

6/18/10 Draft Design Standard

DESIGN TIDES AND PROJECT PLANNING FOR SEA LEVEL RISE

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Purpose: The purpose of this design standard is to provide guidance to the Wastewater Enterprise (WWE) for incorporating the physical impacts of projected sea level rise in planning, design, construction, operation, and maintenance of facilities directly or indirectly related to the wastewater system (e.g. new subdivision developments), coastal erosion, overflow structure protection, and flooding.

1. Use 1.4 meters (55 inches) as the projected eustatic sea level rise by year 2100 due to global climate change for design purposes. This is the highest projection from the paper by Stefan Rahmstorf (Science, 2007), which was adopted by the CALFED Independent Science Board (Healy, 2007) for the bay and delta.
2. Use the 100-year design tide (i.e., a tide with an average return period of 100 years or a one percent chance of happening in any year) for design purposes.
3. Projects must as a minimum design for the tide projected at the end of the project life 50 or more years from project conception taking into account sea level rise due to global climate change.

100-Year Design Tide Projections

Table 1 shows adjusted design tide elevations around San Francisco in the years 2040, 2060 and 2100 assuming 1.4 m (55 in) as the projected sea level rise by year 2100.

Location	1990	2040	2060	2100
Presidio	-2.91	-1.86	-0.96	1.68
San Francisco, North Point, Pier 41	-2.62	-1.57	-0.67	1.97
Rincon Point, Pier 22 ½	-2.48	-1.43	-0.53	2.12
Potrero Point	-2.30	-1.25	-0.34	2.30
Hunters Point	-2.20	-1.14	-0.23	2.41
Yosemite Slough	-1.98	-0.99	-0.11	2.52

100 year tide data from personal communication from Noah Knowles, Trim 2D model

TABLE 1. 100-YEAR DESIGN TIDE ELEVATIONS ALONG THE SAN FRANCISCO COASTLINE ADJUSTED FOR FUTURE PROJECTED EUSTATIC AND STERIC SEA LEVEL RISE DUE TO GLOBAL CLIMATE CHANGE (Relative to City Datum in feet (see Appendix 3)) Note: Eustatic and steric changes refer to changes in ocean volume due to additional mass and thermal expansion, respectively.

Background: In the preparation of this document the Wastewater Enterprise (WWE) of the San Francisco Public Utilities Commission has relied entirely on climate change science performed and published by agencies and entities external to WWE. The WWE is a user of the currently accepted community consensus on the state of climate science knowledge and applicable WWE policies will be periodically reviewed and revised as the accepted consensus changes.

The primary source of historical tide data comes from the Presidio tide gauge, which has been in operation for 150 years. Appendix 1 shows the current location of this gauge. In addition, there are published tides for other points around the city; these locations and where the information may be accessed is in Appendix 2.

There are three datum points that one must become familiar with. These are City Datum, the North American Vertical Datum 1988 (NAVD88,) and the National Geodetic Vertical Datum of 1929 (NGVD 29.) City datum was established at 8.616 feet above NGVD 29. This relationship is equivalent to a height of 11.336 or 11.34 feet above NAVD 88. Most tides are measured from mean lower low water (MLLW.) Mean lower low water is adjusted approximately every 19 or 20 years; the last adjustment was from 1983 to 2001. Appendix 3 has more details on these relationships.

Appendix 4 has estimates of tide increases for return periods from a 2 year to a 100 year return.

Appendix 5 gives some of the background on the sources of the 55 inch sea level rise. The 55 inch sea level rise is essentially based on the worst emissions scenario predicted from the International Panel on Climate Change's Third Assessment Report, and an empirical relationship developed by Stefan Rahmstorf (Science 2009) based on historical sea level rise correlated with temperature increases.

Appendix 6 gives the projections of sea level rise for all of the overflow points, assuming a 55 inch rise by 2100, for the 100 year tide, one year tide and mean higher high water.

Appendix 7 discusses planning considerations to address the impacts of sea level rise.

Recommendations

Sea Level Rise

The recommended projected sea level rise for use in planning should be updated regularly (e.g., every five years) as new data and scientific assessments are revised and become available. Currently, the State of California Resources Agency along with the California Energy Commission and the Department of Water Resources are developing a "Sea Level Rise Assessment Report" with new estimates for regional impacts of sea level rise with the final report due December 1, 2010 (Executive order S-13-08). The rate of local MSL rise at San Francisco for the past decade has been 3.2 mm/yr (0.13 in/yr).

Land development in the low-lying areas of San Francisco faces two problems: 1) rising tide levels, and 2) settlement. In the late nineteenth century and early in the twentieth century, San Francisco was built out to the northeast and east by filling in the bay with debris (much of the debris was from the 1906 earthquake). The fill has since consolidated; therefore, future settlement should be minimal, but must be considered. Sea level rise has a greater potential to put the public at risk of flooding during high tides and storm surges. The City and developers of this land need to plan for this eventual problem.

Sea level rise also effects coastal erosion. Coastal erosion has already occurred along the southwestern cliffs of San Francisco (along the Pacific Ocean) and puts the Great Highway at risk if not mitigated. Wastewater facilities (Oceanside Water Pollution Control Plant and the Lake Merced Tunnel and Westside Transport) are also located near the site of coastal erosion.

Additionally, stormwater runoff (whether as a combined sewer discharge or a separate discharge system) needs to be designed to freely flow to the receiving water. However, there are many parts of the sewer system where the existing ground elevation is or will be at or below the level of the 100-year design tide. These areas will flood unless a system is built to pump out the stormwater and/or the combined stormwater and sewage.

Wastewater discharged through pump stations into deepwater outfalls will need to be designed to optimally and efficiently pump the treated effluent through the deepwater outfall as the design tide changes.

Extreme Tide Analysis

Design tide analysis needs to consider the extreme tides that occur yearly around January when the earth is closest to the sun, the moon is closest to the earth between the earth and sun, and when there is a low pressure storm. It is the frequency of these daily tides that will have the greatest impact. Hence, the tidal analysis should be for the daily high tides that occur in the months of December and January. Figure 1 below shows the projection of the annual highest tides.

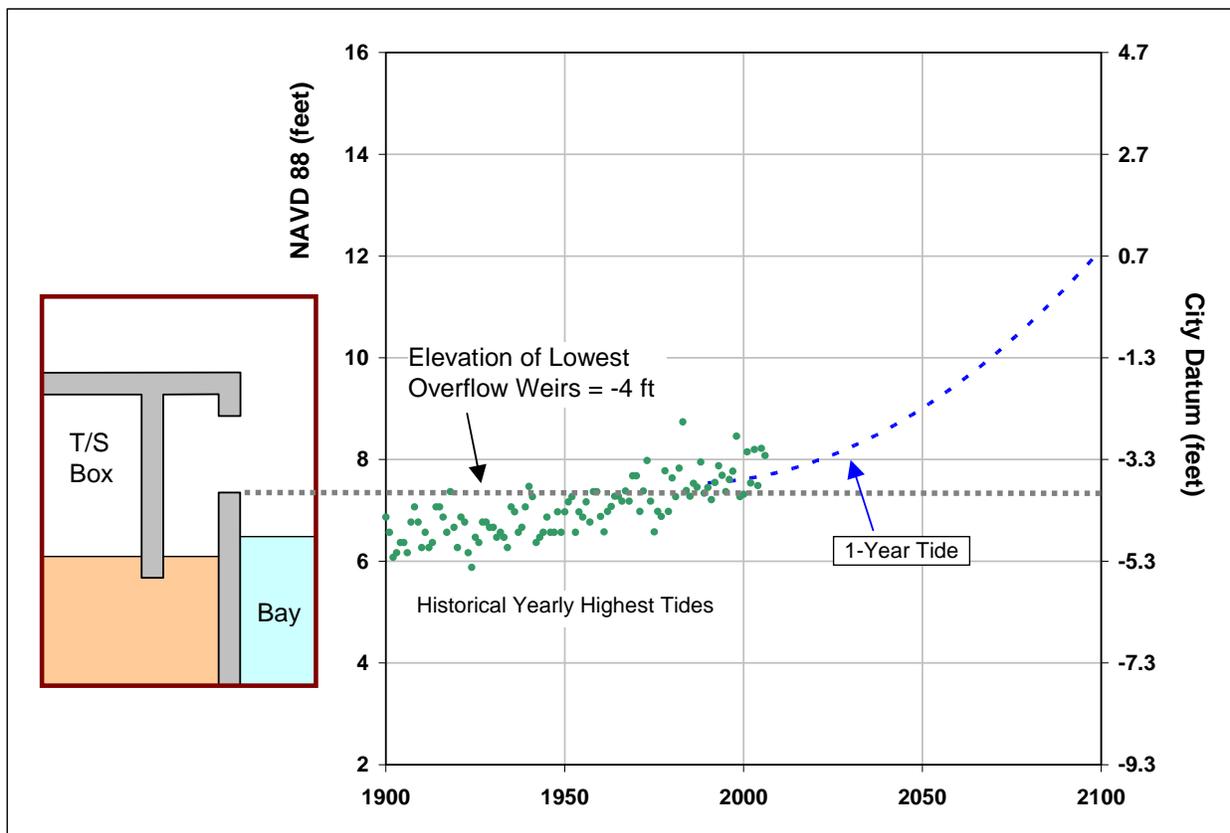


FIGURE 1. PROJECTION OF ANNUAL HIGHEST TIDE FOR SAN FRANCISCO AT THE PRESIDIO

Finally, Noah Knowles produced the graphs shown in attachment, which shows the 55 inches of

sea level rise for all tides as projected from his TRIM 2D model in 2009. An example of this projection is shown for the Pierce St. outfall in Figure 2, which gives the projection for all tides from the highest to the lowest.

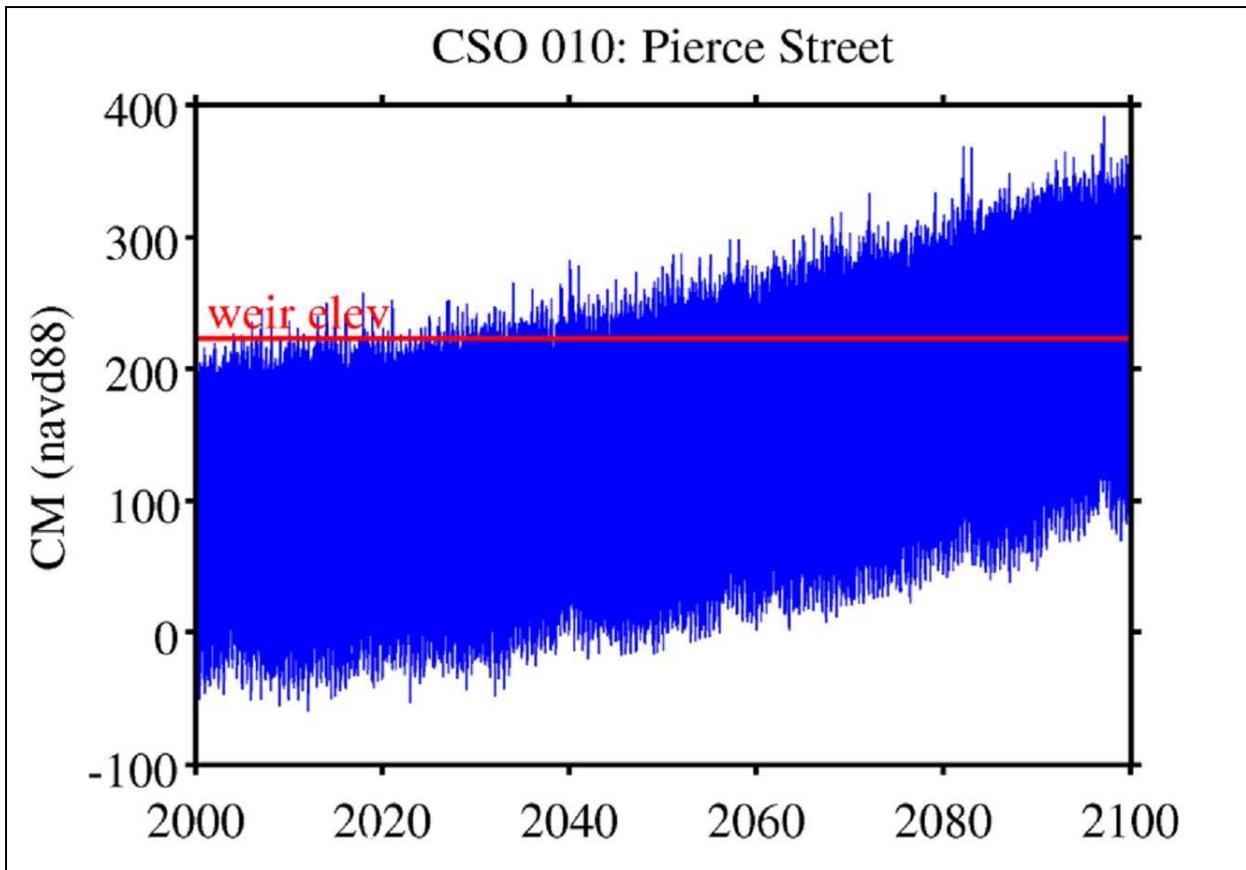


FIGURE 2. PROJECTION OF THE LOWEST AND HIGHEST TIDE RANGE FOR THE PIERCE STREET OUTFALL

References

1. Carollo, Draft Project Memorandum - Climate Change – Sea Level Rise. Prepared for the San Francisco Public Utilities Commission. July 06, 2006.
2. City and County of San Francisco, Department of Public Works, 1982 Subdivision Regulations. 1982.
3. Cheng, R. T., V. Casulli, and J. W. Gartner. "Tidal, Residual, Intertidal Mudflat (TRIM) Model and its Applications to San Francisco Bay, California." *Estuarine, Coastal and Shelf Science* **36**:235–280. 1993.
4. Executive order 2-13-08, Gov. Schwarzenegger, Nov. 2008.
<http://gov.ca.gov/index.php?/executive-order/11036/>. 2008.
5. Healey, Mike, Projections of Sea Level Rise for the Delta, Memorandum to Blue Ribbon Task Force, CALFED Independent Science Board, September 6, 2007.
http://www.deltavision.ca.gov/BlueRibbonTaskForce/April2008/Item2_Attachment1.pdf. 2007.
6. International Panel on Climate Change 2007, Climate Change 2007 Synthesis Report: Summary for Policymakers. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf. 2007.
7. Knowles, Noah, personal communication. 2010.
8. Knowles, Noah, Potential Inundation due to rising sea levels in the San Francisco Bay Region. CCCC. March, 2009.
9. NOAA, Tide Station Locations and Ranges. <http://co-ops.nos.noaa.gov/tides08/tab2wc1a.html>. 2009.
10. NOAA Technical Report NOS CO-OPS 035, October 2002.
11. Rahmstorf, Stefan, A Semi-Empirical Approach to Projecting Future Sea-Level Rise , Volume 315, No. 5810, pp. 368-370 Science Magazine. January 19, 2007.
12. US Army Corps of Engineers, San Francisco District, San Francisco Bay Tidal Stage vs. Frequency Study. October 1984.
13. U.S. Army Corps of Engineers, "Water Resource Policies and Authorities incorporating Sea-Level change considerations in Civil Works Program", Circular EC 1165-2-211. July 1, 2009 (expires July 1, 2011).

Appendices

1. San Francisco Presidio Tide Gauge
2. Other Tide Gauge Reference Locations
3. City Datum Relationship to NAVD 1988 and NGVD 1929
4. Design Tide Return Periods and Future Sea Level Rise
5. Fifty-Five Inches of Sea Level Rise
6. Planning Considerations to Address Sea Level Rise

Appendix 1. San Francisco Presidio Tide Gauge

The NOAA tide gauge in San Francisco near Golden Gate Bridge is the oldest continuous running tide gauge in the U.S. (NOAA, 2004). Installed in 1854, the location of the gauge has moved four times in its history, though always residing close to the Golden Gate Bridge (NOAA, 2002). The gauge was moved to its current location, the Fort Point Coast Guard wharf at Crissy Field in the **Presidio**, in 1927. This gauge has been recording tide levels in San Francisco for over 150 years. The Figure 1A below shows the current location of the tide gauge.

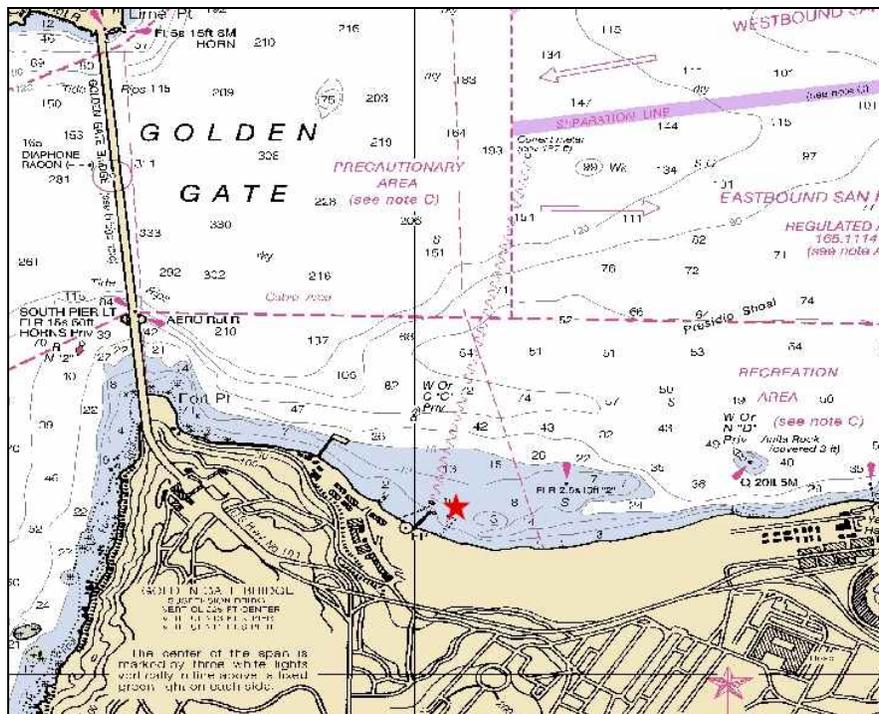


FIGURE 1A. LOCATION OF SAN FRANCISCO GAUGE¹

1. Figure from <http://tidesandcurrents.noaa.gov/images/photos/9414290.jpg>

Appendix 2. Other Tide Gauge Reference Locations

NOAA Tide level Corrections

See Table 1A below and the following link: <http://co-ops.nos.noaa.gov/tides08/tab2wc1a.html>

NO. 1 2008 NOAA TIDE PREDICTIONS: SAN FRANCISCO, NORTH POINT, PIER 41

(Reference station: San Francisco, Corrections Applied: Times: High +0 hr. 13 min., Low +0 hr. 11 min., Heights: High +0.2, Low +0.0)

NO. 2 2008 NOAA TIDE PREDICTIONS: RINCON POINT, PIER 22 1/2

(Reference station: San Francisco, Corrections Applied: Times: High +0 hr. 23 min., Low +0 hr. 25 min., Heights: High +0.4, Low +0.0)

NO. 3 2008 NOAA TIDE PREDICTIONS: POTRERO POINT

(Reference station: San Francisco, Corrections Applied: Times: High +0 hr. 33 min., Low +0 hr. 46 min., Heights: High +0.5, Low +0.0)

NO. 4 2008 NOAA TIDE PREDICATIONS; HUNTERS POINT

(Reference station: San Francisco, Corrections Applied: Times: High +0 hr. 25 min., Low +0 hr. 39 min., Heights: High +0.9, Low +0.0)

NO. 4 2008 NOAA TIDE PREDICTIONS: SOUTH SAN FRANCISCO

(Reference station: San Francisco, Corrections Applied: Times: High +0 hr. 38 min., Low +0 hr. 56 min., Heights: High +1.2, Low +0.0)

NO. 5 2008 NOAA TIDE PREDICTIONS: OCEAN BEACH, OUTER COAST

(Reference station: San Francisco, Corrections Applied: Times: High -0 hr. 49 min., Low -0 hr. 35 min., Heights: High +0.1, Low +0.0)

TABLE 1A. APPLIED TIDE CORRECTIONS FOR TIME AND HEIGHT				
Location	High Time	Low Time	High Height	Low Height
San Francisco, North Point, Pier 41	+0 hr. 13 min.	+0 hr. 11 min	+0.2	+0.0
Rincon Point, Pier 22 ½	+0 hr. 23 min	+0 hr. 25 min	+0.4	+0.0
Potrero Point	+0 hr. 33 min	+0 hr. 46 min.	+0.5	+0.0
Hunters Point	+0 hr. 25 min	+0 hr. 39 min.	+0.9	+0.0
South San Francisco	+0 hr. 38 min	+0 hr. 56 min.	+1.2	+0.0
Ocean Beach, outer coast	-0 hr. 49 min	-0 hr. 35 min.	+0.1	+0.0

Appendix 3. City Datum Relationship to NAVD 88 and NGVD 29

The North American Vertical Datum (NAVD) mean sea level adjustment of 1988 is a fixed datum from a simultaneous least squares and minimum constraint adjustment of Canadian/U.S./Mexican leveling observations.

The National Geodetic Vertical Datum (NGVD) of 1929 is a fixed datum derived from a general adjustment of the first-order leveling networks in the U.S. and Canada after holding mean sea level observed at 26 long-term tide stations as fixed in 1929. It is now superseded by the NAVD 88 datum.

NAVD88 is 2.72 feet below NVGD29 at the Presidio monitoring station as determined from the web site www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.pr1. It is assumed for the purposes of this design guide that the 2.72 foot relationship between NAVD 88 and NGVD29 is the same at all city locations (however, if another latitude and longitude coordinate is chosen other than at the Presidio the relationship between NAVD88 and NGVD 1929 may be different by a hundredth of a foot more or less.

Table 2A below shows the fixed relationship between the City Datum and the two vertical datum sea level adjustments. City Datum is 8.616 feet above NGVD 29 and 11.336 feet above NAVD 88. The table also shows the relationship between mean lower low water (MLLW), which is defined as zero for projecting tides over a specific time period. The relationship below is for the period of 1983 to 2001 at the Presidio Gauge.

TABLE 2A. CITY DATUM RELATIONSHIP RELATIVE TO NAVD, NGVD, AND SEA LEVELS		
Datum	Relative To:	
	Mean Lower Low Water (feet)	City Datum (feet)
City Datum	11.26	0.00
Highest Observed Water Level (01/27/1983)	8.87	-2.39
Mean Higher High Water (MHHW)	5.84	-5.42
Mean High Water (MHW)	5.23	-6.03
Mean Tide Level (MTL)	3.18	-8.08
Mean Sea Level (MSL)	3.12	-8.14
National Geodetic Vertical Datum of 1929	2.64	-8.62
Mean Low Water (MLW)	1.14	-10.12
Mean Lower Low Water (MLLW)	0.00	-11.26
North American Vertical Datum of 1988	-0.08	-11.34
Lowest Observed Water level (12/17/1933)	-2.88	-14.14

Appendix 4. Design Tide Return Periods and Projected Future Sea Level Rise

The Table 3A below shows high tide levels observed in 2007 as well as future levels of different return periods adjusted for projected sea level rise due to global climate change.

TABLE 3A. DESIGN TIDE RETURN PERIODS FOR HISTORICAL AND PROJECTED FUTURE TIDE LEVELS¹				
(Relative to City Datum - feet)				
Return Period	2007	2040	2060	2100
Increase (Meter)	0.00	0.33	0.60	1.38
Increase (foot)	0.00	1.08	1.97	4.5
2 Year	-4.13	-3.05	-2.16	0.37
5 Year	-3.81	-2.73	-1.84	0.69
10 Year	-3.60	-2.52	-1.63	0.9
25 Year	-3.33	-2.25	-1.36	1.17
50 Year	-3.14	-2.06	-1.17	1.36
100 Year	-2.91	-1.86	-0.96	1.68

1. *Current return period levels for San Francisco Presidio Station (source: Increase and 100 year tide, Knowles, Noah 2010; 2,5,10,25 and 50 year tide, 2030 SSMP November 2009)*

Appendix 5. Fifty-Five Inches of Sea Level Rise

The Intergovernmental Panel on Climate Change's (IPCC) third assessment report (TAR) was prepared in 2001 by an international team of scientists to assess the current state of the science on climate change. This report developed six future scenarios of world population and economy that predicts different levels of greenhouse gas emissions. The emissions scenarios are from a Special Report on Emissions Scenarios (SRES.) There is the A1 story line which has three groups, A1F1, A1T, and A1B. There is the A2, B1 and B2 story lines. The most growth and fossil intensive is the A1F1.

Stefan Rahmstorf developed a semi-empirical relation that connects global sea-level rise to global mean surface temperature, based on the scenarios from the IPCC TAR. Stefan Rahmstorf proposed that, for time scales relevant to anthropogenic warming, the rate of sea-level rise is roughly proportional to the magnitude of warming above the temperatures of the pre-Industrial Age. This holds to good approximation for temperature and sea-level changes during the 20th century, with a proportionality constant of 3.4 millimeters/year per °C. When applied to future warming scenarios of the Intergovernmental Panel on Climate Change, this relationship results in a projected sea-level rise in 2100 of 0.5 to 1.4 meters above the 1990 level.

Figure 2A shows the projection of eustatic sea level rise by 2100. This projection was initially proposed by Rahmstorf (2007) in which the rise in global air temperatures is correlated to sea level rise. The figure presents sea level at different years (2010, 2020, 2030, 2040, 2050, 2060, and 2080) and contains the projected global mean temperatures under the IPCC A2 greenhouse gas emissions scenario (medium-high emissions) (from Knowles, 2009 with intermediate heights added).

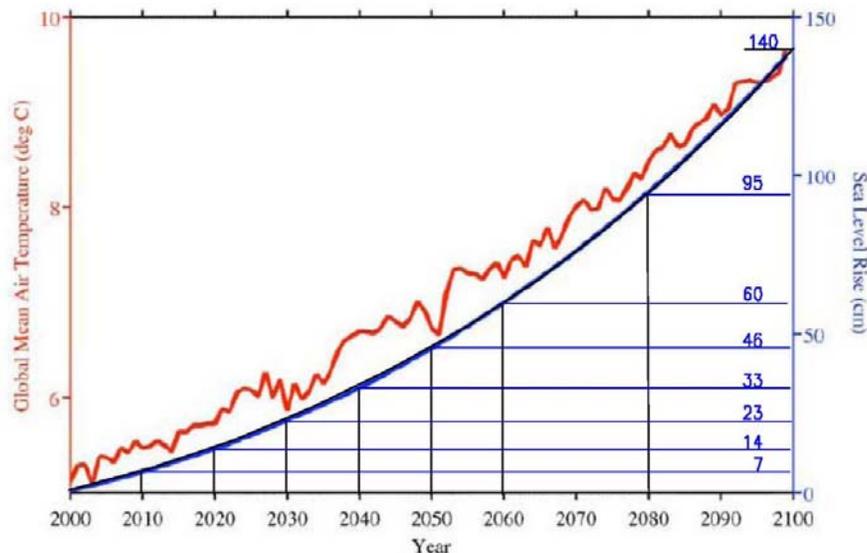


FIGURE 2A. ANNUAL GLOBAL MEAN SURFACE AIR TEMPERATURE AND EUSTATIC SEA LEVEL PROJECTIONS

(Knowles, 2009)

Appendix 6. San Francisco Bay Historical High Water Levels and Projected Sea Level Rise

Figure 3A shows the 100 year tide at the Presidio Tide Gauge as projected by Noah Knowles using the TRIM 2 D model and the 1 year tide as projected from existing data. All projections assume 55 inches of sea level rise by 2100 (see below.)

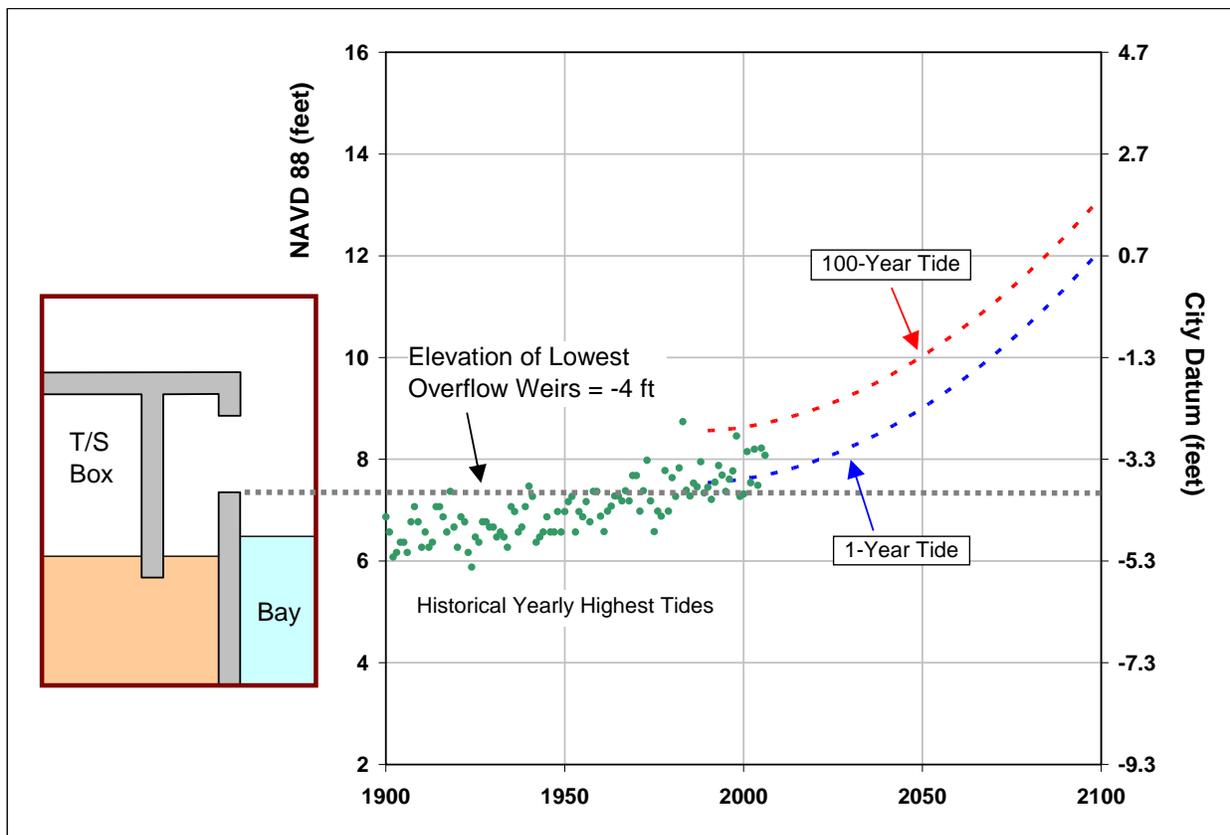


FIGURE 3A. 1-YEAR and 100 YEAR TIDE AT THE PRESIDIO TIDE GAUGE WITH 55 INCHES OF ESTIMATED SEA LEVEL RISE (created by the TRIM-2D model¹ for the 100 year tide)

1. (Knowles¹ personal communication/Knowles, Noah, 2009 Potential Inundation due to rising sea levels in the San Francisco Bay Region. CCCC. March, 2009.)

Figure 4A shows the projected monthly MHHW levels (relative to NAVD 88 and the City Datum) and the elevation at which the lowest overflow weirs exists (-4 feet below City Datum).

The projected sea level rise is based on the work by Rahmstorf, described in section 5 above and adopted in Healy, September 2007, by the CALFED Bay-Delta Program: The CALFED Bay Delta Program, which is responsible for planning future improvements to the California Delta,

asked its Independent Science Board (ISB) to review scientific literature on the current understanding of sea level rise and to make a recommendation for project planning. The letter to the CALFED lead scientist by the ISB (CALFED, 2007) outlined the concerns about using previous sea level rise estimates by the IPCC due to the limits on the IPCC consensus based approach.

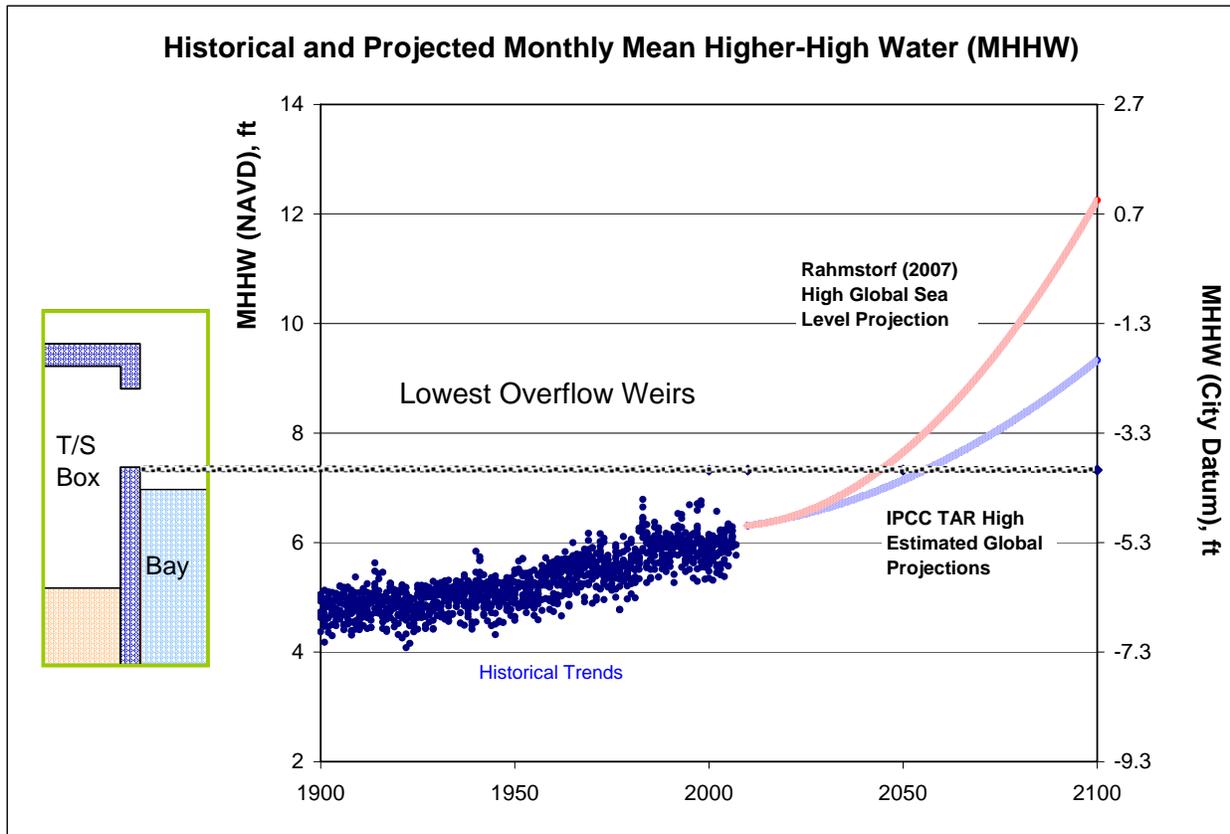


Figure 4A. Estimated Mean Higher High Water Levels Based on Projections estimated by Rahmstorf, Stefan and adopted by the CALFED ISB 2007 (see Ref. 4 and 6)

This projection is for eustatic sea level rise and does not include local effects (called isostatic or relative sea level rise), such as the El Niño Southern Oscillation (ENSO.) Eustatic sea level rise is simply a measure of the increase in the volume of water in the oceans, expressed as a change in the height of the oceans. The ENSO occurs routinely and brings warmer water from the South Pacific Ocean north to the San Francisco Bay, which increases the tide elevation and storm surge.

Noah Knowles prepared the following projections for the bayside combined sewer discharge locations from the Trim 2D model for the 100 year return sea level rise based on the 55 inches of projected sea level rise by 2100 from the base year of 1990 (Knowles, personal communication 2010).

<u>CSD Location</u>	<u>1990</u>	<u>2000</u>	<u>2020</u>	<u>2040</u>	<u>2060</u>	<u>2080</u>	<u>2100</u>
Presidio	256.9	259.0	269.6	288.7	316.2	352.2	396.6
Baker Street	260.4	262.6	273.2	292.3	319.9	355.9	400.3

Pierce Street	261.0	263.1	273.8	292.9	320.5	356.5	400.9
Laguna Street	262.0	264.1	274.8	293.9	321.5	357.5	401.9
Beach Street	265.7	267.9	278.5	297.6	325.2	361.2	405.7
Sansome Street	267.3	269.5	280.1	299.3	326.9	362.9	407.4
Jackson Street	269.0	271.1	281.8	301.0	328.6	364.6	409.2
Howard Street	269.9	272.0	282.7	301.9	329.5	365.6	410.1
Brannan Street	272.1	274.3	285.0	304.2	331.8	367.9	412.4
Third Street	272.1	274.3	285.0	304.2	331.8	367.9	412.4
Fourth Street North	272.1	274.3	285.0	304.2	331.8	367.9	412.4
First Street North	272.1	274.3	285.0	304.2	331.8	367.9	412.4
Sixth Street North	274.2	276.4	287.1	306.3	333.9	370.0	414.5
Division Street	274.2	276.4	287.1	306.3	333.9	370.0	414.5
Sixth Street South	274.2	276.4	287.1	306.3	333.9	370.0	414.5
Fourth Street South	272.1	274.3	285.0	304.2	331.8	367.9	412.4
Mariposa Street	274.2	276.4	287.1	306.3	333.9	370.0	414.5
20th Street	274.7	276.9	287.6	306.8	334.4	370.5	415.0
22nd Street	275.4	277.6	288.3	307.5	335.1	371.2	415.7
Third Street North	275.4	277.6	288.3	307.5	335.1	371.2	415.7
Isalis Creek North	275.4	277.6	288.3	307.5	335.1	371.2	415.7
Marin Street	275.4	277.6	288.3	307.5	335.1	371.2	415.7
Selby Street	275.4	277.6	288.3	307.5	335.1	371.2	415.7
Third Street South	276.9	279.1	289.8	309.0	336.6	372.7	417.2
Evans Avenue	278.6	280.8	291.6	310.7	338.4	374.4	419.0
Hudson Avenue	278.6	280.8	291.6	310.7	338.4	374.4	419.0
Griffith Street South	282.9	285.1	295.9	315.1	342.7	378.8	423.3
Yosemite Avenue	288.1	289.1	297.7	315.4	342.0	377.6	422.2
Fitch Street	288.1	289.1	297.7	315.4	342.0	377.6	422.2

TRIM-2D Model

To assess what land elevations around the Bay are vulnerable to periodic inundation, estimates of high water levels throughout the Bay must be generated. These high water excursions are the result of tides, storm surge, and other dynamic processes, requiring the use of a hydrodynamic model for this task. This model will be used to produce a single 100-year projection of hourly water levels throughout the Bay for use in the subsequent analysis. TRIM-2D (Cheng et al. 1993) is a numerical model that uses a semi-implicit finite-difference method for solving the two dimensional shallow-water equations in San Francisco Bay. The model uses a 200 m horizontal grid with nearly 50,000 grid cells and is configured here with a six-minute time step. It is driven solely by water level time series at its seaward and landward boundaries, which are translated in phase and amplitude from the tide gauges with sufficiently long records nearest these boundaries. Cheng et al. (1993) demonstrated that the TRIM-2D hydrodynamic model accurately reproduces the historical amplitudes and phases of tidal constituents throughout the Bay.

The TRIM-2D model was chosen because it is capable of performing the century-long simulation needed to address the effects of long-term climate change in a reasonable amount of time. While the ideal model for this study would have a boundary condition much farther upstream than Port Chicago to avoid boundary issues and would directly simulate the hydrodynamics of inundated areas, such a model is not yet publicly available. Those proprietary models which do include these features are currently too computationally demanding to perform the needed runs

in a reasonable amount of time.

Appendix 7. Planning Considerations to Address Sea Level Rise

The CALFED ISB report states that sea level rise due to global climate change is well accepted, and the question is not “how much” but “when.” Design capacities for some projects such as new effluent discharge pipes, pump stations, and outfalls or storm water drainage projects near the bay will be affected by rising sea levels. Over time their usefulness will degrade, as they have to work against higher downstream levels. In order to maintain the value of the initial capital investment, allowances for sea level rise must be made in the initial design criteria.

Due to the large range of future projected tide levels and the wide range of uncertainty among the various models used to predict future sea levels, some engineering judgment may be required when projecting future tide levels for infrastructure project planning. In 2007, the CALFED ISB recommended a conservative approach to project planning, using the 2007 IPCC range of projection estimates as minimum for short- and mid-term planning. In the long-term, the CALFED ISB recommends using the results of the models with the latest science (i.e., increased rate of land ice melt) for infrastructure planning and design purposes. This recommendation was to favor design options that can be easily adapted to projected future sea level rise over designs that have a fixed design target.

ENGINEERING CONSIDERATIONS: The design life of the project must be determined and the projected sea level rise at the end of the useful life of the project plus some additional “free board”, which gives a buffer of elevation above the projected tide should be included. All development and adaptations in low lying areas need to take a conservative approach in determining how these areas can be protected and raised, if possible, above the rising tide.

Retreat from the shoreline is another strategy that may be considered over time to protect the people in low lying areas.

The high tides last for a short time. The engineer must look at the frequency, e.g. the 100 year tide, a one year tide, or mean higher high water, when determining what effect the tide will have on infrastructure. Figure 5A illustrates the backflow of bay water over the combined sewer system weir into the combined sewer system. The high tides influence on upstream collection system hydraulic grade lines must be determined and remediated as the tide increases to prevent localized sewer surcharges.

There are also other agencies that will have policies concerning addressing sea level rise, and what response the City may take with regard to infrastructure changes. These agencies include the Bay Conservation and Development Commission, the Corps of Engineers, the State of California through various agencies, and the Federal Government and its agencies most notably the National Park Service on the Westside.

ADAPTATION STRATEGIES: Adaptation to future sea level rise requires implementation of adaptive management practices - the ability to use new information regarding the extent and rate of sea level rise as it becomes available and more accurate. An adaptive management approach to future sea level rise is identifying adaptation measures early in the project planning process that will not only provide flexibility for the future, but will also satisfy the overall project goals.

For project planning, consideration of design criteria can include allowances for sea level during an asset's useful life including future costs to accommodate sea level rise in the asset life cycle costs. Projects should include accommodations such as increased capacities, additional room for future infrastructure, pre-designed connection points, etc., that will allow the infrastructure to adapt. This does not require that all systems be made to meet future design tide levels, only that systems should be designed to adapt to higher tide levels in the future.

For new development along the shoreline, an adaptive management approach would include plans for additional drainage facilities such as additional pumping, additional capacity to account for changing tail water conditions, and leaving space for possible future levees. Plans for residential or commercial development should be able to withstand a minimum of 50 years of potential sea level rise without modifications and require only moderate modifications for 50 to 100 years planning horizon. Planning should also include flexibility for adapting to even higher sea level rise 100 to 200 years planning horizon.

At the time of developing design criteria for major projects, planning must include review of the latest accepted projections of sea level rise projections every 2 years. Various active Federal, Regional, and State agencies in the SF bay area and central California have been evaluating and adapting current knowledge and understanding of the impacts of climate change to the local region and should be consulted for the latest impacts on a regular basis.



FIGURE 5A. BACKFLOW OF BAY WATER INTO A COMBINED SEWER DISCHARGE STRUCTURE