. Reach 1, Marine City to Coyote Creek (60 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1 All within public right of way	6,183	0	6,183	3
Alignment 2	6,298	3,804	10,102	2

REACH 2 - COYOTE CREEK AND BOTHIN MARSH COMPLEX

We mapped three potential alignments around Coyote Creek and the Bothin Marsh complex to provide a range of LDCF barrier options.

- Alignment 1 includes walls/levees to protect built areas of Tam Junction all along the Coyote Creek channel, to prevent direct overbank flooding. We assumed construction of an ecotone horizontal levee as the barrier along the back side of Bothin Marsh as shown in Figure 42 below. This alignment is assumed to be completely in the public right of way.
- Alignment 2 includes adding a significant length of barrier to Alignment 1 to include the popular Mill Valley Sausalito bike/pedestrian pathway. Again, this type of barrier solution is not specified with any alignment and could include raising the pathway, relocating it westward, and building a wall or levee in front—all solutions that would be developed as part of the planning process. To estimate costs, we assumed a more engineered, seawall barrier, since a horizontal levee at this location would involve placing fill well out into the bay. However, these types of assumptions are preliminary and subject to review and revision during the planning process. Constructing a hard barrier at this location would probably require significant mitigation for impacts to wetlands, so we assumed some costs for mitigation.
    - A new high tide-muting gate structure would be required at the existing bridge into Bothin Marsh. Over time this structure would mute the tides in the marsh and impact habitat.

    - The existing tide gate at Ryan Creek may need to be increased in size and would close more often, potentially impacting habitat and water quality.
- Alignment 3 includes a high tide flood barrier across the mouth of Coyote Creek that greatly reduces the length of walls/levees up the Coyote Creek channel. However, high tide flood barriers can have impacts and issues associated with habitat and water quality. We have assumed costs for mitigation of the tidal marsh behind this major tide gate barrier.
- We identified at least 16 existing storm drain outfalls that would probably need to be retrofitted for this level of sea level rise. These costs have not been included in the cost estimate.
- We included a series of horizontal ecotone levees in locations where there is sufficient space to build them and raise marsh grades. We also added engineered beaches to the outer edge of the marsh to inhibit marsh scarping, a current condition likely to get much worse under sea level rise.

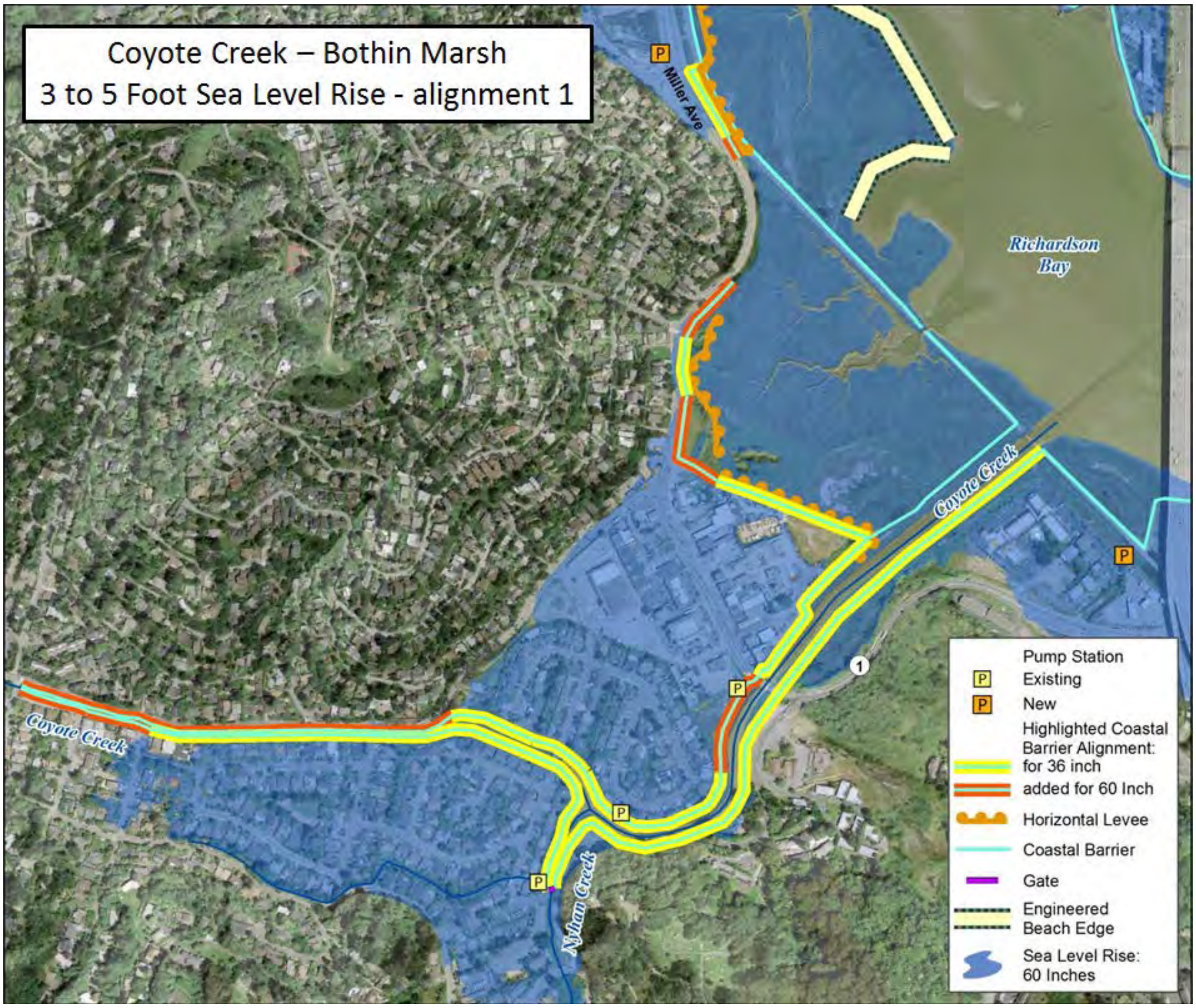

Figure 42: Reach 2, Alignment 1. 36 and 60 Inch Sea Level Rise.

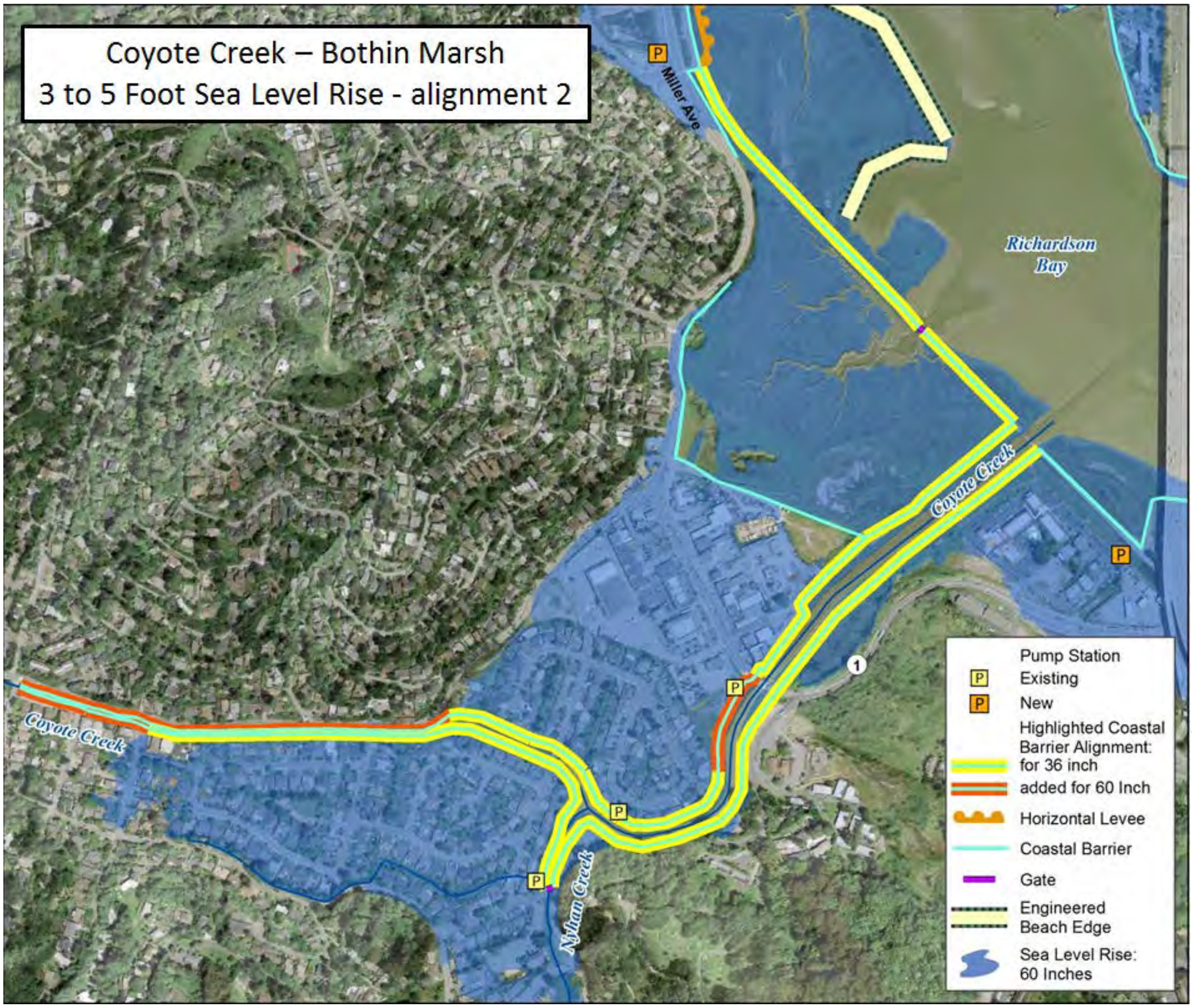

Figure 43: Reach 2, Alignment 2. 36 and 60 Inch LDCF Alignments.

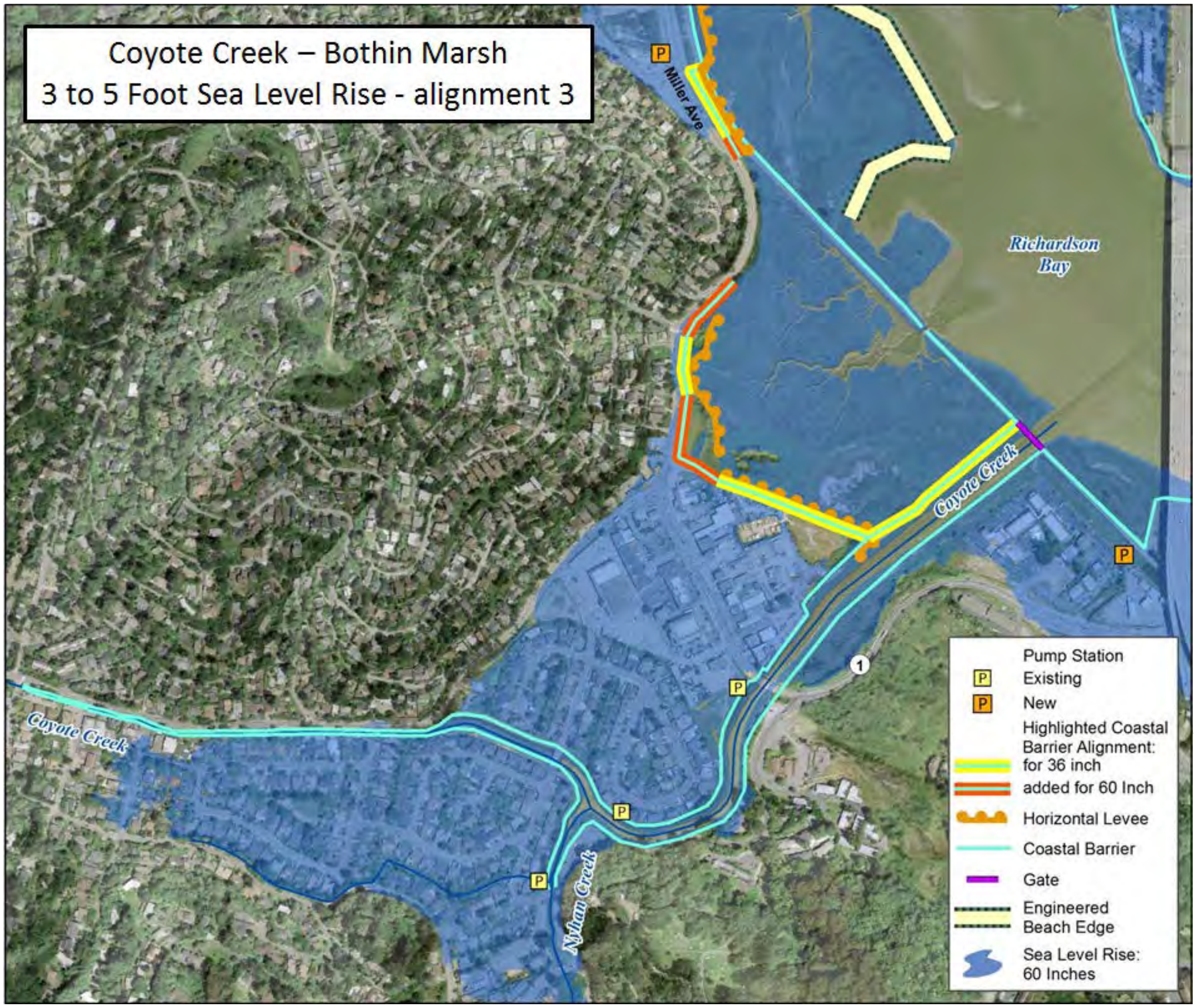

Figure 44: Reach 2, Alignment 3. 36- and 60- Inch LDCF Alignments.

Table 17. Reach 2, Coyote Creek-Bothin Marsh Barrier Lengths (36 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	5,675	4,006	9,681	1
Alignment 2 – protects bike path Requires mitigation for wetlands impacts	8,017	3,267	11,284	2
Alignment 3 – high tide barrier at creek mouth	1,697	738	2,435	1 (major tide gate across mouth of Coyote Creek)

60 inch Scenario

The three previous alignments for Coyote-Creek and the Bothin Marsh complex apply to this scenario except that the barriers extend linearly farther up the creek, and the top elevation is assumed to be raised. The potential impacts from this level of sea level rise are very significant.

Table 18. Reach 2, Coyote Creek-Bothin Marsh (60 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	9,070	4,722	13,792	1
Alignment 2	10,470	3,983	14,453	2
Alignment 3	2,475	738	3,223	1 (major tide gate across mouth of Coyote Creek

REACH 3 –MILL VALLEY WEST

For this reach along the West Mill Valley shoreline, we laid out a number of potential alignment options to facilitate discussion of the various tradeoffs associated with each one. All alignment alternatives contain these elements:

- A barrier along the edge of Miller Avenue to stop flooding of this critical roadway. We did not lay out an alignment that involves relocating or losing this roadway or other built areas as discussed above.
- The cost assumes that a new tide gate for Ryan Creek would replace the current tide gate.
- At least 15 existing storm drain outfalls would need to be retrofitted for this level of sea level rise. These costs have not been included.
  Note that ACMdP Creek is an anadromous steelhead stream, so it will be more difficult to obtain permits for high tide barrier gates along it than up Coyote Creek, which does not have a viable fish run. Tide gates that are designed for fish passage exist, but their effectiveness is disputed.

Specific Alignment Descriptions

- Alignment 1 is drawn along the edge of built areas and has the fewest new tide gate control structures; therefore it requires the longest stretch of barrier. But it does not install any in-stream barriers to fish passage. We assume that a section of shoreline north of ACMdP Creek will use a horizontal ecotone levee as the direct coastal barrier alternative (red line next to yellow line).

- Alignment 2 assumes installation of a high tide flood barrier in ACMdP Creek at a location upstream of the existing marsh. Installing a high tide barrier gate structure at this location will likely be easier to permit then the more downstream location of a new tide gate under Alignments 3 and 4. We assume that the section of shoreline north of ACMdP Creek will use a horizontal ecotone levee as the direct coastal barrier alternative. These sections of horizontal levee are shown as red lines adjacent to the yellow lines.
- Alignment 2a is the same as Alternative 2, but extends out around private development adjacent to the marsh. We assume that a section of shoreline north of ACMdP Creek will use a horizontal ecotone levee as the direct coastal barrier alternative.
- Alignment 3 is directly along the bike path, but assumes a major high tide gate at the current bridge location downstream of the existing marsh. This proposed gate will essentially mute the tidal marsh, impacting habitat, and requiring mitigation and more extensive permitting. We estimated mitigation costs for 16 acres at an assumed 1:1 mitigation ratio. Actual required ratios and costs may vary significantly.
- Alignment 4 is similar to Alignment 3 but expands out to include direct coastal flooding protection for the public parks (sports fields and dog park) along the shoreline. A levee or wall cost is assumed for this alternative given the limited right of way available for a horizontal levee, which would likely require filling in the entire narrow arm of the bay to achieve the required low gradient horizontal levee side slopes. This could be further explored under future phases of the project.

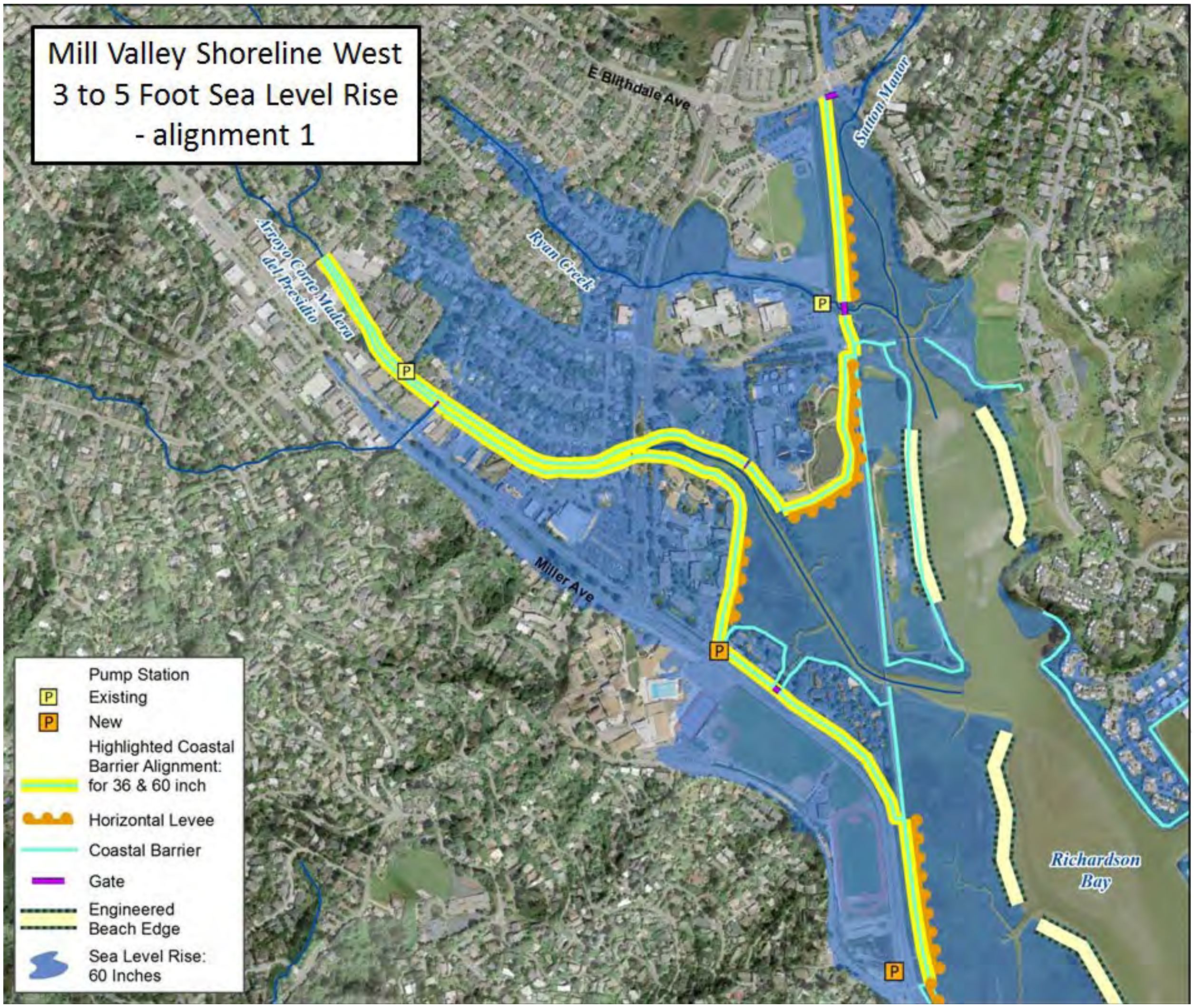

Figure 45: Reach 3, Alignment 1. 36 and 60 Inch Sea Level Rise Alignment.

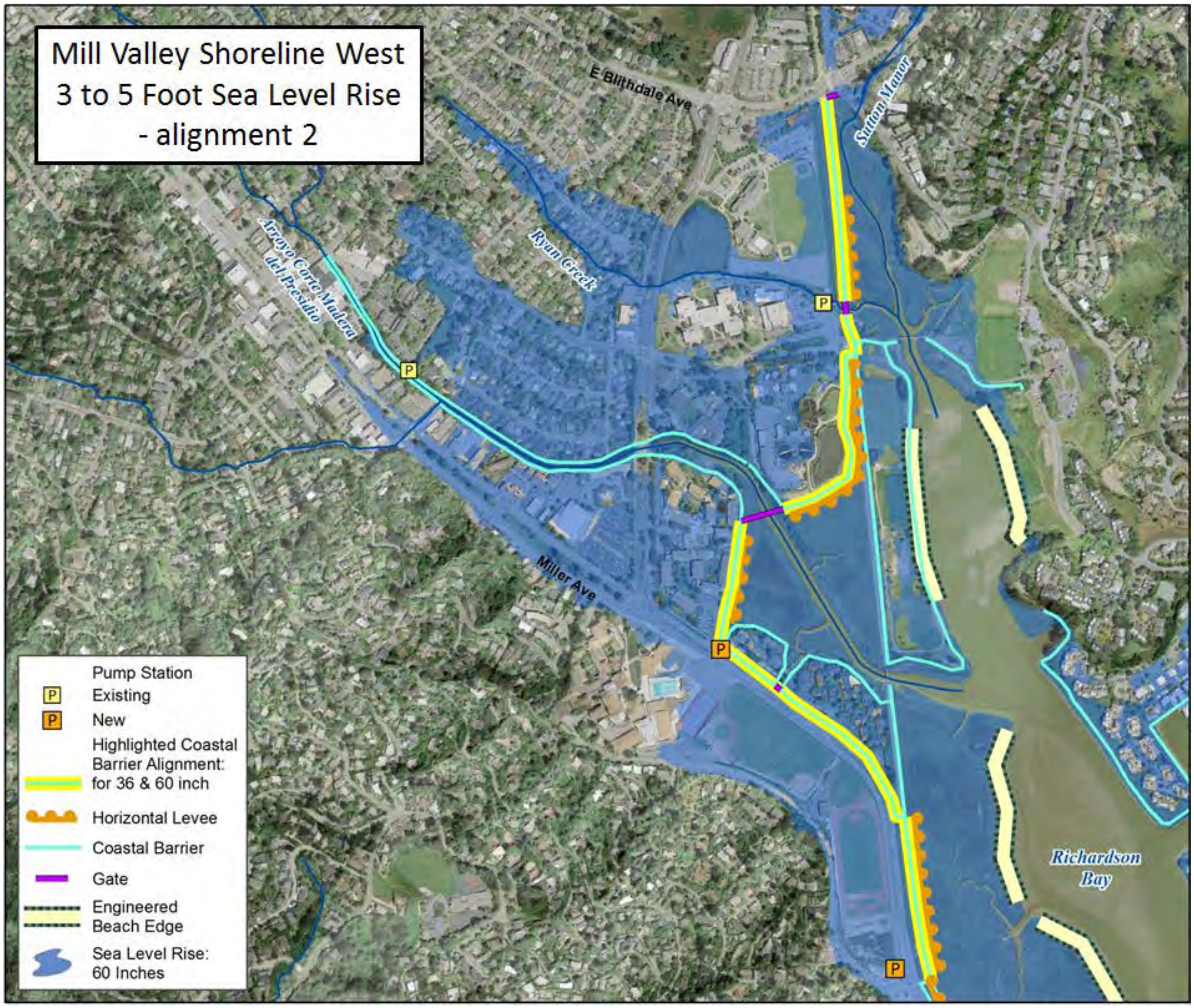

Figure 46: Reach 3, Alignment 2. 36 and 60 Inch LDCF Alignment.

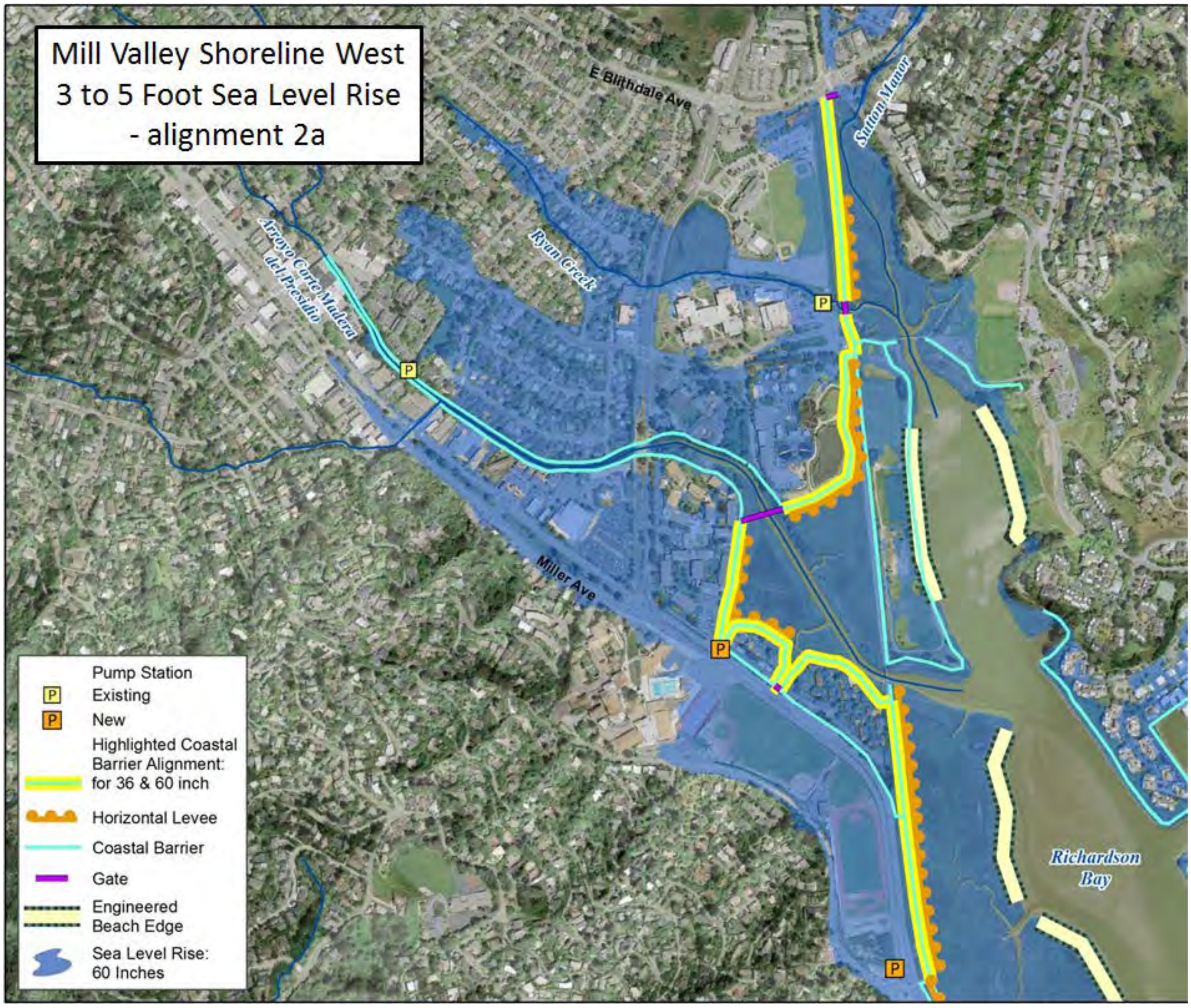

Figure 47: Reach 3 Alignment 2a. 36 and 60 Inch LDCF Alignment.

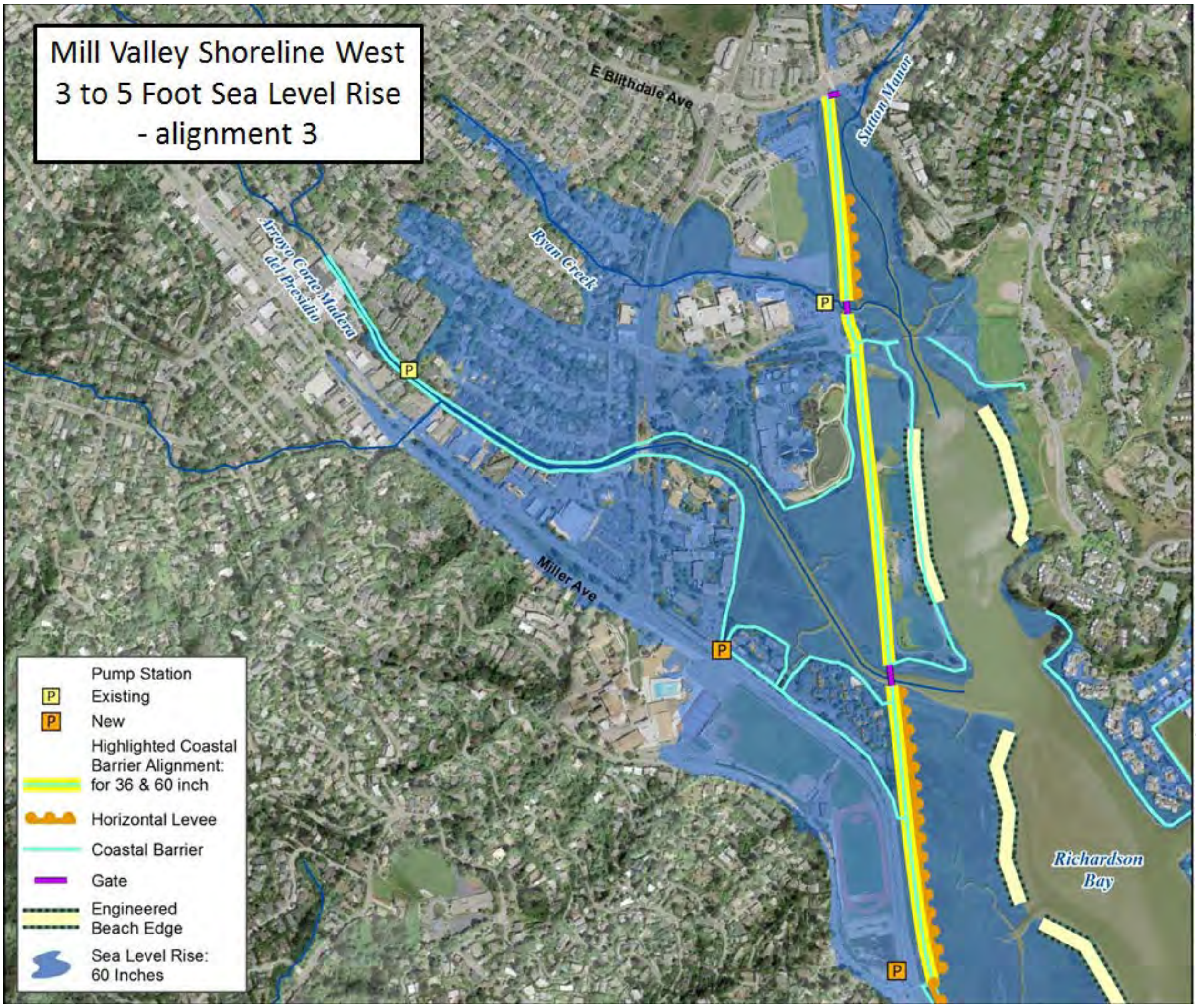

Figure 48: Reach 3, Alignment 3. 36 and 60 Inch LDCF Alignment.

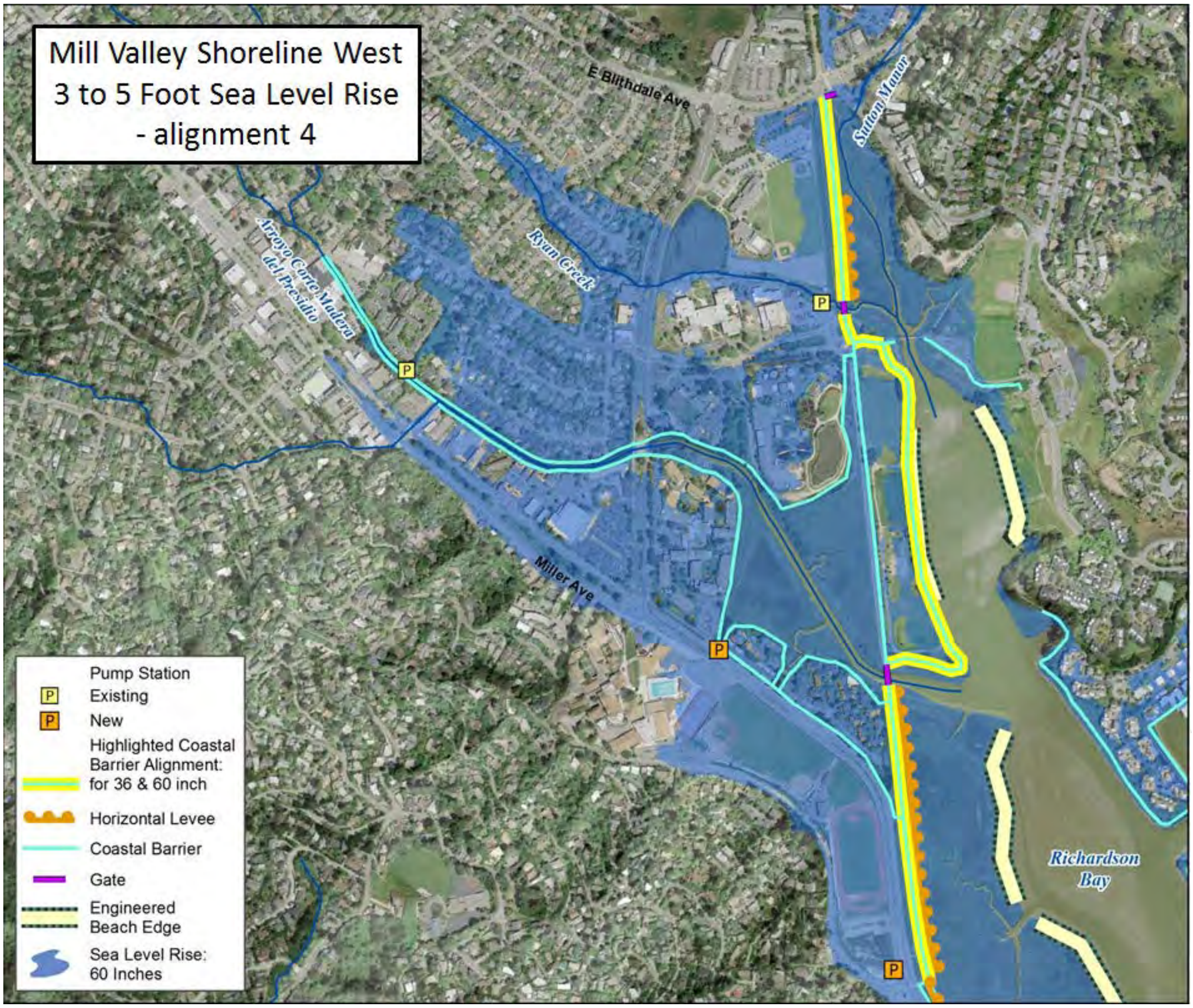

Figure 49: Reach 3, Alignment 4. 36 and 60 Inch Sea Level Rise Alignment.

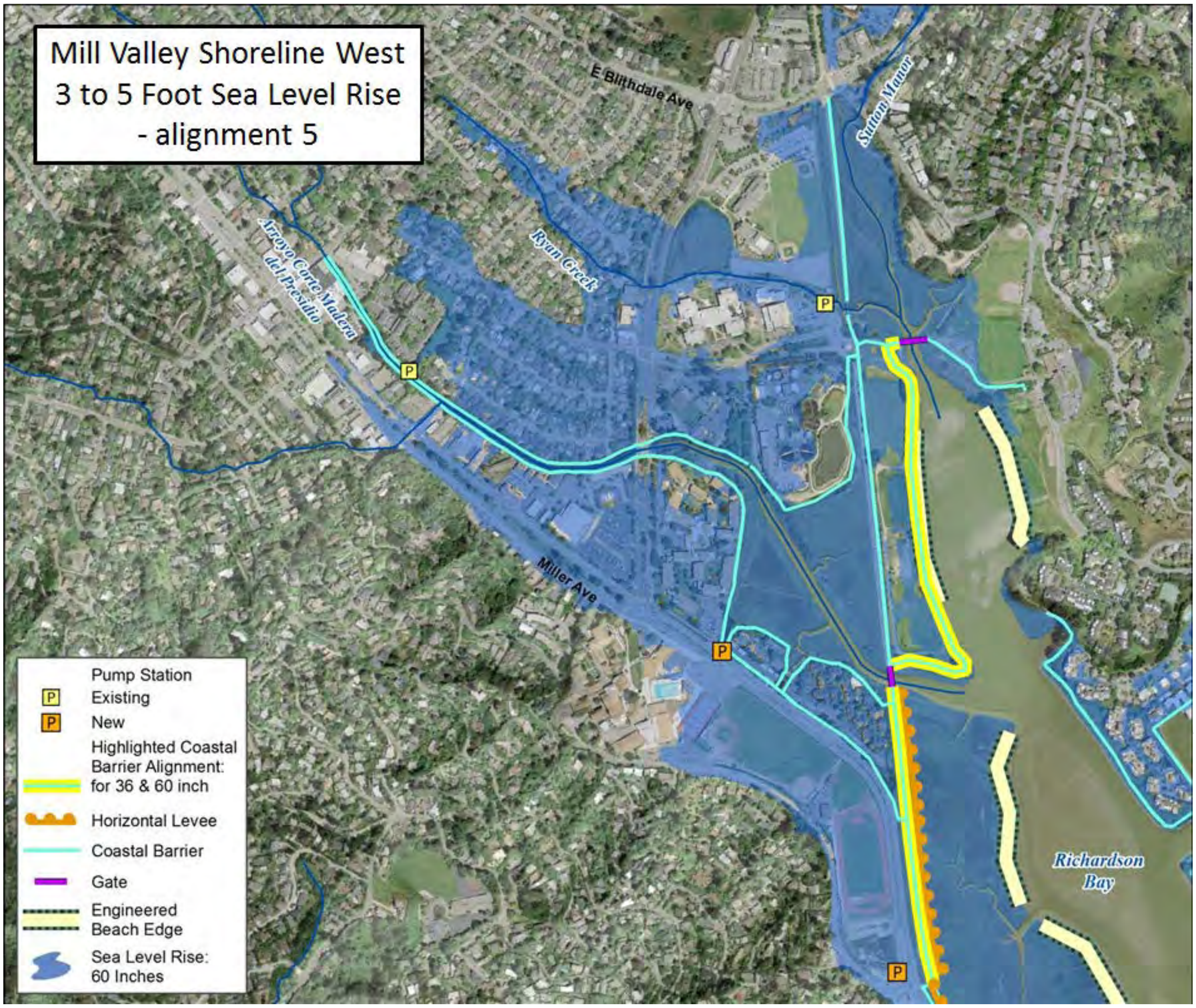

Figure 50: Reach 3, Alignment 5. 36 and 60 Inch Sea Level Rise Alignments.

Table 19. Reach 3, Mill Valley West (36 Inch Sea Level Rise).

Reach	Description	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1-	No new in-stream tide gate across ACMdP Creek required, but the greatest length of new walls/levee is required. Assumes a reach of horizontal ecotone levee	7,538	4,035	11,573	4 (rebuilt gate across Ryan Creek
Alignment 2	One new tide gate across ACMdP Creek upstream of existing marsh—may be easier to permit Assumes a reach of horizontal ecotone levee	4,796	680	5,476	5 (1 across ACMdP Creek but upstream of existing marsh; 1 rebuilt gate across Ryan Creek)
Alignment 2a	Same as A2, but includes private development adjacent to marsh Assumes a reach of horizontal ecotone levee	5,557	680	6,237	5 (1 across ACMdP Creek but upstream of existing marsh, 1 rebuilt gate across Ryan Creek)

Alignment 3	Along the existing bike path—requires major new tide gate at mouth of creek All public right of way	4,662	0	4,662	5 (1 new major across ACMdP Creek below marsh and rebuilt Ryan Creek gate
Alignment 4	Along the existing bike path—requires major new tide gate at mouth of creek, but adds length to protect existing dog park and fields All public right of way	5,370	0	5,370	5 (1 new major gate across ACMdP below marsh and rebuilt Ryan Creek gate)
Alignment 5	Same details as A4 with an additional tide gate installed at the upper arm of the bay to protect Sutton Manor All public right of way	3,995	0	3,995	5 (2 major new gates across ACMdP Creek and Ryan Creek)

Again, these alignments illustrate just a few of the many community planning decisions that will have to be made to protect built urbanized areas in their current locations.

60 inch Scenario

Sixty inches of sea level rise does not increase the aerial extent of the barrier needed for many of the alignments, but the depth of flooding and costs for protection needed will be significantly higher.

Table 20. Reach 3, Mill Valley West (60 Inch Sea Level Rise).

Reach	Description	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	New in-stream tide gates, but most levee required	7,538	4,065	11,603	5
Alignment 2	One new in-stream tide gate, but upstream of existing marsh	4,796	680	5,476	4 (1 across ACMdP Creek)
Alignment 2a	Same as A2 but includes private development adjacent to marsh	5,557	680	6,237	4 (1 across ACMdP Creek)
Alignment 3	Along the existing bike path—requires major new tide gate at mouth of creek	4,662	0	4,662	3 (1 major across ACMdP Creek)
Alignment 4	Along the existing bike path—requires major new tide gate at mouth of creek but adds barrier length to protect existing dog park and fields	5,370	0	5,370	3 (1 major across ACMdP Creek)
Alignment 5	Same as A4 except that another tide gate is installed at the upper arm of the bay to protect Sutton Manor	3,395	0	3,395	2 (1 major across ACMdP Creek)

Illustrative Cross-Section

Figure 51 shows a cross-section of sea level rise adaptation alternatives along an alignment that includes Miller Avenue through Bothin Marsh into the bay.

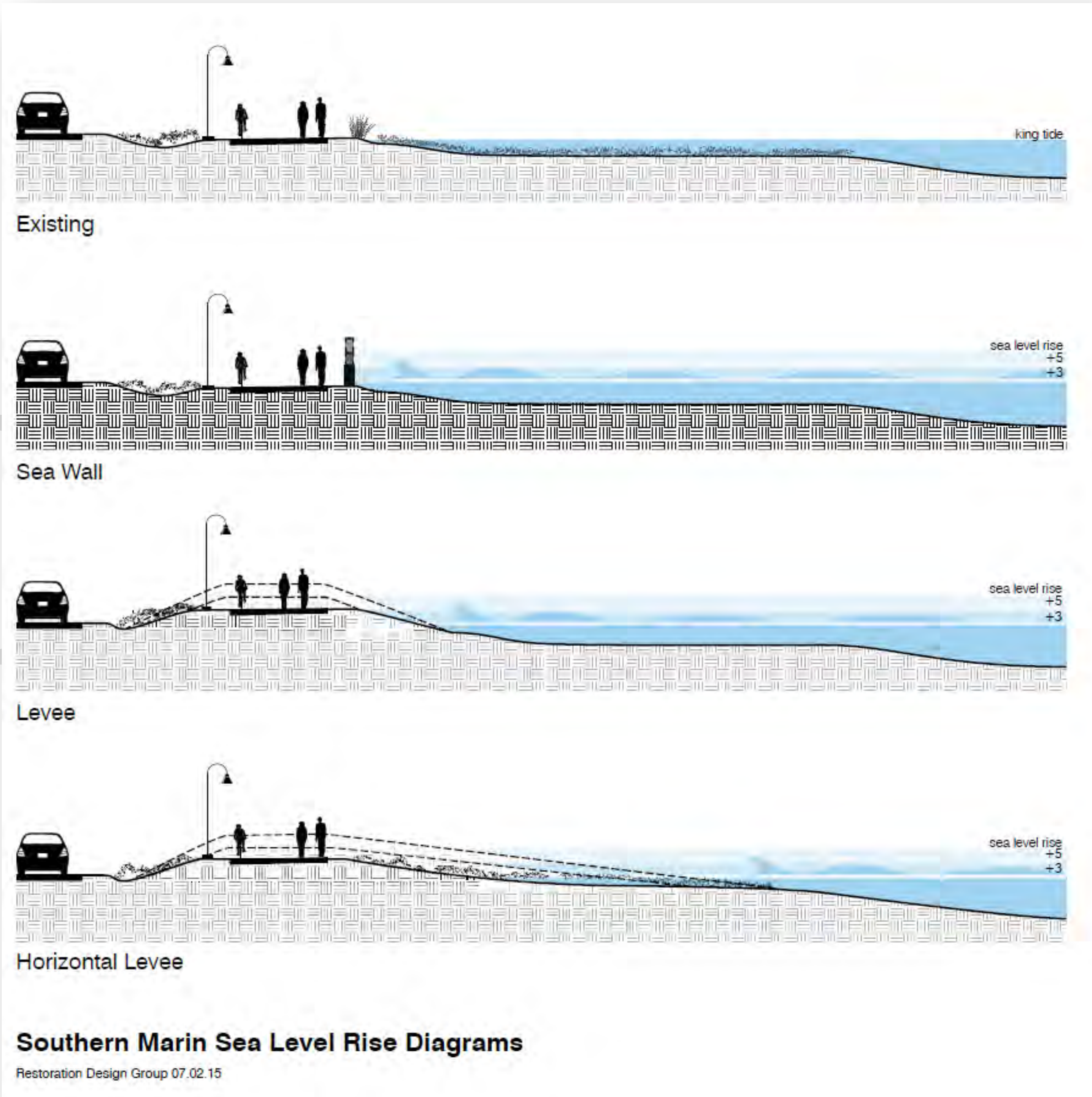

Figure 51: Example Concept Cross-Sections of Miller Avenue with Different Adaptation Options under Varying Levels of Sea Level Rise.

REACH 4 –MILL VALLEY EAST

Mill Valley East is a combination of public and privately owned lands, including parklands along the eastern edge of Mill Valley and roadways and trails adjacent to private developments to the south. The primary impacts to this reach under 60 inches of sea level rise consist of trail and shoreline erosion and potential impacts to the private residential development in Shelter Bay. Except for one area at the north end of the Mill Valley ball fields, all of the impacted areas are on private property.

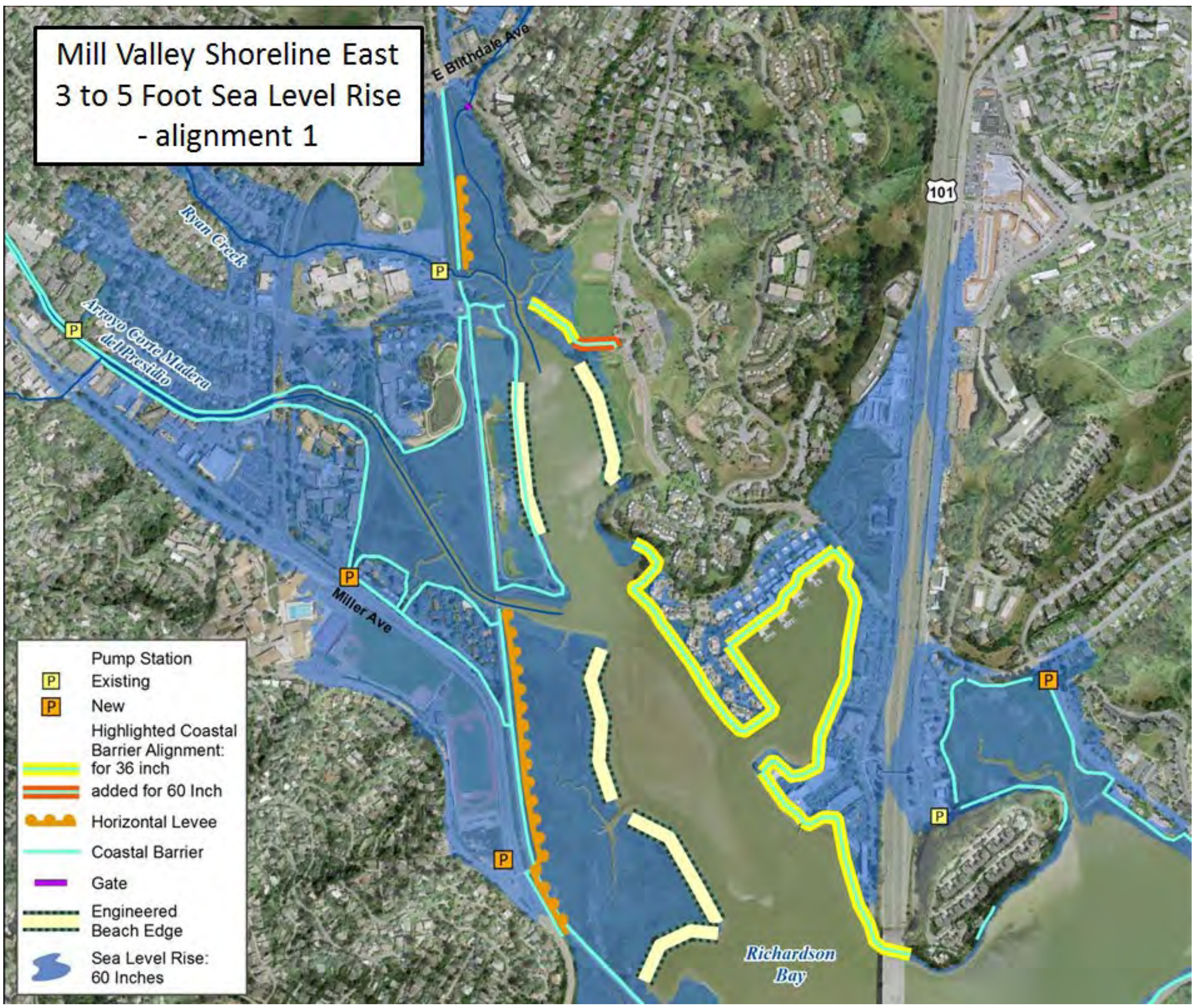

Figure 52: Reach 4, Alignment 1. 36 and 60 Inch LDCF Alignment.

Table 21. Reach 4, Mill Valley East (36 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	771	6,275	7,046	Not estimated

60 inch Scenario

The areas of Mill Valley East requiring protection with 60 inches of sea level rise are larger and include many more of the public areas along the eastern edge. Many of the other areas are privately owned. The main impacts of 60 inches of sea level rise along this reach consist of trail and shoreline erosion and potential impacts to the private residential development in Shelter Bay.

Table 22. Reach 4, Mill Valley East (60 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	1,054	6,275	7,329	1

REACH 5 –SEMINARY MARSH

Sixty inches of sea level rise in this reach would cause flooding all along the back side of Seminary Marsh. A barrier would have to be placed as shown to prevent flooding of commercial areas.

Figure 53: Reach 5, Alignment 1. 36 and 60 Inch LDCF Alignment.

Table 23. Reach 5, Seminary Marsh (36 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Estimated New Hydraulic Gate Structures
Alignment 1	2,016	1,944	3,960	3

60 inch Scenario

Sixty inches of sea level rise would cause flooding all along the back side of Seminary Marsh. A barrier would have to be placed as shown to prevent flooding of commercial areas. The flood barrier would have to be developed to the elevations described above to be effective.

Table 24. Reach 5, Seminary Marsh (60 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of New Hydraulic Gate Structures
Alignment 1	2,016	2,176	4,192	1

REACH 6 –STRAWBERRY PENNINSULA

Sixty inches of sea level rise would primarily impact the private residential properties directly along the shoreline. Potential impacts include both direct flooding of trails and properties, as well as increased shoreline erosion. Numerous outfall structures would likely require retrofitting to address this amount of sea level rise. We did not account for storm drain outfall retrofits in this study.

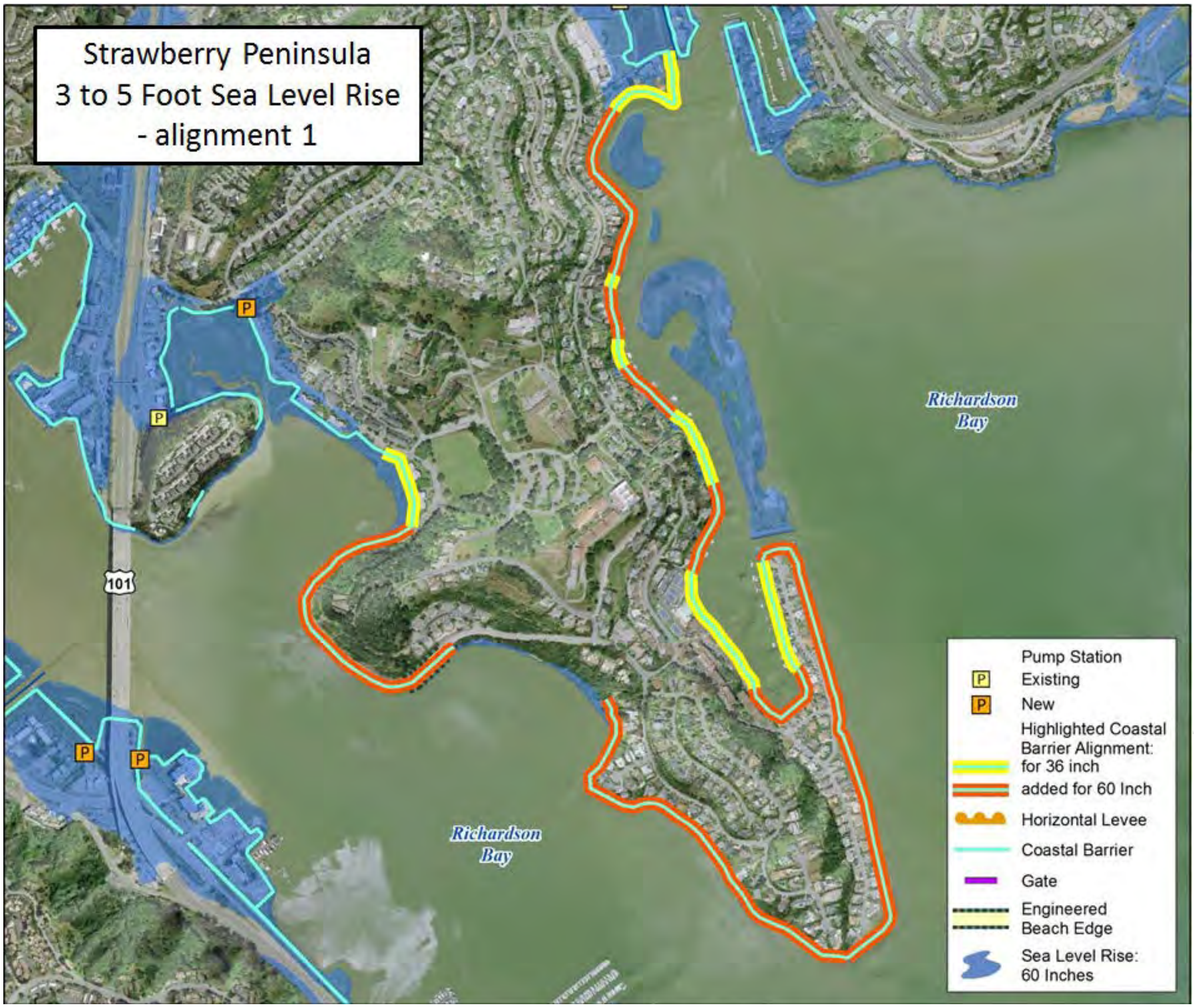

Figure 54: Reach 6, Alignment 1. 36 and 60 Inch LDCF Alignment.

Table 25. Reach 6, Strawberry Peninsula (36 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Estimated Hydraulic Gate Structures
Alignment 1	670	3,830	4,500	Not estimated

60 inch Scenario

Sixty inches of sea level rise would primarily impact the private residential properties directly along the shoreline. A significantly longer reach of barrier protection is required under this scenario, as almost all shoreline properties will now be impacted. The potential impacts include both direct flooding of trails and properties, as well as increased shoreline erosion. In our estimates, we did not include rock rip-rap for protecting the toe of the seawall, but this type of additional protection may be necessary.

Table 26. Reach 6, Strawberry Peninsula Barrier Lengths.

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	15,677	2,295	17,972	0

REACH 7 – STRAWBERRY CIRCLE/GREENWOOD COVE

Three different alignments have been drawn, and each reflects a different LDCF location for protection.

- Alignment 1 is primarily on public right of way where possible (except for a barrier along Strawberry Circle) and along Tiburon Boulevard. The goal of this alignment is to protect this roadway and properties along the north side of the Saltworks Canal. We did not include costs to protect the large private property shoreline development. Of course, additional alignments can be developed that protect a different set of properties.
- Alignment 2 adds additional barrier length (costed out as a seawall on poor soils) to include the private properties along the shoreline shown to be within the inundation footprint. No site-specific design was conducted to confirm that a wall was feasible or the best solution, so these costs are approximate and for informational purposes only. It is certainly possible that more cost-effective approaches to protecting these structures may be available.
- Alignment 3 assumes installation of a high tide gate control structure at the Salt Works Canal entrance to reduce the length of floodwall and levee required.

Numerous storm drain outfall structures will likely need to be retrofitted to address this amount of sea level rise. We did not account for storm drain outfall retrofits with this study. Pump stations will probably be needed for this reach, and we did not estimate those costs either.

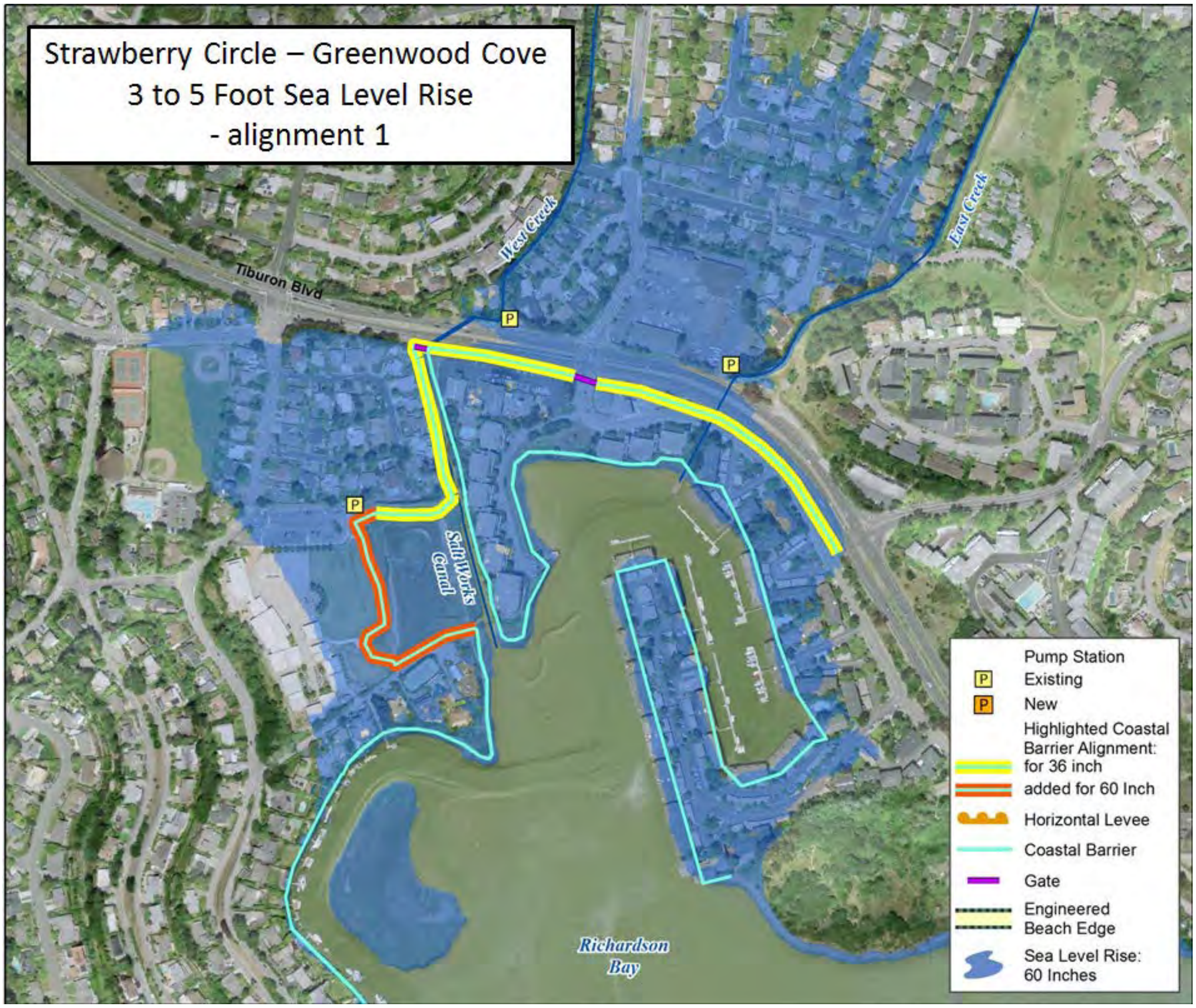

Figure 55: Reach 7, Alignment 1. 36 and 60 Inch LDCF Alignment.

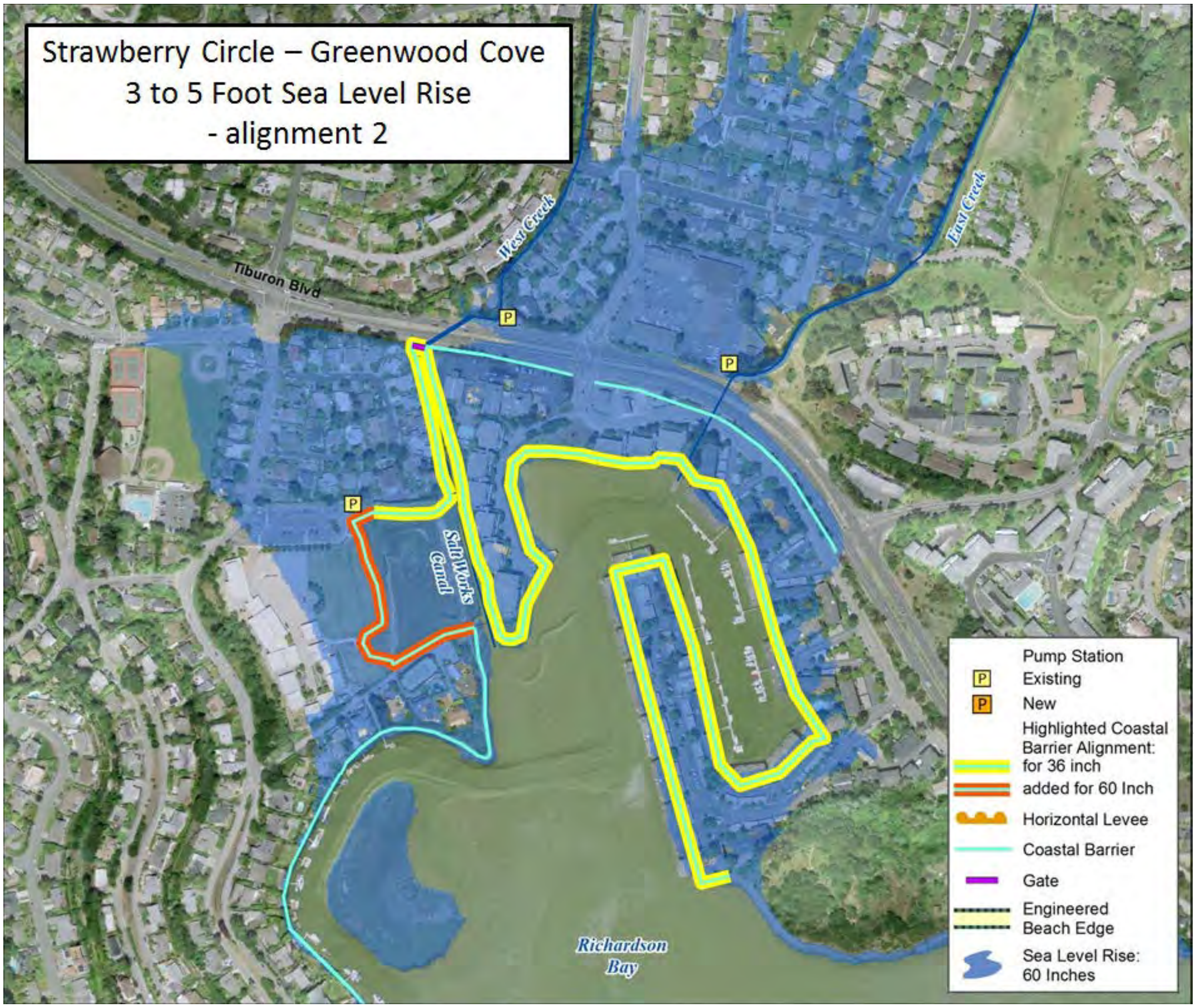

Figure 56: Reach 7, Alignment 2. 36 and 60 Inch LDCF Alignment.

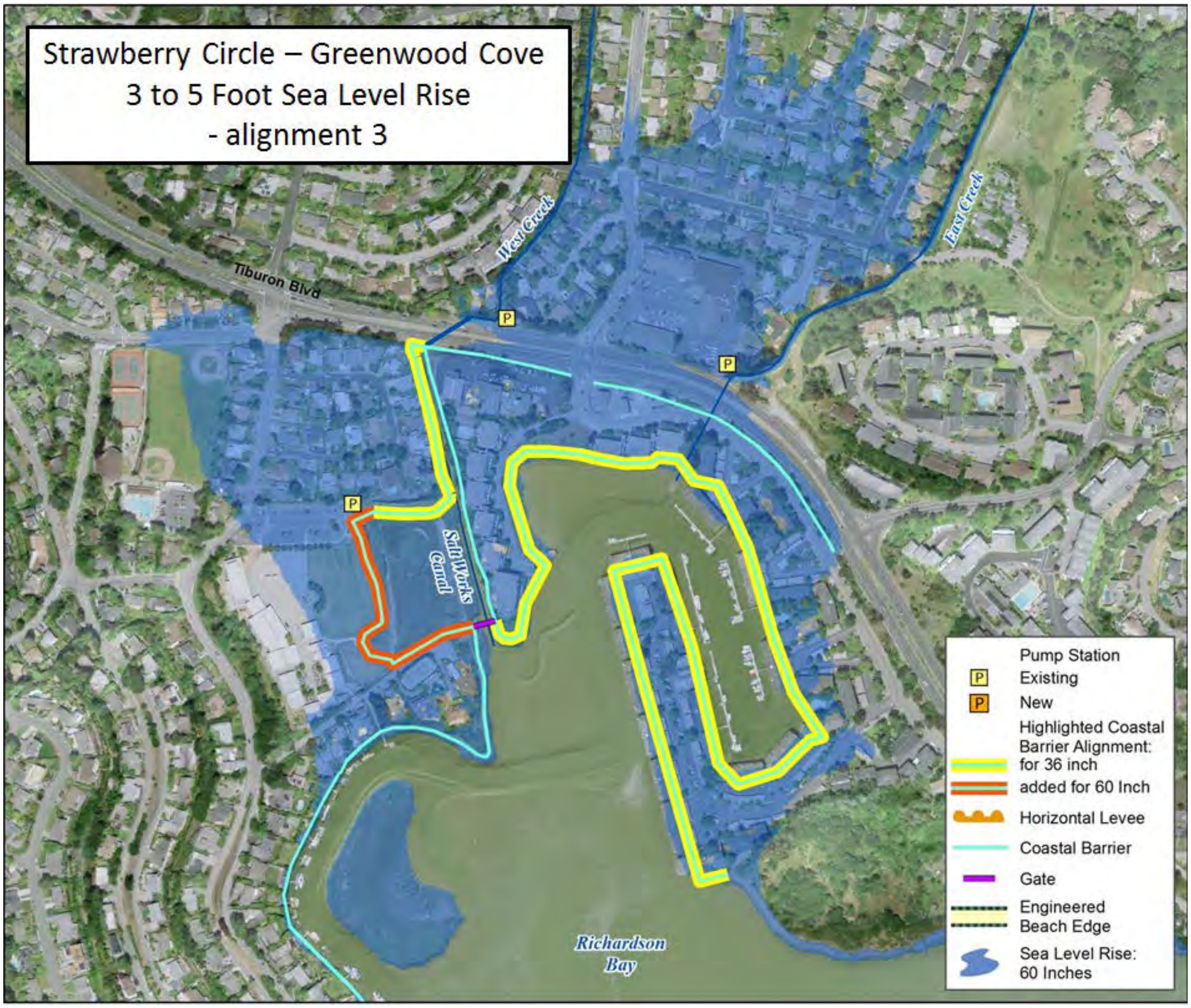

Figure 57: Reach 7, Alignment 3. 36 and 60 Inch LDCF Alignment.

Table 27. Reach 7, Strawberry Circle-Greenwood Cove (36 Inch Sea Level Rise).

Reach	Description	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Estimated Hydraulic Gate Structures
Alignment 1	Drawn to be mostly in public ROW so excludes protection of many private properties	1,775	436	2,211	1 tide gate across Salt Works Canal. Minor outfall modifications are not estimated.
Alignment 2	Expanded to include private developments along the shoreline	1,324	4,878	6,202	Two gate structures across Tiburon Blvd. Minor gate structures are not estimated.
Alignment 3	Expanded to estimate costs to protect private development along shoreline	1,324	4,000	5,324	1 tide gate across Salt Works Canal. Two gate structures across Tiburon Blvd. Minor gate structures are not estimated.

60 inch Scenario

Three different alignments have been drawn. Each reflects a different location for protection developed per the alignment descriptions in the table above for the 36 inch sea level rise scenario. The linear extent of barrier is approximately the same as the last scenario, but the top of the barrier will need to be higher, with a larger and deeper foundation to avoid impacts. This will result in significantly increased costs. Some kind of rock rip-rap protection (or other method) may be required to protect the toe of any barrier wall that is continuously subjected to the tides. These costs have not been included, but could be substantive.

Table 28. Strawberry Circle-Greenwood Cove Barrier Lengths.

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	2,670	436	3,106	1
Alignment 2	2,220	4,878	7,098	1
Alignment 3	2,220	4,000	6,220	1

6.4 Concept Level Cost Estimates

This study makes no specific final design recommendations for engineering adaptation measures or structures along the shoreline to protect existing infrastructure against future sea level rise inundation. It is still too early in the adaptation planning process for DPW to recommend a specific set of adaptation designs for the entire shoreline. In the short-term to address current flooding concerns, we recommend that several site-specific projects in areas of critical flooding under the 12 inch sea level rise scenario be further analyzed and developed to the design phase. In general, the engineering alternatives discussed in this report should be considered for planning and decision making with the community and County planners.

We have developed very preliminary ranges of potential costs to help the community understand the magnitude of adaptation costs to begin to plan accordingly. To provide this range of possible costs, we prepared potential cost ranges assuming seawall/levee barrier alternatives as the starting point for adaptation discussions. For the first three reaches (Marin City to Mill Valley East), we evaluated costs assuming levee and/or seawall barrier solutions along with some wetlands enhancement, and added costs for new pump stations. For other reaches (Seminary to Greenwood), where many of the properties are privately owned, we made a simple assumption that an engineered seawall alternative would be implemented, and developed order-of-magnitude costs using generic unit costs. We have not performed any site-specific design work. Neither have we assumed any costs for pumping or drainage behind these seawalls.

All costs in this study are for discussion purposes only. No site-specific engineering design studies were conducted to verify the feasibility of any structures, especially on private properties; therefore, all costs are conceptual and subject to significant revision and change. We assumed general costs for design, permitting, and right of way acquisitions or easements, but have done no specific estimates.

It is important to understand that the cost of adaptation alternatives in the "toolbox" such as retreat, abandonment, or relocation of major existing infrastructure were not developed or included in this study. While these options are very important, these alternatives are much more controversial and complex and need to be negotiated through a much more in-depth public process. We hope that the costs developed in this study for in-place protection of built resources can provide the basis for discussions about costs for protection in-place versus retreat and relocation.

This following section develops concept level cost estimates for the various alignments along the shoreline for each reach described above. The estimates provide order-of-magnitude cost estimate ranges for protecting the built infrastructure in its current location and at its current elevation. They are intended to allow for comparison of protect-in-place approaches vs. other adaptation approaches, such as planned retreat and/or use of larger, landscape-scale natural approaches to adaptation. These costs are not meant to be exact or inclusive of all costs and should not be relied on for seeking grants for further design or construction but rather to allow for assessing the scale of the issue and to help guide future actions and studies.

Some of the major cost estimation assumptions are as follows:

- All costs are based on broad assumptions and costs from similar projects or published sources or engineering judgment and experience. However, no site specific design studies or hydraulic analyses have been conducted. Any sizes, such as of barrier heights, are solely based on the water level scenarios as presented. Many additional factors can significantly impact costs that are not considered here. Therefore, the final costs are subject to significant revisions following subsequent design phases of the project.

- The costs for each scenario (12, 36, and 60 inches of SLR) were independently estimated and are not incremental. Therefore, to estimate the costs for phasing adaptation from the 12-inch scenario to the 36-inch scenario to the 60-inch scenario, we would need to subtract the total costs from each previous alternative. However, since we did not assume costs for demolishing previously built barriers or for raising barriers, developing phased costs with this approach would be very approximate.
- Costs are based on unit cost estimates obtained from a variety of sources and on our experience. No site-specific inspections or design were conducted for any public or private properties. The list of adaptation options considered and used for cost estimates is not necessarily comprehensive or complete, and there may be other options that could be implemented. But for these first-cut cost estimates, we limited our estimates to adaptation alternatives listed below.
- Assumptions regarding right of way acquisition costs for both public and private properties are based on costs from Marin County's experience in other areas. However, right of way costs depend on a number of factors, many of which are not known until actual negotiations take place. Because of that, our assumptions should be understood to be very approximate. No right of way acquisition discussions have been held with any entity, public or private, as part of this study. Nothing in this study should be understood as the willingness of any entity to provide right of way at any price. In our experience, right of way issues can be very difficult to negotiate, especially when many private property owners are involved.
- It is particularly difficult to estimate costs for Reaches 4 through 7, which contain primarily private properties. Each individual homeowner could try to develop, permit, and construct his or her own structures separately at a higher cost or join other neighbors to try and achieve an economy of scale. Construction costs will also depend on local site constraints on private property areas that are beyond the scope of this study.
    - To estimate design and permitting costs for Reaches 4 through 7, we developed concept costs as a percentage of the total estimated construction cost for that alignment. This is a rough approximation assumption, but suitable for the concept-level scale of this analysis.
    - We have not included costs for interior drainage structures (i.e. pumps) behind private residence barriers for Reaches 4 through 7. Given the large number of small private parcels along some reaches, interior drainage design and costs will have to be developed during subsequent design phases based on local homeowner preferences.
- All levees, both traditional and horizontal ecotone levees, are constructed to the minimum barrier top elevation in Table 3. We have assumed that all

levee tops will be built a little wider to allow for raising the levees if sea level rise exceeds 12 inches (as is likely).

- For the seawall/floodwall costs, a more detailed analysis and cost estimate would account for the actual wall height (difference in elevation from proposed top of barrier to existing ground elevation). For most wall type barriers (such as sheet pile walls), unit costs are often developed as square feet of sheet pile. Calculating that square footage would require determining ground and barrier top elevations along all the barrier alignments and then analyzing costs for each reach. Given the large number of reaches and alignments within the reaches and scope/budget for this project, we assumed a single barrier cost for areas with different soils. But any subsequent phase of adaptation analysis should be more exact in estimating costs once a potential alignment has been identified.
- Horizontal levees are assumed for locations with existing adjacent wetlands and where there is sufficient room to build without excessive filling of the bay. If planned retreat from built areas is further considered as an adaptation option, additional space for wetlands in front of levees may be available.

CONCEPT LEVEL COST ESTIMATE CATEGORIES:

- Right of ways
- Design and permitting
- Construction
- Monitoring, maintenance, and reporting

Note: Costs for any mitigation for impacts to wetlands or natural resources have not been included. Under the current permitting environment, these costs could be significant for options that impact the natural environment.

RIGHT OF WAY COSTS

Acquiring right of ways tends to be very expensive and problematic in Marin County. For this study, we based our right of way costs on the known costs of similar efforts building floodwalls at other locations in the County and where property owners were impacted. We assumed there are no right of way costs for public properties. For private properties, we assumed a wide range of $3,000 to $10,000 per linear foot, which is relatively expensive. The actual right of way cost could be less if there is minimal impact to the private owner. However, the in-place barrier options are all structures (i.e., walls and levees) that require access for maintenance vehicles, so it was assumed that the right of way impacts would be significant, and thus, fall within this range of costs.

Note that unless eminent domain is used, there is no requirement for private homeowners to provide right of way for construction or access. The County currently has no funds for purchasing easements or right of ways, so these costs have been included for completeness and discussion only. Given that most of our barriers cross through private properties, there are likely to be impacts to private property owners that require resolution of right of way issues.

Barrier type alternatives require a continuous barrier connected to higher ground at each end to prevent flood waters from entering through or around a hole in the alignment. For many alignments, the single highest potential cost is the right of way acquisition right and associated costs. Thus, a major obstacle to barrier solutions may be getting agreement from all private property owners to provide right of way access at a reasonable cost. For this study, many of the alignments were developed to provide an estimate of the costs to protect private property owners along the shoreline. However, it is difficult to imagine a scenario where public monies would be spent to compensate private property owners for right of ways to build barriers to protect their properties. However, certain alignments may require acquisition of a right of way to complete a continuous barrier to protect non-shoreline properties and public interests, so for these alternatives right of way costs may be required.

Costs for right of way acquisition and private property concerns are likely to be some of the most difficult and expensive elements of adaptation planning for the shoreline. Tables 29 through 31 present a rough estimate of the right of way costs for all three sea level rise scenarios. Note that we did not estimate a right of way cost for the water-based alternatives (see Section 2.2, Alternative 1) since it is unknown at this time if any right of way costs are required. One of the proposed barrier alternatives (RBBTB) would require approval from Caltrans to anchor the barrier to the Highway 101 bridge footings.

Table 29. Summary of Potential Right Of Way Costs with 12 Inch Sea Level Rise.

Reach/alignment	12 inch SLR Scenario		
	Linear feet of private property	Cost Estimate– Low ($)	Cost Estimate – High ($)
Reach 1			
A1	0	$0	$0
A2	1651 to 1922	$4,965,000	$19,220,000
Reach 2			
A1	0	$0	$0
A2	0	$0	$0
Reach 3			
A1	386	$1,158,000	$3,860,000
Reach 4			
A1	1468	$4,404,000	$14,680,000
Reach 5			
A1	83 to 362	$1,086,000	$3,620,000
Reach 6			
A1	1638	$4,914,000	$16,380,000
Reach 7			
A1	3590	$10,770,000	$35,900,000
Totals:	8,816 to 9,366		

Table 30. Summary of Potential Right of Way Costs with 36 Inch Sea Level Rise.

Reach/alignment	36-inch SLR Scenario		
	Linear feet of private property	Cost Estimate – Low ($)	Cost Estimate – High ($)
Reach 1			
A1	0	$0	$0
A2	6252	$18,756,000	$62,520,000
Reach 2			
A1	4006	$12,018,000	$40,060,000
A2	3267	$9,081,000	$32,670,000
A3	738	$2,214,000	$7,380,000
Reach 3			
A1	4035	$12,105,000	$40,350,000
A2	680	$2,040,000	$6,800,000
A2a	680	$2,040,000	$6,800,000
A3	0	$0	$0
A4	0	$0	$0
A5	0	$0	$0
Reach 4			
A1	6275	$18,825,000	$62,750,000
Reach 5			
A1	1944	$5,832,000	$19,440,000
Reach 6			

A1	3830	$11,490,000	$38,300,000
Reach 7			
A1	436	$1,308,000	$4,360,000
A2	4878	$14,634,000	$48,780,000
A3	4000	$12,000,000	$40,000,000
Totals:	41,021		

Table 31. Summary of Potential Right of Way Costs with 60 Inch Sea Level Rise.

Reach/alignment	60-inch SLR Scenario		
	Linear feet of private property	Cost – Low ($)	Cost – High ($)
Reach 1			
A1	0	$0	$0
A2	3804	$18,894,000	$62,980,000
Reach 2			
A1	4722	$14,166,000	$47,220,000
A2	3983	$11,949,000	$39,830,000
A3	738	$2,214,000	$7,380,000
Reach 3			
A1	4065	$12,105,000	$40,650,000
A2	680	$2,040,000	$6,800,000
A2a	680	$2,040,000	$6,800,000

A3	0	$0	$0
A4	0	$0	$0
A5	0	$0	$0
Reach 4			
A1	6275	$18,825,000	$62,750,000
Reach 5			
A1	2176	$6,528,000	$21,760,000
Reach 6			
A1	2295	$6,885,000	$22,950,000
Reach 7			
A1	3106	$1,308,000	$4,360,000
A2	4878	$14,634,000	$48,780,000
A3	4000	$12,000,000	$40,000,000
Totals:	41,402		

DESIGN AND PERMITTING COSTS

Richardson Bay Tide Gates

Estimating design and permitting costs for the two large tide gates proposed for across Richardson Bay is very difficult. These are both very large and unique projects the size and type of which has not ever been designed or permitted in the San Francisco Bay Area region. Given the uncertainties, we have estimated these costs at $4MD to $6MD as a low and high range. These costs are estimates and are likely to be revised upon further study.

Land Based Alternatives

For the land-based alternatives, the design and permitting costs have been itemized for Reaches 1 through 3 (the more publically owned reaches of the shoreline) in Table 32 below. Rather than try and itemize cost for Reaches 4 through 7, which are mostly privately owned, we calculated the per-foot-cost range for design and permitting using the itemized costs from Table 32 and applied these per-foot costs to engineering design and permitting for one selected alignment for Reaches 4 through 7 adjusted by the length of the alignment. This is admittedly a very crude way to estimate design and permitting costs, and artificially lowers costs for permitting options that have less length (like the options with tide gates) that arguably may actually have higher permitting costs due to environmental impacts. Therefore, these costs are just meant as a very rough estimate and subject to significant change. However, given the relative magnitude of these costs in relation to other costs, this approach was deemed as acceptable for a first cut conceptual analysis and should be refined once a specific alignment has been selected.

Note that actual costs may and will vary greatly by the solution being implemented. Until the actual scope and costs are developed in future phases, we have assumed the following costs:

Table 32. Estimated Design and Permitting Costs for Reaches 1-3.

Item	*Cost ($) – Lower Range*	*Cost ($) – Higher Range*
Biological studies	$150,000	$200,000
Hydraulic modeling	$300,000	$400,000
Preliminary design	$200,000	$300,000
Permitting and CEQA	$600,000	$1,000,000
Final design	$400,000	$600,000
Preparation of plans and specifications	$400,000	$500,000
Construction monitoring	$250,000	$300,000
Total Estimated Design and Permitting Costs	$2,300,000	$3,300,000

Reaches 1 through 3		
Calculated per foot cost for 12-inches SLR (assuming 14200 linear foot of shoreline) used to estimate costs for reaches 4 – 7	$195/linear foot	$280/linear foot
Total Estimated Design and Permitting Costs Reaches 1 through 3 for 36-Inch and 60-Inch SLR Scenarios (associated unit cost/linear foot)	$3,300,000 ($285/linear foot)	$4,300,000 ($350/linear foot)

These costs calculate out as follows:

Table 33. Design and Permitting Cost Estimates for Reaches 4-7 with 12 Inch Sea Level Rise.

Reach/Alignment	*Cost ($) – Lower Range*	*Cost ($) – Higher Range*
Reach 4 (A1)	$ 286,500	$ 411,065
Reach 5 (A1)	$ 70,649	$ 101,366
Reach 6 (A1)	$ 319,678	$ 458,668
Reach 7 (A1)	$ 700,636	$ 1,005,261

Table 34. Design and Permitting Costs for selected Alignments of Reaches 4-7 for 36 Inch Sea Level Rise.

Reach/Alignment	*Cost ($) – Lower Range*	*Cost ($) – Higher Range*
Reach 4 (A1)	$ 2,010,353	$ 2,469,862
Reach 5 (A1)	$ 1,129,861	$ 1,388,114
Reach 6 (A1)	$ 1,283,933	$ 1,577,403
Reach 7 (A3)	$ 1,519,035	$ 1,866,243

CONSTRUCTION COSTS

This section provides the range of capital costs for the adaptation alternatives within each reach as described above. Table 35 presents the concept level costs for the two large tide barriers proposed for Richardson Bay and subsequent tables for the land based alternatives.

Table 35. Concept Level Construction Cost Estimates for Large Tide Gate Structures.

Description	Approx. Length (feet)	Cost – Low ($)	Cost – High ($)	Reference
Tide barrier across Richardson Bay	1,700	$60MD[8]	$1BD[9]	Low end cost estimate assumes sheet pile structure with tide gates and high end cost estimate is based on comparison to Thames and Maeslantkering barrier costs from Wikipedia at $700M to $1B - Thames Barrier is 1,700 linear foot and Maeslantkering is

[8] MD = million dollars

[9] BD = billion dollars

				about 1,300 feet - both smaller then R Bay barriers. Used NOAA "What Will Adaptation Cost?" report 2013 costs for initial cost estimate of $0.21MD to $1.07MD per linear foot of barrier length

Both tide barriers would entail land-based costs for protecting shoreline areas outside of the barrier. Since the barriers are in different locations, the costs for the land-based protection of each are different. A summary table of the total possible costs for the two, large, water-based tidal barriers is included in the Summary and Discussion of Costs Section below.

Tables 36-39 show the unit costs for the various land-based adaptation alternatives. Details of the cost preparation work can be found in the appendix A.

Table 36. Unit Capital Costs for 12 Inch Sea Level Rise Alternatives.

Adaptation Option	*MASTER COSTS for 12-INCH SLR*		*Notes*
	low estimate	*high estimate*	
flood/sea walls – good foundation soils (per foot)	$ 150	$ 300	based on published unit costs - not adjusted for actual wall height
flood/sea walls – poor foundation soils (per foot)	$ 200	$ 500	based on published unit costs - not adjusted for actual wall height
berms and levees – good foundation soils (per foot)	$ 150	$ 200	based on published costs
berms and levees – poor foundation soils (per foot)	$ 180	$ 250	based on published costs
new or expanded pump stations (each)	$ 500,000	$ 1,100,000	based on engineering experience
rock rip-rap (per foot)	$ 80	$ 100	based on published costs
wetlands enhancement (acre)	$ 50,000	$ 80,000	assumed costs based on engineering experience and SFBJV datbase of wetland projects
horizontal levee to attenuate waves (per foot)	$ 350	$ 500	see horizontal levee worksheet for assumptions
small culvert gate structures (each)	$ 400,000	$ 800,000	tide gate structures at small creek mouths - assumed costs based on engineering experience
tidal barrier structures at small creek mouth (each)	$ 1,000,000	$ 2,000,000	guesstimated assumed cost
natural beach enhancements at the shoreline edge (per foot)	$ 100	$ 150	assumed costs based on engineering experience at Aramburu

Note: Low end and high unit cost estimates are approximate for study comparison purposes and not based on site-specific design evaluations.

Table 37. Unit Capital Costs for 36 Inch Sea Level Rise Alternatives.

Adaptation Option	*MASTER COSTS for 36-INCH SLR*		*Notes*
	low estimate	*high estimate*	
flood/sea walls – good foundation soils (per foot)	$ 300	$ 600	based on published unit costs - not adjusted for actual wall height
flood/sea walls – poor foundation soils (per foot)	$ 500	$ 1,200	based on published unit costs - not adjusted for actual wall height
berms and levees – good foundation soils (per foot)	$ 230	$ 300	based on published costs
berms and levees – poor foundation soils (per foot)	$ 280	$ 400	based on published costs
new or expanded pump stations (each)	$ 1,300,000	$ 2,000,000	based on engineering experience
rock rip-rap (per foot)	$ 140	$ 175	based on published costs
wetlands enhancement (acre)	$ 80,000	$ 110,000	assumed costs based on engineering experience and SFBJV datbase of wetland projects
horizontal levee to attenuate waves (per foot)	$ 530	$ 700	see horizontal levee worksheet for assumptions
small culvert gate structures (each)	$ 800,000	$ 1,500,000	tide gate structures at small creek mouths - assumed costs based on engineering experience
tidal barrier structures at small creek mouth (each)	$ 2,000,000	$ 4,000,000	guesstimated assumed cost
natural beach enhancements at the shoreline edge (per foot)	$ 180	$ 300	assumed costs based on engineering experience at Aramburu

Note: Low end and high unit cost estimates are approximate for study comparison purposes and not based on site-specific design evaluations.

Table 38. Unit Capital Costs for 60 Inch Sea Level Rise Alternatives.

Adaptation Option	*MASTER COSTS for 60-INCH SLR*		*Notes*
	low estimate	*high estimate*	
flood/sea walls – good foundation soils (per foot)	$ 700	$ 1,500	based on published unit costs - not adjusted for actual wall height
flood/sea walls – poor foundation soils (per foot)	$ 1,000	$ 2,500	based on published unit costs - not adjusted for actual wall height
berms and levees – good foundation soils (per foot)	$ 350	$ 500	based on published costs
berms and levees – poor foundation soils (per foot)	$ 400	$ 800	based on published costs
new or expanded pump stations (each)	$ 1,800,000	$ 3,000,000	based on engineering experience
rock rip-rap (per foot)	$ 200	$ 240	based on published costs
wetlands enhancement (acre)	$ 100,000	$ 150,000	assumed costs based on engineering experience and SFBJV datbase of wetland projects
horizontal levee to attenuate waves (per foot)	$ 650	$ 1,000	see horizontal levee worksheet for assumptions
small culvert gate structures (each)	$ 1,500,000	$ 3,000,000	tide gate structures at small creek mouths - assumed costs based on engineering experience
tidal barrier structures at small creek mouth (each)	$ 4,000,000	$ 8,000,000	guesstimated assumed cost
natural beach enhancements at the shoreline edge (per foot)	$ 300	$ 500	assumed costs based on engineering experience at Aramburu

Note: Low end and high unit cost estimates are approximate for study comparison purposes and not based on site-specific design evaluations.

Construction Cost Estimate Results

Table 36 summarizes the construction costs for the large tide gates options. Tables 40 through 41 present the cost ranges we developed for the land-based scenarios for each reach and alignment option under the three evaluated scenarios of sea level rise, based on the unit cost assumptions provided above.

Table 39. Summary of Concept Level Construction Cost Estimates for 12 Inch Sea Level Rise.

Reach/alignment	Cost – Low ($)	Cost – High ($)
Reach 1		
A1	$ 2,430,600	$ 5,267,500
A2	$ 3,182,000	$ 7,154,500
Reach 2		
A1	$ 581,450	$ 817,600
A2	$ 1,786,160	$ 3,116,750
Reach 3		
A1	$ 2,985,300	$ 8,029,300
Reach 4		
A1	$ 220,200	$ 440,400
Reach 5		
A1	$ 72,400	$ 181,000
Reach 6		
A1	$ 285,700	$ 566,400
Reach 7		
A1	$ 538,500	$ 1,077,000

Table 40. Concept Level Construction Cost Estimates for 36 Inch Sea Level Rise.

Reach/alignment	Cost – Low ($)	Cost – High ($)
Reach 1		
A1	$ 10,518,500	$ 21,004,400
A2	$ 9,971,000	$ 23,930,400
Reach 2		
A1	$ 4,267,680	$ 7,309,800
A2	$ 7,484,160	$ 12,801,500
A3	$ 4,143,400	$ 7,455,000
Reach 3		
A1	$ 10,073,370	$ 17,933,300
A2	$ 7,647,150	$ 14,275,100
A2a	$ 10,484,250	$ 18,758,100
A3	$ 10,960,530	$ 19,260,900
A4	$ 12,723,070	$ 21,679,100
A5	$ 10,803,720	$ 19,058,000
Reach 4		
A1	$ 4,746,780	$ 8,193,400
Reach 5		
A1	$ 4,808,800	$ 8,084,000
Reach 6		
A1	$ 1,422,000	$ 2,850,000
Reach 7		

A1	$ 1,105,500	$ 2,653,200
A2	$ 3,101,000	$ 7,442,400
A3	$ 4,022,000	$ 8,658,800

Table 41. Concept Level Construction Cost Estimates for 60 Inch Sea Level Rise.

Reach/alignment	Cost – Low ($)	Cost – High ($)
Reach 1		
A1	$ 17,883,000	$ 39,457,500
A2	$ 18,202,000	$ 46,255,000
Reach 2		
A1	$ 10,526,600	$ 21,424,800
A2	$ 16,097,300	$ 37,870,600
A3	$ 8,093,000	$ 16,057,000
Reach 3		
A1	$ 17,487,550	$ 34,457,000
A2	$ 13,603,450	$ 27,266,500
A2a	$ 17,749,350	$ 34,452,000
A3	$ 18,085,750	$ 34,634,500
A4	$ 21,027,950	$ 39,127,000
A5	$ 18,573,200	$ 35,316,000
Reach 4		
A1	$ 7,353,000	$ 14,878,800
Reach 5		

A1	$ 7,976,800	$ 15,353,600
Reach 6		
A1	$ 12,700,400	$ 27,208,000
Reach 7		
A1	$ 7,806,000	$ 16,815,000
A2	$ 7,098,000	$ 17,745,000
A3	$ 7,720,000	$ 18,550,000

MONITORING, MAINTENANCE, AND REPORTING (MMR) COSTS

We estimated costs for maintenance, monitoring, and reporting, assuming annual reports over a 50-year lifecycle. For land-based alternatives, we assumed the following annual costs for maintenance and monitoring and reporting.

- Annual levee, berm, and floodwall maintenance at $100,000 to $200,000 per reach.
- Annual monitoring and reporting at $25,000 to $100,000 per reach.

For the purposes of this study, we assumed the costs to be the same for each reach and alignment. Obviously, costs for maintenance, monitoring, and reporting can and will vary by reach, option, and the length of the area being monitored (there may be economies of scale for larger areas). These costs also depend on the particular adaptation option implemented and the regulatory permit requirements for monitoring, which can greatly depend on level of impact to existing resources. As such, these costs are very preliminary and intended only for an order-of-magnitude estimate until the next stage of design is developed. But for this level of cost estimating, it seemed important to include some costs for this item, even if assumed to be equal for all alignments.

6.5 Summary of Costs

This section summarizes the various costs items developed above to provide some order-of-magnitude estimate of potential range of adaptation costs.

LAND-BASED SHORELINE ALTERNATIVES

Figures 58 through 64 show a summary of costs by reach and alignment for the estimated low and estimated high values for each sea level rise scenario. Please see assumptions and limitations for all cost estimate numbers. Estimates include all potential costs, especially mitigation costs for environmental impacts to existing resources, which can be substantial.

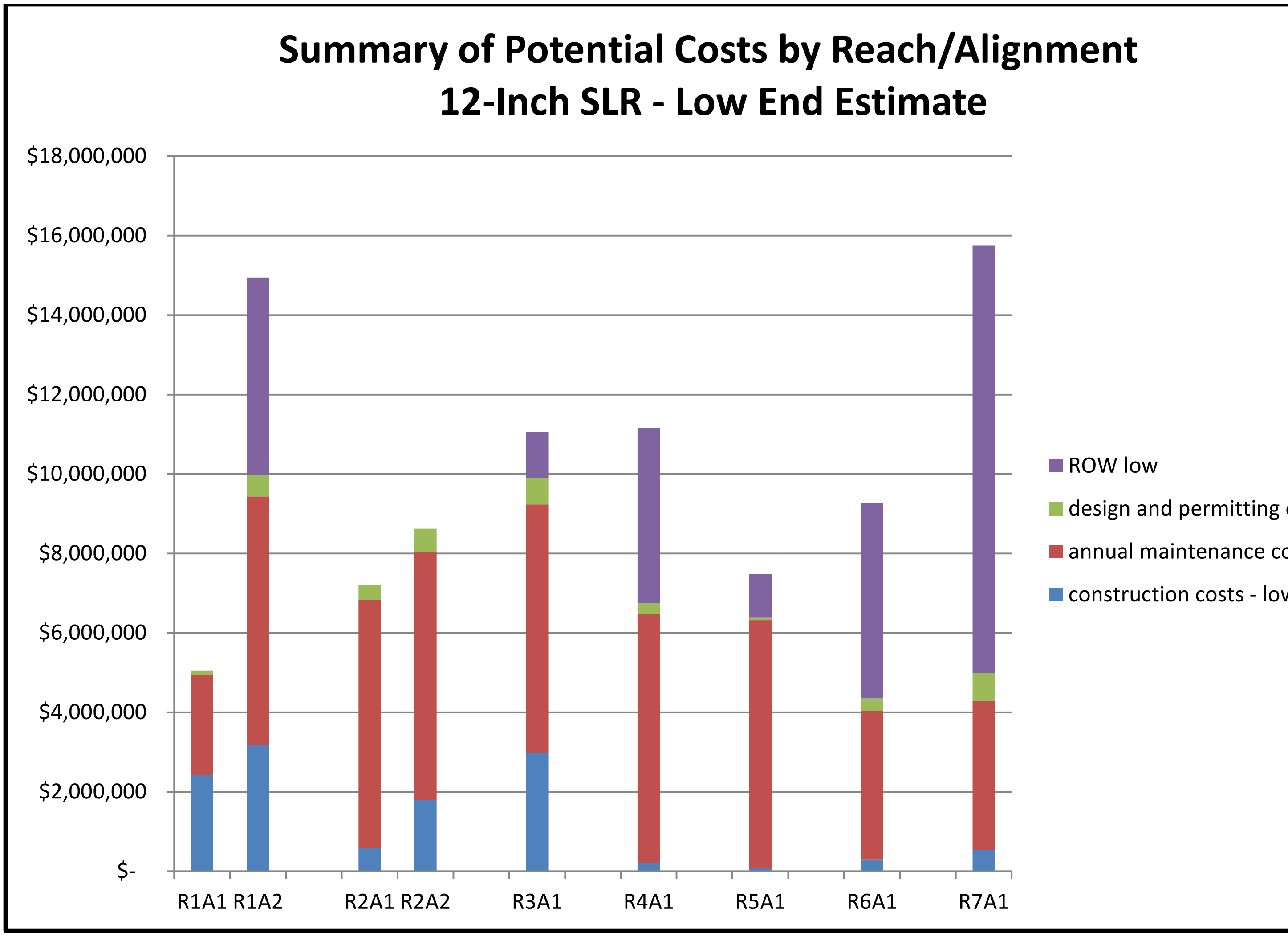

Figure 58: Summary of Potential Adaptation Costs--Low Estimate--By Reach and Alignment for the 12 Inch Sea Level Rise Scenario.

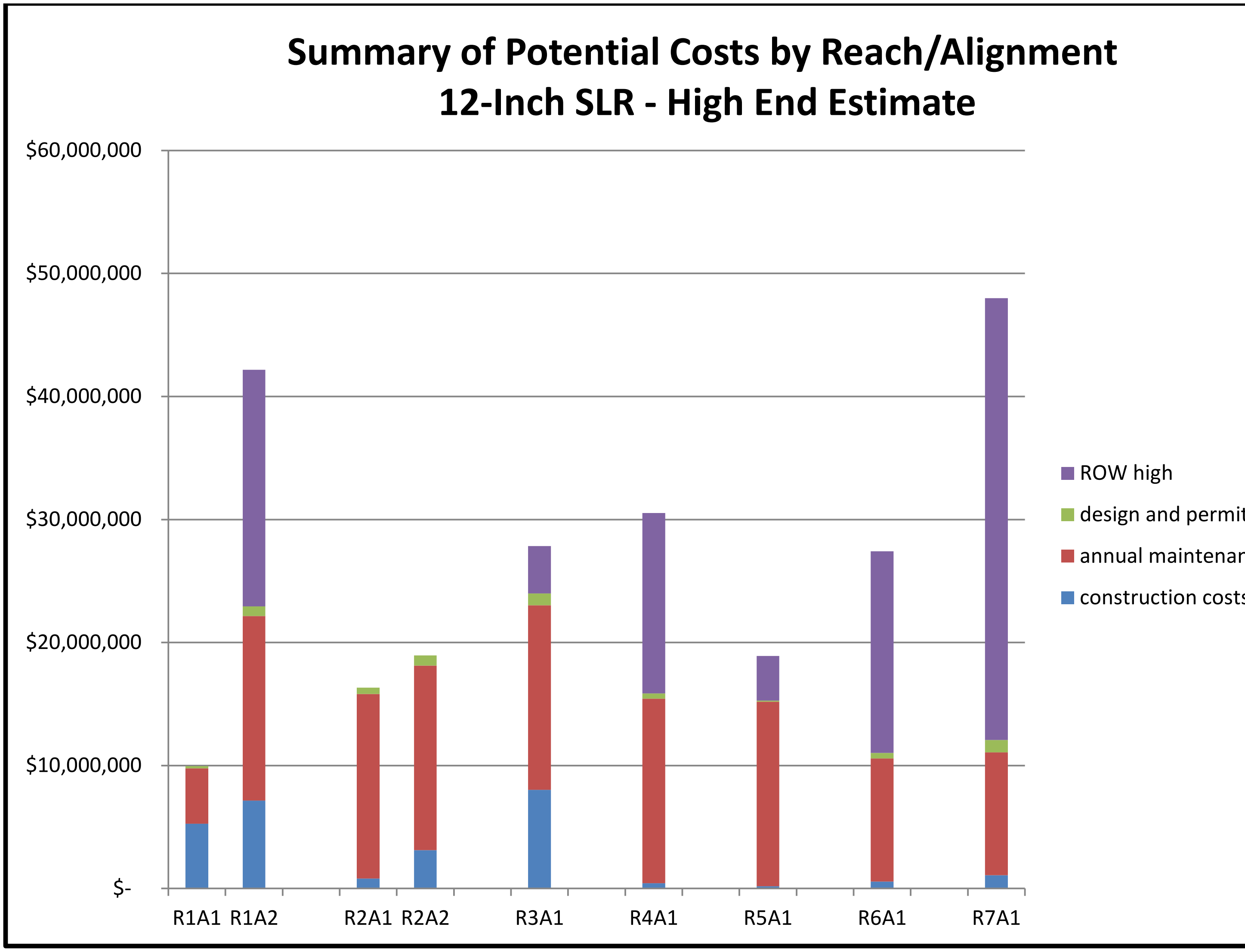

Figure 59: Summary of Potential Adaptation Costs--High Estimate--By Reach and Alignment for the 12-Inch Sea Level Rise Scenario.

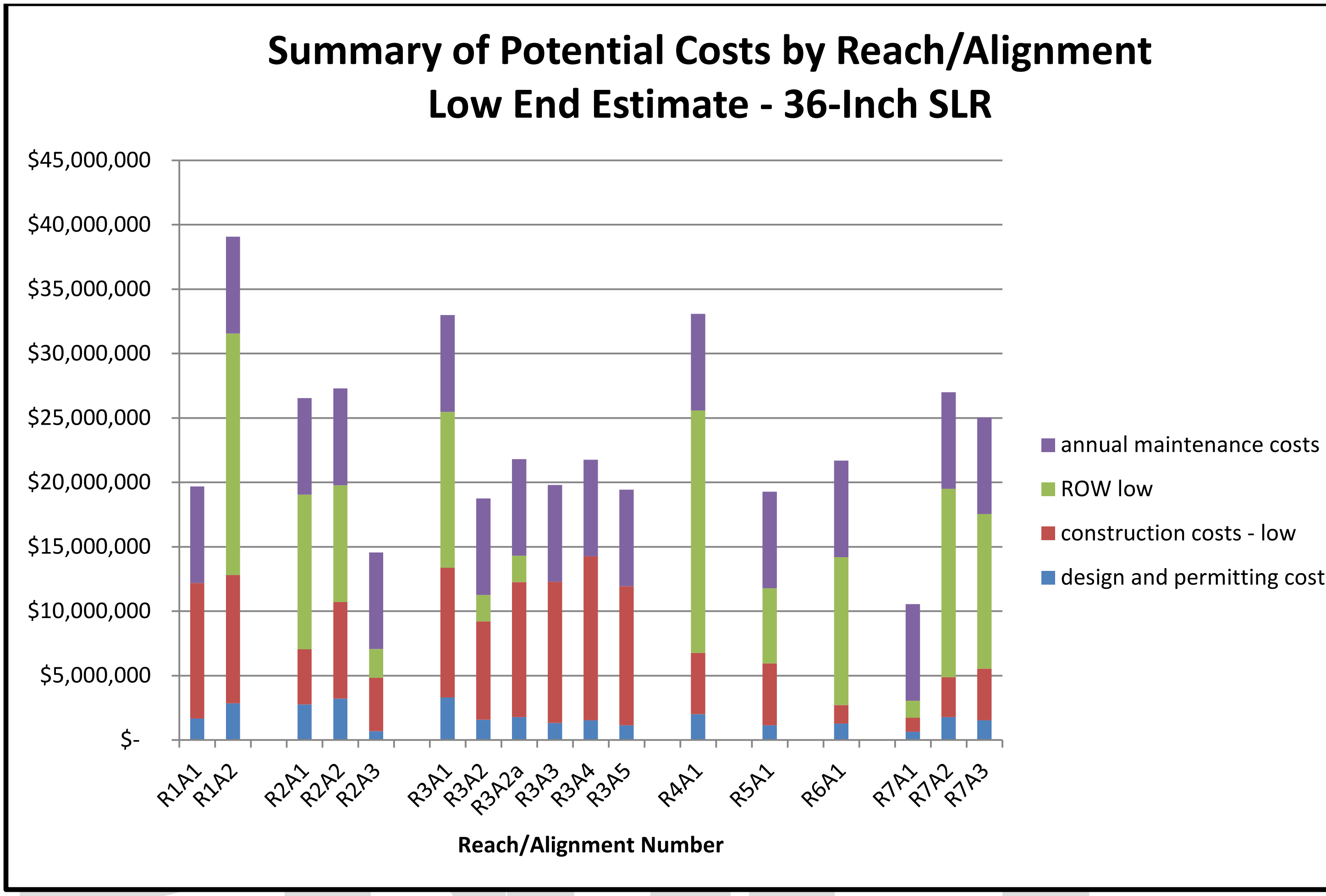

Figure 60: Summary of Potential Adaptation Costs--Low Estimate--By Reach and Alignment for the 36 Inch Sea Level Rise Scenario.

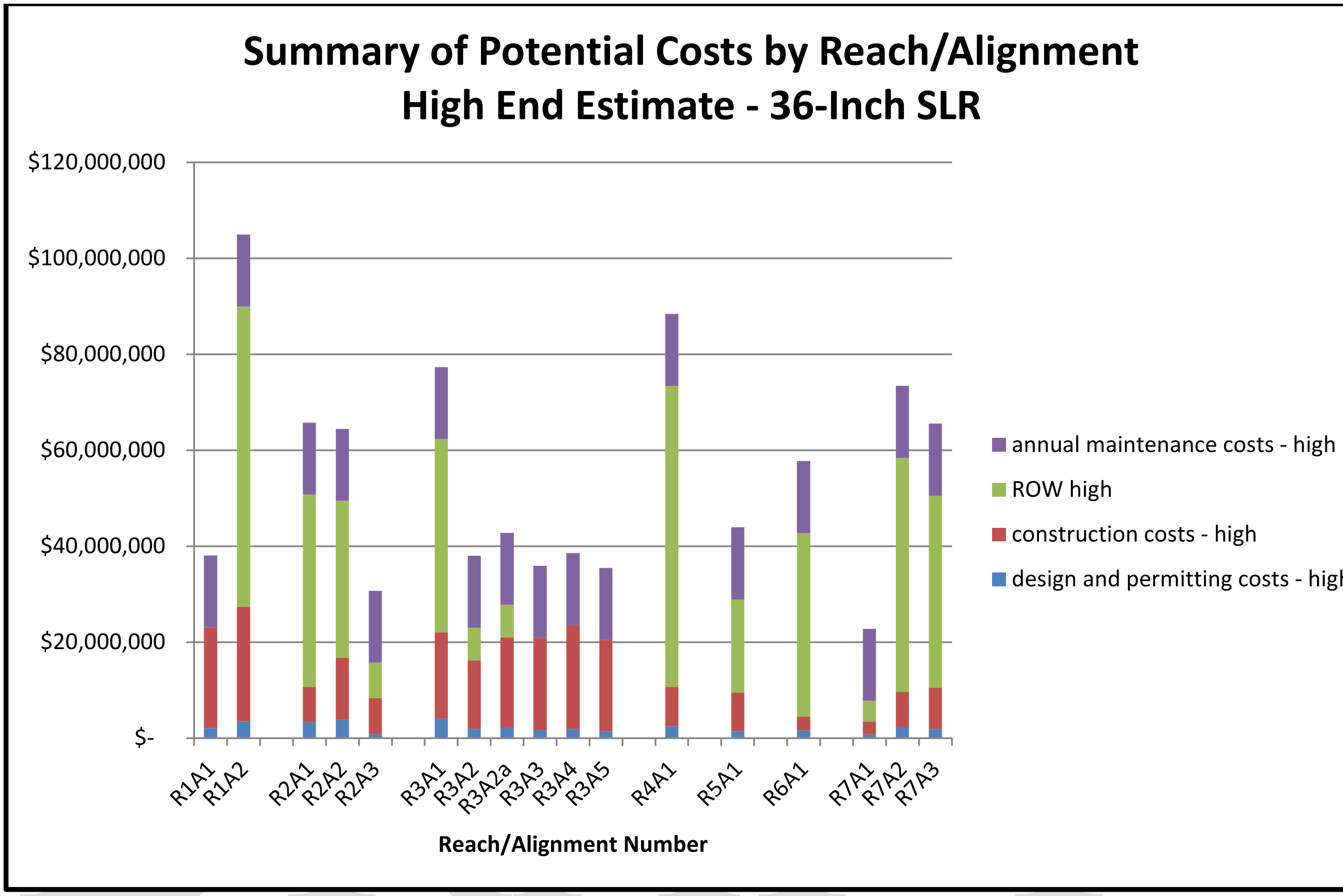

Figure 61: Summary of Potential Adaptation Costs--High End Estimate--By Reach and Alignment for the 36 Inch Sea Level Rise Scenario.

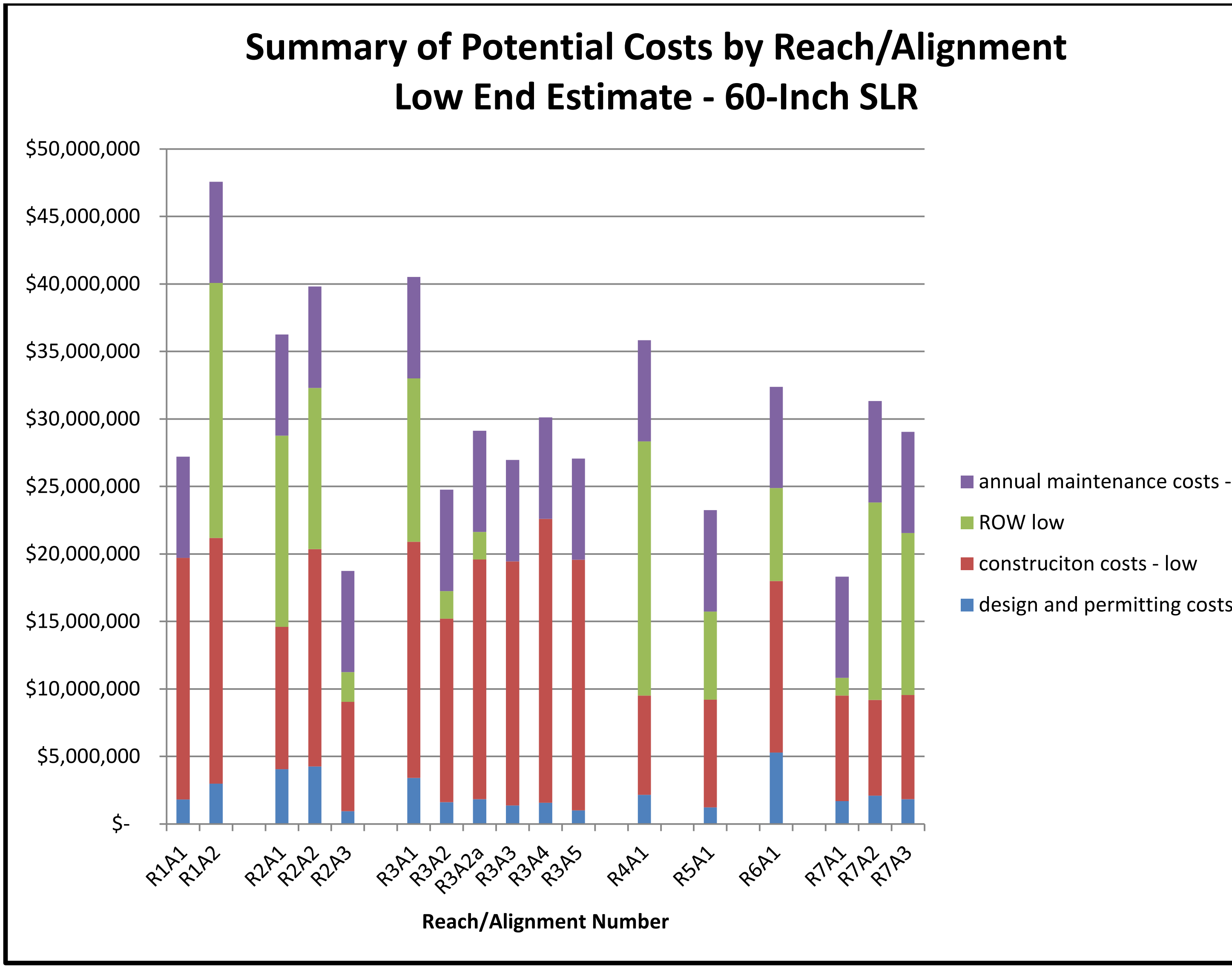

Figure 62: Summary of Potential Adaptation Costs--Low Estimate--By Reach and Alignment for the 60 Inch Sea Level Rise Scenario.

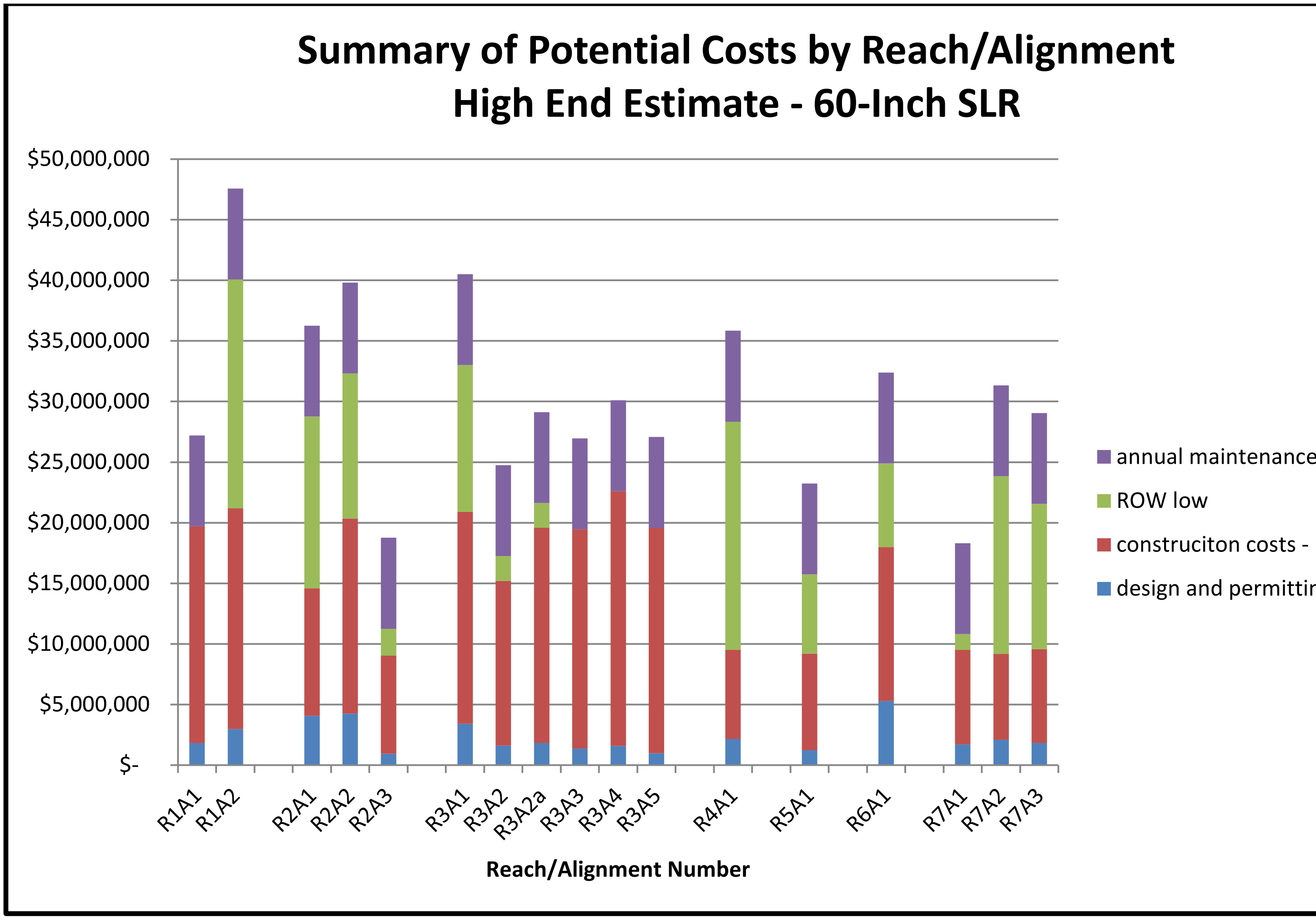

Figure 63: Summary of Potential Adaptation Costs--High Estimate--By Reach and Alignment for the 60 Inch Sea Level Rise Scenario.

Figure 64 below shows the total costs for the entire shoreline using both the lowest and highest alignment cost per reach for land based alternatives (high tide barrier options across Richardson Bay are not shown). The cost do not represent any attempt to optimize or develop trade-offs between impacts. As noted above, these costs should not be considered comprehensive or absolute. Many potentially significant costs, especially any future mitigation costs required by permitting agencies for environmental impacts, are not included. For example, high tide gates that may appear to be less expensive in the cost table above may not include such potentially significant costs.

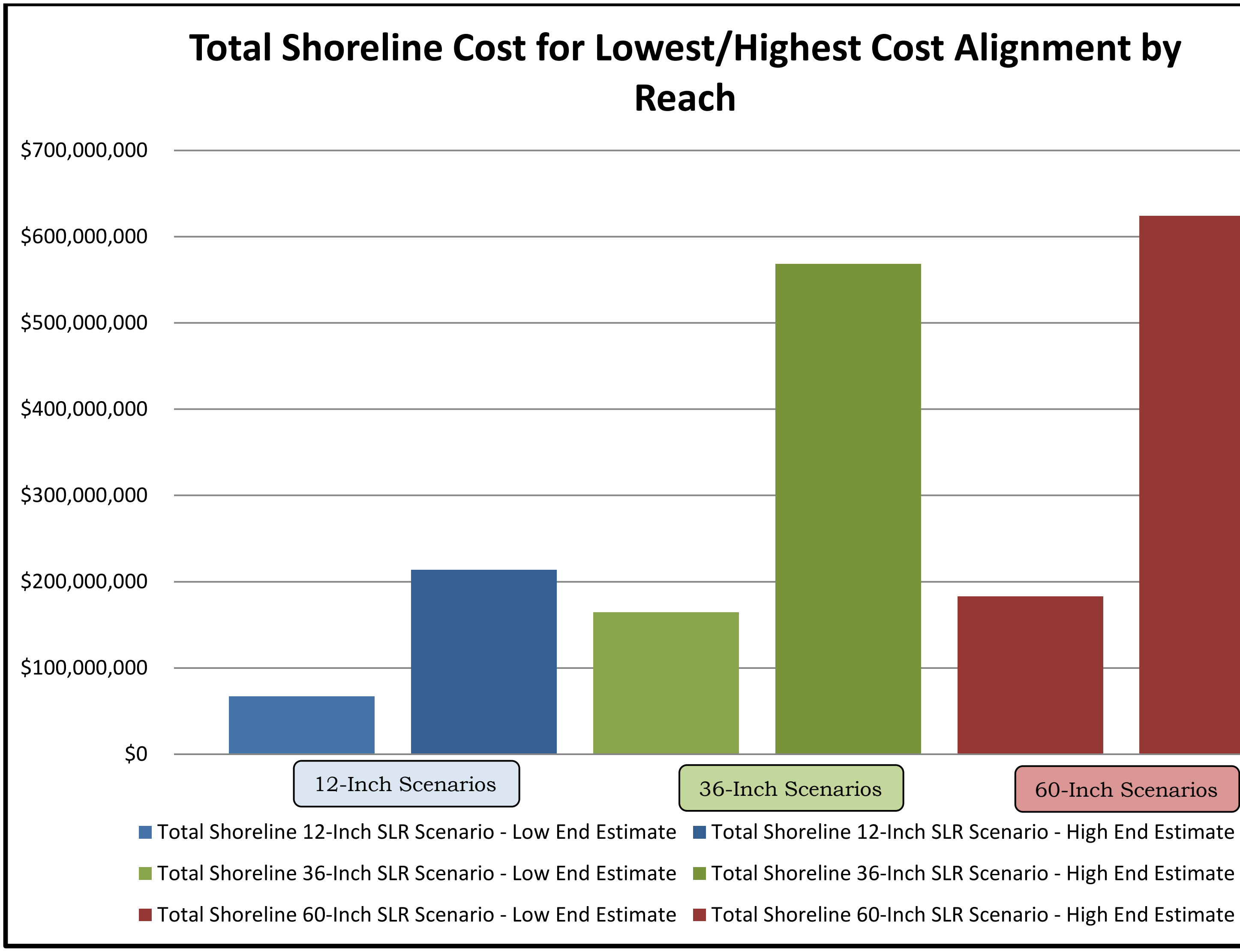

Figure 64: Concept Level Total Costs for the Lowest and Highest Reach Shoreline Alignments.

HIGH TIDE BARRIER OPTIONS

In previous section, we presented the total estimated concept level costs for the two high tide barrier options; RBBTB and FoldingWaters. If these options are continued forward for further consideration, similar to the land based alternatives, costs for engineering design, right of way acquisition, permitting etc. would need to be developed. Given the complexity and scale of these options, separate studies would be required.

7.0 CONCLUSION: PERSPECTIVE ON THE FUTURE OF FLOODING AND FLOOD PROTECTION ALONG THE SHORELINE

This section provides some perspectives on next steps for planning for sea level rise around the Richardson Bay shoreline.

7.1 Next Steps

Sea level rise has been described as a slow moving catastrophe that will unfold over this century. This time frame offers an opportunity to plan ahead since many of the solutions involve long-term planning. However, this longer time frame also allows communities to postpone making hard decisions. DPW has a role in planning, and supporting community planning efforts, while providing flood protection to built areas under current conditions.

Numerous next steps could be implemented. A few of the potential major next steps could include the following:

- Community planning and engineering
- Meet with CalTrans and Cities to evaluate flood reduction alternatives including high tide barrier alternatives
- Continued community education
- Develop funding source for future planning and capital improvement plan development
- Coincident frequency analysis: joint and conditional probability of riverine and coastal flooding for Coyote Creek
- Pilot projects

COMMUNITY PLANNING AND ENGINEERING

DPW should work with local communities and County planning staff to develop a vision and adaptation plan that develops and incorporates community visions into the next planning phases.

Ultimately, adapting to a rising tide level will involve more than traditional flood control engineering. It will likely include a mix of planning and zoning changes, engineering structures, enhancement of wetlands, and even revisioning the shoreline to become more water oriented. The ultimate plan will likely be a mixture of all the various adaptation options including zoning/policy changes, planned retreat, hard and soft engineering, and floodable developments.

CONTINUE COMMUNITY OUTREACH AND EDUCATION

Given the complexities and challenges facing the shoreline in Richardson Bay, it is important to continue education and outreach efforts with the community and political leaders. The first step in the long process of adaptation is to work on agreement on the magnitude and extent of the problem and then to look to solutions. The realities of sea level rise and the challenges of adaptation planning and funding should be included in the outreach process.

DEVELOP FUNDING SOURCE FOR FUTURE PLANNING AND CAPITAL IMPROVEMENT PLAN DEVELOPMENT

The potential costs for the adaptation alternatives considered in this report are significant. Especially for the 36 and 60 inch sea level rise scenarios, adaptation measures will be difficult to build with County funds alone, given the population of the Southern Marin watershed or even all of Marin County. Even if the cost estimates in this study are off by 50 percent or 100 percent, they are still significant and will thus require difficult planning and funding decisions.

Future adaptation planning should be informed by these limitations:

- Property owners and residents of the Southern Marin watershed need to understand the limits of government's ability to intervene to protect life and property from flooding due to sea level rise or other events. Local government probably will not have sufficient funds to undertake these types of projects without a large increase in budgets and capacity to manage them. Therefore, difficult planning decisions will be required.
- Given the high potential right of way costs, it may be unaffordable to compensate property owners at full value for right of way acquisition. A community plan will have to be developed based on individual property owners' willingness to be involved. Where critical properties are required, other ways to construct barriers may have to be considered.
- Planning and collecting revenue for adapting to future conditions and for protection and/or relocation of critical facilities should start now. Some kind of funding source should be identified to fund these studies.

A consistent funding source should be developed for working with the community on a formal vulnerability assessment and adaptation plan. A more formal vulnerability assessment can focus on adaptation and trade-offs including costs to inform and focus future planning efforts.

POST STORM RECOVERY PLANNING

The time period immediately following major storm events that result in significant flood damage is often an important period where people are focused on flooding and there is an opportunity to implement important flood damage reduction projects. It is therefore, useful and important to have a post-disaster plan of specific plans developed and ready to implement following a major storm event where there may be other sources of funding available and the public is focused on the issue. This can include acquisition of key properties, limitations on rebuilding of properties in sensitive areas, implementation of specific flood reduction projects.

COINCIDENT FREQUENCY ANALYSIS: JOINT AND CONDITIONAL PROBABILITY OF RIVERINE AND COASTAL FLOODING FOR COYOTE CREEK

This study considers direct coastal flooding separately from watershed flooding events. However, our cities and residences flood from both ends of the watershed so a more comprehensive risk based analysis would include an evaluation of the probability for large storms and large tides. While an exact correlation between large storms and high tides does not always exist, there is a likely correlation. The observed history of flooding in this area has shown that peak riverine flooding at high tides has worsened overall flooding. A coincident probability analysis that develops the correlation between riverine and tidal flooding would provide additional data for future flood control studies of this area.

THE POWER OF PILOT PROJECTS

To date, the eastern Marin shoreline in Richardson Bay and the Corte Madera marshes have been some of the most useful locations around the entire San Francisco Bay for on-the-ground sea level rise adaptation studies and pilot projects. The Corte Madera Baylands Sea Level Rise Adaptation study led by BCDC (BCDC 2013) developed various alternatives for expanding and protecting marshes along the shoreline for both habitat and flood protection. The Aramburu Island demonstration project successfully completed in 2012 has proven the benefits of coarse grained estuarine bay beaches for inhibiting wind-wave shoreline erosion while providing habitat for several bird species. DPW is currently preparing a feasibility study and a future pilot project (if feasible) for the beneficial reuse of dredged sediments from Coyote Creek to create transition zone, high marsh habitat along Bothin Marsh as part of a horizontal levee type eco-barrier to SLR along the shoreline.

Pilot projects provide especially useful information to managers and designers of natural approaches for shoreline resiliency. Projects that succeed and fail add to our working knowledge of how to plan and construct multi-benefit habitat and flood protection projects around the bay. We need more construction, monitoring, analysis, and dissemination of results to ultimately determine the best suite of alternatives and their limitations and uses for shoreline protection around the bay. The eastern Marin shoreline is an important and key location for this work.

8.0 REFERENCES

References used during preparation of this report include the following:

1. Carollo Engineers, “Sewerage Agency of Southern Marin –Wastewater Treatment Master Plan, Flood Study” July 2014 DRAFT
2. BCDC, “Corte Madera Creek Sea Level Rise Adaptation Study” May 8, 2013
3. Northwest Hydraulics Consultants (NHC), “Technical Memorandum - North San Francisco FEMA Mapping Vegetation Parameters for WHAFIS Modeling”, October 24, 2011.
4. Winzler & Kelly (W&K), “Technical Memorandum #3, Richardson Bay Tidal Flood Study – Final Alternatives Analysis” rev January 2nd 2009
5. NOAA Eastern Research Group, “What Will Adaptation Cost?” June 2013
6. Bay Institute, Analysis of the Costs and Benefits of Using Tidal Marsh Restoration and a Sea Level Rise Adaptation Strategy in San Francisco Bay, February 22, 2013
7. Stetson Engineers, “Appraisal Level Flood Study Report for ACMdP”, January 2013
8. 2012 National Research Council (NRC) report
9. Office of Emergency Response (OES 2012).
10. Habitat Goals Project 1999

Appendix A: Cost Estimates

Appendix B: Climate Change and Sea Level Rise

Sea level rise is a complex phenomenon that results from processes happening at multiple scales. At the global scale, the seas are rising due to thermal expansion of the ocean and melting of global ice. Thermal expansion results from higher water temperatures, leading to an increase in ocean volume. The melting of glaciers and land grounded ice caps, such as the large glaciers in Greenland and Antarctica, increases the mass of water in the oceans, also contributing to sea level rise.

Local sea level rise is also referred to as “relative sea level rise.” Changes in land elevations at the local level can worsen sea level rise impacts when tides are rising and the ground is sinking. Conversely, impacts from sea level rise can be reduced if the tides are rising and the ground is also rising. That phenomenon is happening in some locations—in areas of Alaska, for example. However, in Marin County, sea level is rising, and the ground is either stable or subsiding, so local sea level rise is a concern (we know of no locations where the land elevation is rising).

The local rise in sea level is a combination of three local factors:

1. Changes in Ocean Levels. Changes in sea level in the Pacific Ocean are affected by ocean circulation patterns, storms, and even short-term climatic variations. Winter storms—especially during strong El Niño events—can increase sea levels along the Pacific coast since prevailing winds accompanying these storms pool ocean water along the shore. The warmer waters that prevail during El Niño events also result in higher water levels due to thermal expansion. Other phenomena associated with the El-Niño-Southern Oscillation, such as the frequency and magnitude of storms and storm surges, may also be altered by climate change. Since the mid-1980s, wind patterns in the Pacific Ocean have damped down the rise on sea level as measured at the Presidio tide gage. Many scientists believe that this flattening of the trend line is temporary and predict that at some point, the sea level rise rate will accelerate.

2. Vertical land movement. Relative sea level rise is the sum of global sea level rise plus the change in vertical land movement. Thus, if sea level rises and the shoreline rises or subsides, the relative rise in sea level could be less or greater than the global sea level rise. Vertical land movement can occur due to tectonics (earthquakes, regional subsidence or uplift), sediment compaction, ground level elevation adjustments, and groundwater depletion. Scientists anticipate that as rates of global sea level continue to increase with climate change, at some point in the

future, the rate of upward vertical land movement will become less significant in mitigating sea level rise. Areas that have subsided, such as the Richardson Bay shoreline, are particularly vulnerable to sea level rise.

3. Local hydrodynamic variations. Differences have also been found between the rates of global sea level rise and regional sea level rise in large, semi-enclosed water bodies such as estuaries and large embayments (USACE, 2009). These differences have an impact on tide levels in the South Bay, but are not likely as much of a factor within Richardson Bay.

Appendix C: Regional Projects and Studies Related to Sea Level Rise in San Francisco Bay

Habitat Goals Update Project

An important, ongoing study is the update of the Bay Area Habitat Goals Update for Climate Change (BAHGU), which is itself an update to the original 1999 Bay Area Habitat Goals Report. This study will address some of the key aspects of habitat related to climate change impacts and is due in 2015.

Our Coast, Our Future (OCOF)

The United States Geological Survey (USGS) and Pt. Blue Sciences of Petaluma, California have been performing detailed hydraulic modeling of sea level rise, incorporating wind waves and storms under current and future sea level rise conditions. This work is being completed as this study is being prepared. The OCOF project is a much more in-depth and detailed process and, as such, represents the state of the science in terms of sea level rise impacts. The OCOF project provides results for several parameters in 25 cm increments of sea level rise, but does not necessarily tie specific water elevations to specific time frames. When the report is released, the community will be able to identify which value of sea level rise is of interest for assessing potential impacts.

NOAA Sea Level Rise Viewer

The National Oceanic and Atmospheric Administration (NOAA) has developed an online viewer of sea level rise around the country that allows people to visualize impacts in one-foot increments starting from a mean higher high water (MHHW) elevation. The national NOAA viewer uses a combined dataset that includes a larger scale (and less accurate) digital elevation model (DEM) along the Richardson Bay shoreline. To utilize the more accurate DEM developed by Marin County for this study, we separated out the NOAA elevation sea level rise tide data and imported it onto the higher quality topographic data for the Marin County shoreline. The combined data sets are shown in the inundation figures below.

FEMA West Coast Sea Level Rise Pilot Study

FEMA has undertaken a new pilot program to include sea level rise in their on-going mapping efforts. This work is in the early stages of development and is currently only being implemented along the outer coast of the city of San Francisco. It is expected that the results of this pilot study will become available in 2015 or 2016. Including sea level rise in FEMA flood studies is being undertaken at the request of Congress as part of the 2012 Biggert-Waters Flood Insurance Reform Act.

Other SF Bay Climate Change Groups and Initiatives

Numerous efforts are underway around San Francisco Bay and Marin County related to sea level rise and climate change. Regionally, some of the efforts that have some bearing for Marin County include:

Bay Area Ecosystems Climate Change Consortium: Facilitates collaboration between natural resource managers, scientists, and other interested parties through regular meetings, focused workshops, pilot projects, on-line communications and more to secure nature's ecological and economic benefits for the Bay Area. http://baeccc.org

Bay Area Habitat Goals Update Project (see above)

Bay Area Climate & Energy Resilience Project: A collaborative of more than 250 public, private, and non-profit stakeholders in the nine-county San Francisco Bay Area. The primary purpose of the project is to support and enhance the local climate adaptation efforts of cities, counties and other organizations. http://www.arccacalifornia.org/about/bacerp/