New Understanding: The Baylands and Climate Change
Appendix D: Future Scenarios Evaluated

OVERVIEW

Five future scenarios were produced for evaluation in the BEHGU project. Scenarios 1-4 were related to projections for change in the Baylands under different sediment and sea level rise conditions, including consideration of other climate change drivers based on CASCADE projections. Scenario 5 is a storm event also from CASCADE projections.

BEHGU Scenarios 1-4 address a range in variability for all climate change drivers, as well as sediment supply, over long time periods. The CASCADE scenarios provide a range in variability of temperature, precipitation, etc. that were to be considered in conjunction with the SLR+sediment supply marsh projections of Scenarios 1-4. For example, in Scenario 1 the idea was to consider that particular marsh projection + the projected range in variation of temperature, precipitation, etc., bookended by the two CASCADE scenarios.

Scenario Name	Description
Scenario 1 (Low, Low)	Low sea level rise (52 cm by 2110) and low sediment supply projection for marsh evolution, along with the projected range in variation of temperature, precipitation, etc., bookended by the two CASCADE scenarios.
Scenario 2 (Low, High)	Low sea level rise (165 cm by 2110) and high sediment supply projection for marsh evolution, along with the projected range in variation of temperature, precipitation, etc., bookended by the two CASCADE scenarios.
Scenario 3 (High, Low)	High sea level rise (52 cm by 2110) and low sediment supply projection for marsh evolution, along with the projected range in variation of temperature, precipitation, etc., bookended by the two CASCADE scenarios.
Scenario 4 (High, High)	High sea level rise (165 cm by 2110) and high sediment supply projection for marsh evolution, along with the projected range in variation of temperature, precipitation, etc., bookended by the two CASCADE scenarios.
Scenario 5	Winter storm event drawn from a model run of the CASCADE Ga scenario.

A summary of the projected change in temperature, precipitation, etc., bookended by the two CASCADE scenarios and for use in Scenarios 1-4 is as follows (with more details below).

- Warmer air
- Saltier water

- Possibly a decline in precipitation (little chance of an increase) and runoff, and a very likely decline in snowmelt contribution to runoff
- Earlier runoff, as precipitation is not stored in snowpack for as long
- Possibly lower suspended sediment concentrations (very unlikely to increase)
- Increasing frequency of extreme environmental conditions such as higher water temperatures, higher storm surges (due to sea level rise), higher flood peaks, and possibly droughts

BEHGU science contributors were instructed to take the following approach to using these scenarios:

i. Read the synopsis below of the scenarios and, as necessary, the associated publications.

ii. Consider how the changes projected in these scenarios would impact the subject under consideration in a particular writing assignment. Key tools to use in this process for are the GIS maps, metadata, and acreage summaries created for BEHGU that detail past, present, and future projected habitat extents.
   - Interactive web map: http://gis.sfei.org/behgu
   - How-to document for web map navigation (BEHGU_WebMap_UserGuide.pdf) and other supporting materials are available in the BEHGU Scenarios folder in Google Docs. If you have access issues or questions, please contact both Letitia (Letitia@letitia.org) AND Trisha (hickfrdl@sbcglobal.net) so we can reply as promptly and as fully as possible.

   The future habitat maps contain maps of marsh extent based on a marsh accretion model (Stralberg et al. 2011) and model inputs for SLR curves and time periods that correspond to the chosen scenarios. Where model results were not available that exactly match the scenarios, a similar output was used. For example, GIS summaries are provided for 2110, because results for 2100 were not available. As this GIS/modeling analysis does not include event-based impacts of climate change, it is important to also understand and consider the CASCaDE analysis findings detailed in Cloern et al. (2011).

iii. Incorporate in written contributions to the BEHGU report how trends and extreme events in these scenarios might affect the topic under consideration.

iv. The impact of management actions can be assessed at the segment or local scale, rather than region-wide. For example, in a segment we may explore what could be achieved if levees were realigned. The future marsh extent GIS summaries detail habitat acreages in areas behind levees for this purpose.

Note to Contributors Considering Wildlife Impacts

It may be helpful to focus only on the scenarios where harmful impacts to species or communities are expected. This can narrow down the number of scenarios to be discussed and is in keeping with the general approach of the Wildlife Risk chapter.

In addition to using the scenarios, the science contributors are invited to identify known thresholds related to future change. For example, questions like the following could be addressed and answered:

- What extremes can habitats tolerate before losing essential functions?
- How much wave energy does it take to erode marsh and mudflats significantly?

- How long can marsh plants be submerged before dying?
- How many storms during the breeding season and winter can resident birds tolerate before their populations decline severely?
- Are there thresholds for drought and earthquake effects?

INTRODUCTION

The science contributors to the BEHGU report referenced particular future scenarios in the Science Foundation Chapters. These scenarios were built around climate change models, emissions scenarios, and sediment supply. We recognize that other drivers of change are also occurring around the Bay, such as human population growth, accommodation space and invasion by exotic species. The effects of other such drivers are considered by the workgroups where appropriate, but are not a part of the scenario descriptions. Similarly, levee failures and purposeful land-use change are not included in the regional scenarios but were addressed where appropriate.

The BEHGU climate change scenarios include trends, variability around those trends and extreme events, like storms and droughts. Science contributors were asked to consider how sequencing of events could impact the subjects they are writing about, even though event sequences are difficult to predict.

SCENARIOS 1-4

The scenarios were based on 1) the newest estimates for sea level rise (SLR) for the California coast from the National Research Council (NRC 2012) and 2) two CASCaDE scenarios that were selected to roughly bookend a range of possible future climate outcomes (i.e., those with the most difference in the modeled results) and that are downscaled for our region and modeled for estuarine ecosystem outcomes (Cloern et al. 2011). These key publications are available in Google Docs in the Draft 2 folder as well as on the Sharepoint site at baylandsgoals.org. The NRC report addresses deterministic SLR and does not include stochastic events. The CASCaDE results include events, so BEHGU science contributors will likely find that they need to read Cloern et al. (2011) to gain an understanding of the magnitude, frequency, and duration of such events. Text has been highlighted in the article to facilitate reading in this context.

These studies were chosen to define the BEHGU scenarios because they represent the latest climate change science for our region that has been synthesized into peer-reviewed publications. The CASCaDE results are a uniquely "integrated quantitative assessment of how global signals of climate change would cascade to modify runoff, river discharge, water temperature, sea level, salinity intrusion and suspended sediments in a large watershed-river-estuary-ocean system" (Cloern et al. 2011, p. 11).

Scenario Elements

- *Sea level rise projections* for three time periods: 2030, 2050, and 2100, considering the full range in uncertainty for each time period. For San Francisco Bay, the committee projects that sea level will rise 4–30 cm by 2030 relative to 2000, 12–61 cm by 2050, and 42– 166 cm by 2100."(Table 5.3, p.117, NRC 2012). The modeled GIS results address 52 and 165m cm SLR by 2100, spanning the range of the NRC report projections. Of course, superimposed upon the rise of mean sea level would be shorter-period variations associated with tides, weather (including storm fluctuations and wind waves), and natural climate patterns such as the El Nino/Southern Oscillation.

- High and low *suspended sediment concentration scenarios*. These vary both by location and in also in time. First, in the marsh accretion GIS results, suspended sediment concentrations vary around the shoreline of the Bay from 25-150 mg/L in the low sediment supply scenario to 50-300 mg/L in the high sediment supply scenario. Sediment supply is constant over time in the marsh accretion model. The derivation of these numbers is described in Stralberg et al. (2011). Second, the CASCaDE analysis considered both a constant sediment supply and one that continues to decline over time.

- CASCaDE scenarios and downscaled *projections for temperature, precipitation, snowmelt, runoff, and salinity*. Short names for these two scenarios are provided here, with more information below in Cloern et al. (2011) and Dettinger et al. (poster).

  "Ga: Much warmer and drier (GFDL model - accelerating A2 emissions)"

  "Pb: Not so much warmer with no precipitation change (PCM model - B1 emissions)"

  from Dettinger et al. poster

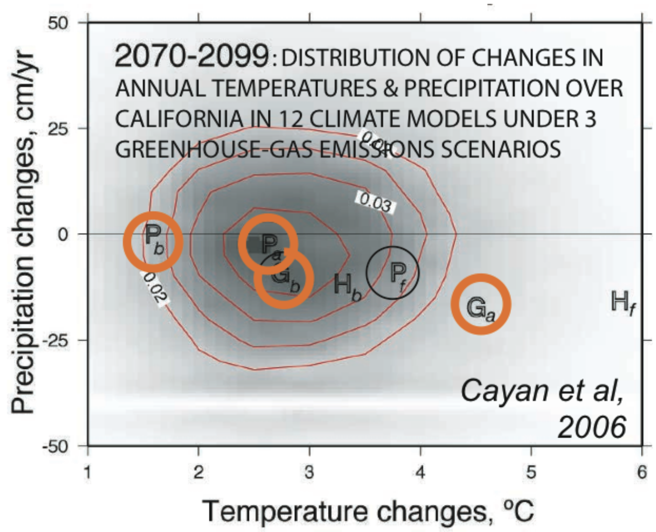
The CASCADE scenarios provide a range in variability of temperature, precipitation, etc. that should be considered in conjunction with the SLR+sediment supply marsh projections of Scenarios 1-4. For example, in Scenario 1 the idea is to consider that particular marsh projection + the projected range in variation of temperature, precipitation, etc., bookended by the two CASCADE scenarios.

CASCaDE Projections

An introduction to the CASCaDE scenarios and how they were downscaled is provided in a poster by Dettinger et al. (attached; excerpt below). BEHGU is focusing on the Pb and Ga "bookend" scenarios.

Choice of global climate-change scenarios

In order to more-or-less span the range of current projections of 21st Century climate change for central California, four scenarios were selected for analysis by the CASCaDE project. These scenarios also have been analyzed in the State's 2006 and 2008 California Scenario Assessments, and might loosely be described according to:



Gb: Medium warmer and drier (GFDL climate model - moderate B1 emissions)

Ga: Much warmer and drier (GFDL model - accelterating A2 emissions)

Pb: Not so much warmer with no ppt change (PCM model - B1 emissions)

Pa: Medium warmer with no ppt change (PCM model - A2 emissions)

Some key results from the CASCaDE analysis are summarized below. It is necessary to read Cloern et al. (2011) to understand the findings in detail. Some of the indicators the CASCaDE effort addressed focused on the Delta, but many of these indicators apply to the Bay as well.

The CASCaDE scenarios address sea level as a long-term trend combined with short-term events. For long-term sea level rise, BEHGU will focus on the NRC (2012) sea level rise projections. For shorter-term variability in sea level (e.g., storm events), the CASCaDE results should be used.

Overall, the CASCaDE downscaled analyses of the two scenarios indicate that the climate of the study area will have:

- Warmer air
- Saltier water
- Possibly a decline in precipitation (little chance of an increase) and runoff, and a very likely decline in snowmelt contribution to runoff
- Earlier runoff, as precipitation is not stored in snowpack for as long
- Possibly lower suspended sediment concentrations (very unlikely to increase)

- Increasing frequency of extreme environmental conditions such as higher water temperatures, higher storm surges (due to sea level rise), higher flood peaks, and possibly droughts

Indicator (Spatial Domain)	Pb (PCM-B1)	Ga (GDFL-A2)
Air Temperature (Sacramento San-Joaquin Delta)	Steady increase, slower rate of change, maximum annual temperature reaches 18.6C	Steady increase, faster rate of change, maximum annual temperature reaches 21C
Precipitation (Sacramento San-Joaquin Delta and its watershed)	Annual precipitation declines steadily, is persistently below the modeled 1970–99 baseline by the latter part of the century	No apparent secular trend, but this projection has large interannual variability that includes years of extreme high precipitation and a simulated multi-year drought in the 2070 decade
Unimpaired Runoff (Sierra Nevada)	Runoff exhibits the same large interannual variability of precipitation, including an extremely wet year in 2023 and two very wet years and large droughts between 2065 and 2085	Runoff is 11–12% below the baseline during the first two–thirds of the century. Then, coincident with the simulated end-of-century drought, runoff drops another 16% and persists at this low level for nearly 15 years.
Snowmelt Contribution (Sierra Nevada)	Snowmelt contribution shows no obvious trend in the B1 scenario until the last two decades when runoff is consistently below the historical mean, continuing shifts toward earlier runoff as a declining fraction of annual runoff occurs during the snowmelt season.	Snowmelt contribution to annual runoff declines, continuing shifts toward earlier runoff as a declining fraction of annual runoff occurs during the snowmelt season
Salinity (San Pablo and Suisun Bays)	Increases 2.2 psu above the 1979–1999 baseline during the last third of the century	Increases 4.5 psu above the 1979–1999 baseline during the last third of the century
Suspended Sediment Concentration (Rio Vista)	Declines slightly with a constant sediment supply, and rapidly with a declining sediment supply	Declines slightly with a constant sediment supply, and rapidly with a declining sediment supply

SCENARIOS 5

Plausibility of the Storm Event

This event is from a CASCADE run, and it is therefore a projected event given current knowledge. It resembles the flood of 1986, being two or three back-to-back atmospheric events. The 1986 flood was the biggest inflow in to the Bay since the 1950's, and it provides a historical precedent. While the future storm scenario is a large storm with heavy precipitation coinciding with a high tide, it is representative of water levels that become more frequent over time (Fig. D1).

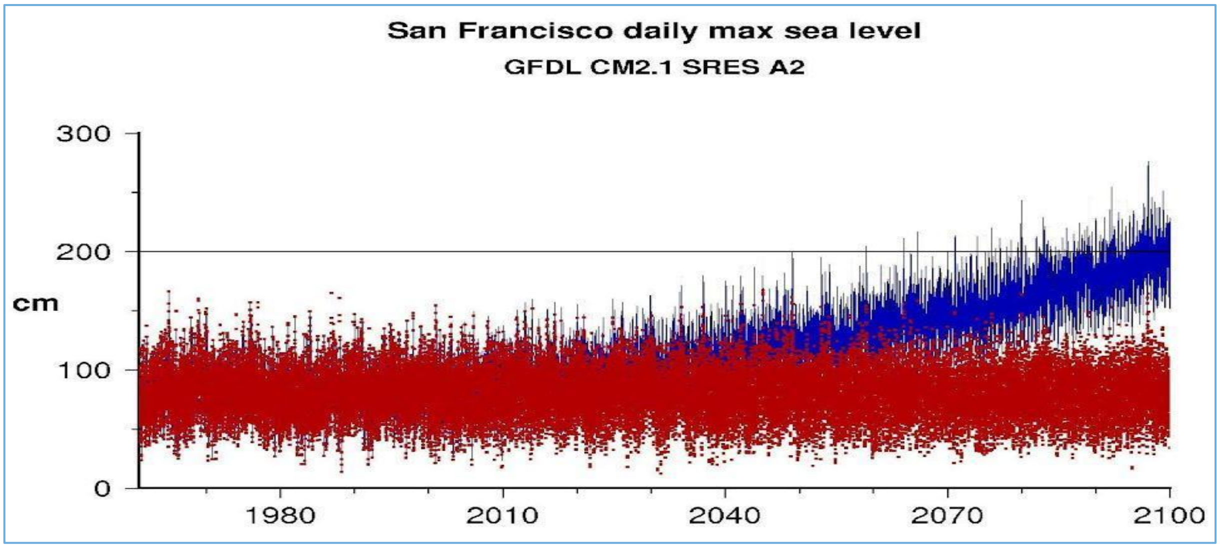


Figure D1. Maximum daily sea level from the CASCADE run with SLR included (blue) and excluded (red).

Basic Scenario Facts

- ***GCM + Emissions Scenario:*** Ga Scenario: GDFL A2 – the "much warmer and drier" of the two CASCADE scenarios considered for BEHGU (see previous scenario descriptions for more information)
- ***Year***: 2045
- ***Time of Year***: Late January
- ***Duration***: 2 weeks, based on rainfall (Fig. 2)
- ***Water level:***
    - Included
        - Anomalous sea level (local storm effects and remote effects from ENSO; Fig. 3)
        - NRC West Coast study (2012) sea level trend (sea level rise curve)[1]
            - The secular change from sea level rise is about 24cm at 2045
        - Astronomical tides + ENSO (El Niño year)
    - Not included
        - Local watershed runoff
            - Could be significant in particular areas; **workgroups will need to infer this for different localities**

[1] The maximum sea level projections are relative to mean sea level over the 1983-2001 epoch, which is what the tide prediction applied to. The NRC sea level trend line, by definition, intersects zero in year 2000. If this trend were shifted so that it hit zero in the middle of the tide epoch in about 1992, it would result in a difference of approximately +4cm from the value plotted in the figures here for 2045. As plotted, the secular change from sea level rise is about 24cm at 2045. All of the other terms (weather, ENSO, tide) would be the same as plotted. Therefore, to make up for the sea level rise that occurred between 1992 and 2000, one should add 4cm (1.6 inches) to the maximum sea level projection.

- Wind waves
  - Varies around the margin of the Bay (see more information below); **workgroups will need to infer this for different localities**
- Rain on bay (negligible)

- ***Spatial Fineness***
  - Regional – tide level is from Golden Gate (Fort Point)

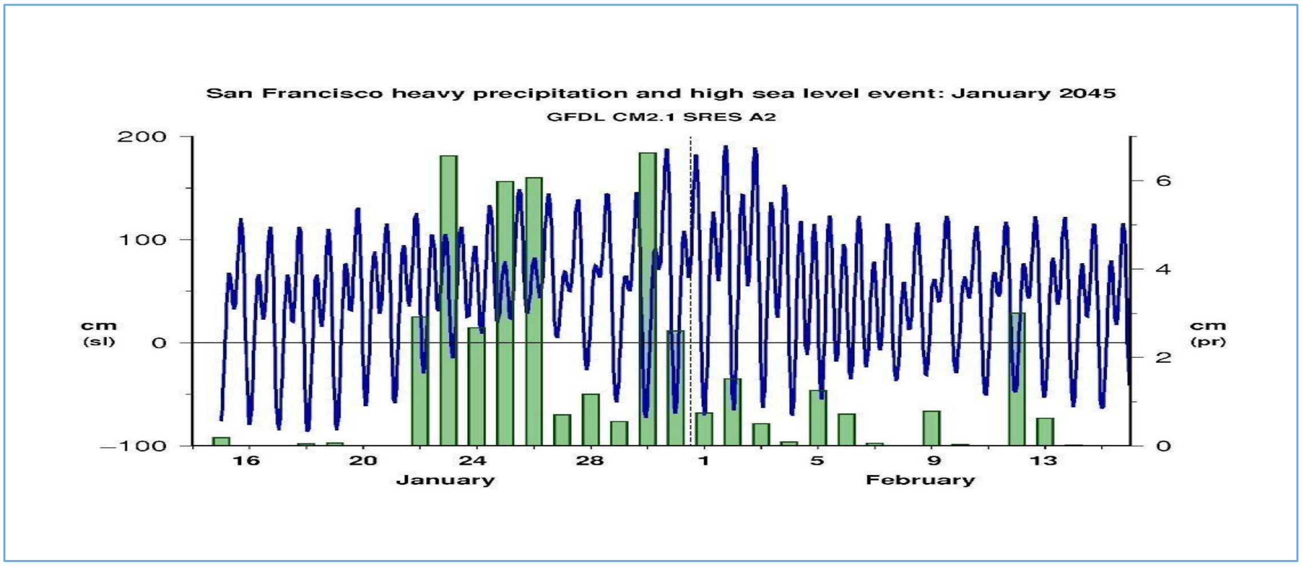


Figure D2. Daily maximum tide (blue) and precipitation (green) for the storm event.

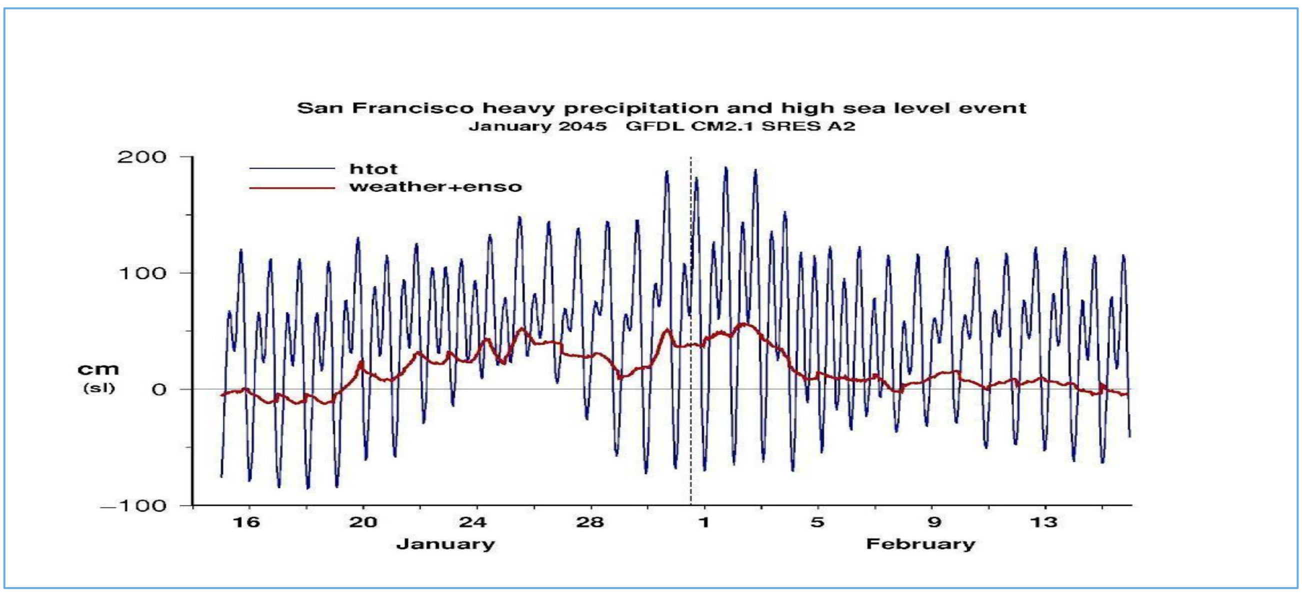


Figure D3. Daily maximum tide (blue) and storm surge or anomalous sea level (red) for the storm event.

Scenario Description

This scenario is for a large storm 32 years from now in the winter, during a king tide and an El Niño. The storm surge lasts for about 2.5 weeks (Fig. 3), and most of the rain falls during a 2-week period (Fig. 2). Water levels are about 20-50 cm higher than they would have been without the storm (storm surge contribution). Sea level has increased by around 24cm relative to 2000. So, maximum tide levels are around 75cm (2.5 ft) higher relative to a non-storm event winter king tide in 2000.

The scenario is regional. Precipitation comes from a grid point centered over Sacramento, and Delta outflows are included (but see important caveats below). Water levels are from the Golden Gate. Projections to a greater degree of spatial fineness are not currently available.

Workgroups will need to estimate local tidal differences from the Golden Gate, flooding from local watershed runoff, and waves. Workgroups should evaluate how runoff from the local watersheds (which is not included in the projected water levels) and any subsequent flooding would affect the areas they are considering. Waves can affect Bay flooding levels in 3 ways: 1) large waves breaking on the San Francisco Bar outside the Golden Gate can increase water levels up to 50 cm, mostly in Central Bay, due to wave set-up, 2) open ocean swell penetrating into Central Bay can local drive up water levels, due to wave set-up and run-up, primarily on the north- and west-facing shorelines, such as Crissy Field and Berkeley, and 3) during storms, strong in-Bay winds can generate local wind waves of up to 2 m or more, having the greatest impact on the stretches of shoreline exposed to the largest fetches and/or with fewer dissipative mud flats present adjacent to the shoreline.

Delta Outflow

Although CASCaDE outputs do a reasonable job of representing long-term trends and relative year-to-year variability of Delta outflows, the response to peak events such as the Jan 2045 storms is overly muted. Therefore, consider the following observations of Delta outflow corresponding to a historical analog of the 2045 event -- the storms of Feb 11-20, 1986.[2] Like the 2045 event, 1986 consisted of back-to-back atmospheric river events.

Although some reservoir operations have changed since the storm event of February 1986, and more mitigating infrastructure and operational changes will likely occur in the next several decades, the even higher precipitation levels of the 2045 storm scenario event suggest that Delta outflow levels of February 1986 may be at least equaled if such an event were to take place. Therefore we use the Delta outflows of Feb 11-28, 1986 to represent the outflow response to the 2045 storm scenario, corresponding specifically to Delta outflows for Jan 22 – Feb 8, 2045.

Over the course of the Feb 1986 event, flows ramped up from ~800 m^3/s on Feb 12 (2nd day of storms) to the peak and then took another week after the storms passed to subside to more typical winter flows. This event produced the peak daily flow rate for the period WY1956-present (http://www.water.ca.gov/dayflow), with a rate on Feb 20, 1986 of 17,815 m^3/s.

Table D4. Delta outflows from DAYFLOW data.

[2] For description of 1986 storms and impacts, see http://www.cnrfc.noaa.gov/storm_summaries/feb1986storms.php.

Date	Delta Outflow (m^3/s)
11-Feb-86	878
12-Feb-86	779
13-Feb-86	1,011
14-Feb-86	1,626
15-Feb-86	2,971
16-Feb-86	4,850
17-Feb-86	9,778
18-Feb-86	14,849
19-Feb-86	15,842
20-Feb-86	17,815
21-Feb-86	16,145
22-Feb-86	12,762
23-Feb-86	10,486
24-Feb-86	8,869
25-Feb-86	7,843
26-Feb-86	7,030
27-Feb-86	6,301
28-Feb-86	5,950

These high flows produced substantial impacts on Bay salinity, pushing X2 out to around Carquinez Strait and depressing salinities at the Golden Gate substantially.[3] Even South Bay was strongly affected: "[Feb 1986 peak flows] rapidly diluted South Bay salinity to [as low as] 8.6 psu (equivalent to only 26% seawater)." [4]

Storm surge can force non-tide fluctuations as high as 70 cm at the Golden Gate, although during extreme events these levels are often exceeded in Suisun Bay due to both surge propagation into the constricted sub-embayment and the commonly coincident timing of high Delta discharge rates due to heavy rainfall (Bromirski and Flick, 2008).

Maps

[3] http://journals.ametsoc.org/doi/full/10.1175/1520-0485%282002%29032%3C3003%3ASAFIVO%3E2.0.CO%3B2, Figs. 1 & 3 and text.

[4] http://sfbay.wr.usgs.gov/access/wqdata/overview/examp/charts/salin.html, see also http://sfbay.wr.usgs.gov/cgi-bin/sfbay/dispsys/display9?cruiz=86058&onescal=off&zoom=none&cstsd=sal&out=Show+Datatable.

Maps of the extent of flooding were not available for this scenario. However, the following sources were listed to give a sense of the spatial extent of flooding.

- Adapting to Rising Tides project, BCDC
  http://www.adaptingtorisingtides.org/wp-content/uploads/2012/09/Ch-2-MapAnalysis.pdf

- NOAA Coastal Services Center SLR viewer
  http://csc.noaa.gov/slr/beta/viewer/http://csc.noaa.gov/slr/beta/viewer/

- Cal-Adapt
  http://cal-adapt.org/sealevel/

Acknowledgements

Special thanks to the following scientists for providing ideas, data, and/or expert review of this document: Patrick Barnard, Dan Cayan, Wendy Goodfriend, Noah Knowles, Jeremy Lowe, Lindy Lowe, Mary Tyree, and Sam Veloz.

Literature Cited

Bromirski, P.D., Flick, R.E., 2008. Storm surge in the San Francisco Bay/Delta and nearby coastal locations. Shore and Beach 76 (3), 29–37.

Cloern, James E., Noah Knowles, Larry R. Brown, Daniel Cayan, Michael D. Dettinger, Tara L. Morgan, David H. Schoellhamer, Mark T. Stacey, Mick van der Wegen, R. Wayne Wagner and Alan D. Jassby. "Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change." PLoS ONE 6, no. 9 (2011): e24465.

NRC 2012. National Research Council (U.S.). Committee on Sea Level Rise for the Coasts of California, Oregon, and Washington.; National Research Council (U.S.). Board on Earth Sciences and Resources.; National Research Council (U.S.). Ocean Studies Board. Sea-level Rise for the Coasts of California, Oregon, and Washington : Past, Present, and Future. 2012 ed. Washington, D.C.: National Academies, 2012. UO Libraries. Web. 18 July 2013.

Stralberg, D., M. Brennan, J. C. Callaway, J. K. Wood, L. M. Schile, D. Jongsomjit, M. Kelley, V. T. Parker, and S. Crooks. 2011. Evaluating tidal marsh sustainability in the face of sea-level rise: A hybrid modeling approach applied to San Francisco Bay. PLoS ONE **6**:e27388. doi:27310.21371/journal.pone.0027388.