# APPENDIX 2

Risk Assessment Methodology and Results, Arup

East Bay Regional Parks District

# San Francisco Bay Trail Risk Assessment

Methodology and Results

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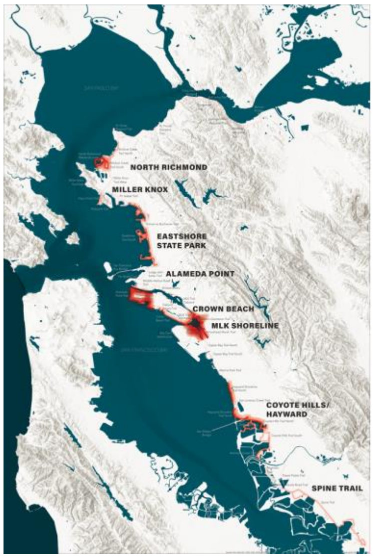
# 1 Executive Summary

The Bay Area is centered around the largest estuary on the west coast of North America, and as it has grown, this region has amassed a substantial network of infrastructure, communities and protected natural lands within low-lying, flood-prone areas. This region is also experiencing sea level rise at a higher rate than the global average, creating a dire need for a coordinated, data-driven approach to plan effective near and long-term adaptation interventions along the shoreline.

In many sections of the Bay Area's existing shoreline, the San Francisco Bay Trail (Bay Trail) acts as the defacto first line of defense against coastal flooding and sea level rise. The Bay Trail is a planned 500-mile pathway that circumnavigates the region's shoreline and provides a crucial link connecting people and communities to parks, open spaces, schools, and transit opportunities. The East Bay Regional Parks District (EBRPD) manages 55 miles of shoreline in the region's East Bay, which includes parks and segments of the Bay Trail that serve as critical recreational spaces and commute corridors in a heavily urbanized region.

To establish an adaptation prioritization plan for specific sections of the Bay Trail, the Park District launched the Risk Assessment and Adaptation Prioritization Plan (RAAPP) and assembled a project team led by WRT. In leading the risk assessment portion of this project, Arup developed a risk matrix to prioritize trail segments and project sites based upon sea level rise risk. This process involved creating evaluation criteria to compare Bay Trail segments under EBRPD management based on exposure to flooding, landscape response to flooding, and potential impacts that may result from flooding both in the near-term and long-term considering sea level rise. Following an initial site selection effort led by WRT, the risk assessment was conducted for 20 trail segments across 8 sites.

The risk matrix approach, which is described in this report, also allows for implementing various weighting schemes to adjust the emphasis applied to various metrics and shift prioritized sites accordingly. For example, if it was desirable to place greater emphasis on trail segments that have large and healthy outboard marshes, this preference could be implemented through a custom weighting scheme and this emphasis would be reflected in the final rankings of the various segments. Over 15 weighting schemes were developed and presented to the Park District. Ultimately, after incorporating feedback from the project team and consolidating all results, the following list, shown in Figure 1, was developed for first, second, and third priority sites ranked according to risk.




**FIRST PRIORITY SITES**

MLK Shoreline
Alameda Point
Coyote Hills/Hayward

**SECOND PRIORITY SITES**

North Richmond
Eastshore State Park
Spine Trail

**THIRD PRIORITY SITES**

Crown Beach
Miller Knox

*Figure 1 First, second, and third priority sites ranked according to risk*

## 1.1 Overall Project Purpose

The EBRPD commissioned a study from a team of experts, including WRT, ESA, San Francisco Estuary Institute (SFEI), OnClimate, and Arup, to assess the risks of coastal flooding and sea level rise on the East Bay section of the Bay Trail to inform an adaptation plan for key trail segments. The team was tasked with producing a Risk Assessment and Adaptation Prioritization Plan, the component parts of which are outlined as follows:

- Site Analysis: Based on criteria from the client, screen 45 segments of trail in the East Bay and narrow them down to 8 sites for further study.
- Risk Assessment: Develop metrics to measure hazard, vulnerability, and consequences from sea level rise and coastal flooding and assess the 8 sites, assigning risk profiles to each.
- Adaptation Prioritization Plan: Based on results from the risk assessment, narrow in on two to three sites that are most appropriate for conceptual design and adaptation planning.

This report memorializes methods and results from the Risk Assessment work conducted as one phase of the larger project scope. The intention of this risk assessment was to inform the project's overall prioritization plan which will also consider project funding feasibility, partnership opportunities, and site-specific EBRPD goals. Ultimately, conducting a Bay Trail risk assessment and subsequently establishing an adaptation prioritization plan will enable the Park District to take action on a shortlist of nature-based, implementable strategies and projects that will have immediate and long-term benefits to the trail, shoreline, and adjacent communities.

## 1.2 Scope

The general approach used for assessing risk of coastal flooding and sea level rise across the eight Bay Trail segments involves four steps: 1) assigning hazard scores, 2) assigning vulnerability scores, 3) assigning consequence scores, and 4) performing a risk assessment.

The **hazard** assessment draws on a previous analysis conducted by ESA which estimates the relative likelihood and corresponding intensity of different hazards affecting each site segment. The natural hazards quantified include tidal inundation, storm flooding, extreme wave conditions, and groundwater emergence. The segments are assigned a score for each metric which add up to one hazard score for each. A weighting is then applied to the scores to allow for different explorations of the hazard results. The different weightings include mid-century focus, end-of-century focus, or present-day focus. Each weighting reveals answers to different questions.

The **vulnerability** assessment considers the susceptibility of each segment to damage with a focus on potential for erosion and overtopping from flooding. The assessment takes into account the various elements of green and grey infrastructure present along the shoreline to determine how vulnerable each segment is, looking at everything from mudflats to trail composition. The same method that is used in the hazard assessment is applied here except with different weighting schemes: outboard protections, trail focus, or marsh focus.

The **consequence** assessment measures the expected severity and extent of the impact of hazards on the trail and surrounding communities. The weighting applied to the consequence scores include economic, environmental, and social equity focuses.

These different weightings allow the client to tailor their decision-making around specific and dynamic priorities, ensuring the tool is flexible enough to meet their needs in the context of a changing climate and a changing funding landscape. In addition to developing thematic weightings based on unique needs for each assessment noted above, Arup administered a survey of the project team to narrow in on importance preferences from subject matter experts. Recognizing that this weighting approach has limitations related to potential bias, we included a 'team weighting' for each assessment noted above.

The final **risk assessment** integrates all of the scores from the assessment to reveal one final risk score for each segment based on the team weighting. The team weighting is used because it is the only consistent weighting scheme across all three assessments. In addition to the team weighting, a combined risk score was calculated by combining multiple weighting schemes and considering each combination equally valid.

## 1.3 Summary of Key Findings

The final risk assessment was consolidated into two final rankings, one relying on a combined weighting approach, the other using the team importance weighting. Even though the two different weighting schemes represented a variety of preferences, the ranked results reveal the same top three, middle three and bottom two trail segments, with MLK Shoreline, Alameda Point, and Coyote Hills/Hayward having the highest risk profiles. Figure 2 below illustrates this result.

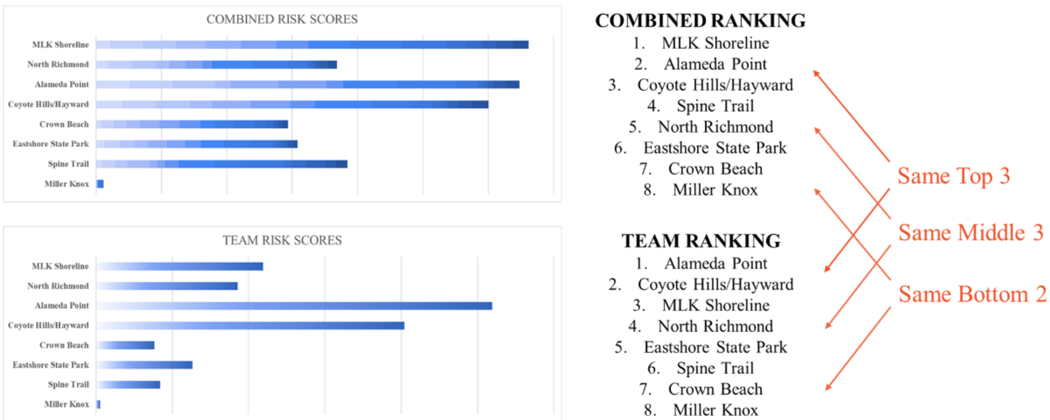



*Figure 2 Final site risk scores and rankings based on a combination of weighting schemes as well as a team weighting scheme; risk scores are unitless*

Resulting scores vary for each individual assessment—hazard, vulnerability, and consequence—not only because they are measuring different elements of risk, but also because they employ different weighting schemes and metrics. The hazard assessment reveals that the MLK Shoreline has the highest overall hazard score based on both end-of century weighting and present-day weighting while Coyote Hills/Hayward received the highest hazard score when the mid-century weighting is applied. Coyote Hills and Alameda Point receive the highest hazard scores based on team weighting. Every site received its highest hazard score when the end-of-century weighting was applied, pointing to the importance of planning for adaptation strategies today in anticipation of increased sea level rise and coastal flooding in the future.

The vulnerability assessment exposes Alameda Point and Miller Knox as particularly vulnerable trail segments with high scores across all weighting schemes, elevating the need for more shoreline protection along these segments. This result also highlighted the lack of protective natural infrastructure at these sites, such as outboard marshes or wetlands.

Finally, the consequence assessment shows the Coyote Hills/Hayward segment as having the highest consequence scores for most weighting schemes, likely caused by its proximity to nearby neighborhoods and community places, while Miller Knox and Crown Beach show low scores across all weighting schemes both of which are further removed from population centers. With a social equity weighting, however, the Spine Trail score spikes as the segment with highest consequences given its proximity to a disadvantaged community. Of note, economic and environmental weighting schemes yield almost identical scores across all sites.

Separately, each assessment, and each weighting within each assessment, tells a different story. Depending on the question being answered, different weighting schemes can be employed to determine a risk ranking that is representative of EBRPD's priorities. Moving into the Adaptation Planning stage of the project, we will employ the risk assessment results derived from the team weighting scheme not only due to the expertise represented on the team, but also because the results from this weighting scheme were generally consistent with the results from the combined weighting scheme. The risk scores will help inform the project team as they prioritize adaptation strategies across the highest risk trail segments.

The section of the Bay Trail that runs along the East Bay is varied and complex, with differing exposure levels to hazards from the Bay, differing coverage and quality of green and grey infrastructure that determine vulnerability, and differing surroundings that define how consequential the impacts of sea level rise and coastal flooding will be on community resources. We know that the impacts from climate change will change our relationship with the Bay as it threatens public access to recreation along the shoreline. This assessment reveals how truly diverse the conditions along the shoreline are and as a result, how diverse the impacts will be, providing a road map for the EBRPD and its stakeholders to prioritize adaption interventions in the near-term to achieve long-term benefits for the region.

# 2 Introduction

The Bay Trail is a 500-mile-long trail that spans 47 cities and nine counties, providing unmatched recreational opportunities and waterfront access for the region's residents and visitors alike. The EBRPD operates much of the section of trail that runs between Contra Costa and Alameda Counties, which positions the agency with a unique responsibility to protect the shoreline. The East Bay's shoreline is complex, and conditions vary widely depending on the historical context and natural features present, putting some segments of the Bay Trail at higher risk to the impacts of climate change than others. Depending on the location, the Bay Trail may be the first line of defense against coastal flooding and inundation, while other segments may benefit from natural infrastructure that protects the shoreline from climate impacts.

The San Francisco Bay Trail Risk Assessment (Risk Assessment) looks at eight segments of the Bay Trail in the East Bay to assess each segment's:

- **Hazard:** The intensity of a particular threat measured at the site with a focus on tidal, storm, waves, and groundwater flooding.

- **Vulnerability**: The susceptibility to damage given a certain demand with a focus on potential for erosion and overtopping.
- **Consequences:** The expected severity and extent of impact given hazard with a focus on economic, environmental, equity, recreation and connectivity.

Together, these three components illustrate each segment's overall risk profile which allows the EBRDP to prioritize interventions on the Bay Trail based on coastal flood risk and sea level rise. Using risk assessment to inform prioritization helps the agency steward precious public dollars and craft a data-driven and strategic roadmap for funding and project implementation moving forward.

The following report details the assumptions, limitations, data, method, and results for each category, followed by in-depth conversation detailing the weighting schemes and methods underpinning the risk assessment. The report closes with a discussion about recommendations and next steps.

# 3 Background

The Bay Trail is the backbone of the region's trail network, creating important connections for recreation and active transportation across the nine-county region. The trail's position along the shoreline, puts it at risk of being impacted by sea level rise and other coastal flood events. This Risk Assessment, which was led by Arup, is the second stage in a larger body of work being conducted by a team consisting of WRT, ESA, SFEI, OnClimate, and Arup to develop an adaptation plan for the Bay Trail. Recognizing that some segments of trail are at higher risk than others, the team narrowed in on eight priority segments in the first stage of this process in which all of the sites were analyzed. The eight priority segments are as follows:

- MLK Shoreline
- North Richmond
- Alameda Point
- Coyote Hills/Hayward
- Crown Beach
- Eastshore State Park
- Spine Trail
- Miller Knox

Based on the literature and data review, analysis of sites revealed those most vulnerable to sea level rise. The team at WRT analyzed them further to understand site constraints and opportunities and identified critical service consequences, social consequences and any economic and financial consequences resulting from sea level rise to narrow in on the top priority sites to explore in the Risk Assessment. The map shown in Figure 3 places the eight priority segments into context with the greater region.

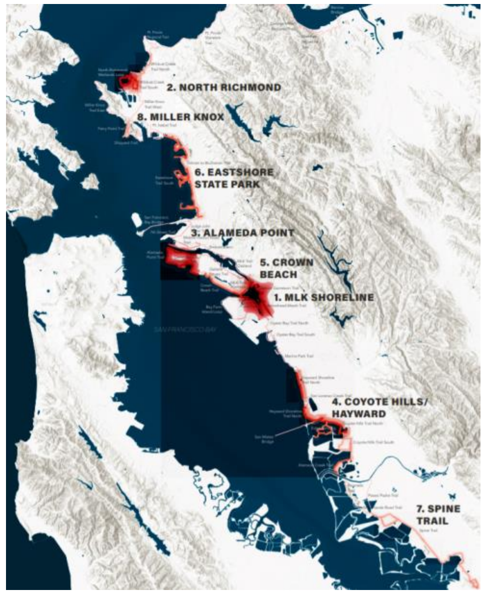



*Figure 3 Locations of eight priority Bay Trail sites included in the Risk Assessment*

The Risk Assessment approach involved the development of a risk assessment matrix to collate data and compare segments based on exposure to flooding, landscape response flooding, and potential impacts that may result from flooding both in the near-term and long-term considering sea level rise. A detailed representation of the overall project process and where the Risk Assessment fits in is shown in Figure *4*.

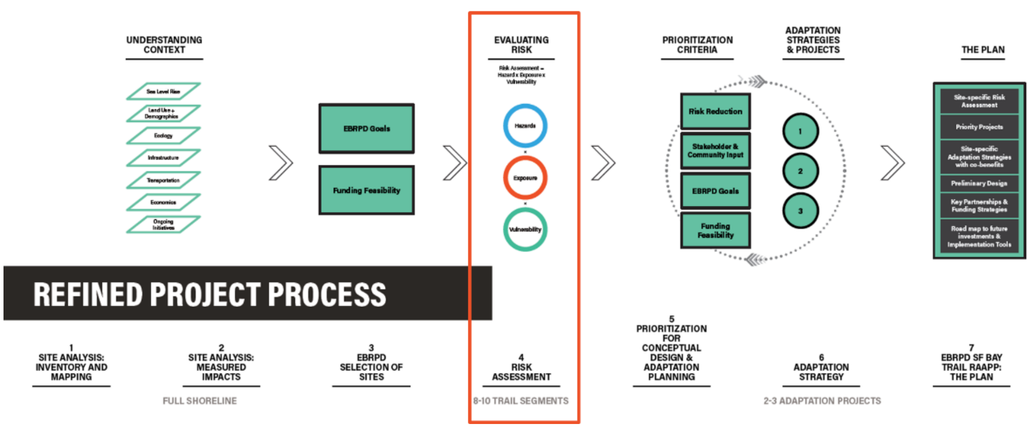



Figure 4 Refined project process

The risk matrix is comprised of three component parts, mentioned above and noted briefly here:

1. Hazard assessment,
2. Vulnerability assessment, and
3. Consequence assessment.

Each assessment is comprised of a series of metrics upon which each segment is scored on a 1-5 basis. The scoring for each metric is based on a set of defined criteria. The scoring system employed in the model is based on a decision theory methodology called, "simple multi-attribute rating (or ranking) technique" that allows engineers or planners to compare multiple and often divergent parameters that influence the risk profile. Generally, 1 indicates that the segment performs positively for that respective metric (i.e., low hazard, low vulnerability, low consequence), and 5 indicates that the segment performs negatively (i.e., high hazard, high vulnerability, high consequence). Each metric is weighted based on its relative importance. The output is one composite score for each segment which rolls up into the overall risk score for each segment. Figure 5 shows the functional approach in greater detail.

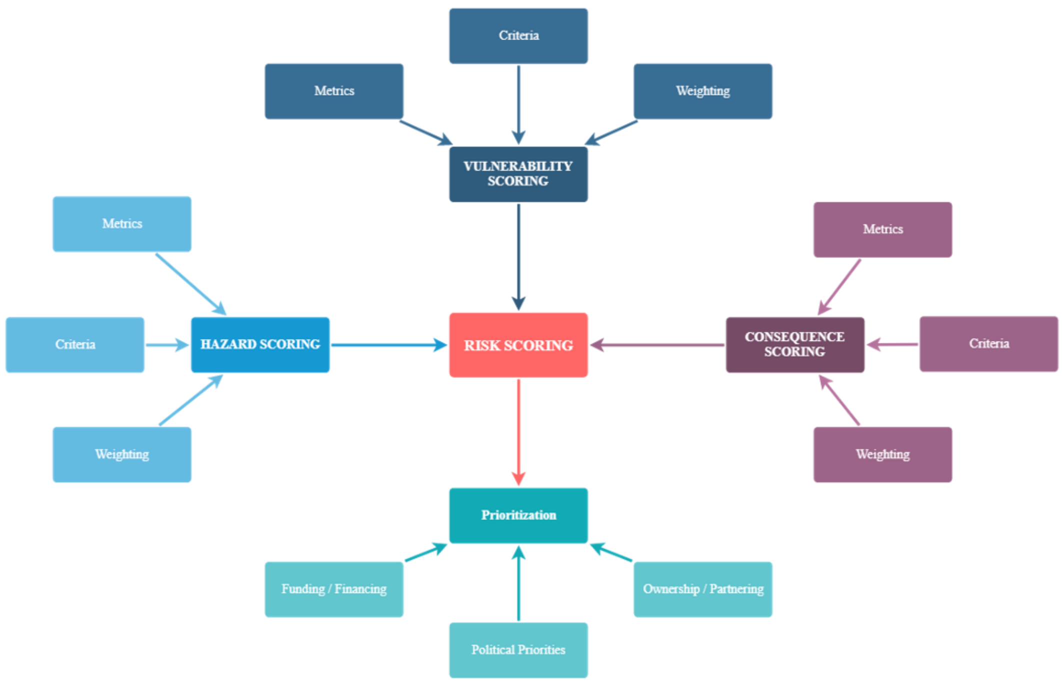



*Figure 5 Risk matrix structure*

In the third and final stage of the project following the Risk Assessment, segments of the Bay Trail within the EBRPD's purview found to be at the highest risk of coastal flooding and sea level rise will be prioritized for additional adaptation design and implementation. Segments will be ranked based upon their risk level, funding needs, ownership structure and partnership opportunities, political support, and co-benefits resulting from adaptation. The Prioritization will inform EBRPD and others on the most critical investments necessary in the near-term, mid-term, and long-term timeframes to enable a strategic funding and implementation strategy for adaptation responses.

# 4 Hazard

The hazard assessment was the first stage of developing the risk matrix. This assessment ingests data for the likelihood and severity of flooding at specific trail segments including various scenarios for sea level rise. Multiple flooding mechanisms were considered, including tidal inundation, storm flooding, extreme wave events, and groundwater emergence.

## 4.1 Assumptions

Sea level rise scenarios considered in the hazard assessment included 0-feet, 3-feet, and 6-feet, assumed to represent a range between present day conditions, mid-century conditions, and end-of-century conditions. It is acknowledged that 3-feet and 6-feet are somewhat conservative scenarios for mid and end-of-century respectively, but the project team reached consensus around these being useful planning scenarios for the purposes of site selection, risk assessment, and prioritization.

## 4.2 Limitations

No new modeling was conducted to support this analysis, instead data was gathered from publicly available sources and processed in GIS by ESA before being provided to Arup. The focus of most flooding scenarios considered the percent of each trail segment that would be inundated by each scenario. Flood depth was not explicitly incorporated into the hazard assessment due to the lack of sufficient data for all sites. High resolution elevation data was also not available which limited the team's ability to compare potential water surface elevations to known existing grade profiles for various segments of trail.

Regarding extreme wave conditions, digital data was not available although a static report (DHI, 2011) was referenced, which included a map of model results for the 100-year wind wave conditions along the East Bay shoreline.

The consideration of various return period events was limited to "normal" tidal flooding and the 100-year storm flood event. Normal tidal flooding is what is expected to occur on average at least once per year. This metric provided a useful proxy for assessing which segments could face permanent flooding under various scenarios of sea level rise.

## 4.3 Data

All input data employed in the hazard assessment was provided by ESA, although WRT supported in the development of groundwater emergence data and project specific maps. For further information on the various sources used and processing of this data, please refer to ESA's portion of the main project report.

The key metric used for the hazard assessment was percent of trail segment inundated. Various scenarios were considered ranging from normal tidal flooding with 0-feet of sea level rise to 100-year storm flood conditions assuming 6-feet of sea level rise. As expected, the range in the percent inundation varied significantly by scenario and by segment. Relying on percentages also meant that the data was well suited for the hazard scoring system described in the methods section below. Figure 6 shows completed hazard maps developed by WRT in collaboration with ESA which helped visualize the data brought into this analysis.

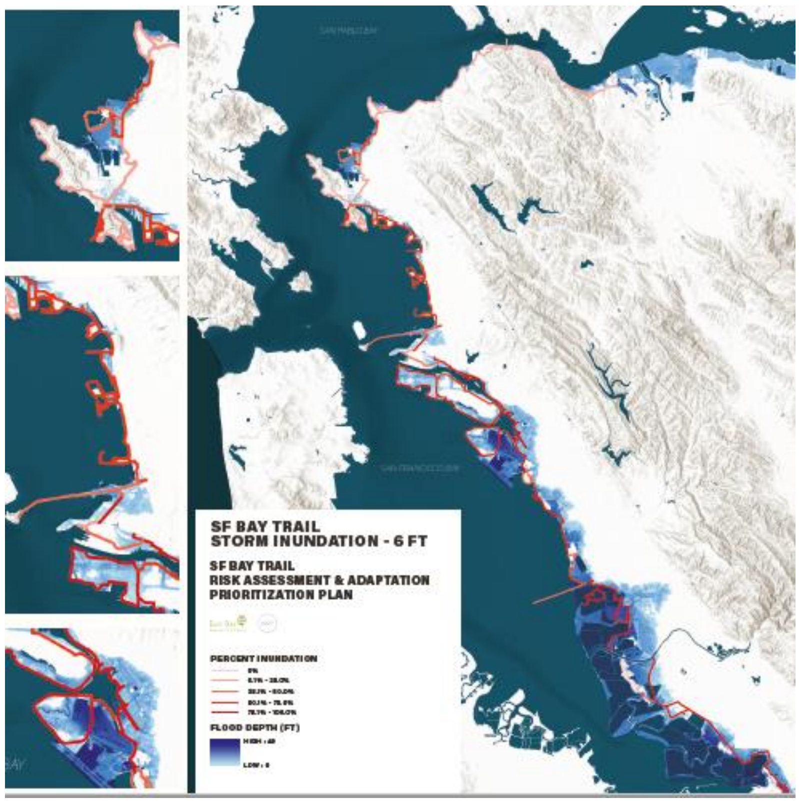



*Figure 6 Sample hazard map developed by WRT showing 100-year storm flood conditions assuming 6-feet of sea level rise*

Table 1 summarizes the data elements included in the overall hazard assessment.

*Table 1 Hazard assessment elements*

| Theme | Metric | Criteria | Data Source |
|---|---|---|---|
| Tidal Inundation | Percent of segment inundated by "normal" tidal flooding assuming 0-feet of SLR (2020 condition) | 1 – Lowest potential for tidal flooding<br>3 – Moderate potential for tidal flooding<br>5 – Highest potential for tidal flooding | ESA |
| | Percent of segment inundated by "normal" tidal flooding assuming 3-feet of SLR (2050 condition) | | |
| | Percent of segment inundated by "normal" tidal flooding assuming 6-feet of SLR (2100 condition) | | |
| Storm Flood Condition | Percent of segment inundated by "100-year" storm flooding assuming 0-feet of SLR (2020 condition) | 1 – Lowest potential for storm flooding<br>3 – Moderate potential for storm flooding<br>5 – Highest potential for storm flooding | ESA |
| | Percent of segment inundated by "100-year" storm flooding assuming 3-feet of SLR (2050 condition) | | |
| | Percent of segment inundated by "100-year" storm flooding assuming 6-feet of SLR (2100 condition) | | |
| Extreme Wave Conditions | 100-year wind wave conditions along trail segment | 1 – Lowest potential for extreme wave conditions<br>3 – Moderate potential for extreme wave conditions<br>5 – Highest potential for extreme wave condition | DHI, 2011 via ESA |
| Groundwater Emergence | Percent of segment with 5 feet to groundwater in 0-feet SLR (2020 condition) | 1 – Lowest potential for groundwater emergence<br>3 – Moderate potential for groundwater emergence<br>5 – Highest potential for groundwater emergence | ESA |
| | Percent of segment with 5 feet to groundwater in 3-feet SLR (2050 condition) | | |
| | Percent of segment with 5 feet to groundwater in 6-feet SLR (2100 condition) | | |

## 4.4 Methods

In general, a single method was used to convert percentage values from the hazard data into 1-5 values to represent relative hazard scores. This method first involved calculating the 'norm' which simply took the global maximum of 100% and the global minimum of 0%, subtracted these values, and divided by 5, which was the chosen maximum for the overall scoring. With this value, 1-5 scores could be computed by dividing the hazard value (percent) for each trail segment by this normalizing value (0.2). This method is illustrated in Figure 7 below.

| Bay Trail Segments | WRT | SFEI | Storm Flooding: % of segment inundated in SLR 3 ft Scenario | |
|---|---|---|---|---|
| | | | Perent | Score |
| Arrowhead Marsh Trail | MLK Shoreline | MLK Shoreline | 51% | 2.6 |
| Damon-Garretson Trail | MLK Shoreline | | 34% | 1.7 |
| Dolittle Pond Trail | MLK Shoreline | | 59% | 3.0 |
| MLK Trail Alameda | MLK Shoreline | | 28% | 1.4 |
| North Richmond Wetlands Loop | North Richmond | Richmond Central | 32% | 1.6 |
| Wildcat Creek Trail South | North Richmond | Richmond South | 38% | 1.9 |
| Wildcat Creek Trail North | North Richmond | Richmond North | 7% | 0.4 |
| Alameda Point Trail | Alameda Point | Alameda Point | 60% | 3.0 |
| Hayward Shoreline Trail South | Coyote Hills/Hayward | Coyote Hills Hayward North | 74% | 3.7 |
| Hayward Shoreline Trail North | Coyote Hills/Hayward | | 56% | 2.8 |
| Coyote Hills Trail North | Coyote Hills/Hayward | Coyote Hills Hayward South | 94% | 4.7 |
| Eden Landing Loop | Coyote Hills/Hayward | | 100% | 5.0 |
| Alameda Creek Trail | Coyote Hills/Hayward | | 91% | 4.6 |
| Coyote Hills Trail South | Coyote Hills/Hayward | | 77% | 3.9 |
| Crown Beach Trail | Crown Beach | Crown Beach | 49% | 2.5 |
| Eastshore Trail North | Eastshore State Park | East State Park North | 7% | 0.4 |
| Eastshore Trail South | Eastshore State Park | East State Park South | 20% | 1.0 |
| Gilman to Buchanan Trail | Eastshore State Park | East State Park Central | 37% | 1.9 |
| Spine Trail | Spine Trail | Spine Trail | 21% | 1.1 |
| Ferry Point Trail | Miller Knox | Miller Knox | 1% | 0.1 |

| | | |
|---|---|---|
| Global Max | 100% | |
| Global Min | 0% | |
| Norm | 0.20 | $= \frac{100 - 0}{5}$ |

$$Score = \frac{Local\ Value - Global\ Min}{Norm}$$

$$2.5 = \frac{49\% - 0}{0.2}$$

*Figure 7 Summary of hazard score conversion from percent to 1-5 scores*

### 4.4.1 Metrics and Criteria

As shown in the data table above, the primary metric used to assess hazard was percent of trail inundated under a specific scenario. In the case of extreme wave conditions, the 100-year wind wave conditions along the trail segment was used as a hazard metric. In the case of groundwater emergence, the percent of the trail segment with 5-feet to groundwater was used for different sea level rise scenarios. By incorporating both normal annual tidal flooding as well as the 100-year storm and wave conditions, these hazard metrics covered a range of likelihoods and intensities of flooding. This approach, therefore satisfied the intent of the hazard assessment which was to collect quality data for each trail segment that would represent to potential for flooding under various sea level rise scenarios.

In converting hazard values (percentages) to scores, a simple criterion was developed that assumed low scores would represent less potential for flooding and higher scores would represent higher potential for flooding. The mathematical approach is described above to conduct the actual conversion of values to 1-5 scores which were then tabulated in the initial hazard portion of the risk matrix.

### 4.4.2 Final Hazard Scores

Once data was collected and the criteria were established, each segment was scored based on potential for flooding under various sea level rise scenarios. Then, various weighting schemes were applied to the scores to incorporate nuance into the model and test the relative importance of each category to the assessment. We developed a set of four weighting schemes (Table 2) to employ depending on the question being answered by the assessment. The mid-century focus scheme places more weight on the 3-foot sea level rise scenario; the end-of-century focus scheme places more weight on the 6-foot sea level rise scenario; the present day focus scheme places more weight on the 0-feet sea level rise scenario; and finally the team composite weighting scheme, which averages team members' weighting preferences, places more weigh on the normal tidal flooding scenarios for both present day and mid-century.

*Table 2 Hazard assessment weighting schemes; GW refers to groundwater*

| Weighting Scheme | Tidal 0ft | Tidal 3ft | Tidal 6ft | Storm 0ft | Storm 3ft | Storm 6ft | Waves | GW 0ft | GW 3ft | GW 6ft |
|---|---|---|---|---|---|---|---|---|---|---|
| Mid-Century | 1% | 30% | 1% | 1% | 30% | 1% | 2% | 2% | 30% | 2% |
| End-of-Century | 1% | 1% | 30% | 1% | 1% | 30% | 2% | 2% | 2% | 30% |
| Present Day | 30% | 1% | 1% | 30% | 1% | 1% | 2% | 30% | 2% | 2% |
| Team Composite | 30% | 25% | 5% | 17% | 9% | 2% | 12% | 0.3% | 0.02% | 0.003% |

To derive the final hazard scores for each segment for each weighting scheme, the scores for each metric were multiplied by the given weights and then summed.

## 4.5 Results

Deploying the methods outlined above, the scores reveal varying levels of hazard, across weighting schemes. From this assessment, the following findings were derived:

- MLK shoreline receives the highest overall hazard score based on end-of-century weighting
- All sites receive the highest hazard score when end-of-century weighting is applied
- Coyote Hills/Hayward receives the highest hazard score with mid-century weighting
- Coyote Hills and Alameda Point receive the highest hazard scores based on team weighting
- MLK shoreline receives the highest hazard score based on present day weighting

The scores within each category show a sensitivity to the weighting as demonstrated in Table 3 and Figure 8 and Figure 9 below.

*Table 3 Hazard assessment results by weighting scheme*

| Hazard Score | Mid-Century | End-of-Century | Present Day | Team Scoring |
|---|---|---|---|---|
| MLK Shoreline | 2.69 | 4.16 | 1.58 | 1.27 |
| North Richmond | 2.08 | 3.02 | 0.64 | 1.14 |
| Alameda Point | 2.37 | 3.30 | 0.81 | 1.72 |
| Coyote Hills/Hayward | 3.27 | 3.59 | 0.98 | 2.17 |
| Crown Beach | 2.15 | 3.31 | 1.10 | 0.93 |
| Eastshore State Park | 1.70 | 2.84 | 0.61 | 1.04 |
| Spine Trail | 1.68 | 3.33 | 1.02 | 0.85 |
| Miller Knox | 0.13 | 1.09 | 0.11 | 0.57 |

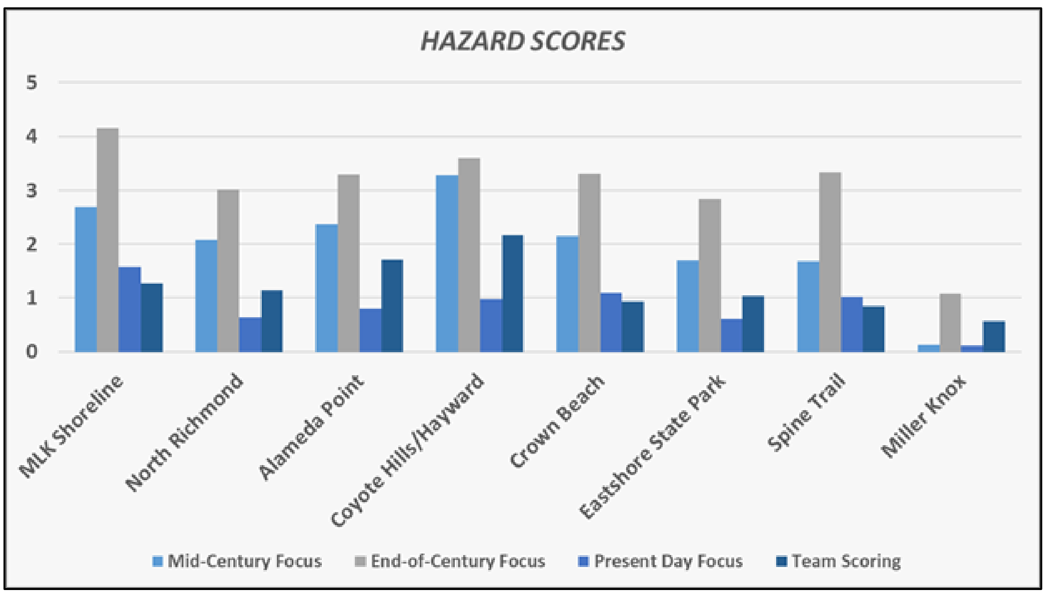



*Figure 8 Hazard scores by weighting scheme*

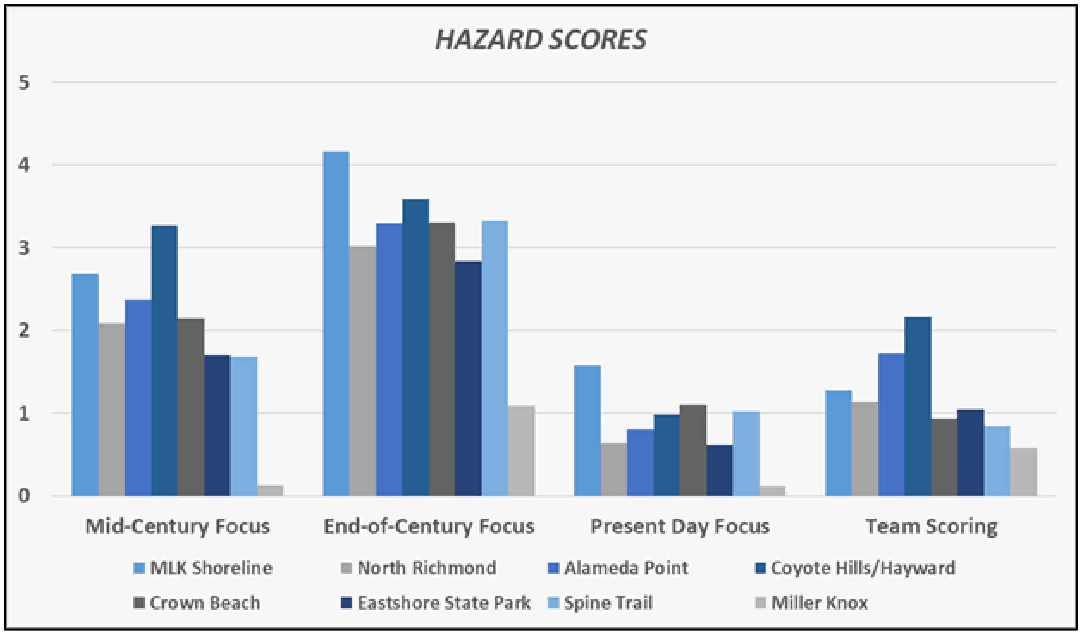



*Figure 9 Hazard score by segment*

While hazard is just one of the three components of the overall Risk Assessment, these results help narrow in on which segments are most susceptible to flooding given various scenarios of sea level rise.

# 5 Vulnerability

The vulnerability assessment evaluates the susceptibility of each of the eight segments to erosion and damage from a severe flood event. Based on our research and consulting with experts at the San Francisco Estuary Institute (SFEI), we defined those attributes which most determine the severity of sea level rise and coastal flood impacts as categories for the vulnerability assessment metrics. The metrics used to assess vulnerability come from several inputs including outboard conditions, shoreline conditions, and trail conditions.

Figure 10 below illustrates the various points of defense (i.e., outboard conditions) between bay and shoreline. The presence of each point of defense provides important benefits to the Bay Trail, especially if shoreline and trail conditions are poor. When such outboard conditions are lacking, the shoreline and trail are much more vulnerable to impacts from coastal flooding and sea level rise, unless the shoreline and trail conditions are able to withstand flood impacts. The vulnerability assessment captures these nuances to build out a complete understanding of conditions at each segment.

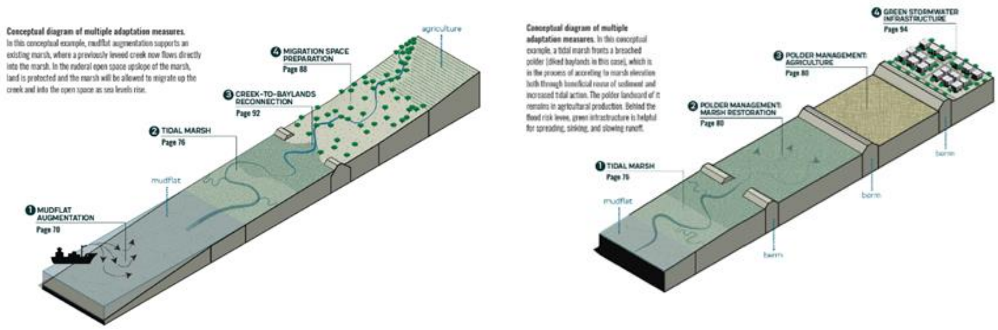



*Figure 10 Conceptual diagrams of adaptation measures along the shoreline. Source: San Francisco Estuary Institute*

The vulnerability assessment looks across several categories that capture outboard conditions, shoreline conditions, and trail conditions—essentially the waterside and the landside conditions.

1. **Mudflats:** Also known as tidal flats, mudflats are un-vegetated areas consisting of mud, sand and/or gravel, and are regularly exposed and flooded by the tides. When present, mudflats provide the first line of defense for the shoreline.
2. **Marshes:** Marshes are areas of low-lying land that flood at high tide, and typically remain waterlogged at all times. Marshes help reduce the impact of coastal storms by absorbing wave energy. For marshes to persist despite rising waters, they must grow at a rate equal to or greater than the rate of sea level rise. Depending on other conditions, marshes might be the first, or last line of defense along the shoreline.
3. **Beaches:** Beaches occur in areas along the coast where wave or current action deposits and reworks sediments. Beaches are often the last line of defense along a shoreline, and also profoundly influences the condition of marshes, as well.
4. **Polders:** Polders are tracts of lowland reclaimed from a body of water, often the sea, by the construction of dikes roughly parallel to the shoreline. While man-made, polders can act as important buffers
5. **Fill:** Fill includes earth or any other substance or material placed in the Bay, including piers, pilings, and floating structures moored in the Bay for extended periods. Virtually all fill in San Francisco Bay is placed on top of Bay mud.
6. **Shoreline:** The shoreline is where land meets water. The shoreline may be natural or could be armored in some way. In some cases, the shoreline is the first defense against coastal flooding if it is not protected by the features noted above.

7. **Trail:** Trail refers to the Bay Trail, a 500-mile recreational path, of which this study considers eight segments. The condition of the trail determines its vulnerability to impacts from coastal flooding and sea level rise.

Each of these categories are broken down into discrete metrics, described in Section 5.3 below. Together, they build a complete picture of the vulnerability of each segment.

## 5.1 Assumptions

The vulnerability assessment assumes a hazard scenario which is equivalent to the current 100-year flood models, or approximately three feet of sea level rise with tidal flooding.

## 5.2 Limitations

Some limitations are present in the elevation and distance to deepwater datasets. The elevation data set employs a mean for each respective trail segment, while the distance to deepwater data employs a median distance. Additionally, the distance to deepwater data measures the distance from the shoreline to deepwater, not the distance from the trail to deepwater. In some cases the trail might not be located along the shoreline, so the metric might misrepresent the actual distance of the trail from deepwater. We applied a 1,000-foot buffer the trail segments to capture as much of the shoreline as possible in our analysis, but this is imperfect and does not account for the additional distance between the trail and the shoreline in cases where they are not one in the same.

The assessment is also limited by the buffers used to capture various shoreline conditions. The model employs 500-foot buffers to capture shoreline characteristics like rip rap, or other armoring. If the trail is further than 500 feet from the shoreline, the model will assume that segment lacks such defenses, making it appear more vulnerable. However, being further away from the shoreline might indeed mean it is less vulnerable than other segments that are closer to the water. This data issue can be addressed outside of the model.

Finally, the trail composition data is limited in that, while it illustrates the percent of each trail segment with pavement, the quality of the pavement is not known. A segment with degraded pavement may score as having low vulnerability in the assessment, but in reality, its vulnerability may be high given the condition.

## 5.3 Data

The majority of data employed in the vulnerability assessment is from an internal SFEI analyses conducted for this project. The marsh data draws on SFEI's work analyzing marsh resilience for three pathways of movement: lateral, vertical, and upland. For shorelines fronted by beaches, the evaluation is based on an analysis of low-tide satellite imagery for a few snapshots in time in addition to best professional judgment based on local knowledge of wind-wave patterns and shoreline orientation of the site. Each beach type is classified into a discrete type which relates to its degree of expected stability over time within each shoreline segment.

Other data was extracted from previous SFEI publications and datasets including the SFEI Shoreline Inventory and Eco Atlas. We also drew from other datasets from the USGS and the Metropolitan Transportation Commission where applicable. Table 4 captures the seven categories, the metrics housed under each, the criteria used for scoring, and data sources, as well as a discussion around the significance of each metric to the model and overall vulnerability score. The criteria scheme scores metrics on a 1-5 basis. 1 indicates that the segment is not susceptible to damage, erosion or flooding, while 5 indicates that the segment is very susceptible.

*Table 4 Vulnerability assessment components*

| Theme | Metric | Significance | Criteria | Data source |
|---|---|---|---|---|
| Mudflats | Presence | Mudflats are important as a first line of defense between the bay and shoreline. As small waves grow with shoaling, they break or are attenuated due to friction on the mudflat. | 1 – Yes<br>5 – No | SFEI internal analysis |
| | Width | Mudflat width is particularly important in determining the level of wave energy reaching the shore. The wider the mudflat, the less vulnerable the shoreline is to wave damage. | 1 – Wide<br>2 – Narrow<br>3 – Both<br>4 – Partial wide or narrow<br>5 – Not present | SFEI internal analysis |
| Marshes | Presence | Marshes provide flood protection for the shoreline. Sometimes they are the first line of defense, other times they are the last. | 1 – Yes<br>5 – No | SFEI internal analysis |
| | Elevation | Marshes are dynamic and constantly evolving. Some marsh surfaces<br>are increasing in elevation due to accretion of organic and inorganic sediments. A higher marsh elevation indicates provides more shoreline protection. | 1 – High<br>2 – Low<br>3 – Both<br>4 – Partial high or low<br>5 – Not present | SFEI internal analysis |
| | Width | Marsh width determines potential for wave attenuation. | 1 – High<br>2 – Low<br>3 – Both<br>4 – Partial high or low<br>5 – Not present | SFEI internal analysis |
| | Edge change | Lateral changes in the position of the marsh edge are extremely important because marsh retreat (erosion) is thought to be the chief mechanism by which coastal wetlands worldwide are being lost. The more stable the marsh edge, the more protection it provides the shoreline. | 1 – Stable<br>2 - Partially stable<br>3 – Eroding<br>4 – Partially eroding<br>5 – Not present | SFEI internal analysis |

| Theme | Metric | Significance | Criteria | Data source |
|---|---|---|---|---|
| | Migration potential | Rapidly rising seas threaten to drown marshes, therefore migration potential is important for marsh resilience and shoreline resilience as a result. Inland migration of the landward marsh edge is often hindered by infrastructure, impeding the marsh’s ability to migrate. Natural shoreline gives the marsh ability to move and adapt. | 1 – Yes<br>3 – Some<br>5 – No | SFEI internal analysis |
| Beach | Presence | Beaches provide additional wave attenuation services for the shoreline. Beaches sometimes front marshes, and other times front shoreline, acting as a barrier. | 1 – Yes<br>3 – Some<br>5 – No | SFEI internal analysis |
| | Coverage | The percent of shoreline fronted by beach directly relates to level of wave attenuation for that segment of trail. The higher the percentage of segment covered by beach, the more wave attenuation. | 1 – > 20% covered<br>2 – 15-19% covered<br>3 – 10-15% covered<br>4 – 5-10% covered<br>5 – < 5% covered | SFEI Shoreline Inventory |
| | Profile | The beach profile determines the level of wave attenuation that can be achieved with the presence of beach. Fringing and pocket beaches offer higher wave attenuation services, while longshore/drift-aligned and barrier beaches have lower wave attenuation potential. | 1 – Fringing<br>2 – Pocket<br>3 – Longshore/Drift-aligned<br>4 – Barrier<br>5 – Not present | SFEI internal analysis |
| Polder | Presence | Polders provide protection from surging seas and long-term sea level rise. | 1 – Yes<br>5 – No / Not present | SFEI internal analysis |
| Fill | Coverage | Shoreline areas comprised predominately of fill are assumed to be more vulnerable to coastal flooding and erosion compared to more natural shorelines due to the fact that natural shorelines have formed through geomorphic processes that respond and adapt to waves, high water events, and other coastal flooding. The use of fill along the East Bay has typically created landmasses that are not designed to withstand coastal flooding and erosion but are also situated in such a way that they are more exposed to waves, high water events, etc., making these areas more vulnerable. | 1 – < 30% fill<br>2 –30-49% fill<br>3 – 50-69% fill<br>4 – 70-89% fill<br>5 – > 90% fill | SFEI EcoAtlas |

| Theme | Metric | Significance | Criteria | Data source |
|---|---|---|---|---|
| Shoreline | Armoring | The shoreline is considered armored if it is comprised of floodwall, shoreline protection structure, or engineered levee. These three armoring schemes protect the shoreline from erosion and damage. The higher the percentage of armoring, the more protected the segment is from damage. | 1 – > 90% armored<br>2 – 70-89% armored<br>3 – 50-69% armored<br>4 – 30-49% armored<br>5 – < 30% armored | SFEI Shoreline Inventory |
| | Rip rap | Rip rap is another form of shoreline stabilization and armoring. The higher the percentage of shoreline covered with rip rap, the more protected it is from erosion and other damage from storm surges or coastal flooding. | 1 – > 95% rip rap<br>2 – 75-94% rip rap<br>3 – 50-74% rip rap<br>4 – 25-49% rip rap<br>5 – < 25% rip rap | SFEI Shoreline Inventory |
| | Distance to deepwater | Distance to deepwater indicates how far the shoreline is from deepwater. Deepwater is defined as water depth greater than 1,000 feet. The distance to deepwater is significant in determining wave energy. In deep water, longer-period waves propagate faster and transport their energy faster. The further the shoreline is from deepwater, the longer the wave will need to travel to reach it, losing power along the way. The further the segment is from deepwater, the less likely it is to experience high energy waves. | 1 – > 8,000 meters<br>2 – 6,001-8000 meters<br>3 – 4,001-6,000 meters<br>4 – 2,001-4,000 meters<br>5 – <2,000 meters | SFEI internal data |
| Trail | Elevation (meters) | Trail elevation is one of the key factors to determining vulnerability. The higher the elevation of the trail segment, the less likely it is to be exposed to waves or coastal flooding events. | 1 – Highest elevation<br>3 – Moderate elevation<br>5 – Lowest elevation | USGS |
| | Composition | Trail composition refers to the percent of the trail covered with pavement. Pavement protects the trail segments from erosion and flood events. Unpaved trail is more vulnerable to erosion and damage. | 1 – > 80% paved<br>2 – 60-79% paved<br>3 – 40-59% paved<br>4 – 20-39% paved<br>5 – < 20% paved | Metropolitan Transportation Commission |

## 5.4 Methods

Various methods were deployed to calculate the vulnerability metrics, determine the scoring criteria, and finalize vulnerability scores.

### 5.4.1 Metrics and Criteria

The majority of the metrics were derived from an internal analysis conducted by SFEI on behalf of this project. A detailed accounting of the methods used to define the metrics in the mudflats, marshes, and beaches categories can be found in documentation provided by SFEI (link).

Metrics which capture the percentage of a specific attribute present in the various segments were generated through intersect analyses in ArcGIS. The metrics that were generated using this method include: percent of segment with beach coverage, percent of segment on fill, percent of segment with armoring, percent of segment with rip rap, percent of segment paved. We projected these data to match the Bay Trail segments shapefile, buffered the metric's shapefile by 500 feet, dissolved the buffered shapefile to avoid any double-counting from overlapping buffers, and then intersected the metric's shapefile with the Bay Trail segments shapefile. To calculate the percent of the segment with that attribute present we divided the results from the intersect analysis by the total length of each segment. The distance to deepwater metric was generated the same way, except with a 1,000-foot buffer. The limitation with this approach to measuring the distance to deepwater are detailed in Section 5.2 above.

The elevation metric was generated from a one-meter digital elevation model (DEM) imported from the USGS's National Map.[1] The model was ported into ArcGIS and the polyline was then draped over the DEM to extract an average elevation by Bay Trail segment.

### 5.4.2 Final Vulnerability Scores

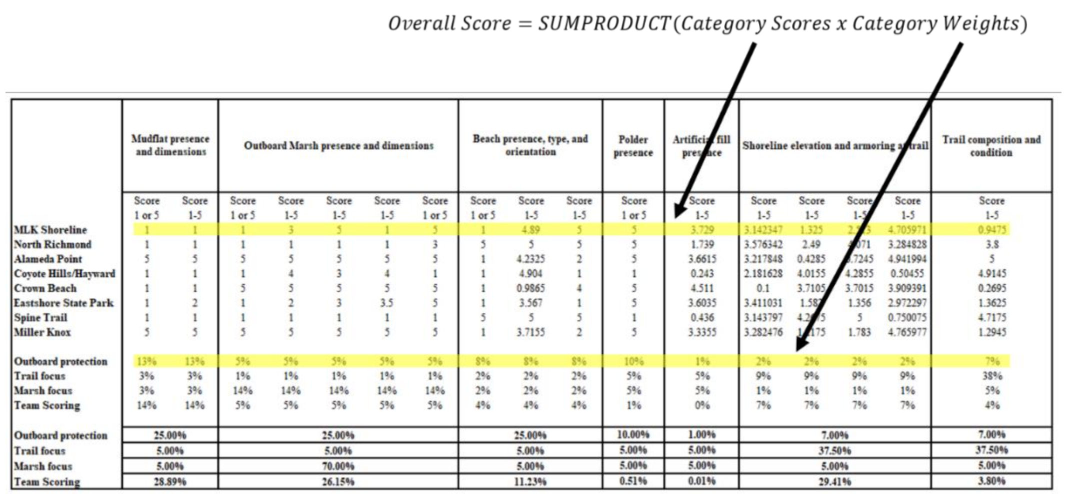
Once the criteria were established, each segment was scored based on its performance across the metrics outlined above. Then, a weighting scheme was applied to the score to incorporate nuance into the model and address the relative importance of each category to the assessment. We developed a set of four weighting schemes (Table 5) to employ depending on the question being answered by the assessment. The outboard protection scheme places more weight on marshes and mudflats; the trail focus places more weight on the trail and shoreline categories; the marsh focus places more weight on tidal mudflats; and finally the team composite weighting scheme, which averages team members' weighting preferences, places more weigh on mudflat and shoreline conditions.

[1] https://viewer.nationalmap.gov/basic/

*Table 5 Vulnerability assessment weighting schemes*

| Weighting Scheme | Mudflats | Marshes | Beaches | Polders | Shoreline | Trail |
|---|---|---|---|---|---|---|
| Outboard protection | 25% | 25% | 10% | 1% | 7% | 7% |
| Trail focus | 5% | 5% | 5% | 5% | 38% | 38% |
| Marsh focus | 70% | 5% | 5% | 5% | 5% | 5% |
| Team composite | 26% | 11% | 1% | 0% | 29% | 4% |

To derive the final vulnerability scores for each segment for each weighting scheme, the scores for each metric were multiplied by the given weights and then summed. Figure 11 demonstrates how the calculation works in practice.



$$Overall\ Score = SUMPRODUCT(Category\ Scores\ x\ Category\ Weights)$$

| | Mudflat presence and dimensions | | Outboard Marsh presence and dimensions | | | | | Beach presence, type, and orientation | | | Polder presence | Artificial fill presence | Shoreline elevation and armoring at trail | | | | Trail composition and condition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score 1 or 5 | Score 1-5 | Score 1 or 5 | Score 1-5 | Score 1-5 | Score 1-5 | Score 1 or 5 | Score 1 or 5 | Score 1-5 | Score 1-5 | Score 1 or 5 | Score 1-5 | Score 1-5 | Score 1-5 | Score 1-5 | Score 1-5 | Score 1-5 |
| MLK Shoreline | 1 | 1 | 1 | 3 | 5 | 1 | 5 | 1 | 4.89 | 5 | 5 | 3.729 | 3.142347 | 1.325 | [illegible] | 4.705971 | 0.9475 |
| North Richmond | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 5 | 5 | 5 | 5 | 1.739 | 3.576342 | 2.49 | [illegible] | 3.284828 | 3.8 |
| Alameda Point | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 4.2325 | 2 | 5 | 3.6615 | 3.217848 | 0.4285 | [illegible] | 4.941994 | 5 |
| Coyote Hills/Hayward | 1 | 1 | 1 | 4 | 3 | 4 | 1 | 1 | 4.904 | 1 | 1 | 0.243 | 2.181628 | 4.0155 | 4.2855 | 0.50455 | 4.9145 |
| Crown Beach | 1 | 1 | 5 | 5 | 5 | 5 | 5 | 1 | 0.9865 | 4 | 5 | 4.511 | 0.1 | 3.7105 | 3.7015 | 3.909391 | 0.2695 |
| Eastshore State Park | 1 | 2 | 1 | 2 | 3 | 3.5 | 5 | 1 | 3.567 | 1 | 5 | 3.6035 | 3.411031 | [illegible] | 1.356 | 2.972297 | 1.3625 |
| Spine Trail | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 1 | 0.436 | 3.143797 | [illegible] | 5 | 0.750075 | 4.7175 |
| Miller Knox | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 3.7155 | 2 | 5 | 3.3355 | 3.282476 | [illegible] | 1.783 | 4.765977 | 1.2945 |
| Outboard protection | 13% | 13% | 5% | 5% | 5% | 5% | 5% | 8% | 8% | 8% | 10% | 1% | 2% | 2% | 2% | 2% | 7% |
| Trail focus | 3% | 3% | 1% | 1% | 1% | 1% | 1% | 2% | 2% | 2% | 5% | 5% | 9% | 9% | 9% | 9% | 38% |
| Marsh focus | 3% | 3% | 14% | 14% | 14% | 14% | 14% | 2% | 2% | 2% | 5% | 5% | 1% | 1% | 1% | 1% | 5% |
| Team Scoring | 14% | 14% | 5% | 5% | 5% | 5% | 5% | 4% | 4% | 4% | 1% | 0% | 7% | 7% | 7% | 7% | 4% |
| Outboard protection | 25.00% | | 25.00% | | | | | 25.00% | | | 10.00% | 1.00% | 7.00% | | | | 7.00% |
| Trail focus | 5.00% | | 5.00% | | | | | 5.00% | | | 5.00% | 5.00% | 37.50% | | | | 37.50% |
| Marsh focus | 5.00% | | 70.00% | | | | | 5.00% | | | 5.00% | 5.00% | 5.00% | | | | 5.00% |
| Team Scoring | 28.89% | | 26.15% | | | | | 11.23% | | | 0.51% | 0.01% | 29.41% | | | | 3.80% |

*Figure 11 Vulnerability score calculation using the "outboard protection" weighting as an example*

## 5.5 Results

Deploying the methods outlined above, the scores reveal varying levels of vulnerability, across weighting schemes. However, Alameda Point scores the highest across all four weighting schemes, elevating this segment as one of high vulnerability regardless of weighting. Miller Knox pops as having the second highest level of vulnerability in all weighting schemes except the trail focus. The Spine Trail appears to have the second highest level of vulnerability in the trail focus weighting, however, given how far it is from the shoreline, this is likely untrue, which instead points to North Richmond. The team scoring favors Alameda Point and Miller Knox, as well.

The scores within each category show a sensitivity to the weighting as demonstrated in Table 6 and Figure 12 and Figure 13 below.

*Table 6 Vulnerability assessment results by weighting scheme*

| Vulnerability Score | Outboard Protection | Trail Focus | Marsh Focus | Team Scoring |
|---|---|---|---|---|
| MLK Shoreline | 2.72 | 2.27 | 2.96 | 2.40 |
| North Richmond | 2.87 | 3.39 | 1.97 | 2.37 |
| Alameda Point | 4.15 | 3.80 | 4.67 | 3.92 |
| Coyote Hills/Hayward | 2.11 | 3.23 | 2.43 | 2.23 |
| Crown Beach | 2.76 | 2.05 | 4.28 | 2.70 |
| Eastshore State Park | 2.36 | 2.13 | 2.81 | 2.16 |
| Spine Trail | 2.41 | 3.42 | 1.47 | 2.26 |
| Miller Knox | 3.88 | 2.55 | 4.48 | 3.89 |

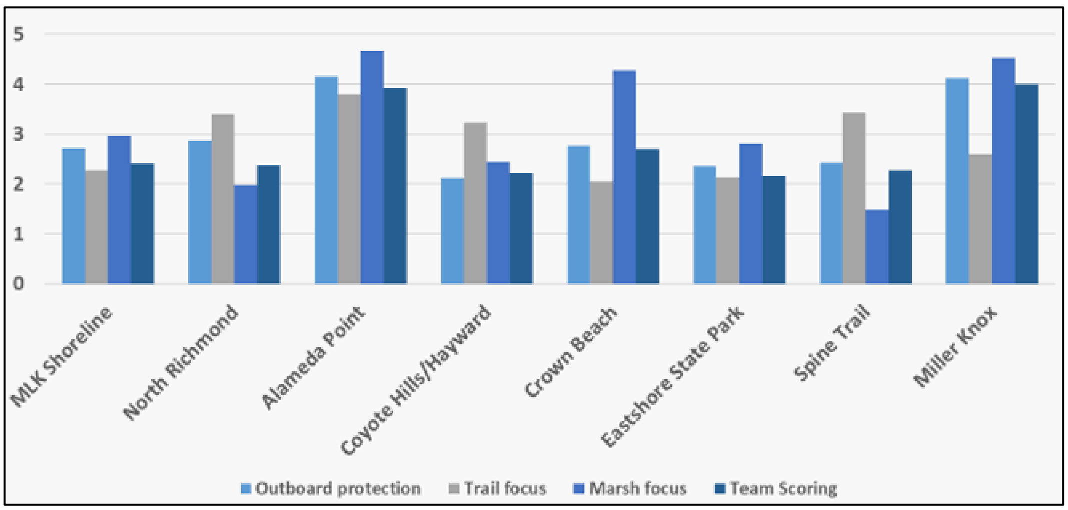



*Figure 12 Vulnerability score by weighting scheme*

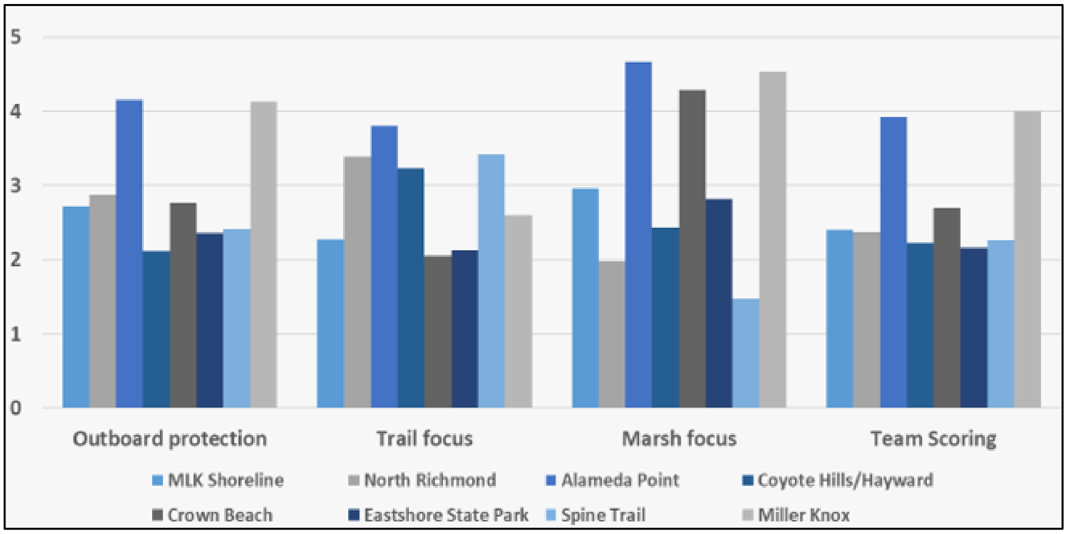



*Figure 13 Vulnerability score by segment*

While vulnerability is just one of the three components of the overall Risk Assessment, these results help narrow in on which segments are most vulnerable to impacts from erosion, waves, and coastal flooding given their natural and man-made features.

# 6 Consequence

The objective of assessing consequences was largely to measure, from a high-level, the multitude of impacts that could result from sea level rise and coastal flooding along each of the eight Bay Trail segments. The approach focused on five categories of potential impact: economic environmental, social equity, recreation, and connectivity. Developing these categories and the associated metrics within each category was done while considering the preferences expressed by the EBRPD while developing the site selection criteria. For example, in that process, the EBRPD highlighted that impacts to the trail could affect adjacent critical infrastructure, disadvantaged communities, access to nature, restoration potential, and recurring maintenance efforts. Each of these items are captured, either implicitly or explicitly, within the themes and metrics applied to the consequence assessment.

## 6.1 Assumptions

There are three core assumptions embedded in this assessment of consequences. The first is that it is appropriate to apply hazard equally across a majority of metrics. In effect, applying this assumption meant that much of the consequence assessment measured the value at risk, which stated another way, is essentially answering the question of what is in harms way. This approach was judged to be appropriate considering that for each segment, a hazard score had been assessed separately and therefore the final risk scores would incorporate the various levels of hazard that impact various segments differently. It is also important to note that, this assumption was not applied to the direct economic impact metrics which explicitly took into account the percentage of the trail expected to be experience either intermittent or permanent flooding as a result of tidal and/or storm flooding under various scenarios of sea level rise. These percentage inundation values were incorporated into a fairly elaborate calculation of net present value for both intermittent and permanent losses. In this approach, intermittent flooding was assumed to be from the 100-year storm event while permanent flooding was assumed to be from the normal tidal flooding. This assumption is based on the idea that if regular tidal flooding was occurring and inundating significant portions of a trail segment, that segment would likely be deemed permanently lost.

The second core assumption was around the appropriateness of the various metrics used to represent each category. For example, assessing the impact of sea level rise and coastal flooding on social equity is a very complex and nuanced exercise. Given the scope of this study, a series of metrics were pulled from the California EnviroScreen database and used as proxies to represent potential social equity concerns across the various segments. It is understood that this approach drastically oversimplifies the issues around the disproportionate impacts of flooding on disadvantaged communities but nonetheless does provide some potentially helpful insights into social equity instead of excluding this category completely from the assessment.

Finally, the third core assumption was around what values, assets, populations, etc. should be included with a given trail segments' consequence area. The obvious approach was to only include what was immediately adjacent to a given trail segment but in many cases a buffer distance had to be chosen and a boundary had to be drawn. Instead of applying a single buffer distance around each segment, a GIS-based approach was taken whereby reasonable boundaries were drawn using judgement around each segment. From these boundary areas, assets were counted. For example, for Alameda Point a boundary was drawn that did not areas off of Alameda island when counting transit stops and ferry terminals. The assumption here was that as if the flooding of Alameda Point was to impact transit connections or critical transportation nodes such as ferry terminals, these impacts would likely be limited to nearby assets on the island. This assumption was particularly relevant for assessing potential marsh and wetland losses as boundaries drawn around the spine trail resulted in a massive amount of marsh and wetland area being counted due to the adjacent salt ponds in the south bay.

## 6.2 Limitations

There are various limitations within the approach used to assess and score each consequence metric. However, perhaps at a higher level it is acknowledged that the documentation of each metric's assessment is limited. This limitation is largely due to the fact that over 25 metrics were assessed and scored across 5 distinct themes for 8 individual sites encompassing 20 segments of trail. Ideally, documentation would be provided to allow for a reader or future analyst to completely repeat the analysis done and replicate the results provided. To accomplish this, an extensive technical appendix would need to be developed which was outside of the scope of deliverables for this risk assessment. Instead, a summary is provided of the key assumptions, limitations, data, methods and results. From this documentation, sufficient evidence should be provided to show that appropriate techniques were applied and results are reliable.

## 6.3 Data

Various data was collected across 25 different consequence categories as summarized in the tables below. The following represents key data points worth highlighting.

### 6.3.1 Trail Repair Cost

Based on discussions with the Park District, an average trail repair cost of $200 per square foot was used in the assessment of direct economic losses from flooding. The Park District also shared that the average trail width was 14 feet along with the lengths of various trail segments. This information was used to estimate the total repair cost of each trail segment as shown in Table 7 below.

*Table 7 Trail repair costs*

| Bay Trail Segments | | Segment Length (ft) | Trail Replacement Cost ($) |
|---|---|---|---|
| MLK Shoreline | Arrowhead Marsh Trail | 16,567 | $46,387,600 |
| | Damon-Garretson Trail | 15,237 | $42,663,600 |
| | Dolittle Pond Trail | 9,460 | $26,488,000 |
| | MLK Trail Alameda | 11,332 | $31,729,600 |
| North Richmond | North Richmond Wetlands Loop | 16,535 | $46,298,000 |
| | Wildcat Creek Trail South | 9,307 | $26,059,600 |
| | Wildcat Creek Trail North | 15,723 | $44,024,400 |
| Alameda Point | Alameda Point Trail | 34,511 | $96,630,800 |
| Coyote Hills/Hayward | Hayward Shoreline Trail South | 9,662 | $27,053,600 |
| | Hayward Shoreline Trail North | 9,835 | $27,538,000 |
| | Coyote Hills Trail North | 18,113 | $50,716,400 |
| | Eden Landing Loop | 19,391 | $54,294,800 |
| | Alameda Creek Trail | 10,131 | $28,366,800 |
| | Coyote Hills Trail South | 24,573 | $68,804,400 |

| Bay Trail Segments | | Segment Length (ft) | Trail Replacement Cost ($) |
|---|---|---|---|
| Crown Beach | Crown Beach Trail | 13,980 | $39,144,000 |
| Eastshore State Park | Eastshore Trail North | 25,379 | $71,061,200 |
| | Eastshore Trail South | 61,820 | $173,096,000 |
| | Gilman to Buchanan Trail | 5,061 | $14,170,800 |
| Spine Trail | Spine Trail | 78,137 | $218,783,600 |
| Miller Knox | Ferry Point Trail | 15,990 | $44,772,000 |

### 6.3.2 Ecosystem Services and Recreational Value

Additional data was obtained from the Parks District *Economic Analysis Impact Report 2017*, specifically for ecosystem services and recreational values assigned to various landscape typologies and activities (see Figure 14). From this data, Table 8 below was created for total ecosystem services and recreational value for each trail segment. Total acres of marshes and wetlands was obtained from the *SFEI BAARI (Bay Area Aquatic Resource Inventory) Version 2* GIS dataset which is a regional dataset of surface aquatic resources. Additionally, data was provided by Alexis Robert from the *InVEST Blue Carbon Module of the Stanford Natural Capital Project* for carbon stored and potential offset value.

**FIGURE 6**

**ECOSYSTEM SERVICES VALUE ESTIMATE**

| Land Cover | Acres | Low Annual Value/Acre | High Annual Value/Acre | Average Annual Value/ Acre | Average Annual Value |
|---|---|---|---|---|---|
| Grassland | 54,800 | $3,300 | $7,000 | $5,150 | $282.2 Million |
| Woodland | 44,300 | $2,600 | $6,200 | $4,400 | $194.9 Million |
| Other * | 20,900 | $1,300 | $2,500 | $1,900 | $39.7 Million |
| **Total** | **120,000** | **$2,700** | **$5,900** | **$4,300** | **$516.8MM** |

** The "Other" category includes a combination of wetlands, water bodies, shrubland, rock, and cropland. The shoreline benefits are captured primarily through the wetlands and water bodies categories.*

*Figure 14 Ecosystem services values from EBRPD Economic Analysis Impact Report 2017*

*Table 8 Ecosystem services and recreation value for each trail segment*

| **Bay Trail Segments** | | **Adjacent Marsh and Wetlands (acres)** | **Ecosystem Services Value ($)** | **Potential Carbon Offset Value ($)** | **Recreation Value ($)** |
|---|---|---|---|---|---|
| MLK Shoreline | Arrowhead Marsh Trail | 107,035 | $499,201 | $142,680,964 | $267,586,542 |
| | Damon-Garretson Trail | 107,035 | $459,125 | $142,680,964 | $267,586,542 |
| | Dolittle Pond Trail | 107,035 | $285,051 | $142,680,964 | $267,586,542 |
| | MLK Trail Alameda | 107,035 | $341,459 | $142,680,964 | $267,586,542 |
| North Richmond | North Richmond Wetlands Loop | 699,074 | $498,237 | $931,890,124 | $1,747,684,131 |
| | Wildcat Creek Trail South | 699,074 | $280,441 | $931,890,124 | $1,747,684,131 |
| | Wildcat Creek Trail North | 699,074 | $473,770 | $931,890,124 | $1,747,684,131 |
| Alameda Point | Alameda Point Trail | 31 | $1,039,895 | $41,455 | $77,746 |
| Coyote Hills/ Hayward | Hayward Shoreline Trail South | 1,559,504 | $291,138 | $2,078,874,675 | $3,898,760,363 |
| | Hayward Shoreline Trail North | 1,559,504 | $296,351 | $2,078,874,675 | $3,898,760,363 |
| | Coyote Hills Trail North | 1,321,275 | $545,786 | $1,761,307,156 | $3,303,188,311 |
| | Eden Landing Loop | 1,321,275 | $584,295 | $1,761,307,156 | $3,303,188,311 |
| | Alameda Creek Trail | 1,321,275 | $305,270 | $1,761,307,156 | $3,303,188,311 |
| | Coyote Hills Trail South | 1,321,275 | $740,440 | $1,761,307,156 | $3,303,188,311 |
| Crown Beach | Crown Beach Trail | 46 | $421,249 | $61,081 | $114,553 |
| Eastshore State Park | Eastshore Trail North | 423,480 | $764,727 | $564,513,431 | $1,058,699,024 |
| | Eastshore Trail South | 52,370 | $1,862,777 | $69,811,431 | $130,925,661 |
| | Gilman to Buchanan Trail | 329,497 | $152,499 | $439,230,667 | $823,741,390 |
| Spine Trail | Spine Trail | 18,946,657 | $2,354,445 | $25,256,569,327 | $47,366,641,475 |
| Miller Knox | Ferry Point Trail | 5 | $481,815 | $6,453 | $12,103 |

In addition to these data, the following key metrics and criteria shown in Table 9 were applied to the consequence assessment.

*Table 9 Consequence assessment themes, metrics, and data sources*

| Theme | Metric | Measurement | Data Source |
|---|---|---|---|
| Economic Impacts | Trail Damages from Permanent and Intermittent Inundation | Net Present Value (NPV) of Trail Repair Costs | EBRPD + Hazard Data |
| | Rail Infrastructure | Nodes and Lines | ArcGIS Online Public Databases |
| | Power Infrastructure | Substations | ArcGIS Online Public Databases |
| | Water Infrastructure | Wastewater Treatment Plants | ArcGIS Online Public Databases |
| | Road Infrastructure | Major Freeways | ArcGIS Online Public Databases |
| | Ferry Infrastructure | Terminals | ArcGIS Online Public Databases |
| Environmental Impacts | Marsh and Wetland Loss from Permanent and Intermittent Inundation | NPV of Ecosystem Services Losses | EBRPD Economic Analysis Impact Report 2017 |
| | Carbon Offset Loss | Offset Value Potential | InVEST Blue Carbon Module of the Stanford Natural Capital Project |
| | Potential Marsh Loss | Marsh Size | SFEI BAARI v2 |
| | Potential Wetland Loss | Wetland Size | SFEI BAARI v2 |
| | Quality Marsh Habitat Loss | Marsh Patch Greater Than 100ha (yes/no) | SFEI BAARI v2 |
| | Threatened or Endangered Species | Yes/No | SFEI |
| | Quality Habitat Loss | Proximity to Larger Marsh (yes/no) | SFEI |
| | Quality Habitat Loss | Core Area > 60% (yes/no) | SFEI |
| Social Equity Impact | Population | Count | California EnviroScreen 3.0 |
| | CES Score | Maximum, Minimum, Median | California EnviroScreen 3.0 |
| | CES Percentile | Maximum, Minimum, Median | California EnviroScreen 3.0 |
| | CES Percentile Range | Maximum, Minimum | California EnviroScreen 3.0 |
| | Community of Concern | Yes/No | California EnviroScreen 3.0 |
| Recreational Impacts | Recreation Value Loss | Present Value ($) | EBRPD Economic Analysis Impact Report 2017 |
| | Water Trail | Yes/No | SF Water Trail |
| Connectivity Impacts | Transit Connectivity | AC Transit Stops | AC Transit |
| | Regional Transit Connectivity | All Transit Stops | Regional GIS Database |

## 6.4 Methods

In general, a single method was used to convert values from the consequence data into 1-5 values to represent relative consequence scores. This method is explained the hazard section of the report above.

### 6.4.1 Metrics and Criteria

As shown in the data table above, 25 individual metrics were used to represent potential impacts from flooding on economics, environmental, social equity, recreation, and connectivity. In general, the 1-5 scores calculated from comparing the relative high and low values from each category were assigned criteria ranging from 1 indicating low impact to 5 indicating high impacts. For example, Eastshore State Park is the segment with the greatest number of rail infrastructure nodes within its immediate proximity and so a consequence score of 5 was calculated in this category. Similarly, Miller Knox scored lowest across metrics representing potential losses from permanent inundation of marshes or wetlands given the lack of marsh or wetland resources within the immediate vicinity of this segment.

### 6.4.2 Final Consequence Scores

Once data was collected and the criteria were established, each segment was assessed based on the potential consequence given significant flooding was to occur. Then, various weighting schemes were applied to the scores to incorporate nuance into the model and test the relative importance of each category to the assessment. We developed a set of four weighting schemes (Table 10) to employ depending on the question being answered by the assessment. The economic scheme places more weight on the direct and indirect economic impacts; the environmental scheme places more weight on the impact to wetlands, marshes, and endangered species; the social scheme places more weight on the metrics used as a proxy to represent social equity; and finally the team composite weighting scheme, which averages team members' weighting preferences, places more weigh on the economic *and* environmental impacts of flooding.

*Table 10 Consequence assessment weighting schemes*

| Weighting Scheme | Direct and Indirect Economic Impacts | Environmental Impacts | Social Equity Impacts | Recreation Impacts | Connectivity Impacts |
|---|---|---|---|---|---|
| Economic Focus | 60% | 10% | 10% | 10% | 10% |
| Environmental Focus | 10% | 60% | 10% | 10% | 10% |
| Social Focus | 10% | 10% | 60% | 10% | 10% |
| Team Composite | 40% | 43% | 4% | 11% | 1% |

To derive the final hazard scores for each segment for each weighting scheme, the scores for each metric were multiplied by the given weights and then summed.

## 6.5 Results

Deploying the methods outlined above, the scores reveal varying levels of consequence across weighting schemes. From this assessment, the following findings were derived:

- Coyote Hills/Hayward receives highest consequences scores for most weighting schemes
- Miller Knox and Crown Beach show low scores across all weighting schemes
- Spine Trail consequence score spikes under social focused weighting scheme
- Team scoring favors Coyote Hills and Alameda Point from an impact perspective
- Economic and environmental weighting schemes yield almost identical scores across all sites

The scores within each category show a sensitivity to the weighting as demonstrated in Table 11 and Figure 15 and Figure 16 below.

*Table 11 Consequence assessment results by weighting scheme*

| Consequence Score | Economic Focus | Enviro Focus | Social Focus | Team Scoring |
|---|---|---|---|---|
| MLK Shoreline | 3.45 | 3.45 | 3.03 | 3.58 |
| North Richmond | 3.06 | 3.06 | 1.76 | 3.44 |
| Alameda Point | 3.33 | 3.33 | 1.15 | 3.86 |
| Coyote Hills/Hayward | 3.75 | 3.75 | 2.42 | 4.19 |
| Crown Beach | 1.63 | 1.63 | 1.76 | 1.52 |
| Eastshore State Park | 2.94 | 2.94 | 2.56 | 2.81 |
| Spine Trail | 2.46 | 2.46 | 4.12 | 2.19 |
| Miller Knox | 0.17 | 0.17 | 0.51 | 0.11 |

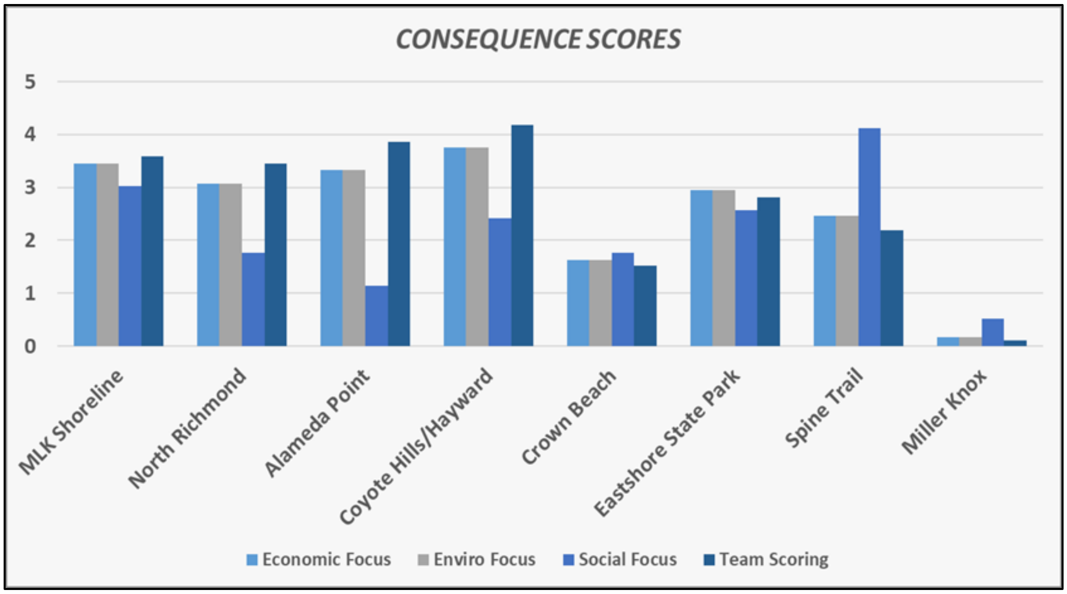



*Figure 15 Consequence scores by weighting scheme*

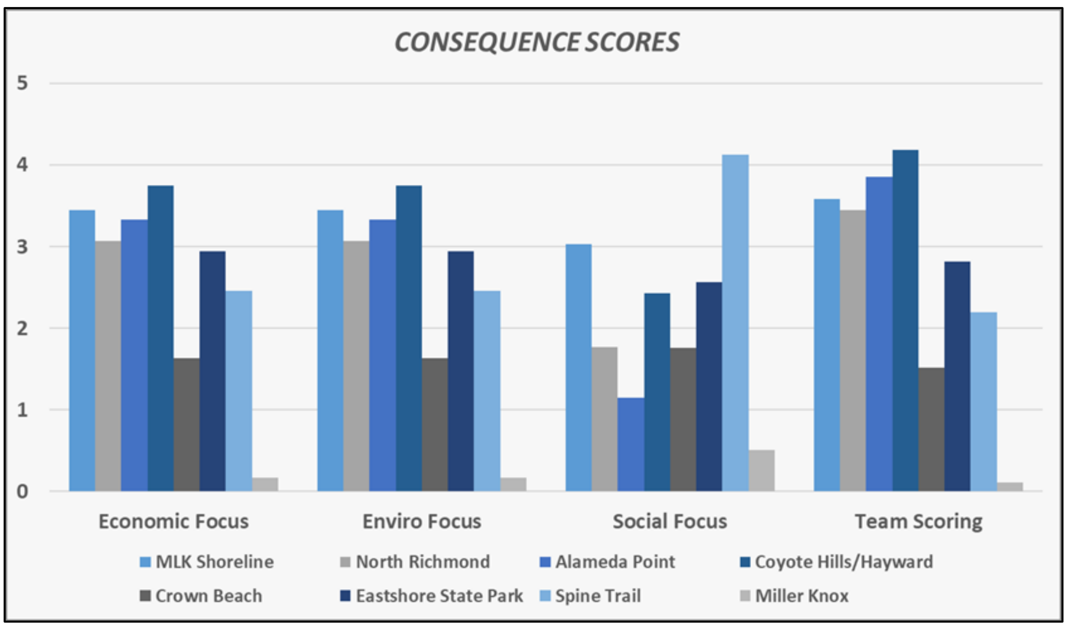



*Figure 16 Consequence score by segment*

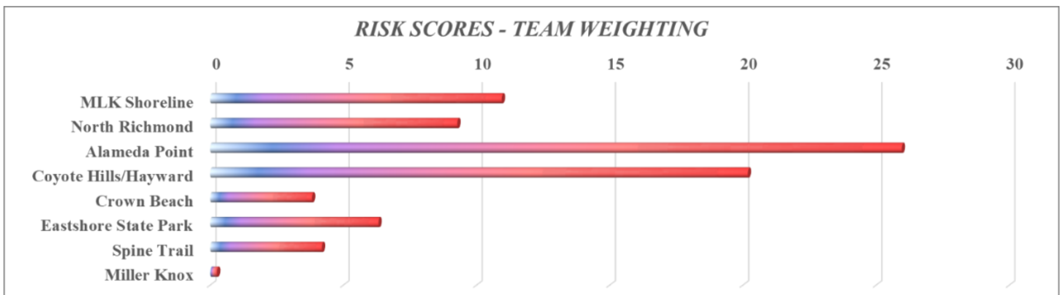
While consequence is just one of the three components of the overall Risk Assessment, these results help narrow in on which segments contain the most value at risk from flooding or stated another way, the most in harm's way.

# 7 Risk Assessment

The Risk Assessment considers the scores from the hazard, vulnerability, and consequence assessments to create one overall score indicating each segment's risk level. Risk is calculated as a product of the hazard, vulnerability, and consequence scores.

$$Risk = Hazard \times Vulnerability \times Consequence$$

As described above, the three component assessments have different weighting schemes specific to each component assessment. Because of the non-uniform nature of the weighting schemes, they cannot all be rolled up neatly into multiple risk profiles, except for the team composite weighting scheme which is featured as a constant across all three component assessments. Figure 17 below illustrates this point as an example, showing the risk results across three discrete weighting schemes from the component assessments. In this scheme, which weights toward mid-century hazards, outboard vulnerabilities, and environmental consequences, Alameda Point, MLK Shoreline, and Crown Beach are revealed as the highest risk segments. Depending on EBRPD and its partners' priorities, this may or may not be helpful. The model allows the agency and its partners to toggle between different weighting schemes to narrow on specific questions they aim to answer.




| Bay Trail Segments | HAZARD | VULNERABILITY | CONSEQUENCE | RISK |
|---|---|---|---|---|
| MLK Shoreline | 1.27 | 2.40 | 3.58 | 10.95 |
| North Richmond | 1.14 | 2.37 | 3.44 | 9.28 |
| Alameda Point | 1.72 | 3.92 | 3.86 | 25.97 |
| Coyote Hills/Hayward | 2.17 | 2.23 | 4.19 | 20.19 |
| Crown Beach | 0.93 | 2.70 | 1.52 | 3.83 |
| Eastshore State Park | 1.04 | 2.16 | 2.81 | 6.32 |
| Spine Trail | 0.85 | 2.26 | 2.19 | 4.20 |
| Miller Knox | 0.57 | 4.00 | 0.11 | 0.26 |

*Figure 17 Risk score example across varying weighting schemes*

WRT, Arup, ESA, and SFEI provided importance preferences in a weighting survey administered by Arup—the same team weighing schemes featured in the component assessments. In an effort to build out one comprehensive risk score, The results of that survey were combined and used to develop a team scoring weighting scheme, shown in Figure 18. Figure 19 was produced by combining multiple weighting schemes and considering each combination equally valid.

While the combined risk scores results tell a less robust story than the team risk scores results, it offers a point of comparison.

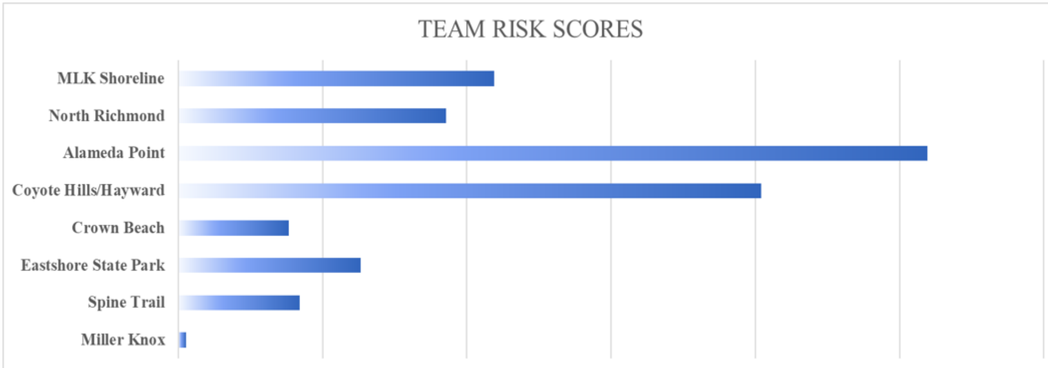



*Figure 18 Risk scores weighted by team preference*

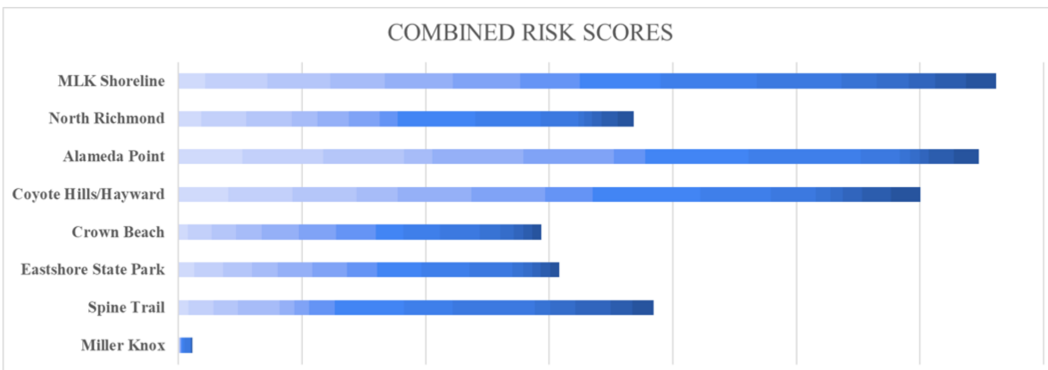



*Figure 19 Combined risk scores*

When considering the scores side-by-side, both weighting schemes reveal themselves to have the same top three, middle three, and bottom two (shown in Table 12), suggesting a general prioritization order for adaptation interventions moving forward.

*Table 12 Risk scoring results*

| **Combined Ranking** | **Team Ranking** |
|---|---|
| MLK Shoreline | Alameda Point |
| Alameda Point | Coyote Hills/Hayward |
| Coyote Hills/Hayward | MLK Shoreline |
| Spine Trail | North Richmond |
| North Richmond | Eastshore State Park |
| Eastshore State Park | Spine Trail |
| Crown Beach | Crown Beach |
| Miller Knox | Miller Knox |

# 8 Next Steps

The Risk Assessment is a decision-support tool to help identify those segments in EBRPD's purview to prioritize for adaptation design and implementation based on risk level (see Figure 20).

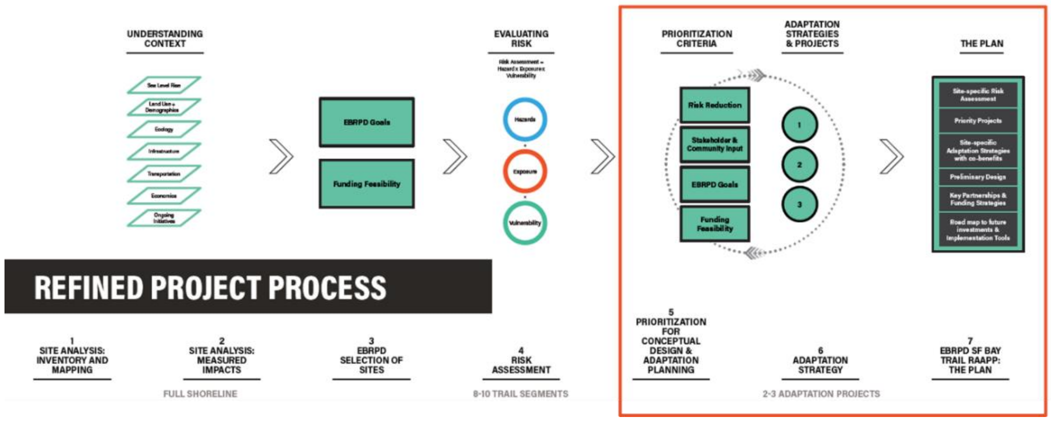



*Figure 20 Next steps in the project process*

The scores and their respective weightings are intended to bring transparency and defensibility to the EBRPD's decisions for prioritization. In some cases, risk level alone will not support prioritization if EBRPD or its partners do not operate the segment, if the funding needed for adaptation measures is out of budget, or if the project lacks the political support needed to mobilize funding or other resources.

# 9 Conclusion

As illustrated below in Figure 21, the overall framework of this risk assessment was developed to feed into the project's overall prioritization effort. The risk scores and rankings coming from this risk assessment are meant to be one of several factors that influence the final prioritization of projects considered by the Park District for adaptation. Other factors include funding and financial potential, political priorities, and ownership and partnering opportunities. Simply put, risk assessment is useful in that it establishes a clear an objective baseline for where to focus attention when pursuing projects with the greatest potential co-benefits across the categories of economic, environmental, social equity, recreational, and connectivity. Risk assessment also given an early indication of which projects may yield the most favorable benefit-cost relationships, which is critical for Capital Planning. Ultimately, this risk assessment provides a critical foundation for risk-informed, strategic decision making around how and when to address sea level rise by leveraging the Bay Trail within the Park District's 55-miles of East Bay shoreline.

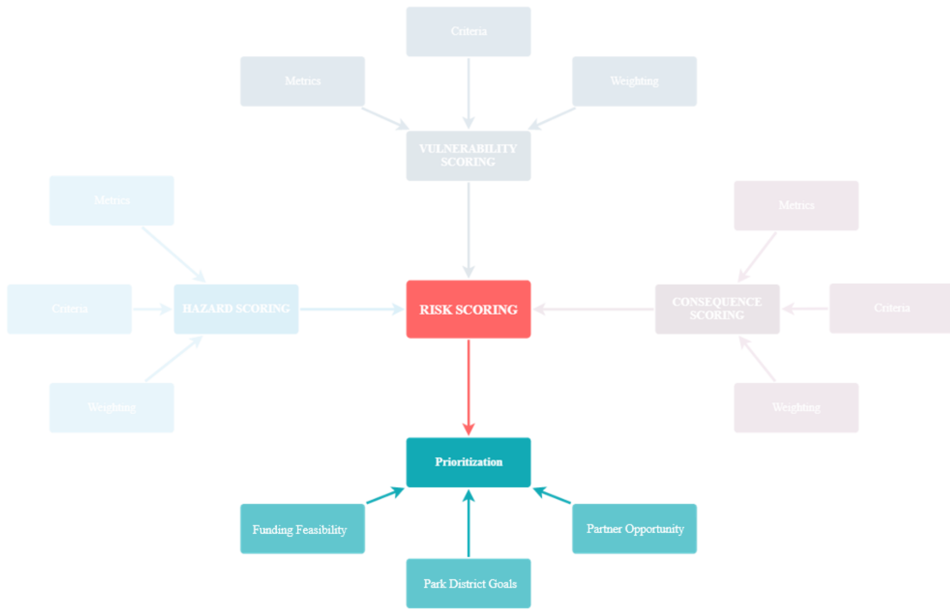



*Figure 21 Risk Matrix framework*