OFFICE OF THE MAYOR
CITY AND COUNTY OF HONOLULU
530 SOUTH KING STREET, Room 300 • HONOLULU, HAWAII 96813
PHONE: (808) 768-4141 • FAX: (808) 768-4242 • INTERNET: www.honolulu.gov

KIRK CALDWELL
MAYOR

ROY K. AMEMIYA, JR.
MANAGING DIRECTOR

GEORGETTE T. DEEMER
DEPUTY MANAGING DIRECTOR

DIRECTIVE NO. 18-2
July 16, 2018

MEMORANDUM

TO: ALL DEPARTMENT AND AGENCY HEADS

FROM: KIRK CALDWELL, MAYOR

SUBJECT: CITY AND COUNTY OF HONOLULU ACTIONS TO ADDRESS CLIMATE CHANGE AND SEA LEVEL RISE

I. PURPOSE

To establish policies to address, minimize risks from, and adapt to the impacts of climate change and sea level rise in accordance with the findings and recommendations of the City and County of Honolulu ("City") Climate Change Commission ("Commission") *Sea Level Rise Guidance* ("Guidance"), and accompanying *Climate Change Brief* ("Brief"), both adopted on June 5, 2018, and the State of Hawai'i *Sea Level Rise Vulnerability and Adaptation Report (2017)* ("Report").

II. SUMMARY

The Report finds that for O'ahu specifically, with no actions, 3.2 feet of sea level rise and its associated erosion, flooding, and waves will chronically impact, displace, and/or permanently inundate:

- 9,400 acres of land (over half of which is designated for urban land uses);
- $12.9 billion in building and land values, which does not account for public infrastructure and other utilities;
- 13,300 residents;
- 3,880 structures; and
- 17.7 miles of major roadway.

The Commission also stresses that impacts from high tide flooding will be observed decades before permanent inundation by sea level rise. Tidal flooding will become more frequent and more damaging as ocean levels rise. Even smaller tide heights, when convergent with rainfall, will impede drainage leading to flooded roads and properties, and disrupt traffic. Furthermore, the Commission finds that, because of continued high levels of global carbon emissions, it is reasonable to set as a planning benchmark up to 6 feet of sea level rise in the latter decades of this century.

III. SCOPE

These guidelines shall apply to all executive branch departments and agencies.

IV. POLICY

Each City department and agency shall, consistent with the Paris Agreement and Chicago Climate Charter, consider the need for both climate change mitigation and adaptation as pressing and urgent matters, to take a proactive approach in both reducing greenhouse gas emissions and adapting to impacts caused by sea level rise, and to align programs wherever possible to help protect and prepare the infrastructure, assets, and citizens of the City for the physical and economic impacts of climate change.

V. PROCEDURES

All City departments and agencies are required to:

1. Use the most current versions of the Commission's Guidance and accompanying Brief, and the Report and associated Hawai'i Sea Level Rise Viewer as resources for managing assets, reviewing permitting requests, and assessing project proposals; and

2. Consider how sea level rise and associated climate change risks will impact the City's residents and visitors, infrastructure, communities, policies and programs, investments, natural resources, cultural and recreational sites, and fiscal security; and

3. Use the Guidance, Brief, and Report in their plans, programs, and capital improvement decisions, to mitigate impacts to infrastructure and facilities subject to sea level rise exposure, which may include the elevation or relocation of infrastructure and critical facilities, the elevating of surfaces, structures, and utilities, and/or other adaptation measures; and

4. Develop place-specific guidance for shoreline policy changes based on additional policy guidance from the Climate Change Commission regarding: new regulations; management procedures for affected coastal assets; and, additional sea level rise projections that are as specific as possible, regularly updated, and delineate associated impacts; and

5. Work cooperatively to develop and implement land use policies, hazard mitigation actions, and design and construction standards that mitigate and adapt to the impacts of climate change and sea level rise; and

6. Work cooperatively to propose revisions to amend shoreline rules and regulations to incorporate sea level rise into the determination of shoreline setbacks and Special Management Area considerations for the safety and welfare of people and structures, provision of municipal services, as well as the protection of open space, the environment, public access to and along the shoreline, public trust resources including beaches, and public use and enjoyment of these resources; and

7. Work cooperatively to develop a process to review applications for new development in shoreline areas in conjunction with other agencies and entities with expertise in shoreline hazards and erosion in order to protect and enhance open space, the environment especially beaches, public access to and along the shoreline, public safety, and public resources; and

8. Work to conserve and enhance a natural, dynamic shoreline wherever possible. Temporary emergency measures may be utilized to address acute erosion events, especially on sandy beaches, where consistent with these guidelines and in alignment with other agencies. Permitting permanent shoreline armoring is generally inconsistent with this directive and should only be considered as a last resort where it supports significant public benefits and will result in insignificant negative impacts to coastal resources and natural shoreline processes.

VI. <u>RESPONSIBILITIES</u>

All City departments and agencies under the Mayor's jurisdiction shall work cooperatively to ensure the success of the missions outlined above. Independent agencies, City-affiliated entities, and City-related institutions are also strongly encouraged to work to help advance these efforts and adopt similar initiatives, where applicable. All actions and outcomes shall be in accordance with applicable local, state, and federal laws.

VII. GENERAL

This Directive shall take effect immediately and remain in effect until amended or rescinded in writing by the Mayor. The current version of the *Hawai'i Sea Level Rise Vulnerability and Adaptation Report* may be found at https://climateadaptation.hawaii.gov.

Attachments:

Sea Level Rise Guidance
Climate Change Brief

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 Hawai'i 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 Hawai'i 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 Hawai'i 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 O'ahu.
    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 Hawai'i 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 Hawai'i 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 Hawai'i 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.

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[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

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 mid-century as it will be an area experiencing chronic high tide flooding.
3. The research finds that it is reasonable to set as a planning benchmark up to 6 ft (1.8 m; 6SLR) of GMSL rise in the later decades of the century, especially for critical infrastructure with long expected lifespans and low risk tolerance, as it will be an area experiencing chronic high tide flooding.
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.

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[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 Hawaiʻi 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 Oʻahu (Report) reveals the following:

1. Homes and businesses on Oʻahu'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 Oʻahu the most vulnerable of all the islands.

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

4. O'ahu 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 O'ahu's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and City 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.

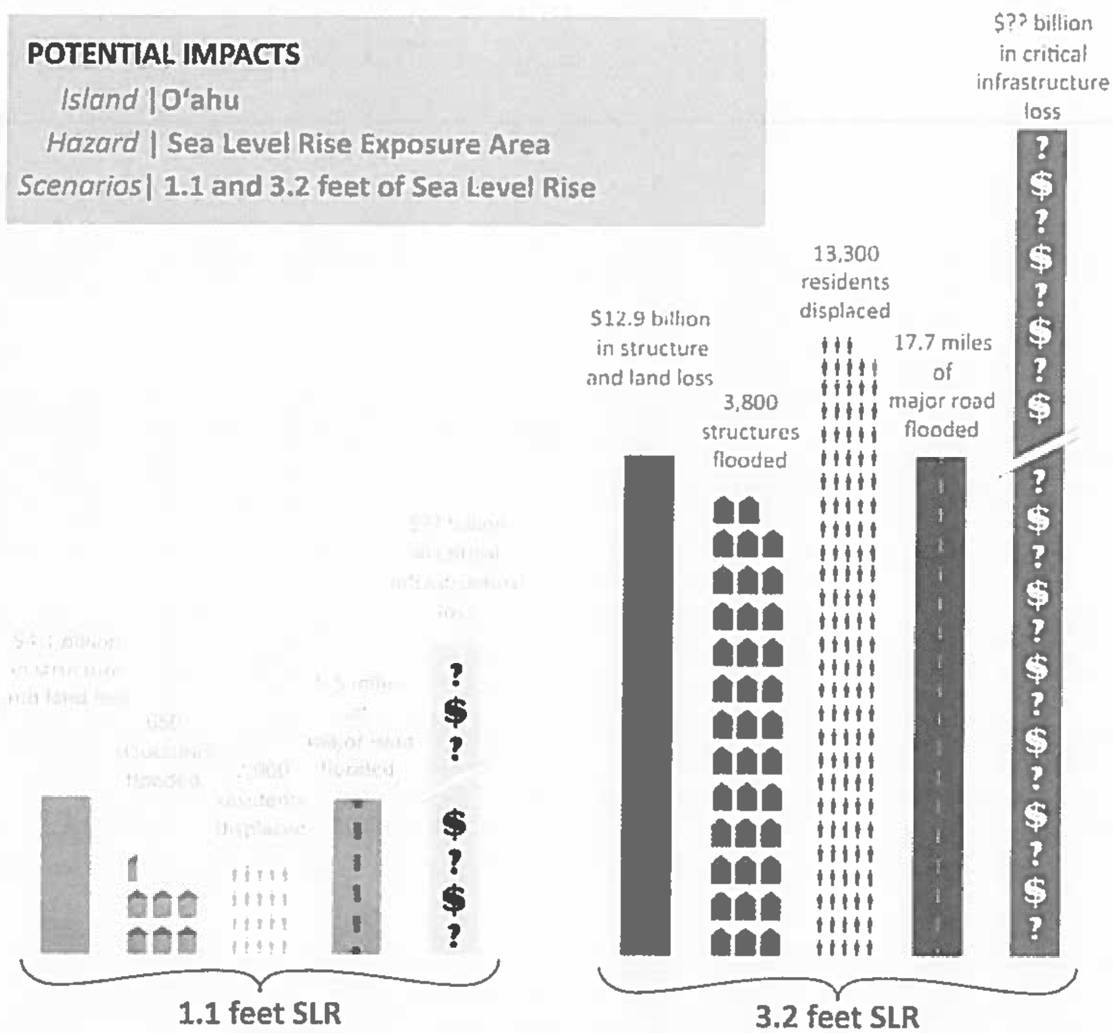

Figure 1. Sea level rise impacts on O'ahu.

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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 Hawai'i 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.

To establish the factual basis and broad impact of climate change, the City Climate Change Commission adopts this CLIMATE CHANGE BRIEF - JUNE 5, 2018. This document describes the local, regional, and global impacts of climate change as documented by the peer-reviewed scientific literature and credible empirical data sources. It provides a benchmark for the commission, attesting to our concern, underpinning our decisions and recommendations, and serving to inform those we serve.

The information in this report reinforces the need for an urgent and sweeping transformation in our energy sources, food systems, and land-use practices to achieve a decarbonized world economy. Mitigation of future climate change must be achieved to avoid the very worst aspects of global warming. In the words of Dr. Jim Hansen, former chief scientist at the NASA Goddard Institute of Space Science, "There is a possibility, a real danger, that we will hand young people and future generations a climate system that is practically out of their control... we have a global emergency. Fossil fuel CO_2 emissions should be reduced as rapidly as practical."[1]

Because many changes in global biogeochemical systems have been irreversibly set into motion, and these threaten the health and welfare of human populations, it is important that the City and County of Honolulu take bold steps to reduce greenhouse gas emissions and build sustainability and resilience in the face of a rapidly changing climate.

INTRODUCTION

Excess heat, trapped by the anthropogenic greenhouse gases carbon dioxide, methane, nitrous oxide, and others in the atmosphere, is causing dramatic changes in ecosystems, the ocean, weather patterns, and other climate-dependent aspects of Earth's surface. Hawai'i, and other Pacific islands are impacted, and these impacts are growing.[2]

The negative impacts of climate change fall disproportionally on disadvantaged groups in a type of "vicious cycle".[3] Initial inequity or vulnerabilities can be exacerbated by climate change; for example, low-income people are less likely to have air conditioning and can be much more susceptible to the effects of a heat wave. This in turn lowers the ability of already disadvantaged groups to cope and recover. It is important to recognize and resolve the impacts of climate change on vulnerable populations as the City pivots to meet the challenges of climate change.

Unrelenting impacts to Earth's ecosystems[4] and natural resources have led researchers to conclude that our planet is perched on the edge of a tipping point[5], a planetary-scale critical transition resulting from human impacts.[6] These changes include the following.

CARBON DIOXIDE

- Carbon dioxide levels in the air have passed 410 ppm compared to a natural level of 280 ppm[7] – an increase of over 45%. This is the highest level in millions of years.[8]
- Today, release of planet-warming carbon dioxide is ten times faster than the most rapid event in the past 66 million years, when an asteroid impact killed the dinosaurs.[9]

TEMPERATURE

- Global temperature has risen approximately 1.8°F (1°C) from the late 19th Century.[10]
- The likely global temperature increase this century is a median 5.76°F (3.2°C). There is only 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).[11]
- The last time it was this warm, 125,000 years ago, global sea level was 20 ft (6.6 m) higher.[12] [13] [14]
- Atmospheric humidity is rising.[15]
- The global water cycle has accelerated.[16]
- Air temperature over the oceans is rising.[17]

HAWAI'I – LOCAL AND REGIONAL IMPACTS

Air Temperature

- In Hawai'i, the rate of warming air temperature has increased in recent decades. Currently, the air is warming at 0.3°F (0.17°C) per decade, four times faster than half a century ago.[18]

- Statewide, average air temperature has risen by 0.76°F (0.42°C) over the past 100 years, and 2015 and 2016 were the warmest years on record.[19]
- Warming air temperatures lead to heat waves, expanded pathogen ranges and invasive species, thermal stress for native flora and fauna, increased electricity demand, increased wildfire, potential threats to human health, and increased evaporation which both reduces water supply and increases demand. Rapid warming at highest elevations impedes precipitation, the source of Hawai'i's freshwater.[20]
- During the strong El Niño of 2015, Honolulu set or tied 11 days of record heat.[21] This compelled the local energy utility to issue emergency public service announcements to curtail escalating air conditioning use that stressed the electrical grid.[22]
- Some model projections for the late 21st century indicate that surface air temperature over land will increase 1.8° to 7.2°F (2° to 4°C) with the greatest warming at the highest elevations and on leeward sides of the major islands.[23]
- Under continued strong greenhouse gas emissions, high elevations above 9,800 ft (3000 m) reach up to 7.2° to 9°F (4 to 5°C) warmer temperatures by the late 21st Century.[24]

Wind and Precipitation

- The frequency of gale-force winds is increasing in the western and south Pacific but decreasing in the central Pacific.[25]
- Average daily wind speeds are slowly declining in Honolulu and Hilo, while remaining steady across western and south Pacific sites.[26]
- Studies indicate there will be future changes to winds and waves due to climate change, which affects ecosystems, infrastructure, freshwater availability, and commerce.[27]
- Hawai'i has seen an overall decline in rainfall over the past 30 years, with widely varying precipitation patterns on each island. The period since 2008 has been particularly dry.[28]
- Declining rainfall has occurred in both the wet and dry seasons and has affected all the major islands. On O'ahu, the largest declines have occurred in the northern Ko'olau mountains.[29]
- Heavy rainfall events and droughts have become more common, increasing runoff, erosion, flooding, and water shortages.[30]
- Consecutive wet days and consecutive dry days are both increasing in Hawai'i.[31]
- There is disagreement regarding precipitation at the end of the century.[32] Model projections range from small increases to increases of up to 30% in wet areas, and from small decreases to decreases of up to 60% in dry areas.[33] [34]
- Generally, windward sides of the major islands will become cloudier and wetter. The dry leeward sides will generally have fewer clouds and less rainfall.[35]
- Stream flow in Hawai'i has declined over approximately the past century, consistent with observed decreases in rainfall.[36] This indicates declining groundwater levels.
- More frequent tropical cyclones are projected for the waters near Hawai'i. This is not necessarily because there will be more storms forming in the east Pacific; rather, it is projected that storms will follow new tracks that bring them into the region of Hawai'i more often.[37]

El Niño-Southern Oscillation

- Frequency of intense El Niño events is projected to double in the 21st century, with the likelihood of extreme events occurring roughly once every decade.[38]
- Models project a near doubling in the frequency of future extreme La Niña events, from one in every 23 years to one in every 13 years. Approximately 75% of the increase occurs in years following extreme El Niño events, thus projecting more frequent swings between opposite extremes from one year to the next.[39]
- Strong El Niño years in Hawai'i bring more hot days, intense rains, windless days, active hurricane seasons, and spikes in sea surface temperature.[40]

Forest Ecosystems

- Hawai'i is home to 31% of the nation's plants and animals listed as threatened or endangered, and less than half of the landscape on the islands is still dominated by native plants. Studies indicate that endemic and endangered birds and plants are highly vulnerable to climate change and are already showing shifting habitats.[41]
- Even under moderate warming, 10 of 21 existing native forest bird species are projected to lose over 50% of their range by 2100. Of those, three may lose their entire ranges and three others are projected to lose more than 90% of their ranges making them of high concern for extinction.[42]
- Warming air temperatures are bringing mosquito-borne diseases to previously safe upland forests, driving several native bird species toward extinction.[43]

Ocean Warming, Acidification, and Reefs

- Globally averaged sea surface temperature (SST) increased by 1.8°F (1.0°C) over the past 100 years. Half of this rise has occurred since the 1990s. North Central Pacific averaged SST trends follow the globally averaged trend. Over the last 5 years almost the entire tropical Pacific, in particular areas along the equator, have seen temperatures warmer than the 30-year average.[44]

- Nearly 30 years of oceanic pH measurements, based on data collected from Station ALOHA, Hawai'i, show a roughly 8.7% increase in ocean acidity over this time.[45]
- Increasing ocean acidification reduces the ability of marine organisms to build shells and other hard structures. This adversely impacts coral reefs and threatens marine ecosystems more broadly.[46]
- In Hawai'i, extended periods of coral bleaching did not first occur until 2014 and 2015 as part of the 2014–17 global scale bleaching event that was the longest ever recorded.[47]
- Ocean warming and acidification are projected to cause annual coral bleaching in some areas, like the central equatorial Pacific Ocean, as early as 2030 and almost all reefs by 2050.[48] This will not only devastate local coral reef ecosystems but will also have profound impacts on ocean ecosystems in general. Ultimately it will threaten the human communities and economies that depend on a healthy ocean.[49]

Sea Level Change

- The mean sea level trend at the Honolulu tide station is 0.055 in (1.41 mm) per year with a 95% confidence interval of ±0.008 in (0.21 mm) per year based on monthly mean sea level data, 1905 to 2015. This is equivalent to a change of 0.46 ft (14.0 cm) over the past century.[50]
- The frequency of high tide flooding in Honolulu since the 1960's, has increased from 6 days per year to 11 per year.[51]
- With 3.2 ft (0.98 m) of sea level rise, 25,800 acres experience chronic flooding, erosion, and/or high wave impacts. One third of this land is designated for urban use. Impacts include 38 mi (61 km) of major roads, and more than $19 billion in assets.[52]
- Due to global gravitational effects, estimates of future sea level rise in Hawai'i and other Pacific islands are about 20%–30% higher than the global mean.[53]
- Over 70% of beaches in Hawai'i are in a state of chronic erosion.[54] This is likely related to long-term sea level rise as well as coastal hardening.[55] [56]
- Coastal hardening of chronically eroding beaches caused the combined loss of 9% (13.4 mi, 21.5 km) of the length of sandy beaches on Kaua'i, O'ahu, and Maui.[57]

Indigenous Communities

- Indigenous populations will be disproportionally impacted by climate change due to their strong ties to place and greater reliance on natural resources for sustenance.[58]
- About 550 Hawaiian cultural sites are exposed to chronic flooding with a sea level rise of 3.2 ft (0.98 m).[59]
- Sea level rise impacts on traditional and customary practices (including fishpond maintenance, cultivation of salt, and gathering from the nearshore fisheries) have been observed.[60]
- Because of flooding and sea level rise, indigenous practitioners have had limited access to the land where salt is traditionally cultivated and harvested since 2014. Detachment from traditional lands has a negative effect on the spiritual and mental health of the people.[61]
- Ocean warming and acidification, sea level rise and coastal erosion, drought, flooding, pollution, increased storminess, and over-development are negatively affecting tourism, fisheries, and forested ecosystems. This directly impacts the livelihood and security of Pacific communities. For example, across all Pacific Island countries and territories, industrial tuna fisheries account for half of all exports, 25,000 jobs, and 11% of economic production.[62] In Hawai'i, between 2011 and 2015, an annual average of 37,386 Native Hawaiians worked in tourism-intensive industries; based on the 2013 U.S. census, this number represents 12.5% of the Native Hawaiian population residing in Hawai'i.[63]
- In Hawai'i, climate change impacts, such as reduced streamflow, sea level rise, saltwater intrusion, episodes of intense rainfall, and long periods of drought, threaten the ongoing cultivation of taro and other traditional crops.[64]

GLOBAL ECOSYSTEMS

- Climate change impacts have been documented across every ecosystem on Earth, including shifts in species ranges, shrinking body size, changes in predator-prey relationships, new spawning and seasonal patterns, and modifications in the population and age structure of marine and terrestrial species.[65]
- In 2017 over 15,000 scientists published a "Warning to Humanity".[66] They said humans have pushed Earth's ecosystems to their breaking point and are well on the way to ruining the planet.
- Human activities have increased the acidity of oceans; increased the acidity of freshwater bodies and soils because of acid rain; increased acidity of freshwater streams and groundwater due to drainage from mines; and increased acidity of soils due to added nitrogen to crop lands.[67]
- Researchers have labeled ecosystem impacts "biological annihilation," and identify that a "sixth major mass extinction" is underway as a result of dwindling population sizes and range shrinkages among vertebrates.[68]
- Humans are causing the climate to change 170 times faster than natural forces.[69]
- Tree lines are shifting poleward and to higher elevations.[70]
- One-third of burnt forests experience no tree regeneration at all.[71]

- Species are migrating poleward and to higher elevations.[72]
- Spring is coming sooner to some plant species in the Arctic while other species are delaying their emergence amid warm winters. The changes are associated with diminishing sea ice.[73]
- Spring is coming earlier.[74]
- The tropics have expanded.[75]
- Warmer winters with less snow have resulted in a longer lag time between spring events and a more protracted vernal window (the transition from winter to spring).[76]
- Plants are leafing out and blooming earlier each year.[77]
- Climate-related local extinctions have already occurred in hundreds of species, including 47% of 976 species surveyed.[78]
- Plant and animal extinctions, already widespread, are projected to increase from twofold to fivefold in the coming decades.[79]

FOOD AND HUMAN HEALTH

- Harvests of staple cereal crops, such as rice and maize, could decline by 20 to 40% as a function of increased surface temperatures in tropical and subtropical regions by 2100.[80]
- One billion people are classified as food insecure.[81]
- Rising CO_2 decreases the nutrient and protein content of wheat, leading to a 15% decline in yield by mid-century.[82]
- Higher levels of CO_2 are lowering amounts of protein, iron, zinc, and B vitamins in rice with potential consequences for a global population of approximately 600 million.[83]
- By 2050, climate change will lead to per-person reductions of 3% in global food availability, 4% in fruit and vegetable consumption, and 0.7% in red meat consumption. These changes will be associated with 529,000 climate-related deaths worldwide.[84]
- Without changes to policy and improvements to technology, food productivity in 2050 could look like it did in 1980 because, at present rates of innovation, new technologies won't be able to keep up with the damage caused by the climate change in major growing regions.[85]
- Certain groups of Americans—including children, elders, the sick and the poor—are most likely to be harmed by climate change.[86]
- Climate change is harming human health now. These harms include heat-related illness, worsening chronic illnesses, injuries and deaths from dangerous weather events, infectious diseases spread by mosquitoes and ticks, illnesses from contaminated food and water, and mental health problems.[87]
- Warming of Earth's surface is changing life on a global scale.[88]

EXTREME WEATHER

- The global percentage of land area in drought has increased about 10%.[89]
- The global occurrence of extreme rainfall has increased 12%.[90]
- Heavy downpours are more intense and frequent.[91]
- Extreme weather events are more frequent.[92]
- Half a degree Celsius of global warming has been enough to increase heat waves and heavy rains in many regions of the planet.[93]
- Storm tracks are shifting poleward.[94]
- The number of weather disasters is up 14% since 1995-2004, and has doubled since 1985-1994.[95]
- There has been a global increase in the frequency and intensity of extremely hot three-day periods.[96]
- The number of unusually cold days and nights has decreased, and the number of unusually warm days and nights has increased.[97]
- Extreme heat waves are projected to cover double the amount of global land by 2020 and quadruple by 2040, regardless of future emissions trends.[98]
- New records continue to be set for warm temperature extremes. For instance, in the U.S. during February, 2017 there were 3,146 record highs set compared to only 27 record lows, a ratio of 116 to 1.[99]
- Nine of the ten deadliest heat waves have occurred since 2000 causing 128,885 deaths around the world.[100]
- Nearly one third of the world's population is now exposed to climatic conditions that produce deadly heat waves.[101]
- Extreme weather is increasing.[102]
- If global temperatures rise 3.6°F (2°C), the combined effect of heat and humidity will turn summer into one long heat wave. Temperature will exceed 104°F (40°C) every year in many parts of Asia, Australia, Northern Africa, South and North America.[103]
- If global temperatures rise 7.2°F (4°C), a new "super-heatwave" will appear with temperatures peaking at above 131°F making large parts of the planet unlivable including densely populated areas such as the US east coast, coastal China, large parts of India and South America.[104]

GLACIERS, SEA ICE, PERMAFROST

- The world's major ice systems including Antarctica and Greenland,[105] and the mountain glaciers[106] of the world are all in a state of decline.[107, 108, 109]
- 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.[110]
- Under high emission pathways, a sea level rise exceeding 8 ft (2.4 m) by 2100 is physically possible.[111]

- The West Antarctic ice sheet is in "unstoppable" retreat.[112]
- Atmospheric warming that exceeds 2.7 to 3.6°F (1.5 to 2°C) above present (ca. 2015) will trigger a centennial- to millennial-scale response of the Antarctic ice sheet that produces an unstoppable contribution to sea-level rise.[113] Substantial Antarctic ice loss can be prevented only by limiting greenhouse gas emissions to RCP2.6 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.[114]
- If emissions continue unabated, 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. 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.[115]
- The Greenland ice sheet is more sensitive to long-term climate change than previously thought. Studies[116] 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.[117]
- Cloud cover over Greenland is decreasing at 0.9 +/-3% per year. Each 1% of decrease drives an additional 27 +/-13 billion tons of ice melt each year.[118]
- Further melting of mountain glaciers cannot be prevented in the current century - even if all emissions were stopped now.[119] 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.
- Alpine glaciers have shrunk to their lowest levels in 120 years and are wasting two times faster than they did in the period 1901-1950, three times faster than they did in 1851-1900, and four times faster than they did 1800-1850.[120]
- Arctic sea ice is shrinking (13% per decade) as a result of global warming.[121]
- Winter Arctic sea ice was the lowest on record in 2017.[122]
- In the Arctic, average surface air temperature for the year ending September 2016 was the highest since 1900, and new monthly record highs were recorded for January, February, October, and November 2016.[123]
- Rapid warming in the Arctic is causing the jet stream to slow down and become unstable.[124]
- Regions of Earth where water is frozen for at least one month each year are shrinking with impacts on related ecosystems.[125]
- Extreme warm events in winter are much more prevalent than cold events.[126]
- Global snow cover is shrinking.[127]
- The southern boundary of Northern Hemisphere permafrost is retreating poleward.[128]
- Large parts of permafrost in northwest Canada are slumping and disintegrating into running water. Similar large-scale landscape changes are evident across the Arctic including in Alaska, Siberia, and Scandinavia.[129]
- In North America, spring snow cover extent in the Arctic is the lowest in the satellite record, which started in 1967.[130]

OCEANS

- The Atlantic Meridional Overturning Circulation has decreased 20%. The North Atlantic has the coldest water in 100 yrs of observations.[131]
- Global sea surface temperature is rising.[132]
- The oceans are warming rapidly.[133]
- Sea level is rising and the rate of rise has accelerated.[134]
- Today global mean sea level is rising three times faster than it was in the 20th Century.[135]
- Between 1993 and 2014, the rate of global mean sea level rise increased 50% with the contribution from melting of the Greenland Ice Sheet rising from 5% in 1993 to 25% in 2014.[136]
- With existing greenhouse gas emissions, we are committed to future sea level of at least 4.3 to 6.2 ft (1.3 to 1.9 m) higher than today and are adding about 0.32 m/decade to the total: ten times the rate of observed contemporary sea-level rise.[137]
- Over 90% of the heat trapped by greenhouse gases since the 1970's has been absorbed by the oceans and today the oceans absorb heat at twice the rate they did in the 1990's.[138]
- Excess heat in the oceans has reached deeper waters,[139] and deep ocean temperature is rising.[140]
- Sea surface temperatures have increased in areas of tropical cyclone genesis suggesting a connection with strengthened storminess.[141]
- Oxygen levels in the ocean have declined by 2% over the past five decades because of global warming, probably causing habitat loss for many fish and invertebrate species.[142]
- Marine ecosystems can take thousands, rather than hundreds, of years to recover from climate-related upheavals.[143]
- Marine ecosystems are under extreme stress.[144]
- The world's richest areas for marine biodiversity are also those areas mostly affected by both climate change and industrial fishing.[145]
- The number of coral reefs impacted by bleaching has tripled over the period 1985-2012.[146]
- By 2050 over 98% of coral reefs will be afflicted by bleaching-level thermal stress each year.[147]
- Scientists have concluded that when seas are hot enough for long enough nothing can protect coral reefs.

The only hope for securing a future for coral reefs is urgent and rapid action to reduce global warming.[148]

- Average pH of ocean water fell from 8.21 to 8.10, a 30% increase in acidity. Ocean water is more acidic from dissolved CO_2, which is negatively affecting marine organisms.[149]
- Dissolved oxygen in the oceans is declining because of warmer water.[150]
- Production of oxygen by photosynthetic marine algae is threatened at higher temperatures.[151]

The likely (66%) range of global temperature increase this century will be a median 5.8°F (3.2°C).[152] [153] If greenhouse gas concentrations were stabilized at their current level, existing concentrations would commit the world to at least an additional 1.1°F (0.6°C) of warming this century.[154] Beyond the next few decades, the magnitude of climate change depends on emissions of greenhouse gases and aerosols and the sensitivity of the climate system. Projected changes range from 4.7° to 8.6°F (2.6° to 4.8°C) under a higher scenario, to 0.5° to 1.3°F (0.3° to 1.7°C) under the lowest scenario.[155] CO_2 concentration has now passed 400 ppm, a level not seen since 3 million years ago, when global temperature and sea level were significantly higher than today. Testing revealed most climate models underestimate the effects of anthropogenic greenhouse gases.[156] Models that do the best job of simulating observed climate change predict some of the worst-case scenarios for the future. If countries stay on a high-emissions trajectory, there is a 93% chance the planet will warm more than 4°C by the end of the century. Previous studies placed those odds at 62%.

What will this >5.4°F (3°C) world look like?

- Heat waves drive a global scale refugee crisis, as low-latitude continental lands lose habitability[157];
- Drought[158], wildfires[159], water scarcity[160], crop failure[161] and other threats to critical resources leading to increased human conflict[162];
- Multi-meter sea level rise continuing over many centuries[163];
- Extreme weather disasters[164], massive floods[165], great tropical cyclones[166], mega-drought[167], and torrential rainfall[168] will be widespread.

Ironically, with the ongoing global revolution in clean power, all this suffering and dystopia will be taking place in a world of solar panels, wind mills, electric cars, and cleaner air.

ENERGY OUTLOOK

Global

The U.S. Energy Information Administration projects the following global energy patterns to the year 2040.[169]

- Strong, long-term economic growth drives an increasing demand for energy;
- World energy consumption grows by 28%;
- China and India alone account for over half of this increase;
- Fossil fuels maintain a market share of 77% through 2040, even though renewable energy experiences explosive growth;
- World energy-related carbon dioxide emissions rise 15% by 2040.

To hold global temperature below an increase of 3.6°F (2°C) per the 2015 Paris Agreement, it is necessary to decrease carbon emissions by 50% per decade.[170] Clearly, the projections by the EIA move in the opposite direction and present a massive challenge to humanity.

Hawai'i

What is Hawai'i's contribution to greenhouse gas emissions?

- In 2007, Hawai'i's total greenhouse gas emissions were 24 million metric tons of CO_2 equivalent;[171]
- Total CO_2 emissions have slightly declined in the last decade, largely due to gains in the electricity sector.[172]

O'ahu had 20.8% of net sales of electricity from sources deemed renewable in 2017, the law requires 100% by 2045.[173]

- Fossil fuel use for transportation continues to increase;[174]
- Hawai'i's CO_2 emissions are 20% lower than the national average;[175]
- However, U.S. CO_2 emissions per capita are over three times the world average and Hawai'i's are approximately 12 times larger than other Pacific Islands;[176]
- Passed in 2018, Act 15 establishes a *Greenhouse Gas Sequestration Task Force* and sets a 2023 deadline for crafting a plan to meet a zero emissions target by 2045.
- Also passed in 2018, Act 16 directs the state Office of Planning to work with the task force to create a *carbon offset program.*

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