San Francisco Waterfront Development Projects
- An Adaptation Strategy -

by
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ABSTRACT

There is a growing impetus by regulatory and resource agencies, as well as community stakeholders, to include the effects of global warming and sea level rise within the design life of major waterfront development projects. However, given the significant amount of uncertainty associated with quantifying the rate of sea level change, projects are not being held to specific standards or codes. Therefore, traditional engineering approaches to solving a problem is difficult when addressing climate change induced sea level change.

This paper describes work completed for two major proposed developments in the City of San Francisco – Treasure Island and Hunters Point Shipyard. The work included extensive review of climate change literature published by local, regional, state and federal agencies as well as the international community and academia. Detailed coastal flooding studies were conducted which included probabilistic analyses of extreme values to develop extreme statistics for water levels including effects of tides, surges, waves, and tsunamis. These values were subsequently combined with sea level rise estimates, and various scenarios of required coastal improvements were developed for discussions with stakeholders.

Based on the analysis and understanding of acceptable levels of risks, a strategy encompassing the near-term, mid-term, and long term was developed for the projects. Immovable structures such as buildings and vital infrastructure are planned to be raised to above the conservative levels of identified sea level rise. Perimeter improvements are planned to be built to mid-term values with adaptation strategies incorporated into the project documents.

Both the Treasure Island and the Hunters Point projects recently received SF Board of Supervisors approvals, and the Coastal Zone Management Agency in SF Bay has singled out the Treasure Island project as a model for bay-front flood protection planning in the presence of uncertainties such as rate of sea level rise and tsunamis.

1. BACKGROUND

The topics of Climate Change and Sea Level Rise (SLR) continue to be the subject of much research and discussion as shoreline communities are facing a shrinking waterfront in the face of rising water levels. Warming oceans combined with the effects of melting ice sheets and glaciers have been causing sea levels to rise globally since the last glacial period. Although the phenomenon is not new (sea levels have varied over hundreds of feet over geologic times), several recent studies are indicating that the rate of SLR may be higher over the past two decades as compared to the past century, and a considerable amount of research is being conducted on this subject.

It is therefore important that SLR be accounted for, in the planning/design process for coastal developments, to prevent future flooding or loss of infrastructure resulting from shoreline erosion. However, SLR is different from most other environmental factors (such as seismic, wind, waves, temperature) because the science is still maturing. Although there is consensus that global warming and SLR should be incorporated into the design of projects, there are no codified methods or policies currently in place. Estimates in the literature vary widely based on the methods used to estimate SLR. Historical observations indicate about 8 inches per century; general circulation models that include greenhouse gas emissions and warming of oceans estimate up to 38-inches per century; empirical studies, which have hypothesized that global sea level responds primarily to global temperature, have estimated as much as 5 feet of SLR over the next 100 years. The effect of ice cap melt when added to these estimates results in even higher values.

What is clear is that the science of climate change and SLR is evolving, and there are no codified methods or policies currently in place nor is there specific guidance from state or federal agencies. In the face of rising tides and extreme, unpredictable weather patterns, local governments and agencies

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are confronted with daunting options as they look towards evaluating their risk and updating their Strategic Plans – to stay or retreat, move a highway, bridge or port facility or a whole city.

This excerpt from an article published in the Contra Costa Times, a San Francisco Bay Area Newspaper, summarizes the issue well:

**Cash-strapped public clients are not inclined to spend millions of dollars on solutions to prevent future flooding problems from rising sea levels when the severity of the threat is difficult to predict. Cities that built neighborhoods, airports and highways by the Bay are already facing huge dollar signs when it comes to addressing today's flood risks. As cities struggle to come up with the money to meet flood protection standards, there is a growing consensus among urban planners and regulators that it's past time to initiate regional strategies that also include retreating from the water. The only thing that is certain is that every time a projection comes out, it's higher than the last one. So this is one of these things where we don't know exactly how high waters will rise, we just know that they will rise.**

Since the Treasure Island and the Candlestick Point/Hunters Point Redevelopment projects represent significant public/private investments for San Francisco, and at the same time offer unique opportunities to plan new communities in a sustainable manner, project specific SLR studies were prepared to develop planning and design guidance through the various phases of the project (Moffatt & Nichol 2008, 2009a, 2009b). The studies were based on a review of guidance policies relevant to SLR, an exhaustive review of the literature and statistical analysis of tidal, wind-wave, and storm-wave processes for Central San Francisco Bay as described below.

**2. CURRENT POLICIES**

Potential solutions may be defined by mandates or policy guidance on the part of those charged with the public interest, including FEMA (Federal Emergency Management Agency), the U.S. Army Corps of Engineers (USACE), Coastal Zone Management Agencies, or Regional entities that oversee the wellbeing of their respective coastlines and coastal communities.

At the federal level, the USACE and U.S. Environmental Protection Agency (EPA) have recognized that global warming and rising seas need to be considered within the design life of all federally funded projects. Prior to 2009, the standard of reference remained a 1987 National Research Council (NRC 1987) report that assumed three hypothetical SLR scenarios for the year 2100: ½ meter, 1 meter, and 1½ meters. In July 2009, the USACE adopted a multiple scenario approach where levels of risk corresponding to the three NRC scenarios would be evaluated for the no-project and proposed-project conditions, and a decision would be made in concert with the local sponsor. Again, this process applies to federally funded projects only and would not be triggered for projects for which the only USACE involvement is a permit.

The National Flood Insurance Program administered by FEMA, which is the primary mechanism for communities receiving flood protection, does not include SLR in its flood mapping criteria for flood insurance. However, as a result of recent disasters, FEMA embarked upon a map modernization program, which involves updating flood insurance rate maps, many of which date from the 1970s and 1980s. Since sea levels have risen and levees have settled, many of the areas no longer meet CFR 65.10 requirements, which has resulted in “preliminary” flood maps to be issued that show several communities in the flood plain, the implication being that some communities have lost “protected” status. This has already happened in many urban areas, including Sacramento and Redwood City in Northern California. FEMA has also updated its mapping approach for areas vulnerable to coastal flooding to a risk-based methodology. This involves re-evaluating present sea levels in the project area, estimating extreme high water elevations due to tides, surges, tsunamis etc., and coming up with local sea level trends. Then, using the new FEMA evaluation approach, coastal protection concepts need to be developed and designed such that the Special Flood Hazard Area designation of the project area can be removed.

In some coastal states, specific policies and mandates have been issued to address the effects of climate change, resulting in relevant state and local coastal zone management agencies taking on the mantle of addressing SLR issues in terms of development permits for projects. California requires all state-funded and state agency projects to incorporate the effects of SLR and climate change in project planning, and has recommended guidance to evaluate SLR. These include reports by the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT 2013) and the NRC (2012).
The California Natural Resources Agency (CNRA 2009) has also authored an adaptation strategy, and now requires state agencies to demonstrate that new state-funded projects account for SLR.

3. SEA LEVEL RISE ESTIMATES

Thousands of peer-reviewed publications on the topic of climate change and associated SLR have been published in the past 20 years. However, the majority of guidance papers produced by federal, state, and other governmental agencies have relied on the following literature:

- Assessments based on General Circulation Models (GCM) that use emission scenarios such as those by the Intergovernmental Panel on Climate Change (IPCC 2001, 2007, 2013).
- Assessments based on Semi-empirical models (Rahmstorf, 2007, Vermeer & Rahmstorf, 2009)
- Illustrative Assessments (National Research Council (NRC 1987, USACE 2009)
- Assessments based on a combination of GCMs and Semi-empirical models such as those by the NRC (2012) and the California Climate Change Center (CCCC 2006)

Of note, the reports by the IPCC contain exceptionally detailed syntheses of the available peer-reviewed science of climate change and sea level modeling, and have received contributions and comment from a vast array of respected researchers in the field. The range of SLR projections was 4 to 35 inches by 2100 for the 2001 assessment, and 7 to 30 inches by 2100 for the 2007 assessment. Many scientists regarded the IPCC third and fourth assessments (IPCC 2001, 2007) to be scientifically conservative in that less-understood mechanisms such as ice melt, which could also contribute to SLR, were not considered in the SLR projections because of a lack of broad scientific consensus or understanding of these processes. In particular, the projections did not include potentially large and nonlinear effects such as instability and accelerated loss of the Antarctic and Greenland Ice Sheets because no broadly accepted models of these processes exist. In fact the 2007 IPCC document admits that the predictions may be either over or under estimated, at either end of the projected range. High-resolution global altimetry data, through the end of 2009, suggest that in the last two decades, global mean sea level has increased at a rate closer to the upper end of the IPCC 2007 projections.

The fifth assessment (IPCC 2013) uses a new set of emissions scenarios, the Representative Concentration Pathways (RCP) for climate model simulations. The RCPs are mitigation scenarios which explore the effects of 21st century climate policies and thus differ from the no-climate policy scenarios used in previous assessment reports. The report also acknowledges that more comprehensive and improved observations have strengthened the evidence that the ice sheets are losing mass, glaciers are shrinking globally, sea ice cover is reducing in the Arctic, and snow cover is decreasing and permafrost is thawing in the Northern Hemisphere. The report projects SLR over the next 100 years to be in the range of 11 inches to 38 inches.

The 1987 report by the NRC focuses on the anticipated effects of SLR and the recommended responses. It does not make specific projections of SLR: rather, it adopts three plausible conditions of 20, 39, and 59 inches by 2100 (0.5, 1, and 1.5 meters). The most recent USACE guidance (Engineering Circular EC 1165-2-211, dated July 1 2009) uses the NRC curves as projections for global SLR. The 2012 NRC report on the other hand uses a combination of data from emission models and recent observations of rates of loss of ice to estimate SLR ranges. For the California coast south of Cape Mendocino, the committee projected that sea level will rise 5 to 24 inches by 2050, and 17 to 66 inches by 2100.

Semi-empirical assessments to project SLR avoid the difficulty of estimating individual contributions to sea-level rise by postulating that sea level rises faster as the Earth gets warmer. This approach reproduces the sea-level rise observed in the past, but reaching the highest projections would require acceleration of glaciological processes to levels not previously observed or understood as realistic (NRC 2012). The Rahmstorf 2007 assessment estimated 20 to 55 inches by 2100, and the 2009 update estimated 32 to 71 inches by 2100.

The San Francisco Bay Conservation & Development Agency (BCDC) in its guidance policy (BCDC 2011) recommended that a SLR allowance of 16 inches by 2050 and 55 inches by 2100 be used by applicants for bayfront development. A summary of various SLR projections, which also includes the BCDC estimates, is shown on Figure 1.
An update of the literature was summarized in The Copenhagen Diagnosis, 2009: Updating the World on the Latest Climate Science, which reviewed recent research related to climate change. The independent group of authors point out the uncertainties in developing SLR estimates and summarize several peer-reviewed articles. A few quotes from the report specific to SLR are reproduced below:

“Future sea level rise is highly uncertain, as the mismatch between observed and modeled sea level already suggests.”

“Based on a number of new studies, the synthesis document of the 2009 Copenhagen Climate Congress (Richardson et al. 2009) concluded that updated estimates of the future global mean sea level rise are about double the IPCC Projections from 2007.”

“Although it is unlikely that total sea level rise by 2100 will be as high as 2 meters (Pfeffer et al. 2008), the probable upper limit of a contribution from the ice sheets remains uncertain.”

Houston and Dean in another very recent study (Houston and Dean 2010) evaluated long term U.S. tide gauge records for the 20th century. Their analyses do not indicate any acceleration in sea level over the last century. Instead, for each time period they considered, the records show small decelerations that are consistent with a number of earlier studies of worldwide-gauge records.

![Figure 1: Summary of Various Sea Level Rise Projections](image)

4. PLANNING FOR SEA LEVEL RISE

The impacts of SLR along San Francisco Bay and the California coastline are already occurring during combined occurrences of high tides, surge, and wind storms, particularly during El Niño years, when areas along the coast that did not experience flooding in the past now do. As a result of that, there has been an increased awareness of the potential for flooding, and local agencies have incorporated SLR into their planning. Examples of increased flooding are shown on Figure 2.

It is also important to note that the most significant criteria that affect potential for flooding along the California coast are astronomical tides and storm waves, versus the East Coast of the US, where storm surge dominates extreme water levels. This is shown on Figure 3. Within San Francisco Bay, given the shallow depths and limited fetch lengths, astronomical tides predominate.
Therefore, it is critical that developments first address coastal inundation by conducting appropriate flooding studies, and subsequently augment the designs by adding in sea level rise allowances. Given that the science of climate change is evolving, and SLR projections have a wide range of values, projects should adopt a reasonable planning horizon and include appropriate design measures that can accommodate various levels of SLR over the planning horizon rather than design to a specific report or estimate. Addressing SLR is not as simple as “building it higher,” because of the significant constraints posed by soil conditions and elevations of backland areas, including drainage and transportation infrastructure, which limit the ability to just elevate the waterfront areas.
Project designs should be based on life-cycle analysis and risk assessments using statistical probabilistic methods such that appropriate SLR allowances can be estimated. Given the enormous challenges associated with funding and building for a future uncertain condition, flexible designs that can be adapted in the future are the most logical approach moving forward. Therefore, an Adaptation Strategy should be developed which must be able to accommodate future flood protection improvements, if and when they become necessary to account for rising sea levels.

However, many of the issues related to addressing SLR for design of waterfront facilities are complex and require a diverse range of input. Some of the questions that arise include:

- Can each adaptation or design option be pursued in an environmentally responsible way?
- How can land rights be addressed?
- How cautious should one be in allowing for climate change?
- Will lenders or capital investors concur with the strategies in the absence of codified criteria from local, state, or federal agencies?

In addition to rising seas, ancillary issues related to climate change can affect waterfront developments, namely storminess (increase in magnitude of storms), changes in precipitation, increase in emissions, and others. Because SLR is better understood than storm frequency and intensity, it makes sense that plan formulation should commence with SLR. Guidance should be beta-tested for selected projects in several important areas because of regionally unique conditions. In addition, guidance should address protection, retreat, land rights and living shoreline concepts. Implementation of planning techniques should follow testing and review.

An approach that has been used successfully by the authors on large infrastructure developments, particularly where typical structure elevations are relatively vulnerable to overtopping, is described below:

- Statistically evaluate extreme water levels to develop design and operational water levels;
- Review mean sea level records for the area to develop historical sea level change trends;
- Determine a range of credible SLR projections based on widely accepted peer-reviewed reports;
- Select a level of acceptable risk (in terms of water levels) based on project design life and develop a SLR allowance;
- Integrate the extreme water levels and SLR allowance into the elevation criteria;
- Integrate the SLR allowance into structural design criteria such that wharves, bulkheads and other structures are built to work with present backland elevations, but can be adapted in the future to higher sea levels (such as jacking up abutment landings, decks, etc.);
- Develop an Adaptive Management Strategy that ties in a Monitoring Program based on published data sources (such as NOAA tidal records) to specific Management Measures;
- Obtain consensus from local coastal management agencies on the approach.

4.1 Regional Planning Efforts in San Francisco Bay

BCDC, which is the regional agency that guides and regulates shoreline and Bay development in San Francisco Bay, embarked upon a climate change initiative and produced inundation maps for SF Bay that show areas along the Bay that are flooded under a 16-inch SLR scenario and a 55-inch SLR scenario. These are shown on Figure 4. As part of its regulatory function, BCDC now requires that project applicants conduct a risk assessment based on the estimated 100-year flood elevation that takes into account the best estimates of future sea level rise.

In addition, FEMA has initiated a Map Modernization initiative for SF Bay that uses recent data on sea levels and storms, and is overlaying them onto current topography to produce new Flood Rate Insurance Maps (FIRM). A representative map of vulnerabilities to different aspects of coastal flooding is shown on Figure 5. Although the FIRM maps do not include sea level rise, the identification of inundation potential from extreme storms has galvanized local communities into action, who are now looking at flood risk mitigations that will include some amount of sea level rise in their plans.
Figure 4: Areas Inundated by Average Highest Monthly Tide With 16 Inches of SLR [Left] and 55 Inches of SLR [Right]

Figure 5: Areas Vulnerable to Different Factors (FEMA Regionwide Floodplain Mapping)
5. DESIGNING FOR SEA LEVEL RISE – THE TREASURE ISLAND EXAMPLE

The Treasure Island Development Authority (TIDA), which is a redevelopment agency in San Francisco, and Treasure Island Community Development (TICD) are working together in a public-private partnership to redevelop the island. Development plans for Treasure Island include 6,000 to 8,000 new homes, up to 500 hotel rooms, a 400-slip marina, restaurants, retail and entertainment venues, and nearly 300 acres of parks and open space as shown on Figure 6.

Projected to be one of the most environmentally-sustainable large development project in U.S. history, the project was selected as one of 16 founding projects of the Clinton Climate Initiative's Climate Positive Development Program. Treasure Island's location in the Bay and typical low-lying terrain makes the proposed development a perfect example of the need to plan for sea level rise.

5.1 Assessing Vulnerability to Coastal Flooding

The island was constructed using sand mined from San Francisco Bay in ca. 1936 for the Golden Gate International Exposition. The sandy fill layer is susceptible to liquefaction, and the underlying compressible bay mud layer is subject to settlement over time, which makes it challenging to build tall levees along the perimeter. Given the comparatively higher elevations of land along the south west portion of the island, the decision was made to raise the development footprint rather than rely on flood control levees along the perimeter. Several segments of shoreline areas are presently overtopped by waves and are within the 100-year floodplain, as mapped by FEMA. It was recognized that development within the flood prone parcels would require a detailed statistical analysis of tides, waves, and tsunamis, and constructing appropriate mitigations.

Coastal flooding in the area is due to varying water levels resulting from a combination of astronomical tides, storm surge, waves on the island shoreline, and tsunamis. Unlike rivers, where guidance on minimum crest elevation of riverfront areas is provided by FEMA and/or the Army Corps of Engineers due to a high degree of confidence on water levels, coastal areas need to be analyzed on a site-specific basis because water levels in coastal areas are influenced by several factors, each of which varies statistically. FEMA’s recommended procedure to establish the Base Flood Elevation is to conduct a Probabilistic Analysis of these factors, based on a combination of coincident events that results in a 1% annual chance of flooding. Additional factors that need to be considered include sea level rise, settlement, structure or project design life, and planned uses within the area to be protected.

The detailed analysis was supplemented with a Risk & Uncertainty Assessment, which evaluated factors that have a high level of variability such as tsunamis, and the various global warming scenarios described earlier. The analysis resulted in an identification of the deficiencies in the system, or the Vulnerability of the perimeter system. This allowed project planners to evaluate the consequences of different levels of improvements along the perimeter, as well as different site grades. In the case of
Treasure Island, the areas that could not tolerate flooding (low adaptive capacity such as urban promenades, building pads, City parks) should be raised, whereas passive use open space areas where infrequent flooding could be tolerated (high adaptive capacity) did not need to be raised as much.

5.2 Addressing Sea Level Rise

Sea level rise was not included in the probabilistic analysis because it is not an episodic phenomenon; in fact it has a high probability (virtually certain) of occurrence but the variable is the rate at which it will occur. In developing the estimates of future flood elevations for the project, it was necessary to select a set of sea level rise projections based on the literature. However, given the wide spread in SLR projections in the scientific documents, and in the absence of any guidance from agencies, a risk-based approach was used to estimate the SLR allowance that should be added on to the proposed grades from the preceding analysis.

The CO-CAT report (2013) has a good discussion on risks and consequences related to coastal flooding and SLR, and identifies a practical decision-making process. Although the report was not published at the time of this analysis, the analysis conducted for the Treasure Island study was almost identical, therefore the discussion and related graphics from the report are presented below.

Risk is usually evaluated by comparing the probability that impacts would occur (or likelihood), to the consequence of these impacts. Criteria such as the extent, scale and magnitude of the impact, combined with the adaptive capacity of an asset, define the consequence (see Figure 7).

 Several documents (CO-CAT 2013, IPCC 2007, NRC 2012) have also defined risk as the product of the likelihood of damage and the consequence of damage, which can be expressed as:

\[
\text{Risk} = \text{Likelihood} \times \text{Consequence}
\]

To evaluate risk to an asset, both likelihood and consequence need to be characterized. An asset could be a commercial, residential, or recreational property, an infrastructure facility, public health and safety, and/or the environment.

The likelihood factor in the above expression can be described by the scientific studies that have estimated projections of SLR, both globally as well as for SF Bay.

The consequence of failing to address SLR for a particular project will depend on both the Vulnerability of the asset to SLR and the Adaptive Capacity of the asset, which is a measure of the ability of a system to cope with consequences of climate change. For example, an asset which is highly vulnerable to SLR and also has a low adaptive capacity will have a high consequence of failing.
An asset that has high adaptive capacity and/or low potential impacts will experience fewer consequences. This is summarized in Figure 8. Based on the above, a typical Risk Assessment should therefore consist of the following tasks:

- Assess Vulnerability
- Determine Adaptive Capacity and Risk Tolerance
- Estimate Value of Asset Over its Expected Life (tangible as well as intangible)
- Develop Adaptation Strategy

![Figure 8: Evaluating Risk Based on Likelihood and Consequences](image)

### 5.3 Project Specific Sea Level Rise Projections

For the Treasure Island project, two criteria were used in the SLR analysis to evaluate the likelihood and the range of projections.

- First, it was important to distinguish between scientific projections (such as those based on modeling of emissions and/or semi-empirical models) and illustrative cases such as those in the NRC 1987.
- Second, the science of climate change and sea level rise is evolving and improving, even if it does not lead to a narrower spread of projections over time. For example, ice sheet dynamics is a very active research field, and measurements of the polar ice caps are showing rapid melt in some areas. Therefore, more recent projections should be given more consideration than those made earlier.

The study therefore focused on the reports authored by the IPCC, the NRC, and Rahmstorf. The different projections of sea level rise between 1990 and 2100 summarized earlier (see Figure 1) shows the spread of data, especially after 2050. All projections start at zero in 1990. This is also a convenient start date for investigating the effects of sea level rise on the base flood elevation, because the Mean Lower Low Water datum – used in the estimation of coastal flooding – is based on the 1983-2001 tidal epoch. 1990 is close to the midpoint of this tidal epoch, therefore it is not necessary to “normalize” the projections by setting the increase in sea level to the present day (2009) or the projected construction date.

In discussions with project planners related to the planning horizon for the development, the desire was to have a low risk of SLR related impacts over at least a 70-year duration. A typical financing mechanism (loans and/or bonds) takes about 30 years to service the debt; a 70-year duration would allow a minimum of two such debt mechanisms after the planning/construction phase of about 10 years. This was also perceived to be about the length of time at which significant infrastructure improvements are made to communities. Over this period, even with the most aggressive projection of
sea level rise, the increase in sea level reaches 36 inches between 2075 and 2080 (see Figure 9). In fact for many of the projections shown in Figure 9, the 36-inch increase is not reached until after 2100.

![Figure 9: Sea Level Rise Projection Used For the Treasure Island Project](image)

5.4 Project Design Features

Based on the above review and quantitative estimates of SLR for San Francisco Bay, and numerous discussions with TIDA, TIDC, and other City agencies, a strategy for protection against SLR was adopted for the project which varied with the adaptive capacity of different elements. Since building structures are generally “immovable”, whereas a shoreline protection system and/or storm drain system can be adapted to keep up with changing sea levels, different planning horizons were adopted for the different elements. In general, the SLR strategy was built around the following key elements which are also summarized in Figure 10:

- Raise grades for the new development to accommodate SLR over a 70-year horizon;
- Improve the perimeter protection and interior drainage for a shorter time horizon to prevent obstruction of view corridors and ponding, while providing protection against coastal flooding;
- Develop an Adaptation Strategy for long-term improvements to the shoreline protection system and drainage system in the event that actual sea level rise exceeds that value.
- Include development setbacks to allow improvements along the perimeter
- Identify a stream of funding to construct these improvements as part of the Adaptation Strategy.

Specific implementation strategies are described below.

Development Areas

Since building pads and finished floors are not adaptable, all buildings and entrances to subterranean parking and streets would be set at an elevation that is 36-inches higher than the present day 100-yr return period water level in the Bay. This 36-inch SLR allowance plus a freeboard of 6 inches would be used for finished floor elevations of all buildings. This would ensure that even if no shoreline protection improvements are undertaken, or in the event of a slope failure along the shoreline, buildings and transportation infrastructure would not be flooded for water levels 42 inches higher than current BFE.
This would put it beyond the 2080 time frame according to the most aggressive sea level rise, and well beyond 2100 according to the highest IPCC projection.

**Figure 10: Treasure Island Project - Sea Level Rise Strategy**

**Shoreline Protection System**

It is not practical to build a high wall around the project for a design condition that may not happen for several decades, because it would pose a visual obstruction and severely limit public access. At the same time, it is not practical to build to present sea level conditions and keep raising it as sea levels rise. Therefore, the perimeter elevation would be raised to prevent coastal flooding associated with the 1% annual chance storm event for present day conditions, and include an additional allowance of 16-inches of SLR at the time of initial construction.

Future SLR related improvements would be accounted for by setting back the shoreline development by an adequate distance to allow elevation increases in the future. The setback distance should be sufficient to allow future elevation increases along the perimeter of least 3 feet, and the ability to go even higher (up to the 55-inch estimate recommended by the CALFED committee) with either the same or a different structural configuration. This will ensure that the project will not be mapped as a FEMA flood zone either now or in the future when SLR could approach 3 feet.

**Storm Drain System**

The storm drain system will be constructed such that it can gravity-drain, even with a SLR of 16-inches, and will be adaptable to higher levels of SLR with minimal intervention. It will thus function as a gravity-drained system until such time that SLR reaches 16-inches, beyond which the Adaptation Strategy will be implemented consisting of installing storm drain pumps.

**Adaptation Strategy**

A project-specific Adaptation Strategy will be implemented that will provide guidance, identify relevant stakeholders, define appropriate management actions and triggers, and establish a long-term, project-specific funding mechanism. The strategy envisions incorporating ongoing measurements of SLR from
the scientific community into Monitoring and Adaptive Management Plans that would guide the decision making process for future improvements.

It will be administered by an entity created for Treasure Island which would have taxing authority and funding responsibility. A Monitoring Program would be put in place to periodically compare published changes in sea level values with the crest elevations of the shoreline protection system. For example, the strategy could include 5- or 10-year updates based on a comparison between observed changes in sea levels and perimeter elevations to facilitate an appropriate, informed decision about raising perimeter grades.

The Adaptation Strategy would define specific triggers for action based on observed changes in sea level, and would include the following:

- When a sea level increase of 16 inches is reached, the crest elevation of the shoreline protection system would be raised to mitigate more frequent wave overtopping, and storm drain system pumps installed.

- When a sea level increase of 36 inches is reached, the shoreline protection system would be improved to act as a flood barrier (levee or floodwall).

The elevation and structural characteristics of the island’s perimeter are key components of Treasure Island’s Adaptation Strategy. The proposed development setback distances will enable a variety of future modifications along the shoreline protection system to accommodate the projected future values of SLR, with the ability to accommodate even higher values of SLR if necessary. Shoreline modifications would likely include a combination of the following strategies depending on desired open space uses and wave runup characteristics at different locations around the island:

- Raising the shoreline embankment in place to function as a storm surge or flood barrier;

- Constructing a series of embankments of increasing heights away from the water. Land between sets of embankments can hold periodic wave overtopping that drain out between high tides while creating habitat;

- Constructing sea walls – particularly at the proposed ferry quay and along the marina promenade, where they would also function as a public amenity;

- Laying back the shoreline to create cobblestone beaches to limit wave runup and overtopping, creating accessible public amenities.

Some representative examples of future adaptations are presented on Figure 11. The project has completed its environmental documentation process and is currently in the design phase, with construction anticipated to start in 2015.
Figure 11: Potential Adaptation Strategies - Raise Edge [Top], Raise Edge with New Trail [Middle], Retreat and Replace Riprap with Cobble Beach [Bottom]
References


