Climate Impacts, Scenarios and Total Water Levels

Projects conducted by the ART Program evaluate current and future flooding that is either temporary or permanent.

Temporary flooding is generally short in duration but can have long lasting consequences. Some areas along the Bay shoreline or along creeks and rivers already experience temporary flooding. This temporary flooding usually occurs when there are storms over the Pacific Ocean during the winter, when high tide coincides with strong winds or when significant rainfall causes creeks and rivers to rise over their banks. While some assets and areas can maintain their function after the water recedes, other assets can suffer irreversible damage if exposed to any amount of water, even temporarily.

Permanent inundation occurs if an area is exposed to regular daily inundation. Currently, only natural areas such as tidal flats, wetlands, ponds and creeks, are permanently inundated.

As sea level rises, higher water levels will become more frequent, increasing the extent, depth, and duration of temporary flooding and extending the area that is permanently inundated. These impacts will not be confined to the shoreline as sea level rise will also affect tidal creeks. As the Bay rises, water levels in tidal creeks will also rise, pushing the extent of tidal influence further upstream, potentially making riverine flooding that already occurs worse in some locations. Furthermore, many urbanized areas are served by a network of infrastructure that require gravity to drain. Near the shoreline these networks typically outfall to the Bay or tidal creeks. Some of these systems are already at capacity or are already experiencing back ups during high Bay water levels. As sea levels continue to rise the ability of these systems to move water effectively and efficiently will be impaired, and additional areas may begin to experience localized nuisance (i.e., road, basement, and parking lot) flooding.

Climate Impacts

Current and future flooding can have a number of impacts on communities, infrastructure and natural areas. The following impacts that could occur from either temporary or permanent coastal flooding, riverine, or localized nuisance flooding:

- **Areas that currently flood may flood more frequently.** Rising sea levels can lead to more frequent flooding in existing flood-prone areas. This flooding can result in more frequent disruption of power, access to goods, services and jobs; can strain regional and local disaster response and recovery resources; and, result in economic losses if job sites, government services, and businesses are disrupted by a loss in communications, utilities, or goods or commuter access.
- **More extensive, longer-duration flooding in areas that currently flood and flooding of new areas:** As sea levels rise, there is the potential that storm events will flood larger areas for longer periods of time, including areas that flood now and areas that do not currently experience

flooding. This can result in damage to structures and contents, disruption of power, water supply and wastewater services, and reduced access to goods, medical care, schools, jobs and other critical services. Power outages can damage homes and businesses that rely on electric sump pumps to keep below grade work, living or storage spaces dry. More extensive and longer duration flooding can also create a disproportionate burden on community members that are the least able to prepare, respond or recover from a hazard event.

- **Permanent inundation of areas currently not exposed to regular tides:** Sea level rise can cause areas that are not currently exposed to regular high tide inundation to be flooded, resulting in the need to either protect or move people and infrastructure, and the loss of trails, beaches, vistas, and other shoreline recreation areas. Prolonged inundation may cause the mobilization of pollutants from contaminated lands such as closed landfills, the release of sewage, hazardous or toxic materials from wastewater treatment plants, storage tanks, pipelines, or industrial facilities, and can increase sedimentation in tidal creeks and flood control channels.
- **Shoreline erosion**: More extensive, longer duration flooding can cause shoreline protection, such as levees, berms and revetments, to be damaged or fail to due to increased water levels and wave energy. Erosion or scouring due to tidal and wave energy can damage structures such as roads, bridges, culverts, stream banks, embankments, foundations, bridge footings or piers.
- **Elevated groundwater and increased salinity intrusion:** As sea levels rise, groundwater and salinity levels are also predicted to rise. This will cause damage to below grade living spaces, finished basements, and electrical/mechanical equipment that is below or at-grade. In addition increasing groundwater levels can increase liquefaction susceptibility, require pumping in areas that are currently gravity drained, and increase both operations maintenance costs.

Climate Scenarios

Climate scenarios are used to assess how and when temporary or permanent flooding may occur, and to determine what assets may be impacted and how far reaching the consequences may be.

The ART Program evaluates current coastal and riverine flooding for the 100-year flood as depicted in FEMA's Effective Flood Insurance Rate Maps (see side bar). Coastal flooding is evaluated for a range of possible futures using a "total water level" approach that helps eliminate the sometimes challenging step of scenario selection. This approach also reduces the total number of maps needed because each map represents different unique combination of sea level rise and extreme tides (storm surge) that can result in current or future flooding[1].

Current Coastal and Riverine Flooding

The flood management standard used in the United States is an event with a 1 percent probability of occurrence in any given year, also known as the 100-year flood. The most readily available information for the current 100-year flood are FEMA's Flood Insurance Rate Maps (FIRMs) that depict 100-year floodplain boundaries, also referred to as Special Flood Hazard Areas (SFHAs), and are the basis for flood insurance and floodplain management requirements under the National Flood Insurance Program (NFIP)

FEMA's maps for the San Francisco Bay and the Outer Coast are publically available at: http://www.r9map.org/Pages/California.aspx?choState=California.

The best way to visualize the total water level approach is through the matrix that depicts different levels of current and future flooding presented in Table 1. This matrix is used to understand a range of total water levels, from 0 to 100 inches above mean higher high water (MHHW), both in terms of

[1] Extreme tides are the maximum high tide level that has occurred over a specific return period (recurrence interval) that correlates to a specific occurrence probability. For example a 100-year extreme tide has a return period of 100 years, and therefore a 1% chance of occurring in any given year.

current and future tides as sea level rises. Each box in the matrix represents a combination of sea level rise (0 to 60 inches) and current tide levels (MHHW to a 100-year extreme event). As an example, the likely mid-century daily high tide is projected to be 12 inches above today's high tide, or 12"+MHHW. This water level is the same as that observed during King Tide, which is an astronomical tides that occur approximately twice per year when the Moon and the Sun simultaneously exert their gravitational influence on the Earth. So, 12 inches of water above MHHW can represent today's King Tide and result in temporary flooding or 12 inches of sea level rise that results in permanent inundation.

Because of the uncertainties associated with modeling and mapping sea level rise it is reasonable to allow for a +/- 3-inch range when interpreting the water levels in Table 1. As an example, the likely end-century high tide is projected to be 36 inches above today's high tide, or 36"+MHHW. If you were to take the +/- 3-inch range into account when evaluating 36 inches, then you would also include water levels ranging from 33 to 39 inches.

The values presented in the Table 1 are generally applicable to central San Francisco Bay[2] and are therefore appropriate for local and regional scale climate adaptation planning, although it may not be as precise for some areas of South and North Bay because tide levels vary. Therefore, locally specific information about tide levels should be used for site-scale planning. Additionally, values in Table 1 are based on an analysis that did not include the effects of local wind waves and assumed that future Pacific Ocean storms will behave like past Pacific Ocean storms.

Table 1. The total water level matrix depicts current and future flood scenarios that could result in temporary or permanent flooding.

Total water level above today's daily high tide, MHHW (inches NAVD88)

Sea Level Rise	MHHW (≈ daily high tide) Permanent inundation	Extreme Tide (by recurrence interval) Temporary flooding						
		1-yr (≈ King Tide)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr (1% annual chance)
+0	0	12	19	23	27	32	36	41
+6	6	18	25	29	33	38	42	47
+12	12	24	31	35	39	44	48	53
+18	18	30	37	41	45	50	54	59
+24	24	36	43	47	51	56	60	65
+30	30	42	49	53	57	62	66	71
+36	36	48	55	59	63	68	72	77
+42	42	54	61	65	69	74	78	83
+48	48	60	67	71	75	80	84	89
+54	54	66	73	77	81	86	90	95
+60	60	72	79	83	87	92	96	101

2 Existing condition water levels in the first row of Table 1 are based on FEMA model results for Central San Francisco Bay, http://www.r9map.org/Pages/San-Francisco-Coastal-Bay-Study.aspx, and are being used by Alameda and San Francisco Counties. Existing water level conditions for the other Bay Area counties will be available in 2015.

To help understand when different future water levels may occur, the ART program is using the National Research Council (NRC) *Sea-Level Rise for the Coasts of California, Oregon, and Washington* study, released June 2012, that provides regionally specific sea level rise projections (see Table 2).

Table 2. Regional Sea Level Rise Projections Relative to Year 2000 for the California Coast South of Cape Mendocino (National Research Council Sea-Level Rise for the Coasts of California, Oregon, and Washington study released June 2012).

	Sea Level Rise (inches)		
Year	**NRC 2012 Projection** (mean ± the standard deviation for the A1B Scenario[3])	**Low** (mean of the B1 scenario)	**High** (mean of the A1F1 scenario)
2030	**5.6** (±1.9)	2	12
2050	**11.0** (±3.6)	5	24
2100	**36.1** (±10)	17	66

[3] The A1 scenario family assumes high economic growth, low population growth that peaks mid century, and the rapid introduction of more efficient technologies (A1B is balanced and A1FI is fossil fuel intensive). The B1 scenario family assumes the same low population growth as the A1 scenarios, but a shift toward a lower-emission service and information economy and cleaner technologies.