Short Title: Sea Level Rise
Full Title: Population living in sea level rise inundation areas

Domain: Environmental Exposure

Why is this important to health?

Sea level has already risen along the California coastline, with 7 inches of rise documented at the San Francisco tidal gauge.[1] By 2100, sea level rise is projected to reach up to 66 inches above the 2000 sea level along much of the California coast.[1] Sea level rise threatens coastal resources and may lead to displacement from homes and employment. In addition, sea level rise threatens coastal wetlands, which contribute to community resilience by protecting groundwater from contamination and guarding against flooding and erosion.[2] Impacts of sea level rise are intensified by storms and high tides. Resulting health effects of rising sea levels include the following: gastrointestinal illness from contaminated drinking water; respiratory or wound infections from flood waters contaminated with sewage overflow and hazardous substances; respiratory issues caused by mold in flood-damaged homes; mental health issues due to displacement from home and sources of employment, trauma, or changes to known surroundings; and food insecurity, leading to malnutrition or obesity.[3-6] Sea level rise can exacerbate coastal flooding from coastal storms and can result in drowning, motor vehicle accidents, electrocutions, injuries, hypothermia, and stress.[7, 8] Residents in coastal flood-prone areas are at greatest risk of exposure to sea level rise.[9, 10] Populations with lower socioeconomic status or mobility barriers and the elderly may have difficulty preparing for storms and flooding events, evacuating, and receiving access to care.[3] Those with language and communication difficulties may not receive adequate information for evacuation or recovery. Women, children, elderly, and those of lower socioeconomic status may be more vulnerable to mental health issues after coastal storms.[3, 6]

Summary of Evidence for Climate and Health

A review of coastal storms and hurricanes found that drowning in flood waters was the leading cause of the 2,544 deaths from 1963 to 2012.[6] In two of the largest storms to affect the United States, Superstorm Sandy and Hurricane Katrina, almost half or more of the deaths were in people over the age of 65.[6] One year after Hurricane Katrina, mental health issues persisted.[11] Among a cohort including those displaced from their homes, 39% of respondents were classified as having had any clinically defined anxiety or mood disorder in the past 30 days.[12] For children returning to New Orleans after the flooding from Hurricane Katrina, mold growth at home was associated with a 50% increase in lower respiratory symptoms.[13]

Key References:

1. California Coastal Commission. California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits. San Francisco, CA: California Coastal Commission; 2015.
2. Heberger M, Cooley H, Herrera P, et al. The Impacts of Sea Level Rise on the California Coast. Oakland, CA: Pacific Institute; 2009.
3. Lane K, Charles-Guzman K, Wheeler K, et al. Health Effects of Coastal Storms and Flooding in Urban Areas: A

Review and Vulnerability Assessment. *Journal of Environmental and Public Health.* 2013.
4. Luber G, Knowlton K, Balbus J, et al. Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment: U.S. Global Change Research Program; 2014.
5. Ahern M, Kovats RS, Wilkinson P, et al. Global Health Impacts of Floods: Epidemiologic Evidence. *Epidemiologic Reviews.* 2005; 27: 36-46.
6. Bell JE, Herring SC, Jantarasami L, et al. Chapter 4 Impacts of Extreme Events on Human Health. In: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Washington DC: U.S. Global Change Research Program; 2016. p. 99-128.
7. Smith KR, Woodward A, Campbell-Lendrum D, et al. Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. . Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014. p. 709-754.
8. Falanagan B, Gregory E, Hallisey E, et al. A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management.* 2011; 8(1).
9. Balbus JM, Malina C. Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. *Journal of Occupational and Environmental Medicine.* 2009; 51(1): 33-37.
10. Confalonieri U, Menne B, Akhtar R, et al. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.
11. Fussell E, Waters M, Paxson C, et al. The Impact of Hurricane Katrina on the Mental and Physical Health of Low-Income Parents in New Orleans. *American Journal of Orthopsychiatry.* 2010; 80(2): 237-247.
12. Sastry N, VanLandingham M. One Year Later: Mental Illness Prevalence and Disparities Among New Orleans Residents Displaced by Hurricane Katrina. *American Journal of Public Health.* 2009; 99(3): S725-S731.
13. Rath B, Young EA, Harris A, et al. Adverse Respiratory Symptoms and Environmental Exposures Among Children and Adolescents Following Hurricane Katrina. *Public Health Reports.* 2011; 126(6): 853-860.

What is the Indicator?

Detailed Definition

- Indicator (percent) = % Population Living in 100-year flood zone and 55 inches of sea level rise
- Stratification: 8 race/ethnicity strata (African American, American Indian/Native Alaskan, Asian, Latino, Multiple, Native Hawaiian and Other Pacific Islander, White, Total).
- Interpretation: Climate resilient communities will have lower values of population living in inundation areas.

Data Source and Description

- Sea Level Rise data from Pacific Institute (http://pacinst.org/the-impacts-of-sea-level-rise-on-the-california-coast-gis-data-downloads/)
  - Years available: 2009
  - Geographies available: California, excluding the San Francisco Bay
- Sea Level Rise data from United States Geological Survey (USGS) (http://escholarship.org/uc/search?entity=jmie_sfews;volume=8;issue=1)
  - Years available: 2010
  - Geographies available: San Francisco Bay
- 2010 U.S. Census Blocks, U.S. Census Bureau Redistricting File for California (http://www2.census.gov/census_2010/01-Redistricting_File--PL_94-171/California/).
  - Years available: 2010
  - Geographies available: census block, census tract, city, county, county division, region (derived), state

The 2009 Pacific Institute spatial data represented the extent of inundation due to Mean Higher High Water (MHHW), after a 1.4 meter or 55 inch sea-level rise scenario for year 2100 and inundation by 100-year unimpeded coastal flooding, for the California coast (excluding the San Francisco Bay). The 2010 USGS spatial data represented areas around San Francisco Bay at

risk of inundation under scenario with 140 cm or 55 inch sea level rise with 100-year high-water levels. Percent of census block area within coastal inundation areas was calculated in ArcGIS. Data was exported into SAS to calculate population-weighted percent of population living in inundation areas within each census block using proportional allocation method. Total population living in inundated areas was summed up at higher geographic aggregations and divided by total population with each geographic unit (e.g., census tract, county subdivision, county, region, and state). Regions in the CalBRACE project are based on county aggregations in the *Adaptation Planning Guide Understanding Regional Characteristics*. Decile rankings for places and census tracts as well as relative risk were calculated.

Limitations

For Pacific Institute sea level rise data, areas of Santa Barbara, Los Angeles, and Orange counties were unable to be mapped due to data limitations. The breakdown of mappable areas for those counties is: 49% of Santa Barbara County, 23% of Los Angeles County, and 65% of Orange County. USGS used a hydrodynamic model to simulate water levels throughout the San Francisco Bay under conditions of projected sea level rise. USGS high resolution LiDAR elevation data was determined to have an estimated vertical accuracy of ± 50 cm. Both Pacific Institute and USGS applied "bathtub" model which can help identify areas of potential vulnerability, but does not account for protective structures, such as levees, or hydrodynamical processes such as wave run-up.

Acknowledgement and Disclaimer

This publication was supported by Cooperative Agreement 5UEE1EH001052 from the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention.

Examples of Maps, Figures, and Tables:

Figure 1. Percent of Population Living in Inundation Areas by Race/Ethnicity, weighted by population, San Diego County, 2100 scenario

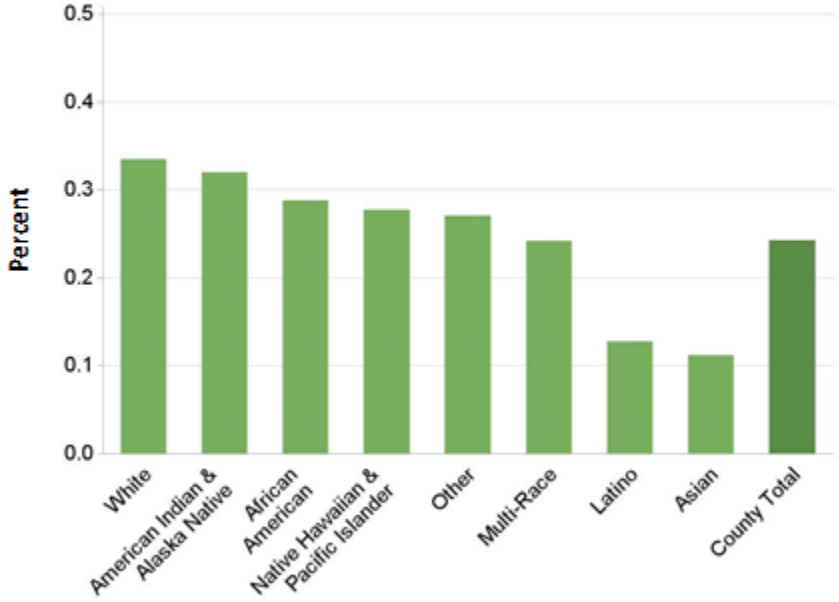

Table 4. Cities and Towns (> 1,000 Population) with Highest Population Living in Inundation Areas, weighted by population, San Diego County, 2100 scenario

Location	Percent at Risk	Population at Risk	Total Population
Del Mar city	5%	252	5,215
Imperial Beach city	4%	1,079	27,110
National city	1%	1,276	99,619
San Diego County	**0.2%**	**8,050**	**3,323,348**

Inundation areas include 100 year flood zone and 55 inches of sea level rise in 2100 high emissions scenario.

Source: Cal-Adapt; Pacific Institute, 2009; USGS, 2009; U.S. Census, 2010. Analysis by UC Davis and CDPH.

Figure 10. Population Living in Projected Inundation Areas, by census tracts, San Diego County, California, 2100 Scenario

Inundation areas include 100 year flood zone and 55 inches of sea level rise in 2100 high emissions scenario.

Source: Data obtained from Cal-Adapt; Pacific Institute, 2009; USGS, 2009; U.S. Census 2010. Analysis done by UC Davis and CDPH.

Only cities with population greater than 1,000 were labeled.