PURPOSE

Pursuant to the Revised Charter of Honolulu ("RCH") Section 6-107(h), the City and County of Honolulu ("City") Climate Change Commission is charged with gathering the latest science and information on climate change impacts to Hawaiʻi and providing advice and recommendations to the mayor, City Council, and executive departments as they look to draft policy and engage in planning for future climate scenarios and reducing Honolulu's contribution to global greenhouse gas emissions. This report provides a description of findings and recommendations with regard to adapting to sea level rise.

INTRODUCTION

There has been considerable detailed research on the global and local implications of accelerating sea level rise. This report by the City Climate Change Commission builds on findings in the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (2017), Sweet et al. (2017), USGCRP (2017), Sweet et al. (2018), and other scientific literature to provide specific policy and planning guidance on responding to sea level rise by the City.

SUMMARY OF KEY FINDINGS

1. The projected median global temperature increase this century is 5.8°F (3.2°C).[1]
    a. The likely range of global temperature increase is 3.6 to 8.8°F (2.0 to 4.9°C), with a 5% chance that it will be less than 3.6°F (2°C) and a 1% chance that it will be less than 2.7°F (1.5°C) by the end of this century.[2]
2. Relative to the year 2000, the projected rise of global mean sea level (GMSL) by the end of this century is 1.0 to 4.3 ft (0.3 to 1.3 m).[3]
    a. Relative to the year 2000, GMSL is very likely (90 to 100% confidence) to rise 0.3 to 0.6 ft (0.09 to 0.18 m) by 2030, 0.5 to 1.2 ft (0.15 to 0.36 m) by 2050, and 1.0 to 4.3 ft (0.3 to 1.3 m) by 2100.[4]
3. High tide flooding will arrive decades ahead of any GMSL rise scenario.[5]
    a. Table 1 (supplementary information) provides estimates of when minor high tide flooding will arrive in Honolulu 6, 12, and 24 days per year.
    b. Based on the location of the Honolulu Tide Station,[6] high tide flooding will occur by mid-century, and as early as 2028, at least two dozen times per year, at certain locations in the 3.2SLR-XA.[a]
4. Modeling results, as mapped in the Hawaiʻi Sea Level Rise Viewer,[b] reveal a critical elevation in GMSL rise between 2.0 and 3.2 ft (0.6 to 1 m) relative to mean higher high water.[c]
    a. This is a critical range of rising sea level where there is a rapid increase in the amount of land exposed to hazards on low-lying coastal plains, such as characterize the urbanized south shore of Oʻahu.
    b. This is a dangerous elevation range, where reacting after the fact to establish adaptation strategies is likely to be less successful and costlier than taking proactive measures.
5. Globally, energy-related carbon dioxide emissions are projected to grow an average 0.6% per year between 2015 and 2040, 1.3% per year below the level from 1990 to 2015.[7]
6. Future emission pathways have little effect on projected GMSL rise in the first half of the century, but significantly affect projections for the second half of the century.[8]
    a. Table 2 (supplementary information) provides estimates of projected GMSL under NOAA scenarios.[9]
7. Regardless of emissions pathway, it is extremely likely (95 to 100% confidence) that GMSL rise will continue beyond 2100.[10]
8. The world's major ice systems including Antarctica and Greenland,[11] and the mountain glaciers[12] of the world are all in a state of decline.

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[a] "SLR-XA" is an acronym that stands for *sea level rise-exposure area*. The Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (2017) recommends (p. 217) that the SLR-XA at 3.2 ft (0.98 m) of sea level rise be recognized as a state-wide vulnerability zone and that it be employed by agencies to formulate comprehensive adaptation strategies. 3.2 ft (0.98 m) of sea level rise is modeled by Church et al. (2013) as the worst case scenario at the end of the century. However, the scenario does not take into account potential instability in marine-based sectors of the Antarctic ice sheet.

[b] The online Hawaiʻi Sea Level Rise Viewer is served by the Pacific Islands Ocean Observing System at the School of Ocean and Earth Science and Technology, University of Hawaiʻi at Mānoa: http://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

[c] Mean higher high water (MHHW) is the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch, a 19 year period determined by the National Oceanic and Atmospheric Administration.

a. Research indicates that on multiple occasions over the past three million years, when global temperatures increased 1.8 to 5.4°F (1 to 3°C), melting polar ice sheets caused global sea levels to rise at least 20 ft (6 m) above present levels.[13]
b. If atmospheric warming exceeds 2.7 to 3.6°F (1.5 to 2°C) above present (ca. 2015), collapse of the major Antarctic ice shelves triggers a centennial- to millennial-scale response of the Antarctic ice sheet that produces a long-term commitment (an unstoppable contribution) to sea-level rise.[14] Substantial Antarctic ice loss can be prevented only by limiting greenhouse gas emissions to RCP2.6[d] levels. Higher-emissions scenarios lead to ice loss from Antarctica that will raise sea level by 1.9 to 9.8 ft (0.6 to 3 m) by the year 2300.[15]
c. Antarctica has the potential to contribute more than 3.28 ft (1 m) of sea-level rise by 2100 and more than 49.2 ft (15 m) by 2500, if emissions continue unabated. In this case atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.[16]
d. Emerging science regarding Antarctic ice sheet stability suggests that under high emission pathways, a GMSL rise exceeding 8 ft (2.4 m) by 2100 is physically possible.[17]
e. The Greenland ice sheet is more sensitive to long-term climate change than previously thought. Studies[18] estimate that the warming threshold leading to an essentially ice-free state is in the range of 1.4 to 5.8°F (0.8 to 3.2°C), with a best estimate of 2.9°F (1.6°C) above preindustrial levels. The Arctic is on track to double this amount of warming before mid-century.[19]
f. Further melting of mountain glaciers cannot be prevented in the current century - even if all emissions were stopped now.[20] Around 36% of the ice still stored in mountain glaciers today will melt even without further emissions of greenhouse gases. That means: more than one-third of the glacier ice that still exists today in mountain glaciers can no longer be saved even with the most ambitious measures.

9. Rising seas threaten human communities and natural ecosystems in multiple ways.
    a. Urbanized coastal areas become increasingly vulnerable to four types of flooding during high water and high wave events:
        1) Flooding across the shoreline due to wave run-up.
        2) Saltwater intrusion of engineered drainage systems.
        3) Groundwater inundation.[21]
            a) Intrusion of buried infrastructure and other buried assets that are not sealed.
            b) Formation of new wetlands, initially concurrent with high tide.
        4) Rainstorms, especially concurrent with high tide.
    b. Land loss and coastal erosion.
        1) If the back-beach area is composed of sand-rich dunes, sandy paleo shoreline deposits, or high wave sand berms, the released sand nourishes the retreating beach.
        2) If the back-beach area is hardened, a beach is prevented from retreating. This leads to beach erosion, beach narrowing, and beach loss. Hardening has caused at least 5.4 mi (8.7 km) of beach loss on O‘ahu.[22]
    c. Saltwater will intrude streams and coastal wetlands, increasing the salinity of the environment and threatening low-lying agriculture (e.g., kalo farming) and wildlife sanctuaries.
    d. Wave, and eventually still water overtopping of Loko I‘a kuapā (fishpond walls) will increase.
        1) Interior circulation will change (including at mākāhā).
        2) Upland discharge into the pond will change.
        3) Fishpond connections to the shore will become unstable.
    e. Wave energy at the shore will increase.
        1) Muddy shore deposits may be released.
    f. Damaging flooding will increase when hurricanes, tsunamis, and seasonal high waves strike.
    g. Annual high waves, which arrive in Hawai‘i seasonally, will flood further landward and cause more damage, as sea level continues to rise.

[d] To provide guidance for developing mitigation and adaptation strategies, scientists have defined four different 21st century pathways of greenhouse gas emissions called "RCP's" for Representative Concentration Pathways. The RCP's include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high greenhouse gas emissions (RCP8.5).

RECOMMENDATIONS (underlined & ital proposed re-rewording)

Given the tools available to planners, stakeholders and policy-makers with the Hawai'i Sea Level Rise Viewer, the NOAA SLR Viewer, and the Climate Central–Surging Seas Risk Finder,[e] the City Climate Change Commission, pursuant to RCH Section 6-107(h), recommends that:

1. The mayor, City Council, and executive departments of the City utilize the 2017 Hawai'i Sea Level Rise Vulnerability and Adaptation Report (hereafter "Report") and online Viewer, for baseline planning activity and infrastructure assessment and development with regard to sea level rise.
2. The research finds that it is reasonable to set as a planning benchmark up to 3.2 ft (~1 m; 3.2SLR-XA) of GMSL rise by the end of the century. High-tide flooding will arrive decades earlier and the 3.2SLR-XA will be an area experiencing chronic high tide flooding by mid-century.
3. Because global emissions are currently on a warming pathway of over 5.4°F (3.0°C) by the end of this century, the research finds that it is reasonable to set as a planning benchmark up to 6 ft (1.8 m; 6SLR) of GMSL rise toward the end of 2100. Critical infrastructure projects with long expected lifespans and low risk tolerance will want to plan accordingly, as the 6SLR will be an area experiencing chronic high tide flooding decades earlier.
4. The Special Management Area (SMA) boundary be revised to include parts of the 3.2SLR-XA that are not currently in the SMA.
5. Disclosure of all lands be required in the 3.2SLR-XA and 6SLR.
    a. Disclosure on all real estate sales, City Property Information Sheets, and all other real estate transactions.
6. The 3.2SLR-XA and 6SLR be adopted as a vulnerability zone (hazard overlay) for planning by the City.
    a. The hazard overlays should be used for planning purposes, for example in the general plan, all development plans, and sustainable community plans.
7. That all City departments and agencies be directed to use the Report, the 3.2SLR-XA, and the 6SLR in their plans, programs, policies, and capital improvement decisions, to mitigate impacts to infrastructure and critical facilities related to sea level rise.
8. All ordinances related to land development, such as policy plans and regulations should be reviewed and updated, as necessary.
9. Relevant City departments and agencies be supported with adequate resources and capacity to implement these recommendations and proactively plan for sea level rise, as it will rapidly become a major challenge to City functions.

The City Climate Change Commission adopts the precautionary principle and a scenario-based planning approach and supports these recommendations as planning targets informed by the best available science. This set of recommendations are important each and in their own right and are designed to complement each other and be implemented together. Implementing one does not eliminate the need to adopt the others. The City Climate Change Commission fully acknowledges that there is uncertainty in the timing and magnitude of sea level rise projections globally and for Hawai'i. This is a living document that will be updated as additional information becomes available.

[e] Surging Seas Viewer: https://riskfinder.climatecentral.org/county/honolulu-county.hi.us?comparisonType=postal-code&forecastType=NOAA2017_int_p50&level=3&unit=ft

SUPPLEMENTARY INFORMATION

NOAA has published a model of high tide flooding for the Honolulu Tide Station (Sweet et al., 2018). Relative to MHHW, the threshold for minor high tide flooding is 1.7 ft (0.52 m), for moderate high tide flooding is 2.6 ft (0.8 m), and for major high tide flooding is 3.8 ft (1.17 m). High tide flooding will arrive decades ahead of global mean sea level rise.

High tide flooding, as defined by NOAA, has never occurred at the Honolulu Tide Station as none of these thresholds has ever been crossed. Table 1 provides estimates of when minor high tide flooding will arrive in Honolulu 6, 12, and 24 days per year using the NOAA model.

Table 1 - When will minor (0.52 m) high tide flooding occur in Honolulu?			
Scenario	6 x per year	12 x per year	24 x per year
Intermediate Scenario	2038	2041-2042	2044-2045
Intermediate High Scenario	2030	2033	2035-2036
High Scenario	2025-2026	2028-2029	2030-2031
Extreme Scenario	2024	2026	2028-2029

Because of the exponential nature of the NOAA sea level scenarios, the doubling time of high tide flooding is rapid in all scenarios. High tide flooding events are likely to cluster around the summer and winter solstices. High tide flooding will occur first at certain locations in the 3.2SLR-XA as defined in the Hawai‘i Sea Level Rise Vulnerability and Adaptation Report (2017).

High tide flooding can take several forms. Beach erosion will be pronounced during high tide flooding events. Storm drain flooding will occur where marine water blocks drainage and spills out onto the street, or where runoff cannot drain and causes flooding around storm drain sites. Groundwater inundation will develop where the water table rises to break the ground surface and creates a wetland.

At first this flooding will be most common when high tide and precipitation occur simultaneously, but eventually will occur without precipitation at high tide. Rainfall that occurs at high tide when storm drains are blocked and the ground is saturated will lead to widespread flooding. Marine flooding will occur at high tide when seawater flows across the shoreline. Wave flooding will occur at high tide during typical seasonal swell events as waves run-up past the shoreline and into the backshore. Tsunami and storm surge occurring at high tide will cause greater flood damage than historically.

Global mean sea level will rise 3.2 ft (~1 m) relative to the year 2000. NOAA (Sweet et al., 2017) has published scenarios that provide estimates, by decade, of when GMSL will hit this benchmark (Table 2).

Table 2 - When will global mean sea level rise 3.2 feet (~1 m)?	
Intermediate Scenario	end of the century
Intermediate High Scenario	decade of the 2080’s
High Scenario	decade of the 2070’s
Extreme Scenario	decade of the 2060’s

Gravitational forces will cause regional sea level in the North Central Pacific to rise above the global mean (Spada et al., 2015). NOAA suggests planners use higher scenarios for large projects with low risk tolerance. This recommendation is also made by the U.S. Army Corps of Engineers.

Modeling of sea level rise impacts on O‘ahu (Report) reveals the following:

1. Homes and businesses on Oahu’s shorelines will be severely impacted by sea level rise. Nearly 4,000 structures will be chronically flooded with 3.2 ft (~1 m) of sea level rise (**Figure 1**).
2. Of the 9,400 acres of land located within the 3.2SLR-XA, over half is designated for urban land uses, making O‘ahu the most vulnerable of all the islands.

3. With 3.2 ft (~1 m) of sea level rise, almost 18 mi (30 km) of Oahu's coastal roads will become impassible, jeopardizing access to and from many communities.

4. Oʻahu has lost more than 5 mi (8 km) of beaches to coastal erosion fronting seawalls and other shoreline armoring. Many more miles of beach will be lost with sea level rise if widespread armoring is allowed. In the Report, Chapter 5 (Recommendations) explores opportunities to reduce beach loss by improving beach protection policies.

5. A more detailed economic loss analysis is needed of Oahu's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure.

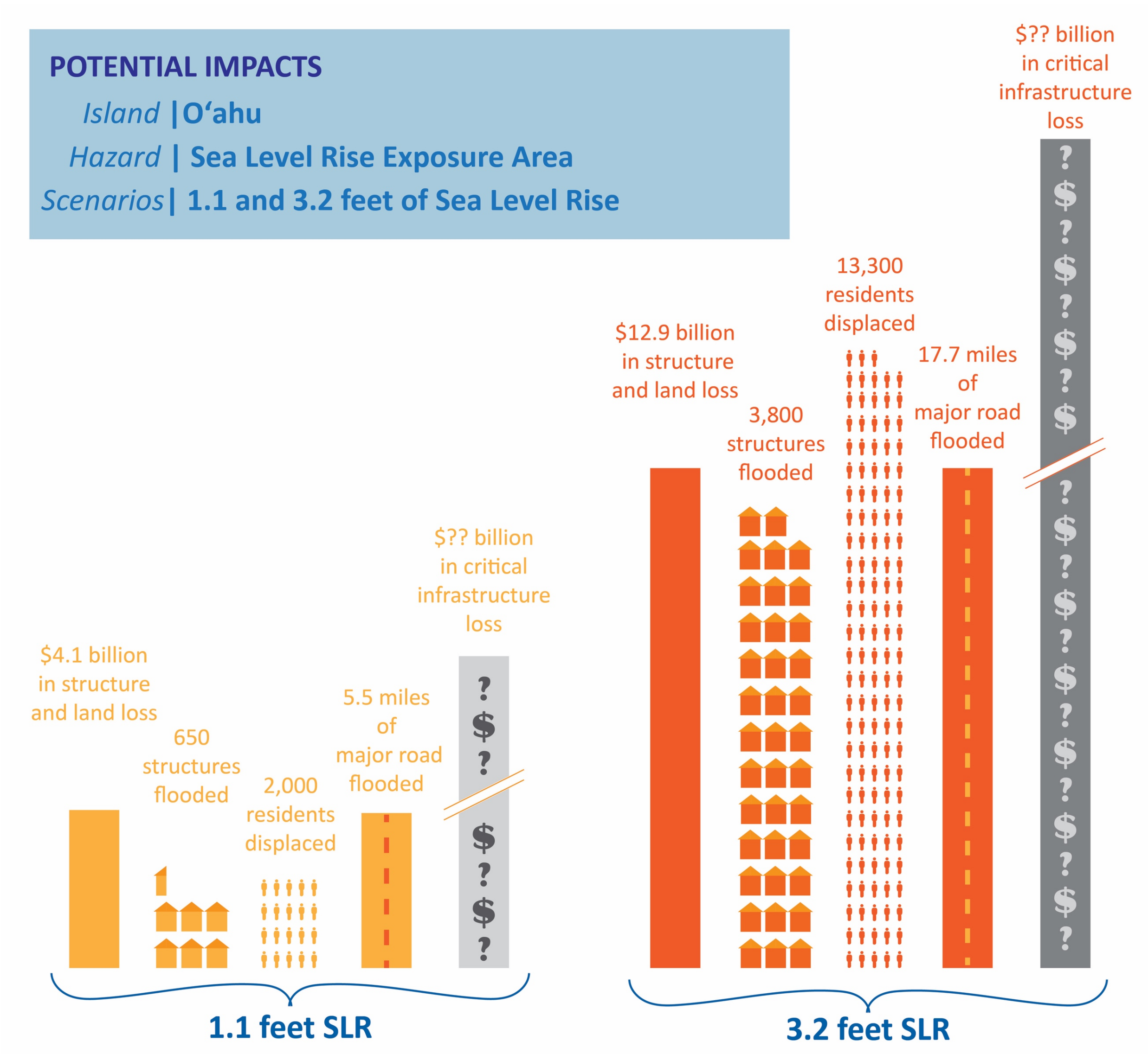

Figure 1. Sea level rise impacts on Oʻahu.

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