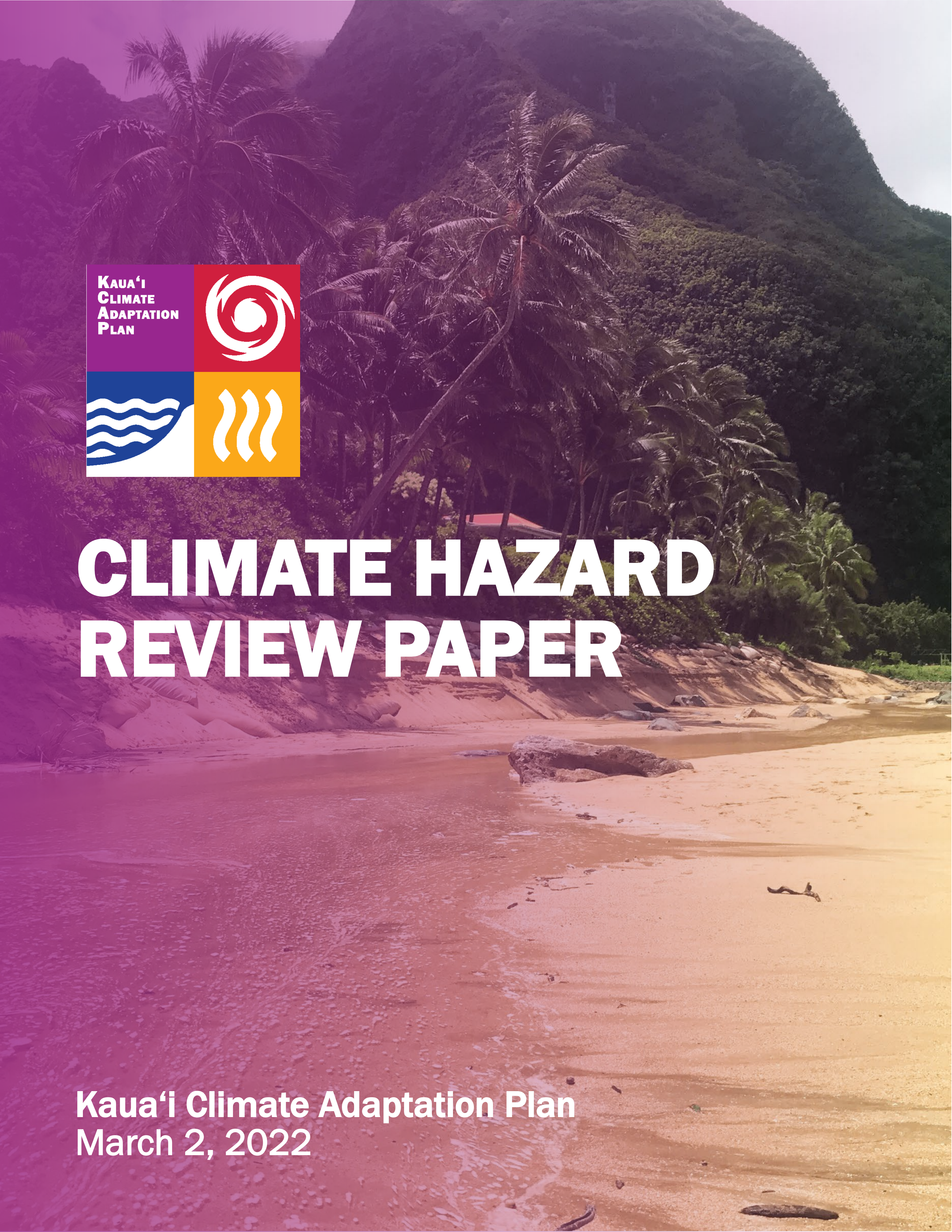
APPENDIX A: TECHNICAL ANALYSIS

KAUAʻI CLIMATE ADAPTATION AND ACTION PLAN



Kaua'i Climate Adaptation Plan

CLIMATE HAZARD REVIEW PAPER

Kaua'i Climate Adaptation Plan
March 2, 2022

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CLIMATE HAZARD REVIEW PAPER

The Climate Hazard Review Paper synthesizes the current scientific knowledge of the climate change hazards that Kauaʻi, and Hawaiʻi at large, face now and in the future. It builds on scientific studies and existing local plans to provide a comprehensive baseline understanding of climate change, which will inform the next steps of the Kauaʻi Climate Adaptation Plan.

Key Findings

1. Compared to the late 1800's, human greenhouse gas (GHG) emissions have warmed average annual air temperature at Earth's surface by 1.1 to 1.3^{o}C (2 to 2.3^{o}F). Climate change is likely accelerating, and impacts are growing in frequency and magnitude.
2. Kauaʻi is facing unavoidable, costly, and dangerous impacts from climate change and the islands future socio-economic viability is at risk.
3. In the County of Kauaʻi, climate change hazards are expressed as both shocks and stressors related to an accelerated water cycle.
4. Five climate change hazards stand out above others as warranting special concern and the need to develop specific adaptation plans and policies:
    a. Increasing ambient and extreme **heat** bringing new challenges to emergency response, grid resilience, public health, community design, and ecosystems;
    b. **Declining rainfall**, expanding **drought**, and related hazards such as **wildfire** and threats to **food production**;
    c. Growing **storminess**, and related hazards such as **landslides**, **floods**, **infrastructure damage**, and **public safety**;
    d. **Sea level rise**, lasting millennia, punctuated by **extreme tides**, **compound events** (e.g., high tide plus heavy rain, waves, onshore winds, and others), and ultimately requiring the community to **retreat from the coast**; and
    e. Expanding **supply chain disruptions** as ports, manufacturing centers, global bread baskets, and transportation systems experience growing climate change impacts.

1. Executive Summary

Human activities are polluting the atmosphere with "greenhouse" gases that trap heat and warm the air.[1] Compared to the late 1800's, these emissions have warmed average annual air temperature at Earth's surface by 1.1 to 1.3°C (2 to 2.3°F).[2] Climate change is accelerating, and related hazards are growing in frequency and magnitude. According to the Intergovernmental Panel on Climate Change,[3] it is *unequivocal* that human influence has warmed the atmosphere, ocean, and land. As a result, widespread, unprecedented, and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.

Rising temperatures are causing phenomena such as loss of sea ice and ice sheet mass, sea level rise, longer and more intense heat waves, and shifts in plant and animal habitats and behaviors. Understanding these long-term climate trends is essential for preserving the safety and quality of human life, allowing humans to adapt to the changing environment in ways such as planting different crops, new ways of managing water resources, designing resilient, low carbon communities, and preparing for extreme weather events.

Global surface temperature will continue to increase until at least mid-century regardless of any changes in Human-made emissions.[4] Global warming of 1.5°C (2.7°F) and 2°C (3.6°F) will be exceeded during the 21st Century unless there are deep and rapid reductions in carbon dioxide (CO_2) and other emissions. Even though the pace of climate change has been rapid and the impacts severe, until recently, few people have noticed. Now, however, a range of key socio-economic sectors (e.g., investors, public agencies, supply-side community) show broadening acceptance of the need to act quickly.[5] But progress remains too slow to avoid dangerous levels of warming.[6]

1.1. CLIMATE CHANGE HAZARDS

1.1.1. Global Climate System

Many changes in the climate system become larger in direct relation to increasing global surface temperature. These include increases in the frequency and intensity of hot extremes,[7] the risk and extent of vector-borne

[1] See Appendix I for discussion of Human-made global warming.
[2] NASA *2021 Tied for Sixth Warmest Year in Continued Trend, NASA Analysis Shows*, https://www.giss.nasa.gov/research/news/20220113/; See also Global Warming index, https://www.globalwarmingindex.org
[3] IPCC (2021) Summary for Policymakers (SPM). In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. et al. (eds.)]. In Press.
[4] IPCC (2021) SPM
[5] "Get ready for ESG Investing to Quadruple by End of Decade" Dec. 6, 2021: https://www.nasdaq.com/articles/get-ready-for-esg-investing-to-quadruple-by-end-of-decade
[6] Fletcher, C. (2021) COP26 has failed our children - political compromise cannot be the answer, https://thehill.com/opinion/energy-environment/582048-cop26-has-failed-our-children-political-compromise-cannot-be-the
[7] Ma, F., and Yuan, X. (2021) Impact of climate and population changes on the increasing exposure to summertime compound hot extremes, *Science of The Total Environment*, v772, https://doi.org/10.1016/j.scitotenv.2021.145004.

disease,[8] marine heatwaves,[9] heavy precipitation,[10] compound events,[11] agricultural and ecological droughts,[12] extreme rainfall and the chance of floods,[13] and the proportion of intense tropical cyclones.[14] Arctic Sea ice,[15] snow cover[16] and permafrost[17] decline annually, and the transition from a snow- to rain-dominated Arctic in the summer and autumn may occur as early as 2040, with profound climatic, ecosystem and socio-economic impacts.[18]

Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.[19] Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events, and warming substantially larger than those assessed in the "very likely" range (>90%), cannot be ruled out.[20]

1.1.2. Local Context

Climate on the island of Kauaʻi is embedded in the larger Pacific and global climate system. Changes in atmospheric circulation (e.g., the Polar Jet Stream), the ocean (e.g., North Pacific sea surface temperatures), and in bio-physical systems such as tropical forests, permafrost, and others, will be seen in some fashion as changes in the climate on Kauaʻi as well.

For instance, loss of Arctic summer sea ice drives Arctic Amplification[21] wherein the Arctic warms 4 times[22] faster than the global average. This reduces Northern Hemisphere atmospheric circulation which depends on regional gradients (differences) in temperature. Researchers hypothesize that the Polar Jet Stream has become unstable as a result[23] and large meanders in the jet stream generate frontal lows associated with severe weather events. Jet stream meanders may cause Kauaʻi to experience stormy weather such as happened on December 6, 2021 when Līhuʻe Airport recorded 8.31 cm (3.27 in) of rain, a record for that date.[24] **Figure ES-1** shows that a deep meander in the jet stream on that date created a frontal low, generating

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[8] Science Brief (2021) paper compilation on "Climate change increases the risks and extent of vector-borne diseases," https://sciencebrief.org/topics/climate-change-science/vector-borne-diseases
[9] Laufkötter, C., *et al.* (2020) High-impact marine heatwaves attributable to human-induced global warming, *Science*, https://doi.org/10.1126/science.aba0690
[10] Fowler, H.J., Lenderink, G., Prein, A.F. *et al.* (2021) Human-made intensification of short-duration rainfall extremes. *Nat Rev Earth Environ* 2, 107–122. https://doi.org/10.1038/s43017-020-00128-6
[11] Robinson, A., *et al.* (2021) Increasing heat and rainfall extremes now far outside the historical climate, *Climate and Atmospheric Science*, https://doi.org/10.1038/s41612-021-00202-w
[12] Pokhrel, Y., Felfelani, F., Satoh, Y. *et al.* (2021) Global terrestrial water storage and drought severity under climate change. *Nat. Clim. Chang.* 11, 226–233. https://doi.org/10.1038/s41558-020-00972-w
[13] Blenkinsop, S., *et al.* (2021) Science Brief Review: Climate change increases extreme rainfall and the chance of floods. In: *Critical Issues in Climate Change Science*, edited by: C. Le Quéré, P. Liss & P. Forster. https://doi.org/10.5281/zenodo.4779119
[14] Knutson, T. R., *et al.* (2021) Science Brief Review: Climate change is probably increasing the intensity of tropical cyclones. In: *Critical Issues in Climate Change Science*, edited by: Corinne Le Quéré, et al. https://doi.org/10.5281/zenodo.4570334
[15] Andersson, T.R., *et al.* (2021) Seasonal Arctic Sea ice forecasting with probabilistic deep learning. *Nat Commun* 12, 5124. https://doi.org/10.1038/s41467-021-25257-4
[16] Niittynen, P., *et al.* (2020) Decreasing snow cover alters functional composition and diversity of Arctic tundra, *PNAS*, 117 (35) 21480-21487; DOI:10.1073/pnas.2001254117
[17] Plaza, C., *et al.* (2019) Direct observation of permafrost degradation and rapid soil carbon loss in tundra. *Nat. Geosci.* 12, 627–631. https://doi.org/10.1038/s41561-019-0387-6
[18] McCrystall, M.R., *et al.* (2021) New climate models reveal faster and larger increases in Arctic precipitation than previously projected. *Nat Commun* 12, 6765 https://doi.org/10.1038/s41467-021-27031-y
[19] IPCC (2021) Headline statements SPM, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Headline_Statements.pdf
[20] Ibid.
[21] Previdi, M., *et al.* (2021) Arctic amplification of climate change: a review of underlying mechanisms, *Environmental Research Letters*, v16, n9, https://doi.org/10.1088/1748-9326/ac1c29
[22] https://public.wmo.int/en/media/press-release/wmo-recognizes-new-arctic-temperature-record-of-38^{0}c
[23] Francis, J.A. and Vavrus, S.J. (2012) Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters*. 39 (6): L06801. doi:10.1029/2012GL051000.
[24] https://www.weather.gov/wrh/Climate?wfo=hfo

extreme rain. This illustrates that global and regional climate change can have meaningful localized impacts on the island of Kaua'i.

Figure ES - 1. Weather Map December 6, 2021

A deep meander in the Polar Jet Stream (gray band) generated record precipitation of 8.31 cm (3.27 in) at Līhu'e Airport. Researchers have tied these meanders to Arctic Amplification caused by global warming.

Source: Honolulu Star Advertiser

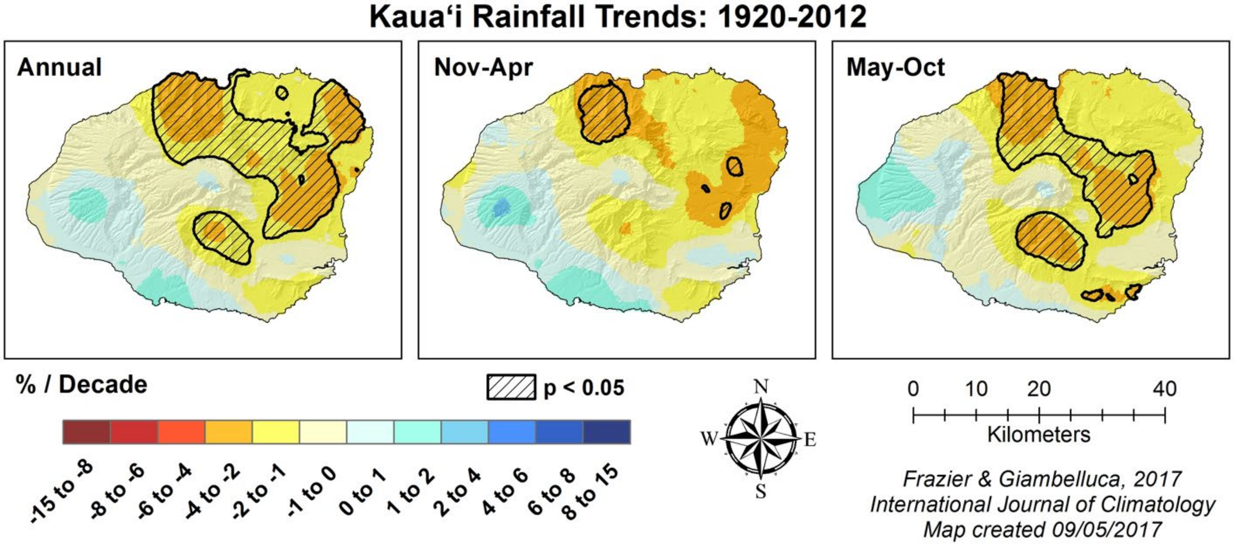
1.1.3. Local Climate Change Hazards

Kaua'i is facing unavoidable, costly, and dangerous impacts from climate change. Studies[25] show that the impacts of climate change fall disproportionately on vulnerable populations. The remote and currently vulnerable socio-economic framework of Kaua'i, and Hawai'i at large (demonstrated by critical reliance on imported goods and services), constitutes a significant weakness. This was starkly illustrated by the severe environmental and socio-economic impacts caused by Hurricane Iniki.[26] Growing exposure to tropical cyclones and the effects of marine and atmospheric warming, put Kauai's food and water security and economy at risk. These risks are more than sufficient to motivate deep inspection and analysis of island policies with the intention of enacting transformational changes to ensure strengthened resilience and sustainability.

As an isolated, and remote group of islands without the capacity to rapidly exchange critical resources such as freshwater, food, or medical supplies with neighboring communities, the state of Hawai'i, and Kaua'i specifically, are especially vulnerable to the accelerating impacts of climate change. Five impacts stand out above others as warranting special concern and the need to develop specific adaptation plans and policies: 1.) Increasing ambient and extreme heat, 2.) Declining rainfall and expanding drought, 3.) Growing storminess, 4.) Sea level rise, and 5.) Supply chain disruptions. These five represent direct challenges to long-term sustainability (declining rainfall, drought, supply chain disruptions), public health and safety (heat, storminess), and chronic and growing socio-economic disruption (sea level rise).

[25] UN (2020) World Social Report 2020: Inequality in a Rapidly Changing World, https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/01/World-Social-Report-2020-FullReport.pdf
[26] Coffman, M. and Noy, I. (2009) A hurricanes long-term economic impact: the case of Hawaii's Iniki, *Working Paper No. 09-5*, June. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.366.1272&rep=rep1&type=pdf

Figure ES - 2. Annual Average Rainfall



Average annual rainfall is declining on Kaua‘i at a rate of about 1% per decade (Scale- % change rainfall per decade). *Source: Frazier, A. G., and Giambelluca, T. W. (2017)*

Several major categories illustrate the breadth of impacts to Kaua‘i:

1. **Global Tipping Points** - Some major global bio-physical systems (e.g., terrestrial Carbon sinks) show early indications of abrupt, potentially irreversible change that could accelerate warming and related climate change impacts.[27]
2. **Global Disease** - Climate change alters the range of pathogens, allowing infections, particularly vector-borne infections, to expand to new locations. The continued uptick in global travel, trade and mobility transports pathogens rapidly. Even relatively remote locations such as Kaua‘i are at risk from an emerging class of zoonotic diseases related to habitat and biodiversity loss, extreme weather, and expanded vector range.
3. **Accelerated Sea Level Rise** - Collapse of Thwaites Glacier ice shelf could rapidly accelerate sea level rise. Thwaites Ice Shelf has doubled its outflow speed over the last 30 years, and its base has eroded rapidly. Thwaites could raise global sea level by >61 cm (2 ft) and could lead to 3 m (10 ft) if it draws surrounding glaciers with it. New giant fractures have been observed, and researchers are concerned that part of the shelf could shatter within 5 years.[28]
4. **Sea Level Rise Flooding** - Sea level rise, extreme tide flooding, and compound coastal flood events are increasing.[29] Coastal erosion and land loss is increasing with growing threats to private and public

[27] Steffen, W. et al. (2018) Trajectories of the Earth system in the Anthropocene, *PNAS – Perspective*, Aug. 14, v115, no33, 8252-8259, www.pnas.org/cgi/doi/10.1073/pnas.1810141115
[28] Giant cracks push imperiled Antarctic glacier closer to collapse (2021) https://www.nature.com/articles/d41586-021-03758-y *Nature*, Dec. 14.
[29] Hawai‘i Sea Level Rise Vulnerability and Adaptation Report (2017) Tetra Tech, Inc. and the State of Hawai‘i DLNR, OCCL, DLNR Contract No: 64064.

property, transportation systems, bridges and other forms of public infrastructure, and when shoreline armoring is used to mitigate erosion, loss of beaches,[30] a public trust.[31]

5. **Ocean Heat Content** - Last year (2021) was the warmest year on record for ocean heat content, which increased markedly between 2020 and 2021.[32] The oceans absorbed the heat equivalent of seven Hiroshima atomic bombs detonating each second, 24 hours a day, 365 days a year.[33] Studies document increasing sea surface temperature with growth in marine heat waves as well as compound heat, acidification, and deoxygenation events.[34]

6. **Declining Rainfall** - In Hawai‘i, on average, there has been a decline of 1.78% of annual rainfall per decade since 1920. A significant downward trend in annual rainfall per decade is seen in mountainous regions of Kaua‘i, while leeward areas mostly show no trend in annual rainfall. Wet season, and dry season precipitation has decreased in mountainous and windward areas of Kaua‘i.[35]

7. **Water Resources** - Climate change has fundamentally altered the water cycle on tropical islands which is a critical driver of freshwater ecosystems and water resource renewal.[36] Long-term decreases in precipitation result in negative impacts to water resources, stream discharge, watershed and coastal ecosystems, and mauka to maka‘i watershed connectivity. Streamflow has declined with increasing numbers of perennial streams running dry between direct rain events.[37] Kauai’s water supply is mainly derived from groundwater.[38] The probability of chronic water shortages may grow as rainfall decreases and the water requirements of a growing population increase.

8. **Drought** - Drought has increased with longer and drier periods between rain events. Leeward areas are projected to experience significant drying, temperatures will continue to rise, and drought severity and frequency in the future will increase because of greater evaporative demand. Already-dry, drought-prone leeward areas are projected to become drier. These leeward areas are expected to be at high risk for drought in the future.[39] The frequency of extreme El Niño events is projected to increase which will likely result in more extreme drought.[40]

9. **Variability and Storminess** - Extreme precipitation and rainfall intensity have increased with related flooding.[41] Exposure to hurricanes has increased as they have become larger, wetter, more intense,

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30 Summers, A., Fletcher, C.H., Spirandelli, D., *et al.* (2018) Failure to protect beaches under slowly rising sea level. *Climatic Change* 151, 427–443. https://doi.org/10.1007/s10584-018-2327-7

31 Lee, C. A. (2021). Eliminating the Hardship Variance in Honolulu's Shoreline Setback Ordinance: The City and County of Honolulu's Public Trust Duties as an Exception to Regulatory Takings Challenges. *University of Hawai'i Law Review*, 43(2), 464-518.

32 Cheng, L., Abraham, J., Trenberth, K.E., *et al.* (2022) Another Record: Ocean Warming Continues through 2021 despite La Niña Conditions. *Adv. Atmos. Sci*. https://doi.org/10.1007/s00376-022-1461-3

33 https://thehill.com/changing-america/sustainability/climate-change/589187-oceans-absorbed-heat-equivalent-to-7-hiroshima

34 Gruber, N., *et al.* (2021) Biogeochemical extremes and compound events in the ocean. *Nature* 600, 395–407.

35 Frazier, A.G. and Giambelluca, T.W. (2017) Spatial trend analysis of Hawaiian rainfall from 1920 to 2012, *International Journal of Climatology,* 37, 2522-2531, DOI: 10.1002/joc.4862

36 Leta, O.T., *et al.* (2018) Impact of climate change on daily streamflow and its extreme values in Pacific Island watersheds, *Sustainability*, 10, 2057, doi:10.3390/su10062057

37 Bassiouni, M., and D. S. Oki (2013) Trends and shifts in streamflow in Hawai‘i, 1913–2008. *Hydrological Processes*, 27 (10), 1484–1500. doi:10.1002/hyp.9298

38 Oki, D. S., *et al.* (1999) Hawaii. *Ground Water Atlas of the United States*, Segment 13, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. Miller, J. A., et al., Eds., U.S. Geological Survey, Reston, VA, N12–N22, N36.

39 Longman, R.J., *et al.* (2015) Sustained increases in lower-tropospheric subsidence over the Central Tropical North Pacific drive a decline in high-elevation rainfall in Hawaii. *Journal of Climate*. 28(22): 8743–8759. See also: Zhang, C., *et al.* (2016) Dynamical downscaling of the climate for the Hawaiian Islands. Part II: Projection for the late 21st century. *Journal of Climate.* 29(23): 8333–8354.

40 Wang, G., *et al.* (2017) Continued increase of extreme El Niño frequency long after 1.5 °C warming stabilization. *Nature Climate Change*. 7(8): 568–572. See also: Cai, W., *et al.* (2014) Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change*. 5(2): 1–6.

41 Chen, Y.R. and Chu, P.-S. (2014) Trends in precipitation extremes and return levels in the Hawaiian Islands under a changing climate, *International Journal of Climatology*, 34, 3913-3925, DOI: 10.1002/joc.3950

and are migrating poleward.[42] On Kauaʻi and across Hawaiʻi, extreme precipitation events are more frequent in La Niña years and less frequent in El Niño years.[43] The frequency and intensity of large El Niño and La Niña events is projected to increase bringing more extreme weather to Hawaiʻi and Kauaʻi.[44]

10. **Compound Events** - The probability of compound events such as hurricanes followed by heat waves, and the co-incidence of intense rain-king tide-and large swell are increasing.[45]

11. **Heat** - Human communities globally are experiencing increased heat stress, and extreme weather events.[46] State-wide, there has been an increase in air temperature with growth in record-setting hot days, rising urban heat, increased general heat stress, and increases in compound heat and humidity.[47]

12. **Winds** - The frequency of Hawaiian northeast trade wind days has decreased, and the frequency of east trade winds has increased.[48] Changes in wind direction from NE to E bring warmer air than in the past and interact with ridgelines in ways that reduce precipitation.[49]

13. **Wildfire** – Wildfire frequency & size has increased,[50] often related to invasive grasses that act as tinder and fuel.[51]

14. **Ecosystems** - Land and ocean *ecosystem* impacts associated with changes in precipitation, water availability, ambient temperature, ocean acidification and sea surface warming, extreme events, disease, and recovery time are numerous and widespread.[52]

Table ES-1 provides a list of key observed and projected climate change hazards and threats to Kauaʻi.

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[42] Sharmila, S., and Walsh, K.J.E. (2018) Recent poleward shift of tropical cyclone formation linked to Hadley cell expansion. *Nature Clim Change* 8, 730–736. https://doi.org/10.1038/s41558-018-0227-5
[42] Kossin, J.P., *et al.* (2020) Global increase in major tropical cyclone exceedance probability over the past four decades. *PNAS*, DOI: 10.1073/pnas.1920849117
[43] Chen, Y. R., P.-S. Chu (2014)
[44] Cai, W., *et al.* (2014) Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change*. 5(2): 1–6.
[45] December 6, 2021: National Weather Service, https://twitter.com/WMO/status/1468530412163149824
[46] IPCC, 2021, SPM
[47] Keener, V., *et al.* (2018)
[48] Garza, J. A., P.-S. Chu, C. W. Norton, and T. A. Schroeder (2012), Changes of the prevailing trade winds over the islands of Hawaii and the North Pacific, J. Geophys. Res., 117, D11109, doi:10.1029/2011JD016888.
[49] Marra, J.J. & Kruk, M.C. (2017) State of Environmental Conditions in Hawaiʻi and the U.S. Affiliated Pacific Islands under a Changing Climate: https://coralreefwatch.noaa.gov/satellite/publications/state_of_the_environment_2017_hawaii-usapi_noaa-nesdis-ncei_oct2017.pdf.
[50] Trauernicht, C., *et al.* (2015) The Contemporary Scale and Context of Wildfire in Hawaiʻi. Pacific Science, v. 69, no 4, October, pp. 427–444. https://doi.org/10.2984/69.4.1
[51] Trauernicht, Clay, & Elizabeth Pickett (2016) Pre-fire planning guide for resource managers and landowners in Hawaiʻi and Pacific Islands, Forest and Natural Resource Management, College of Tropical Agriculture and Human Resources, https://www.ctahr.hawaii.edu/oc/freepubs/pdf/RM-20.pdf
[52] Keener, V., *et al.* (2018)

Table ES - 1. Historical and Expected Climate Hazards on Kauaʻi

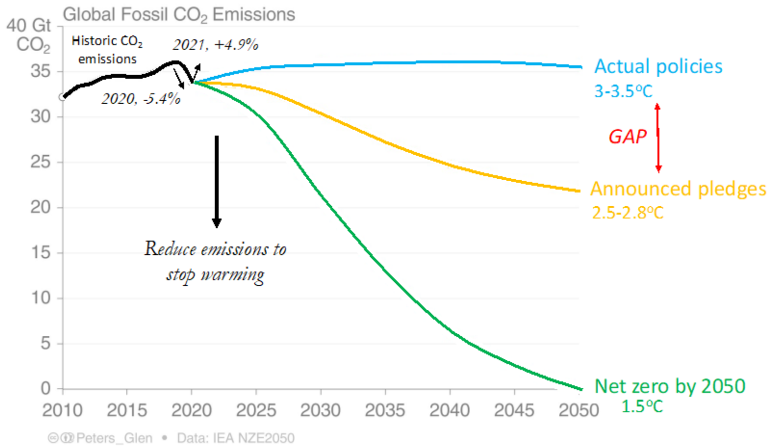
Climate Hazard	Past Trend	Future Trend	Confidence
Average Rainfall	↓ Declining (last 100 years)	↓ Decreasing wet and dry season rain	High
Heavy Rainfall Events	↑ Increasing (last 100 years)	↑ Increasing	Moderate
Drought	↑ Increasing length	↑ Increasing with changing rainfall and temperature	Moderate
Stream flow	↓ Decreasing (last 20 years)	↓ Decreasing with declining rainfall	Moderate
Wildfire	↑ Increasing (last 50 years)	↑ Increasing with changing rainfall and temperature	High
Average Temperature	↑ Increasing (last 70 years)	↑ Increasing	High
Warm Days & Nights	↑ Increasing (last 45 years)	↑ Increasing	High
Trade Winds	↓ Decreasing, turning easterly	↑ Continuing	Moderate
Sea Level Rise	↑ Increasing (last 65 years)	↑ Increasing	High
Tidal Flooding	↑ Increasing	↑ Increasing with higher SLR	High
Tropical Cyclones	↑ Increasing (last 40 years)	↑ Increasing	Moderate
Marine Heatwaves	↑ Increasing (last 40 years)	↑ Increasing	High
Global Disease	↑ Increasing (last 40 years)	↑ Increasing	High

1.2. GLOBAL PROGRESS IN MITIGATING EMISSIONS

In the 2015 Paris Climate Agreement,[53] parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed to stop global warming before 2ºC (3.6ºF) and pursue efforts to end warming before 1.5ºC (2.7ºF). To what degree is progress being made on these goals?

- To stop warming at 1.5ºC, GHG emissions must decrease 50% by 2030, and emissions must end by 2050 (**Figure ES-3**).[54]
- Updated national pledges cut emissions only 7.5% by 2030, leaving a 34% probability of staying below 2ºC and a 1.5% probability of staying below 1.5ºC.[55]
- As of the beginning of 2022, *national pledges* under the Paris Agreement put the climate on track to warm 2.5 to 2.8ºC (4.5 to 5ºF) globally by the end of the century.[56]
- *National energy policies* put the climate on track to warm 3 to 3.5ºC (5.4 to 6.3ºF) by 2100.[57]
- On average, global GHG emissions are underreported by 23%.[58] Global emission assessments generally underestimate future temperature pathways.
- The terrestrial biome, historically responsible for sequestering over 30% of human-made CO_2 emissions, is nearing, and has already temporarily crossed, a photosynthetic maximum and is projected to grow increasingly unstable potentially losing 50% capacity as a carbon sink by 2040.[59]
- Global GHG emissions dipped 5.4% in 2020 and rebounded 4.9% in 2021, reaching 36.4 $GtCO_2$, only 0.8% below their pre-pandemic high of 36.7 $GtCO_2$ in 2019.[60]

Figure ES - 3. Global Fossil CO_2 Emissions



Global fossil CO_2 emissions and temperature projections based on national policies (blue), UNFCCC pledges (yellow), and modeled pathway to limit warming to 1.5ºC.

Source: International Energy Agency (2021)

[53] The Paris Agreement is a binding international treaty on climate change adopted by 196 Parties at COP 21 in Paris on 12 December 2015 and entered into force on 4 November 2016: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[54] International Energy Agency (2021) Net Zero by 2050: https://www.iea.org/reports/net-zero-by-2050
[55] Ou, Y., *et al.* (2021) Can updated climate pledges limit warming well below 2ºC? *Science*, 5Nov, v374, Iss.6568, DOI:10.1126/science.abl8976
[56] UNEP (11/4/21) Addendum to Emissions Gap Report: https://wedocs.unep.org/bitstream/handle/20.500.11822/37350/AddEGR21.pdf
[57] Ibid.
[58] Mooney, C., *et al.* (Nov. 7, 2021) Countries' climate pledges built on flawed data, Post investigation finds; Washington Post, https://www.washingtonpost.com/climate-environment/interactive/2021/greenhouse-gas-emissions-pledges-data/
[59] Duffy, K.A., *et al.* (2021) How close are we to the temperature tipping point of the terrestrial biosphere? *Science Advances*, v.7no.3, DOI: 10.1126/sciadv.aay1052
[60] Friedlingstein, P., *et al.* (2021) Global Carbon Budget 2021, *Earth Syst. Sci. Data Discuss*. [preprint], https://doi.org/10.5194/essd-2021-386, in review.

2. Kauaʻi Climate Hazards

2.1. INTRODUCTION

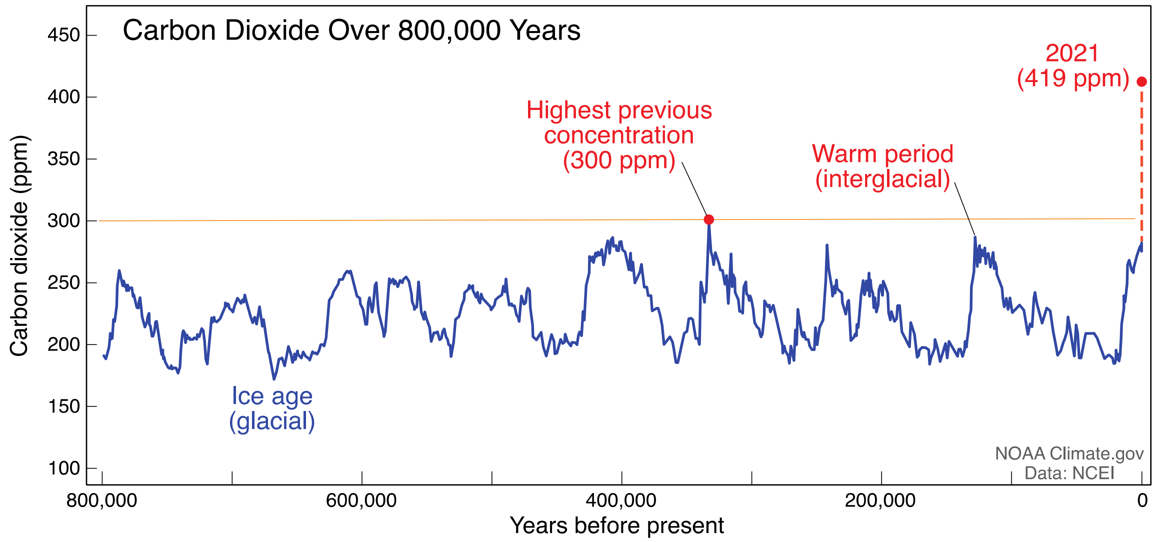
Scientists worked out the basic physics of Earth's climate in the 1800's[61] and made the first quantitative prediction of *global warming* in 1896[62] from the combustion of *fossil fuels* and the release of *carbon dioxide* (CO_2). Although CO_2 makes up just a small fraction of the atmosphere, it is effective at trapping some of the planet's heat before it escapes into space. This warms the air which increases *humidity*. *Water vapor* (H_2O) is even more effective at trapping heat than CO_2, leading to an *amplifying feedback* that raises Earth's surface temperature. This phenomenon has been named the *greenhouse effect*.

A natural greenhouse effect is why Earth, so far from the Sun, has liquid water and life, without it the average surface temperature would be below freezing and life as we know it would not be possible. During the *Industrial Revolution*, people burned increasing volumes of coal and other fossil fuels to power factories, smelters and steam engines, which added more *greenhouse gases* (GHG) to the atmosphere and increased the natural greenhouse effect. We call this enhanced effect *global warming* and the resulting impacts of global warming are called *climate change*.

For most of human history, the amount of CO_2 in the troposphere, the lowest layer of Earth's atmosphere, remained in a stable range between 260 to 280 parts per million (ppm).[63] However, during the past 200 years, increased combustion of fossil fuels, cement production, deforestation, and other human activities that produce GHG's[64] have raised the average concentration of CO_2 in the atmosphere. A record 419 ppm[65] was measured in 2021 – higher than any time in at least 800,000 years.[66] Notably, more than half of all human emissions of CO_2 have occurred since 1988, a period in which the occurrence, causes, and impacts of climate change have been widely known and understood.[67]

[61] Foote, E. (1856) Circumstances affecting the heat of the Sun's rays: Art. XXXI, *The American Journal of Science and Arts*, 2nd Series, v. XXII/no. LXVI, November, p. 382-383. https://ia800802.us.archive.org/4/items/mobot31753002152491/mobot31753002152491.pdf
[62] Arrhenius, S. (1896) XXXI. On the influence of carbonic acid in the air upon the temperature of the ground, *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 41:251, 237-276, DOI: 10.1080/14786449608620846
[63] Lourantou, A., *et al.* (2010) Changes in Atmospheric CO_2 and Its C Isotopic Ratio During the Penultimate Deglaciation, 29 *QSR*,1983.
[64] Friedlingstein, P., *et al.* (2020) Global Carbon Budget 2020, *Earth Syst. Sci. Data*, 12, 3269–3340, https://doi.org/10.5194/essd-12-3269-2020
[65] NOAA Global Monitoring Laboratory (2021) Trends in Atmospheric Carbon Dioxide, https://gml.noaa.gov/ccgg/trends/weekly.html
[66] Masson-Delmotte, V., *et al.* (2013) Information from Paleoclimate Archives. In: *Climate Change 2013: The Physical Science Basis.* Contribution WG I to AR5, IPCC [Stocker, T.F., et al. (eds.)] Cambridge University Press, Cambridge, UK and New York, NY, USA.
[67] Frumhoff, P.C., *et al.* (2015) The climate responsibilities of industrial carbon producers. *Climatic Change* 132, 157–171, https://doi.org/10.1007/s10584-015-1472-5

Figure 1: CO_2 concentrations over the last 800,000 years

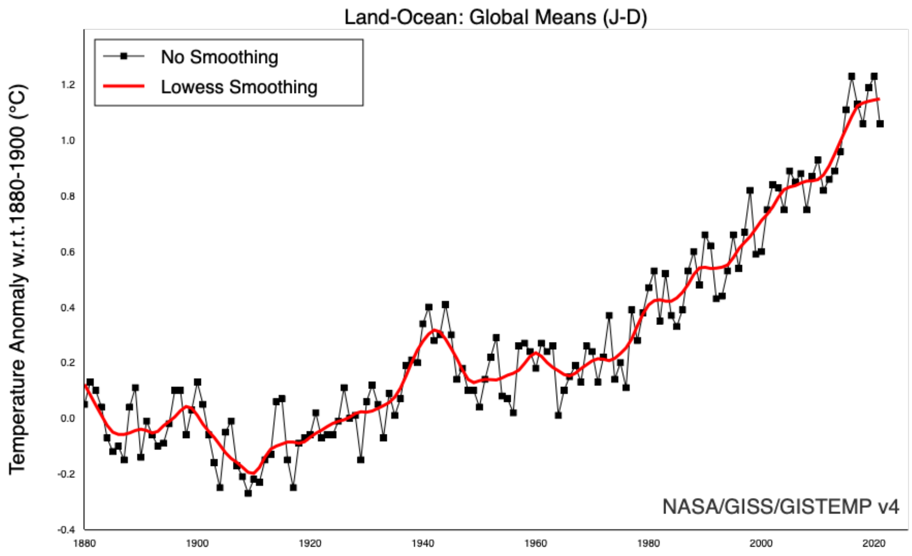


Geologic CO_2 levels from ice core data. Red Dot - peak 2021 concentration from Mauna Loa Observatory.

Source: Modified from NOAA

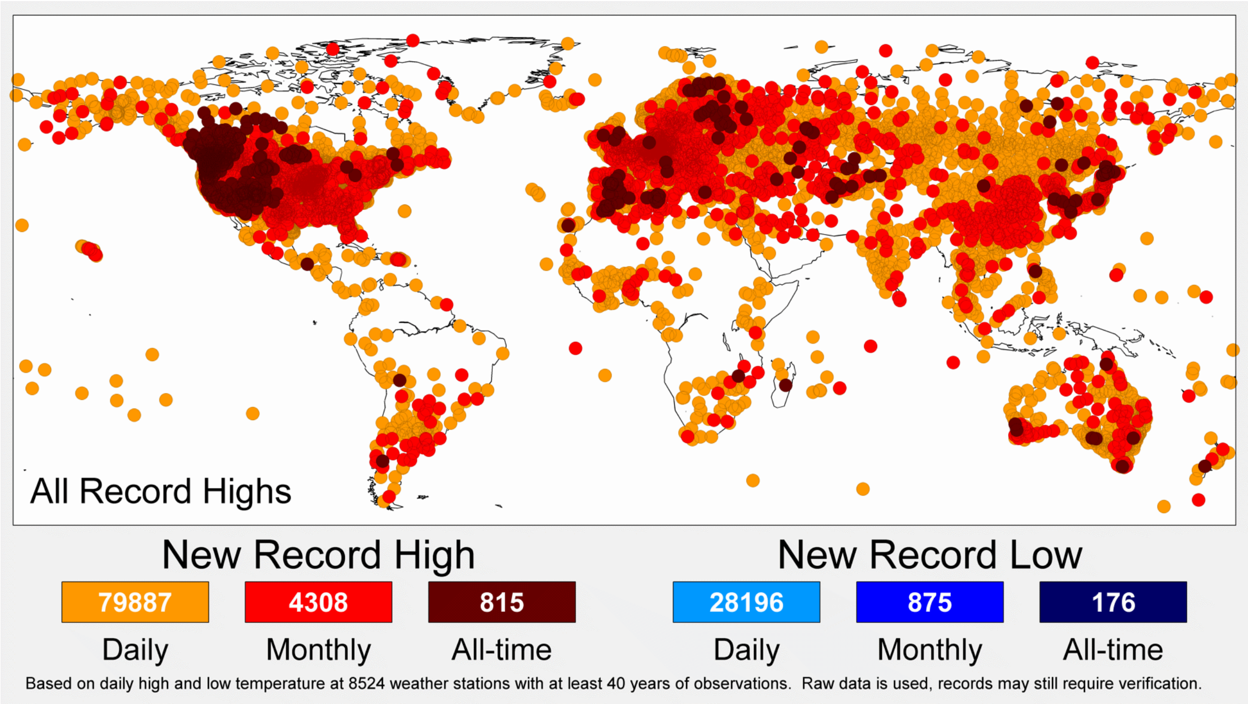
The global rise of GHG has continued to heat the planet. We know this is true thanks to an overwhelming body of evidence that begins with temperature measurements taken at weather stations and on ships starting in the mid-1800s. Now satellites and clues about climate change in geologic deposits add to the evidence. Together, these data all tell the same story: Earth's surface temperature is getting hotter (Figure 2).

Figure 2. Global Temperature since the late 1800's



Compared to the late 1800's, human GHG emissions have warmed average annual air temperature at Earth's surface 1.1 to 1.3ºC (2 to 2.3ºF).[68] Climate change is accelerating, and impacts are growing in frequency and magnitude. According to the 2021 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC),[69] it is *unequivocal* that human influence has warmed the atmosphere, ocean and land. As a result, widespread, unprecedented, and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. Land areas have warmed more than the sea surface and the Arctic has warmed the most — by more than 2.2ºC (4ºF) just since the 1960s. Temperature extremes have also shifted. Globally all-time record high temperatures exceeded all-time record low temperatures by more than 4 to 1 in 2021 (Figure 3).[70]

Figure 3. Long-term weather stations that saw new record high temperatures in 2021.



Given weather variability, it is normal to see both new highs and new lows, but due to global warming, new highs have become significantly more common than new lows. Earth's temperature has risen by 0.08ºC (0.14ºF) per decade since 1880, and the rate of warming over the past 40 years is more than twice that: 0.18ºC (0.32ºF) per decade since 1981.[71] The past seven years have been the hottest in recorded history, and global temperatures in 2021 were among the highest ever observed, with 25 countries setting new annual records. From 1900 to 1980, a new temperature record was set on average every 13.5 years; from 1981–2019, a new record was set every 3 years.[72]

[68] NASA *2021 Tied for Sixth Warmest Year in Continued Trend, NASA Analysis Shows*, https://www.giss.nasa.gov/research/news/20220113/; See also Global Warming index, https://www.globalwarmingindex.org
[69] IPCC (2021) SPM
[70] https://twitter.com/RARohde/status/1490991224198955009.
[71] NOAA Climate Change: Global Temperature, https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
[72] Ibid.

2.2. GLOBAL CLIMATE CHANGE IMPACTS

Raising Earth's surface temperature[73] has led to devastating consequences that threaten human habitability, especially in the tropics and the Arctic.[74] Global warming risks food[75] and water[76] availability with the global land area and human population in conditions of extreme to exceptional drought more than doubling by 2100 under a scenario of continued emissions. Climate change threatens natural ecosystems that provide life-sustaining resources,[77] human security,[78] and livable conditions for human communities.[79]

With only 1.2°C (2.16°F) of warming, we see nearly one-third of the world population exposed to deadly heat waves,[80] a nine-fold increase in large North American wildfires,[81] animal and plant extinctions projected to increase 2 to 5-fold in coming decades,[82] and a weakened global ecosystem,[83] described in one paper with over 15,000 co-authors, as "pushed to its breaking point."[84]

We have now increased the CO_2 level of the atmosphere by 50% compared to the eighteenth century.[85] As Earth warms, polar ice is melting faster and faster. The global nature of glacier retreat, with almost all of the world's glaciers retreating synchronously since the 1950s, is unprecedented in at least the last 2000 years.[86] This is especially true in the Arctic. Greenland has started losing ice seven times faster than it did in the 1990s,[87] and between July 30 and Aug. 2, 2019, approximately 90% of the surface of Greenland's ice sheet melted, causing about 55 billion tons of ice to melt into the ocean.[88] There is concern that with less than 0.5°C (0.9°F) of additional warming, melting on the Greenland ice sheet will become unstoppable.[89]

Arctic Sea ice is in free-fall (Figure 4). Sea ice is Earths refrigeration system as the white surface reflects sunlight back to space. But as the snow and ice are replaced by the dark water of the Arctic Ocean, the rate of warming in the Arctic has quadrupled compared to the rest of the planet.[90] In 1985, 33% of Arctic ice pack was

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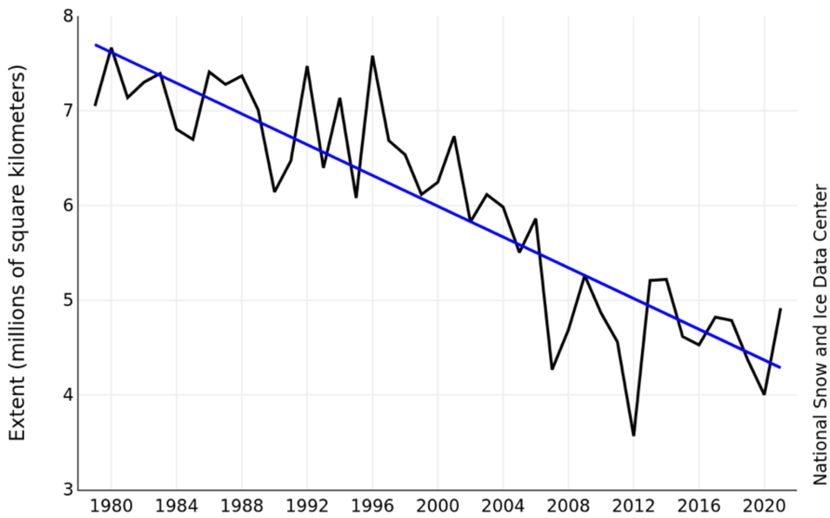
73 Haustein, K. *et al.* (2017) A global warming index. *Nature Scientific Reports*, doi:10.1038/s41598-017-14828-5
74 Xu, C., *et al.* (2020) Future of the human climate niche. *PNAS* May, 117 (21) 11350-11355; DOI: 10.1073/pnas.1910114117
75 Belay, T. (2021) Impact of Climate Change on Food Availability—A Review. *International Journal of Food Science and Agriculture*, 5(3), 465-470. DOI: 10.26855/ijfsa.2021.09.017
76 Pokhrel, Y., *et al.* (2021) Global terrestrial water storage and drought severity under climate change. *Nat. Clim. Chang.* 11, 226–233. https://doi.org/10.1038/s41558-020-00972-w
77 Nolan, C., *et al.* (2018) Past and future global transformation of terrestrial ecosystems under climate change. *SCIENCE*, 31 Aug., doi: 10.1126/science.aan5360
78 Brock, S., *et al.* (2021) The World Climate and Security Report 2021. Expert Group of the International Military Council on Climate and Security. Sikorsky, E. and Femia, F. (eds) Center for Climate and Security, an institute of the Council on Strategic Risks. June.
79 Clement, V., *et al.* (2021) Groundswell Part 2: Acting on Internal Climate Migration. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/36248 License: CC BY 3.0 IGO.
80 Mora, C., *et al.* (2017) Global risk of deadly heat, *Nature Climate Change*; DOI: 10.1038/NCLIMATE332
81 Abatzoglou, J.T., Williams, A.P. (2016) Impact of Human-made climate change on wildfire across western U.S. forests. *PNAS*; 201607171 doi: 10.1073/pnas.1607171113
82 Wiens, J.J. (2016) Climate-related local extinctions are already widespread among plant and animal species, *PLOS Biology*, 14(12), e2001104, doi: 10.1371/journal.pbio.2001104
83 Diaz, S., *et al.* (2019) Pervasive human-driven decline of life on Earth points to the need for transformative change, *Science*, 13 Dec., v. 366, iss. 6471, https://doi.org/10.1126/science.aax3100
84 Ripple, W.J., *et al.* (2017) World Scientists' Warning to Humanity: A Second Notice. *BioScience*. DOI: 10.1093/biosci/bix125
85 UK MET Office (2021) https://www.metoffice.gov.uk/research/climate/ seasonal-to-decadal/long-range/forecasts/co2-forecast-for-2021
86 Ibid.
87 Shepherd, A., *et al.* (2019) Mass balance of the Greenland Ice Sheet from 1992 to 2018. *Nature*. https://doi.org/10.1038/s41586-019-1855-2
88 National Snow and Ice Data Center (2019) Europe's warm air spikes Greenland melting to record levels, http://nsidc.org/greenland-today/2019/08/europes-warm-air-spikes-greenland-melting-to-record-levels/
89 Climate tipping points—too risky to bet against Nature (2019) https://nature.com/articles/d41586-019-03595-0
90 https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/898204.

very old ice (>4 years old), by March 2019 old ice constituted only 1.2% of the ice pack in the Arctic Ocean.[91] In 2011–2020, annual average Arctic Sea ice area reached its lowest level since at least 1850.[92] Late summer Arctic Sea ice area was smaller than at any time in at least the past 1000 years.[93] Reductions in Arctic Sea ice, regional snow cover, and permafrost grow annually, and the transition from a snow- to rain-dominated Arctic in the summer and autumn may occur as early as 2040, with profound climatic, ecosystem and socio-economic impacts.[94]

Figure 4. Average Monthly Arctic Sea Ice Extent (Sept. 1979 - 2021)



September sea ice extent has declined 12.7% per decade relative to the 1981 to 2010 average. September marks the month of the largest linear trend in ice extent, both in absolute terms and percentage loss. Overall, since 1979, September has lost 3.49 million km² (1.35 million mi²) of ice, based on the linear trend values. This is equivalent to about twice the size of Alaska. Source: Arctic Sea Ice News and Analysis (2021)

2.2.1. Future Global Impacts

The extent and characteristics of future climate change depend in part on the amount of Human-made GHG emissions now and in the future, and on *climate feedbacks* that can either amplify (a positive feedback) or diminish (a negative feedback) the effects of GHG emissions. Reports from the IPCC have concluded that the combined effects of all feedbacks are likely to be significantly positive.[95] Additionally, scientists have expressed concern that self-reinforcing feedbacks in the climate system could push Earth toward a planetary threshold beyond which the climate cannot be stabilized at intermediate temperatures.[96]

Human emissions are driven by economic development, extractive land use, transportation and energy systems, and other social, economic, and political factors. As such, climate scientists cannot be certain how emissions and the climate will change in the future. To reduce this uncertainty, scientists use numerical models to simulate specific socio-economic futures and assess their impact on global climate processes.

[91] Perovich, D., *et al.* (2019) Sea Ice. *NOAA Arctic Report Card 2019*, J. Richter-Menge, M. L. Druckenmiller, and M. Jeffries, Eds., http://www.arctic.noaa.gov/Report-Card.
[92] IPCC (2021) SPM
[93] Ibid.
[94] McCrystall, M.R., *et al.* (2021) New climate models reveal faster and larger increases in Arctic precipitation than previously projected. *Nat Commun* 12, 6765 https://doi.org/10.1038/s41467-021-27031-y
[95] IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
[96] Steffen, W., *et al.* (2018)

GHG Emissions

Scientists use model scenarios of socio-economic global changes up to 2100 called *shared socio-economic pathways* (SSPs). These are used to project GHG emissions under different policies and from there derive a future climate. The scenarios are: SSP1: Sustainability, SSP2: Middle of the Road, SSP3: Regional Rivalry, SSP4: Inequality, SSP5: Fossil-fueled Development. Each SSP is a logical quantitative description that relates national populations, urbanization, and per capita GDP. Each SSP explores possible future pathways of socio-economic activity, climate, policies, and other social and physical factors. The latest modeling was published in IPCC Assessment Report 6 (Figure 5).[97]

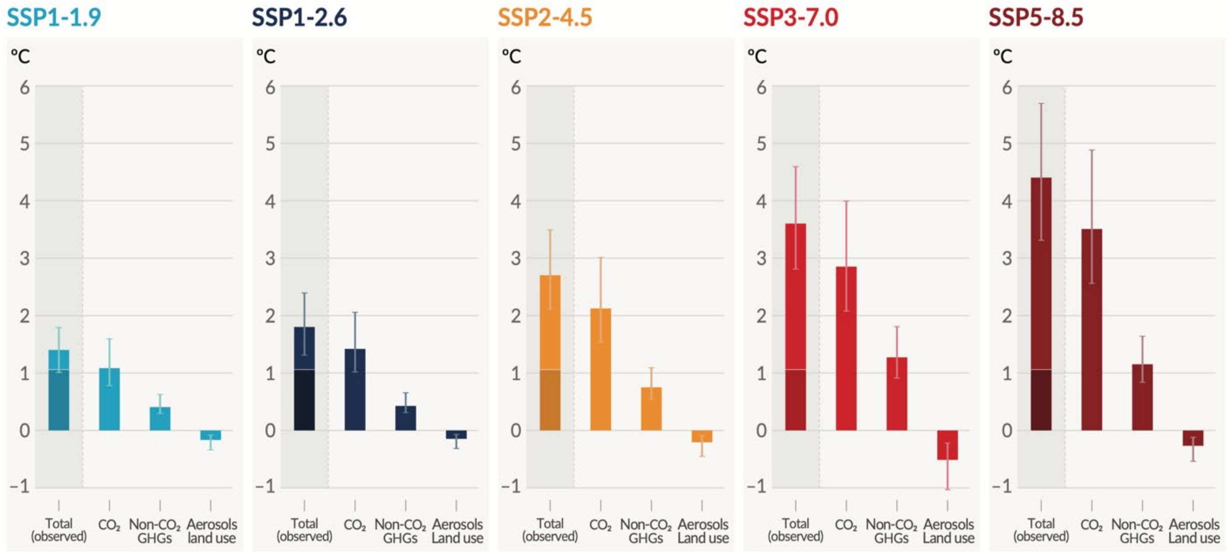


Figure 5. Warming Contributors by Groups of Human-made Drivers by SSP Scenario

Warming contributions by groups of Human-made drivers and by SSP scenario, shown as the change in global surface temperature (°C) in 2081–2100 relative to 1850–1900, with indication of the observed warming to date. Bars and whiskers represent median values and the "very likely" range, resp. Within each scenario bar plot, the bars represent: total global warming (°C, 'total' bar); warming contributions (°C) from changes in CO_2 ('CO_2' bar) and from non-CO_2 greenhouse gases (GHGs, 'non-CO_2 GHGs' bar: comprising well-mixed greenhouse gases and ozone); and net cooling from other Human-made drivers ('aerosols and land use' bar: Human-made aerosols, changes in reflectance due to land-use and irrigation changes, and contrails from aviation). The best estimate for observed warming in 2010–2019 relative to 1850–1900 is indicated in the darker column in the 'total' bar.[98] *Source: IPCC (2021)*

[97] IPCC (2021) SPM
[98] Ibid. Figure SPM.4, p. 13

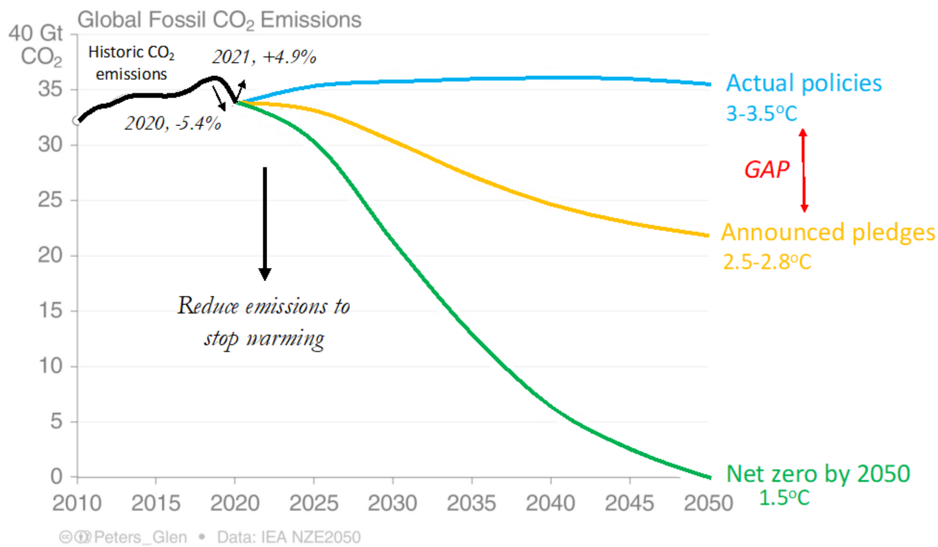
In the 2015 Paris Climate Agreement,[99] parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed to stop global warming before 2°C (3.6°F), and pursue efforts to end warming before 1.5°C (2.7°F). In 2018, the IPCC[100] published *Global Warming of 1.5°C*[101] from which the world learned that warming from the pre-industrial period to the present will persist for centuries to millennia with increases in severe impacts to human communities, threats to global security and world trade, increased human inequality, damage to global terrestrial and marine ecosystems, and increased extreme weather events including drought, heat waves, and flooding.

Following the 2018 report, the default target for reducing emissions became 1.5°C (2.7°F). What is the emissions pathway to this goal, and to what extent is progress being made?

- To stop warming at 1.5°C, emissions must decrease 50% by 2030, and end by 2050 (Figure 6).[102]
- Updated national pledges only cut emissions 7.5% by 2030, leaving a 34% probability of staying below 2°C and a 1.5% probability of staying below 1.5°C.[103]
- As of the beginning of 2022, national pledges under the Paris Agreement put the climate on track to warm 2.5 to 2.8°C (4.5 to 5°F) globally by the end of the century.[104]
- Publicly stated energy policies put the climate on track to warm 3 to 3.5°C (5.4 to 6.3°F) by 2100.[105]
- On average, global emissions are underreported 23%,[106] and therefore these pledges and policies generally represent underestimates of future temperature.
- The terrestrial biome, historically responsible for sequestering about 30% of Human-made CO_2 emissions, is nearing a photosynthetic maximum and projected to grow increasingly unstable potentially losing 50% capacity as a carbon sink by 2040.[107]
- Emissions dipped 5.4% in 2020 and have rebounded 4.9% in 2021, reaching 36.4 $GtCO_2$, only 0.8% below their pre-pandemic high of 36.7 $GtCO_2$ in 2019.[108]

[99] The Paris Agreement is a binding international treaty on climate change adopted by 196 Parties at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[100] The IPCC is an organization of governments that are members of the United Nations Environmental Program or the World Meteorological Organization. The IPCC has 195 members. The objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies. IPCC reports are also a key input into international climate change negotiations, https://www.ipcc.ch/about/
[101] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., et al. (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.
[102] International Energy Agency (2021) Net Zero by 2050: https://www.iea.org/reports/net-zero-by-2050
[103] Ou, Y., *et al.* (2021) Can updated climate pledges limit warming well below 2°C? *Science*, 5Nov, v374, Iss.6568, DOI:10.1126/science.abl8976
[104] UNEP (11/4/21) Addendum to Emissions Gap Report: https://wedocs.unep.org/bitstream/handle/20.500.11822/37350/AddEGR21.pdf
[105] Ibid.
[106] Mooney, C., *et al.* (Nov. 7, 2021) Countries' climate pledges built on flawed data, Post investigation finds; Washington Post, https://www.washingtonpost.com/climate-environment/interactive/2021/greenhouse-gas-emissions-pledges-data/
[107] Duffy, K.A., *et al.* (2021) How close are we to the temperature tipping point of the terrestrial biosphere? *Science Advances*, v.7no.3, DOI: 10.1126/sciadv.aay1052
[108] Friedlingstein, P., *et al.* (2021)

Figure 6. Global Fossil CO2 Emissions



Global fossil CO_2 emissions and temperature projections based on national policies (blue), UNFCCC pledges (yellow), and modeled pathway to limit warming to 1.5°C. Source: International Energy Agency (2021)

2.2.2. Abrupt Change and Global Context

Scientists speculate[109] that because of Human-made warming, certain aspects of future climate may be beyond our control. Some major global bio-physical systems (e.g., West Antarctic Ice Sheet and Shelves) show early indications of abrupt, potentially irreversible change that could accelerate many climate change impacts (Table 1). This would mean that, despite efforts to mitigate GHG emissions, some aspects of planetary climate change may become self-actuated and continue on their own, placing global security and socio-economic structures at risk, possibly beyond our control.[110]

According to the IPCC AR6,[111] the way that the Earth system is responding to warming is currently

> "*…proportionate to the rate of recent temperature change*", but "*…some aspects may respond disproportionately*".[112]

There is evidence of abrupt change in Earth history that was associated with significant changes in the global climate, such as deglaciations when an ice age came to an end. According to AR6

> *"Such events changed the planetary climate for tens to hundreds of thousands of years, but at a rate that is actually much slower than projected Human-made climate change over this century, even in the absence of tipping points."*

Paleoclimate evidence has fueled concern that continued emission of GHGs could tip the global climate into a permanent hot state. However, IPCC-AR6 counters this thinking

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[109] Lenton, T., *et al.* (2019) Climate tipping points – too risky to bet against. *Nature*, 575, 592-595: https://doi.org/10.1038/d41586-019-03595-0
[110] Steffen, W., *et al.* (2018)
[111] IPCC (2021) SPM
[112] CarbonBrief (2021) In-depth Q&A: The IPCC's sixth assessment report on climate science, https://www.carbonbrief.org/in-depth-qa-the-ipccs-sixth-assessment-report-on-climate-science

> *"…there is no evidence of such non-linear responses at the global scale in climate projections for the next century, which indicate a near-linear dependence of global temperature on cumulative GHG emissions."*

Nonetheless, the report notes with *high confidence* that abrupt responses and tipping points in the climate system

> "*…cannot be ruled out*" and that it is *virtually certain* that "*irreversible, committed change is already underway for the slow-to-respond processes as they come into adjustment for past and present emissions*".

The report states:

> *"For global climate indicators, evidence for abrupt change is limited, but deep ocean* ***warming***, ***acidification***, *and* ***sea level rise*** *are committed to ongoing change for millennia after global surface temperatures initially stabilize and are* <u>*irreversible on human time scales*</u> *(very high confidence)."*

Table 1: Earth system components susceptible to abrupt change, irreversibility, and projected 21st Century change[113]

Earth System Component	Potential Abrupt Change?	Irreversibility	21st Century Change with Continued Warming
Global Monsoon	Yes w/AMOC[114] collapse, medium confidence	Reversible within years to decades, medium confidence	Medium confidence, Global monsoon increase; Asian-African strengthening & North American weakening
Tropical Forest	Yes, Low confidence	Irreversible for many decades, medium confidence	Medium confidence, Decreasing carbon storage depending on human disturbance
Boreal Forest	Yes, Low confidence	Irreversible for many decades, medium confidence	Medium confidence, Offsetting lower latitude dieback & poleward extension depending on human disturbance
Permafrost Carbon	Yes, High confidence	High confidence	Virtually certain, Decline in frozen carbon; Low confidence in net carbon change
Arctic Summer Sea Ice	No, high confidence	Reversible within years to decades, High confidence	Likely complete loss

[113] Lee, J. Y., *et al.* (2021) Future Global Climate: Scenario-Based Projections and Near-Term Information. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press. In Press.
[114] AMOC – Atlantic Meridional Overturning Circulation, also known as the conveyor belt current of the North Atlantic.

Arctic Winter Sea Ice	Yes, High confidence	Reversible within years to decades, High confidence	High confidence in moderate winter declines
Antarctic Sea Ice	Yes, Low confidence	Unknown, Low confidence	Low confidence in moderate winter and summer declines
Greenland Ice Sheet	No, High confidence	Irreversible for millennia, High confidence	Virtually certain mass loss under all scenarios
West Antarctic Ice Sheet and Shelves	Yes, High confidence	Irreversible for decades to millennia, High confidence	Likely mass loss under all scenarios; Deep uncertainty in projections above 3°C
Global Ocean Heat Content	No, High Confidence	Irreversible for centuries, very high confidence	Very high confidence oceans will continue to warm
Global Sea Level Rise	Yes, High confidence	Reversible within years to decades, High confidence	High confidence in moderate winter declines
Atlantic Overturning Circulation (AMOC)	Yes, Medium confidence	Reversible within centuries, High confidence	Very likely decline; Medium confidence of no collapse
Southern Overturning Circulation (MOC)	Yes, Medium confidence	Reversible within decades to centuries, Low confidence	Medium confidence in decrease in strength
Ocean Acidification	Yes, High confidence	Reversible at surface; irreversible for centuries to millennia at depth, very high confidence	Virtually certain to continue with increasing CO_2; Likely polar aragonite undersaturation
Ocean Deoxygenation	Yes, High confidence	Reversible at surface; irreversible for centuries to millennia at depth, very high confidence	Medium confidence in deoxygenation rates and increased hypoxia

2.3. CLIMATE SHOCKS AND STRESSORS

The impacts of climate change can be broadly categorized into those that happen suddenly, a *shock*, and those that happen gradually, a *stressor* (Table 2). Climate change brings to the County of Kauaʻi both shocks and stressors related to an accelerated water cycle. Climate-related shocks are rapidly developing, high impact events such as hurricanes, wildfires, heat waves, and extreme rainfall. Climate-related stressors are persistent, slowly developing negative influences, such as sea level rise that exacerbates chronic coastal erosion and flooding, rising ambient heat, expanding drought, and declining rainfall.

Table 2: Climate Change Shocks & Stressors in Hawaiʻi.[115] To the extent that shocks and stresses are related, they are listed within the same row.

Shocks	Stressors
Tropical Cyclones (TC) – Rising intensity, high winds, waves, storm surge, heavy rainfall & flooding, shifting into Hawaiian waters[116]	
Extreme Rainfall and Flooding – Increasing frequency, floods & "brown water" alerts[117]	**Declining Precipitation** - Stress to aquifer recharge, watershed & forest ecology, streams & aquatic ecosystems, increasing aridity, new wildfire-prone land, Ag. impacts[118]
Drought - Temperatures are expected to increase, drought severity and frequency will increase because of increased evaporation. Already-dry, drought-prone leeward areas are projected to become drier and at high risk for future drought.	
Landslides and Rock Falls – Related to extreme rainfall and localized geology and topography[119]	**Soil Erosion** – Especially heavy rainfall events, cumulative impact to aquatic ecosystems and coastal water quality
High Winds[120] (Not TC) –Windstorms, local topography can create especially vulnerable "wind speed-up" areas[121]	**Declining Trade Winds**[122] - Poor air circulation & quality, physical discomfort, reduced renewable energy capacity
Heat Waves[123] – More days with high temperature; impacts to health, transportation, energy, agriculture, and construction sectors	**Rising Heat Stress** – Amplifies urban heat island effect, increased power demand, physical discomfort; increasing health problems with elderly, ill and young
Wildfire[124]– Burned area has increased over 4x in the past century, fire propagates rapidly in dry nonnative grasslands	**Growing Aridity** – Increasing wildfire & associated costs (personnel, air quality), impacts food production & native ecosystems
Extreme Tides – coastal erosion, increased high tide flooding, high surf, damage from tsunami & storm surge increased[125]	**Sea Level Rise & Chronic Coastal Erosion** – Rising demand for seawalls & retreat strategies, at-risk buried infrastructure, drainage failure, polluted groundwater, flooding[126]

[115] Honolulu Climate Change Commission (2020) Climate change financial risk: https://resilientoahu.org/climate-change-commission/#guidance
[116] Widlansky, M. J., *et al.* (2018) Tropical Cyclone Projections: Changing Climate Threats for Pacific Island Defense Installations. Weather, Climate, and Society, 11(1), 3–15. https://doi.org/10.1175/WCAS-D-17-0112.1
[117] Keener, V., *et al.* (2018)
[118] Ibid.
[119] Stephen D. E., *et al.* (1995) Relation of slow-moving landslides to earth materials and other factors in valleys of the Honolulu District of Oahu, Hawaii. *USGS Open-File Report 95-218*. https://pubs.usgs.gov/of/1995/0218/report.pdf
[120] https://www.staradvertiser.com/2019/02/09/breaking-news/weekend-storm-to-bring-damaging-winds-and-destructive-surf-to-hawaii/
[121] https://dod.hawaii.gov/hiema/files/2018/06/Draft-Section-4.10-High-Wind-Storms.pdf
[122] Chu, P.-S. (2002). Large-Scale Circulation Features Associated with Decadal Variations of Tropical Cyclone Activity over the Central North Pacific. *Journal of Climate*, 15(18), 2678.
[123] Keener, V., *et al.* (2018)
[124] Trauernicht, C., *et al.* (2015) Contemporary Scale and Context of Wildfire in Hawaiʻi. *Pac Sci*, 69(4), 427–444 https://doi.org/10.2984/69.4.1
[125] Keener, V., *et al.* (2018)
[126] Ibid.

Marine Heat Waves and Compound Events[127] – heat/deoxygenation/acidification, increasing frequency, regionally associated with El Niño	**Coral Bleaching** – Bleaching, reef collapse, impacts to fish & ecosystems, sea surface temperature & ocean acidification[128]
Compound Events - Tropical Cyclone + Heat Wave[129]; Tropical Cyclone + Wildfire[130] Extreme High Tide +Large Swell + Large-Scale Intense Precipitation; Multiple Large-Scale Wildfires	
El Niño (extreme) - frequency of events doubles under the 1.5^{o}C Paris target and continues to increase long after global temperatures stabilize due to emission reductions[131]	
Distant Events[132]- potential trade and supply-line interruptions with global impacts; Simultaneous Crop Failure,[133] Wheat, Maize, Soybean, Rice micronutrient losses; Saltwater flooding of major Ag areas (e.g., Mekong Delta); Blackouts at key west coast ports; Global trade reductions; Global disease	
Disease[134] - Rapidly warming climate is a threat to global public health. The risks to health of increases above 1.5°C are now well established. Indeed, no temperature rise is "safe." In the past 20 years, heat-related mortality among people over 65 years of age has increased by more than 50%. Higher temperatures have brought increased dehydration and renal function loss, dermatological malignancies, tropical infections, adverse mental health outcomes, pregnancy complications, allergies, and cardiovascular and pulmonary morbidity and mortality. Harms disproportionately affect the most vulnerable, including children, older populations, ethnic minorities, poorer communities, and those with underlying health problems	

Compound events are related to the overlap, or end to end sequencing of shocks. For example, a hurricane that produces damaging storm surge which partially incapacitates government services and exceeds the resilience capacity of local communities would be a disaster of significant scale. Potentially electrical, waste handling, freshwater, and transportation services might all become unavailable for a period of days to weeks. Because heat waves develop at the same time of the year as hurricanes, a heat wave developing in the aftermath of a hurricane constitutes a potential compound event in Hawaiʻi. In this case extreme daytime heat, in the absence of cooling evening and nightime temperatures (a projected reality[135]) can lead to mortality among the elderly, young, and ill in this compound event.

Climate impacts that affect Kauaʻi can be of distant origin, such as the simultaneous failure of two breadbaskets. The global food distribution system is sufficiently robust that a single breadbasket failure can be absorbed by its inherent resilience. However, the probability of two failures in one Northern Hemisphere summer is growing.[136] This would send shock waves across global trade with ripple effects leading to price spikes, food shortages, and enhanced potential for conflict in fragile communities. If the world continues on a

[127] Gruber, N., *et al.* (2021) Biogeochemical extremes and compound events in the ocean. *Nature* 600, 395–407, https://doi.org/10.1038/s41586-021-03981-7
[128] Ibid.
[129] Chen Y, *et al.* (2019) Half-a-degree matters for reducing and delaying global land exposure to combined daytime-nighttime hot extremes, *Earth's Future* 7 953–66
[130] Alison D. Nugent, *et al.* (2020) Fire and Rain: The Legacy of Hurricane Lane in Hawaiʻi. *Bulletin of the American Meteorological Society*; 101 (6): E954 DOI: 10.1175/BAMS-D-19-0104.1
[131] Chowdhury MR, Chu P-S. (2019) A study of the changing climate in the US-Affiliated Pacific Islands using observations and CMIP5 model output. *Meteorol Appl*.;1–14. https://doi.org/10. 1002/met.1781
[132] Gaupp, F., Hall, J., Hochrainer-Stigler, S. *et al.* (2020) Changing risks of simultaneous global breadbasket failure. Nat. Climate Change, 10, 54–57. https://doi.org/10.1038/s41558-019-0600-z
[133] Janetos, A., *et al.* (2017) The risks of multiple breadbasket failures in the 21st Century: A science research agenda, F. S. Pardee Center for the Study of the Longer-Range Future: https://www.bu.edu/pardee/files/2017/03/Multiple-Breadbasket-Failures-Pardee-Report.pdf
[134] https://www.nejm.org/doi/full/10.1056/NEJMe2113200?query=featured_home
[135] Chen Y, *et al.* (2019)
[136] Janetos, A., *et al.* (2017)

high GHG pathway that fails to hold warming to under 1.5ºC, there are almost no parts of the world where agriculture will be unaffected.[137]

2.4. CLIMATE CHANGE IMPACTS TO KAUAʻI

This review synthesizes existing scientific research relevant to developing an improved understanding of climate change hazards on Kauaʻi. However, Hawaiʻi, and Kauaʻi-specific data are limited. Thus, this is a living document that can incorporate additional data through the planning process. In addition, localized endemic knowledge can make a significant contribution to mitigation, adaptation, and sequestration efforts.

In light of the continued upward trajectory of global GHG emissions, Kauaʻi is facing unavoidable, costly, and dangerous impacts from climate change and the islands future socio-economic viability is at risk. The impacts of climate change fall disproportionately on vulnerable populations.[138] As an isolated, and remote group of islands without the capacity to exchange critical resources such as freshwater, food, or medical supplies with neighboring states, Hawai'i, and specifically Kauaʻi, are especially vulnerable to the impacts of climate change. Several major categories illustrate the breadth of risk to Hawaiʻi: Global change, Air temperature, Heat, Marine heat waves, Ocean warming and acidification, Trade winds, Drought, Wildfire, Precipitation, Streamflow, Tropical cyclones, Sea level rise, and Disease.

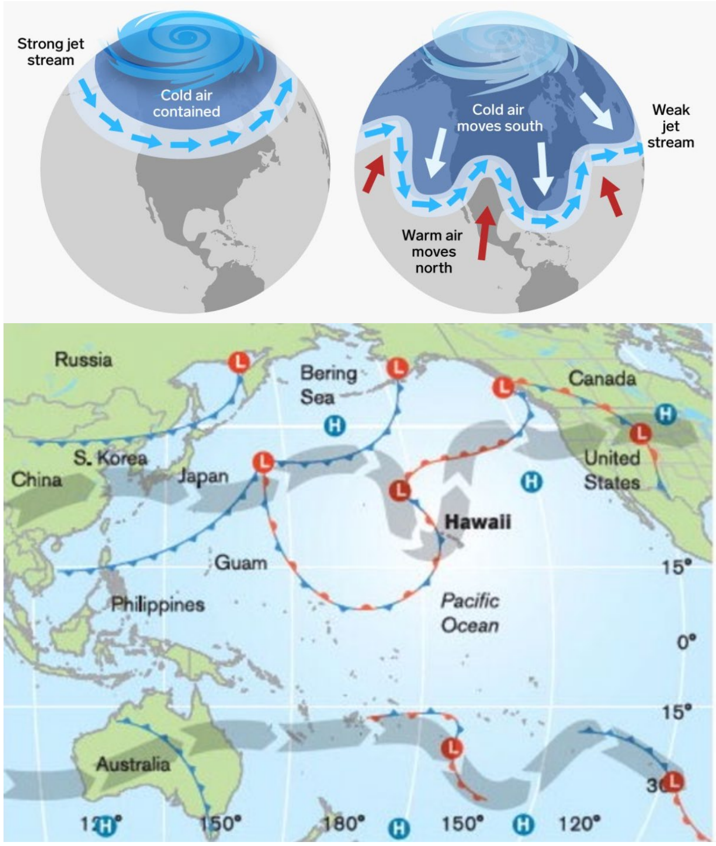
2.4.1. Global Change

Climate on the island of Kauaʻi is embedded in the larger Pacific and global climate systems. Changes in atmospheric circulation (e.g., the Polar Jet Stream), the ocean (e.g., North Pacific sea surface temperatures), and in bio-physical systems such as tropical forests, permafrost, and others, will be seen in varying degrees of intensity and impact, as changes in the climate on Kauaʻi as well.

For example, loss of Arctic summer sea ice drives Arctic Amplification[139] wherein the Arctic warms 4 times[140] faster than the global average. This reduces Northern Hemisphere atmospheric circulation which depends on regional differences (gradients) in temperature. The Polar Jet Stream has become unstable as a result and large southerly meanders in the jet stream may cause Kauaʻi to experience stormy weather. This is exactly the set of circumstances that occurred on December 6, 2021 when Lihue Airport recorded 8.3 cm (3.27 in) of rain, a record for that date. Figure 7 shows that a deep meander in the jet stream on that date was associated with that extreme weather event. This serves to illustrate the point that global and regional climate change can have meaningful localized impacts on the island of Kauaʻi, and Hawaiʻi in general.

[137] Jägermeyr, J., Müller, C., Ruane, A.C. *et al.* (2021) Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nat Food* 2, 873–885. https://doi.org/10.1038/s43016-021-00400-y
[138] UN (2020) World Social Report 2020: Inequality in a Rapidly Changing World, https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/01/World-Social-Report-2020-FullReport.pdf
[139] Previdi, M., *et al.* (2021) Arctic amplification of climate change: a review of underlying mechanisms, *Environmental Research Letters*, v16, n9, https://doi.org/10.1088/1748-9326/ac1c29
[140] https://public.wmo.int/en/media/press-release/wmo-recognizes-new-arctic-temperature-record-of-38ºc

Figure 7. Jet Streams and Extreme Weather Events



Top left – stable jet stream without Arctic Amplification. Top right – Unstable jet stream caused by Arctic Amplification. Bottom - Weather map December 6, 2021. A deep meander in the Polar Jet Stream (gray band) associated with record precipitation of 3.27 inches at Lihue Airport.[141] *Source: Honolulu Star Advertiser (2021)*

2.4.2. Air Temperature

In Hawaiʻi, the rate of air temperature increase has accelerated in recent years.[142] At a rate of 0.17°C (0.31°F) per decade, the air is warming four times faster than half a century ago.[143] Statewide, the average air temperature has risen by 0.42°C (0.76°F) over the past 100 years, and 2015 and 2016 were the warmest years on record (Figure 8).[144]

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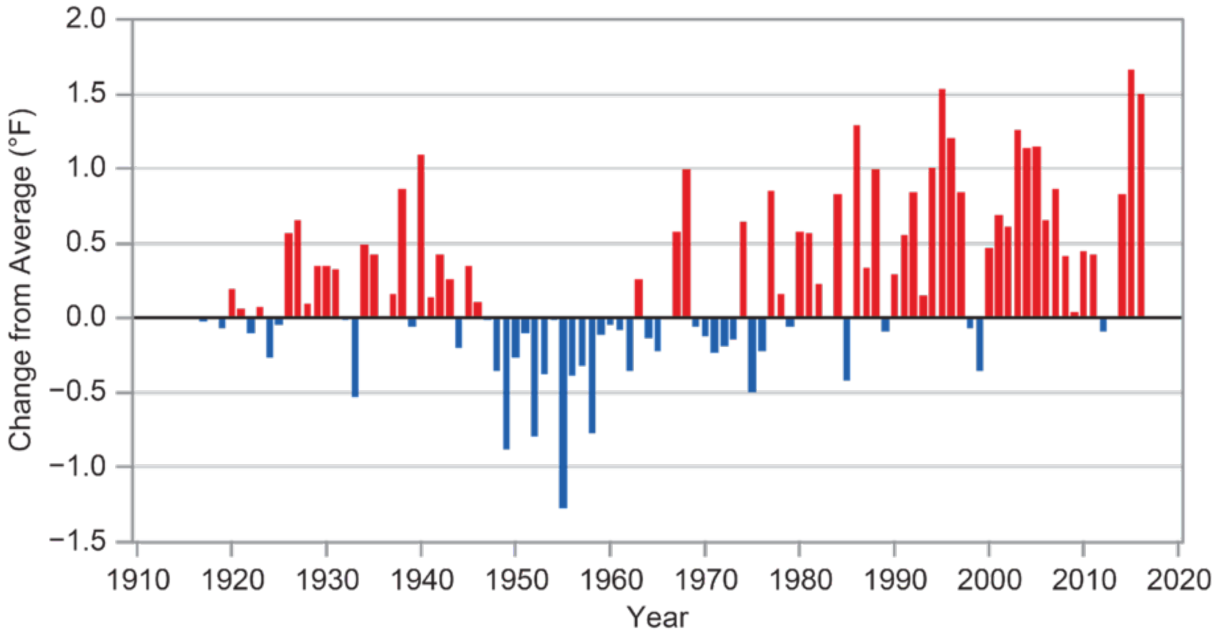
[141] Honolulu Star Advertiser Print Replica for December 6, 2021(A12), https://printreplica.staradvertiser.com/?token=8e39557241d765a62e7a4400521a2856
[142] Giambelluca, T.W., *et al.* (2008) Secular Temperature Changes in Hawaiʻi, *Geophysical Research Letters*, 35:L12702.
[143] Ibid.
[144] McKenzie, M.M. (2016) Regional temperature trends in Hawaiʻi: A century of change, 1916–2015 (MS thesis). Dept. of Geog., University of Hawaiʻi at Mānoa.

Figure 8. Difference in Annual Average Temperature Compared to the Average from 1944-1980 in Hawai'i



Although both warming and cooling periods have occurred, the average annual temperature change in Hawai'i over the past century shows a statistically significant warming trend. Red bars-years with above average temperatures; Blue bars-years with below average temperatures. *Source: Keener, V., et al. (2018)*

Rapidly increasing air temperature is detrimental to the delicate balance of Hawaii's ecosystems.[145] Modeling[146] results suggest that for every 1°C (1.8°F) temperature change projected at sea level, the high elevation zones of Kaua'i may experience 1.2°C (2.16°F) change near 1500 m elevation and about 1.5°C (2.7°F) warming at 4000 m elevation (Figure 9). Rapid warming increases thermal stress on native flora and fauna, sets the stage for increased invasive plant and animal life, increases the likelihood of wildfire, threatens human health, and impedes precipitation (the source of Hawaii's freshwater).[147]

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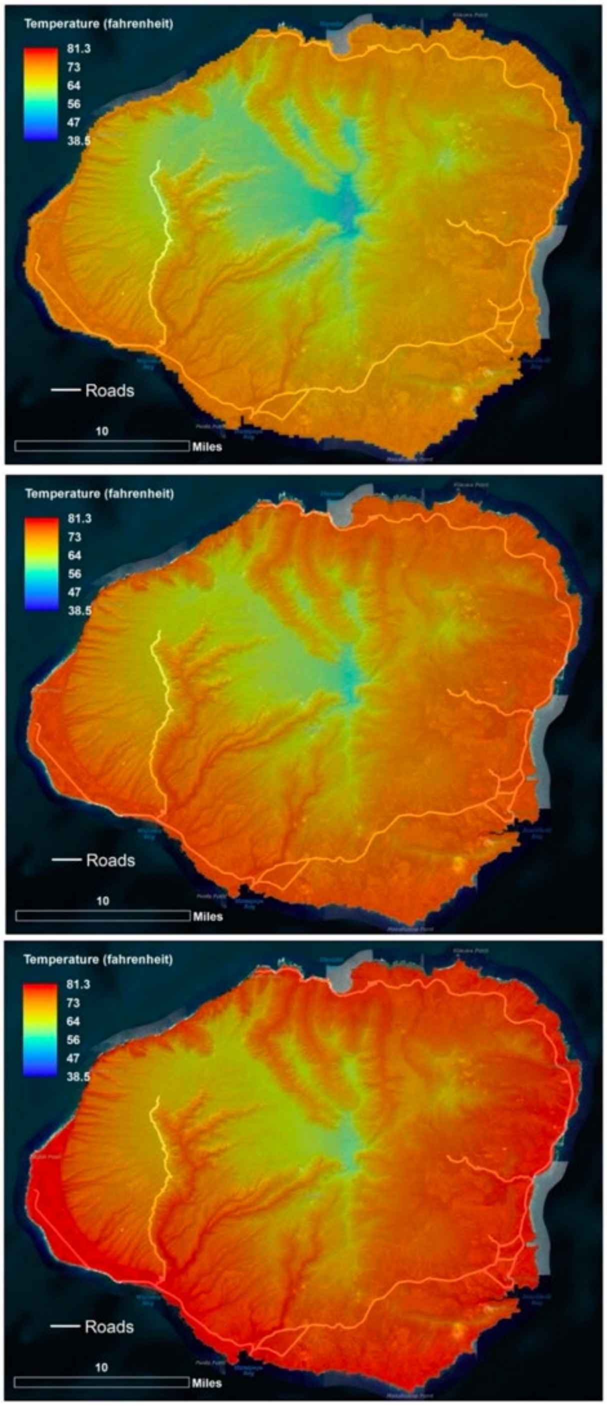
[145] Fortini, L., *et al.* (2013) A Landscape-Based Assessment of Climate Change Vulnerability for all Native Hawaiian Plants. Hawai'i Cooperative Studies Unit. University of Hawai'i at Hilo. Technical Report HCSU-044

[146] Timm, O.E. (2017) Future Warming Rates over the Hawaiian Islands Based on Elevation-Dependent Scaling Factors. *Int. J. Clim.*,doi:10.1002/joc.5065.

[147] University of Hawai'i Sea Grant College Program (2014) Climate Change Impacts in Hawai'i-A summary of climate change and impacts to ecosystems and communities. UNIHI-SEAGRANT-TT-12-04.

Figure 9. Mean Annual Temperature Values for Kauaʻi



Historical

Mid-Century

End-of-Century

Downscaled 97.5th percentile ensemble mean temperature changes (°C) for RCP 8.5[148] scenario. The highest mountain elevations warm by a factor 1.5±0.2 compared to the surface temperature at sea level. In scenario RCP 8.5, high elevations above 3000 m reach up to 4–5 °C (7.2–9 °F) warmer temperatures by the late 21st century.

Source: Hawaii Highways, Climate Adaptation Plan, Exposure Assessments (April, 2021) based on projections by Timm, O.E. (2017)

[148] RCP or Representative Concentration Pathway, is a GHG concentration trajectory adopted by the IPCC and used in projecting future climate change. Four RCPs were modeled in the IPCC 5th Assessment Report (2014). Their use has been continued and expanded in SSP models used in the IPCC 6th Assessment Report (2021). The RCPs describe possible climate futures depending on the volume of GHGs emitted in the years to come. The RCPs – originally RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5 – are labelled after radiative forcing (net heating) values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, resp.). RCP 8.5 is now considered unlikely given the rapid deployment of renewable technologies that have replaced traditional fossil fuels, but still possible as feedbacks are not well understood.

As air temperature rises, the impact of El Niño events also grows. During the strong El Niño of 2015/16, where Honolulu experienced 11 days of record heat,[149] the local energy utility was compelled to issue emergency public service announcements asking residents and businesses to curtail escalating use of air conditioning that stressed the electrical grid.[150] El Niño years affect Hawai'i specifically by hosting record-breaking hot windless days, intense rains, active hurricane seasons, and spikes in sea surface temperatures.[151]

Climate models project that there will be increasing frequency and strength of El Niño[152] and La Niña[153] events as a result of continued warming in the 21st Century. Strong El Niño events are associated with extreme rainfall and flooding, drought, high heat, extreme tides, active hurricane seasons, high sea surface temperatures and coral bleaching, extraordinary high waves on north-facing shores, and compound events such as intense rain at high tide which lead to urban flooding (Figure 10).

Figure 10. Compound flooding – king tide, intense rain, El Niño 2015

El Niño and La Niña years tend to have episodes of intense rainfall. When these occur in urban settings during high tide, flooding is likely. Source: Honolulu Star Advertiser

149 New York Times https://www.nytimes.com/interactive/2016/02/19/us/ 2015-year-in-weather-temperature-precipitation.html#honolulu_hi.
150 http://www.hawaiinewsnow.com/story/26551141/hawaiian-electric-asks-oahu-customers-to-conserve-power-tonight
151 Keener, V., *et al.* (2018)
152 Cai, W., *et al.* (2015) Inc. frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change 4, 111–116, doi:10.1038/nclimate2100.
153 Cai, W., *et al.* (2015)

Models project a near doubling in the frequency of future extreme La Niña events, from once every 23 years to once every 13 years.[154] 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.

2.4.3. Heat

Records were set across Hawaiʻi in the summer of 2019.[155] At Lihue, temperatures of 32.8°C (91°F) on August 25 and 31 tied the all-time record high previously set on seven other occasions (twice in July 1918, once in September 1936, and once each in October 1926, 1930, and 2012). The average temperature for August, 28.6°C (83.5°F) made it the warmest single month on record (previously 28.2°C [82.7°F] in August 2017) and of the 92 days of summer (June 1-Aug. 31), a total of 31 days set or tied daily record highs. An amazing 21 of these were in August alone, which may itself be a record for so many daily heat records in a single month at any site in the U.S. with a long period of record.

A total of 33 daily max/min records were set that summer in Lihue, including all-time record-warm minima of 27.2°C (81°F) on Aug. 3, 12, 21, and 24 (beating 26.7°C [80°F] from multiple previous occasions). As of September 9, every day since August 24 had either broken or tied the site's daily record high, 17 consecutive days. Weather experts comment that for a site with a period of record since 1905, that level of persistent warmth is astonishing.[156] Furthermore, five consecutive days of the all-time record of 32.8°C (91°F) were measured on September 4-8.

Of four long-running weather monitoring stations in Hawaiʻi, three saw their warmest summer on record. Only Hilo, did not. In Lihue, Aug 24 to Sept 12 set daily heat records. In July, Aug, and Sept, 48 days set record highs, 44 nights set record high lows, and zero days or nights set record lows. Over 300 records were tied or broken in 2019. Only 5 of these were for record lows, revealing a strong warming shift in median temperature across Hawaiʻi. The likely cause, a record-setting marine heat wave, was the result of weak atmospheric circulation that produced very calm wind patterns.[157]

2.4.4. Marine Heat Waves

Ocean waters were abnormally warm in 2019 (Figure 11).[158] August 2019 was the warmest month for global ocean water temperatures on record, with records to 1854. 2019 also saw the weakest North Pacific atmospheric circulation patterns in at least the last 40 years.[159] 2019 was the warmest year for global ocean water temperatures on record.

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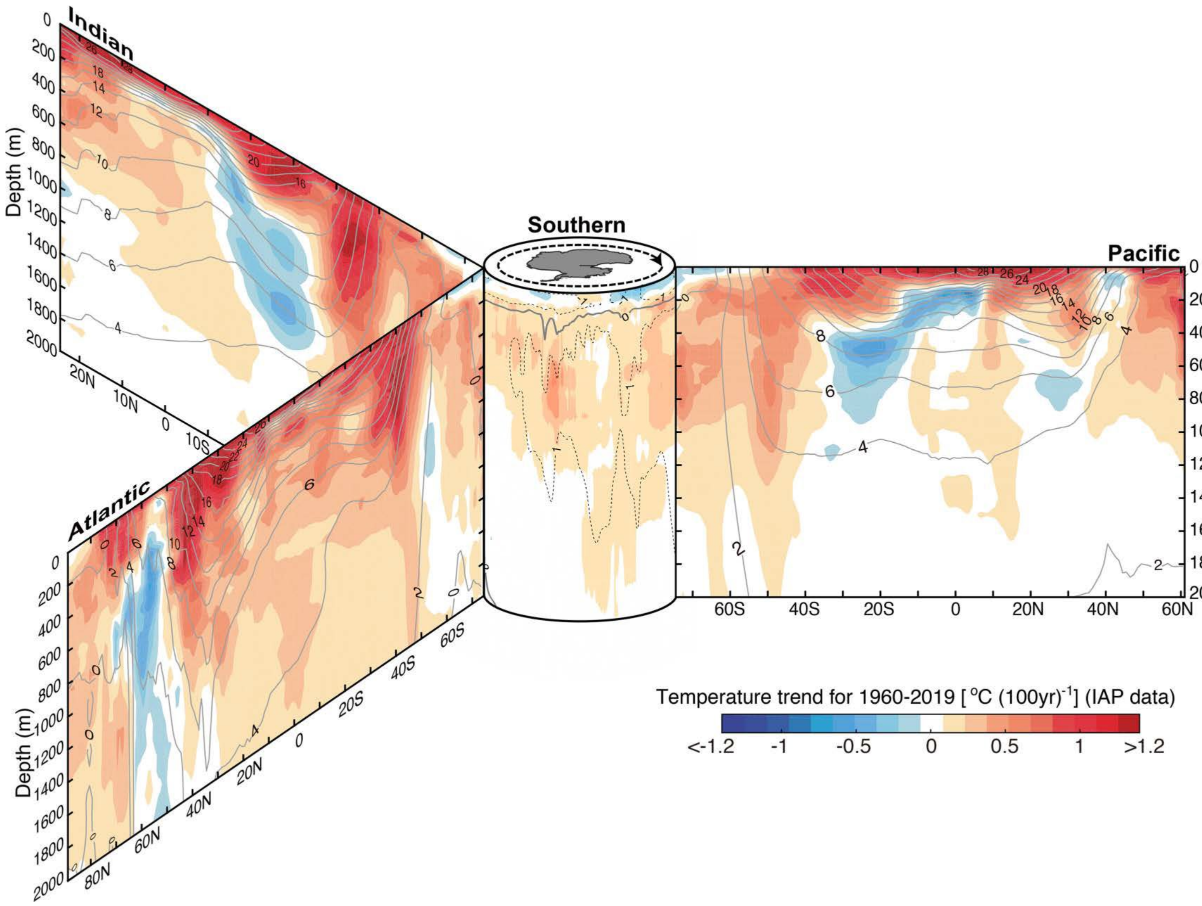
[154] Ibid.
[155] WASHINGTON POST, HAWAII GOES 20 DAYS IN A ROW SETTING A HEAT RECORD DURING ITS HOTTEST SUMMER EVER: HTTPS://WWW.PENNLIVE.COM/NATION-WORLD/2019/09/HAWAII-GOES-20-DAYS-IN-A-ROW-SETTING-A-HEAT-RECORD-DURING-ITS-HOTTEST-SUMMER-EVER.HTML
[156] Wunderground.com (September 10, 2019) Hawaii's warmest summer on record, https://www.wunderground.com/cat6/Hawaiis-Warmest-Summer-Record-and-Alaskas-Second-Warmest
[157] Amaya, D.J., *et al.* (2020) Physical drivers of the summer 2019 North Pacific marine heatwave. *Nature Communications*; 11 (1) DOI: 10.1038/s41467-020-15820-w
[158] Cheng, L., *et al.* (2020) Record-Setting Ocean Warmth Continued in 2019. *Adv. Atmos. Sci*. 37, 137–142. https://doi.org/10.1007/s00376-020-9283-7
[159] Amaya, D.J., *et al.* (2020)

Figure 11. Ocean Temperature Trends from the Sea Surface to 2000 m 1960-2019



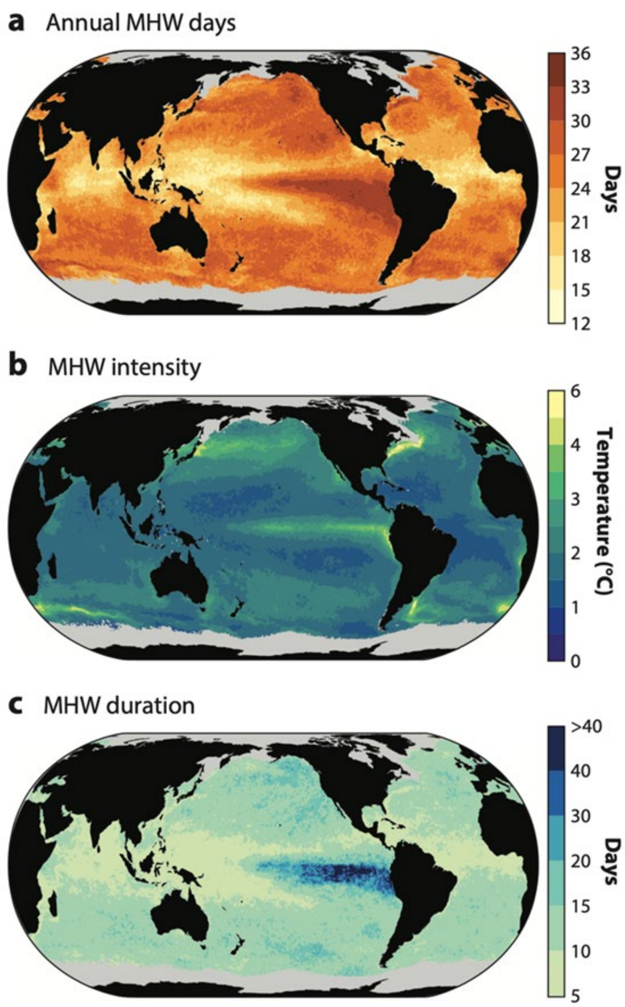
Shown are the zonal (E-W) mean sections in each ocean basin organized around the Southern Ocean (south of 60°S) in the center. Black contours show mean temperature with intervals of 2°C (3.6oF) (in the Southern Ocean, 1°C (1.8oF) intervals are provided in dashed contours). Source: Cheng, L., et al. (2020)

The record setting air temperatures in Hawai‘i during the summer of 2019 were caused by a marine heatwave located in regional Hawaiian waters. A marine heatwave is a short period of abnormally high sea surface temperatures. Marine heatwaves are caused by a variety of factors and have been associated with severe biodiversity changes such as sea star wasting disease, toxic algal blooms, and mass mortality of benthic communities.[160] Marine heatwaves can be caused by a whole range of factors, and not all factors are important for each event. The most common drivers of marine heatwaves include ocean currents which can build up areas of warm water and air-sea heat flux, or warming through the ocean surface from the atmosphere.

[160] Oliver, E.C.J., *et al.* (2021) Marine Heatwaves, *Annual Review of Marine Science*, 13:1, 313-342, https://www.annualreviews.org/doi/pdf/10.1146/annurev-marine-032720-095144

Studies[161] find that from 1925 to 2016, global average marine heatwave frequency and duration increased by 34% and 17%, respectively, resulting in a 54% increase in annual marine heatwave days globally (Figure 12). Importantly, these trends can largely be explained by increases in mean ocean temperatures, suggesting that we can expect further increases in marine heatwave days under continued global warming.

Figure 12. Statistical Properties of Historical Marine Heatwaves



Source: Oliver, E.C.J., et al. (2021)

Increases in ocean temperature reduce dissolved oxygen in the ocean and significantly affect sea life, particularly corals and other temperature- and chemistry-sensitive organisms. Warming increases evaporation, and the extra moisture in the warmer atmosphere nourishes heavy rains and promotes flooding. Increased heat and evaporation leads to a more extreme hydrological cycle and more extreme weather, in particular hurricanes. The warm ocean water of 2019 is one of the key reasons why Earth experienced increasing catastrophic fires in the Amazon, California, and Australia in 2019.

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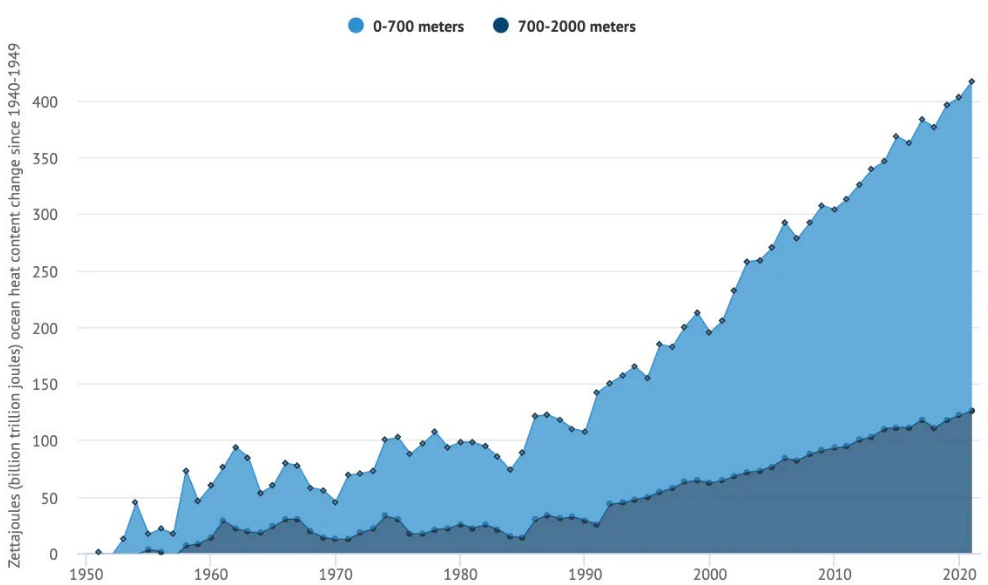
[161] Oliver, E.C.J., et al. (2018) Longer and more frequent marine heatwaves over the past century. *Nat Commun* 9, 1324. https://doi.org/10.1038/s41467-018-03732-9

2.4.5. Ocean Warming and Acidification

Because of climate change, the oceans are becoming warmer and more acidic.[162] 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 1990s.[163] Globally averaged, sea surface temperatures have already increased by 1.0°C (1.8°F) over the past 100 years, with half of this rise occurring during the 1990s.[164] In 2021, the world ocean was the hottest ever recorded by humans (Figure 13).[165]

Figure 13. Ocean Heat Content 1950 through 2021



Annual global ocean heat content (in zettajoules – billion trillion joules, or 10^21 joules) for the 0-700 m and 700-2000 m layers. Data from Cheng et al 2021. Ocean warming is attributed to increased GHG concentrations. Ocean warming has far-reaching consequences and should be incorporated into climate risk assessments, adaptation, and mitigation. *Source: Climate Brief https://www.carbonbrief.org/state-of-the-climate-how-the-world-warmed-in-2021*

In addition to warming, an average 26% of annual Human-made CO_2 emissions are dissolved in ocean water causing ocean acidification. This is because of the chemical reaction that occurs when water bonds with CO_2. Data collected from station ALOHA regarding marine pH levels portray an 8.7% increase in ocean acidity over the past 30 years. Ocean acidification interferes with natural processes of marine organisms and ecosystems. It reduces the ability of marine organisms to build shells and other hard structures. It also contributes to coral bleaching where entire coral reefs turn white and are more vulnerable to mortality.

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[162] Barton, A., *et al.* (2012) The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects, *Limnology and Oceanography* 57(3), 698-710.
[163] Cheng L., et al. (2015) Global upper ocean heat content estimation: recent progress and the remaining challenges. *Atmospheric and Oceanic Science Letters*, 8. DOI:10.3878/AOSL20150031. Glecker, P.J., et al. (2016) Industrial era global ocean heat uptake doubles in recent decades. *Nature Climate Change*.
[164] Marra and Kruk (2017)
[165] Cheng, L., Abraham, J., Trenberth, K.E. *et al.* (2022) Another Record: Ocean Warming Continues through 2021 despite La Niña Conditions. *Adv. Atmos. Sci.*. https://doi.org/10.1007/s00376-022-1461-3

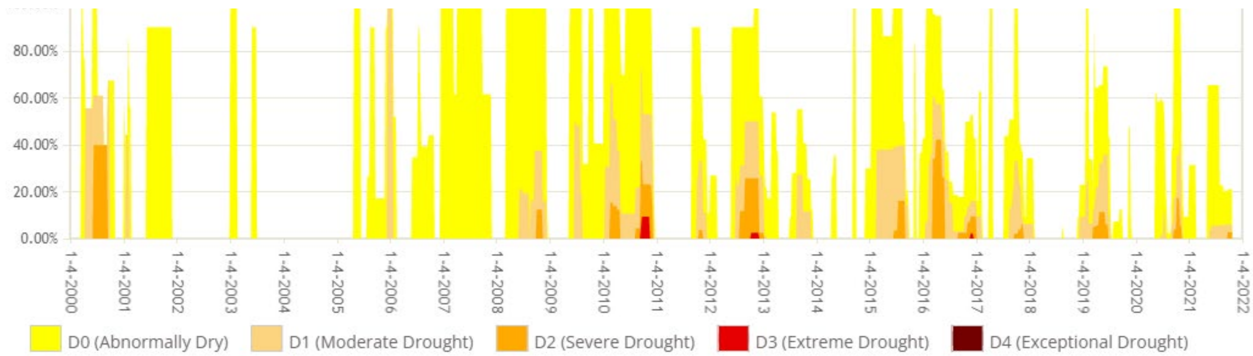
2.4.6. Trade Winds

Average daily wind speeds are declining on Kaua'i and statewide. Winds have declined regionally in the North Central Pacific but have remained steady across Western and South Pacific sites.[166] Already, trade winds interact with ridgelines in ways that produce less cloud cover and less rainfall, resulting in reduced water supply and higher water demand.[167]

2.4.7. Drought

Droughts are becoming more common in Hawai'i and on Kaua'i, with longer periods of drought experienced more recently. Continued changes in precipitation patterns (decline in rainfall, higher intensity events) may increase drought frequency, intensity, and duration. Figure 14 indicates that frequent periods of abnormally dry to severe drought characterize the past two decades.

Figure 14. Drought Severity History for Kaua'i County 2000-2022



Source: National Integrated Drought Information System

All areas on Kaua'i are susceptible to drought and the effects of heat may be worse in urban areas due to the urban heat area effect. Future temperatures in Hawai'i are expected to increase,[168] and periods of reduced cloud formation and drying are projected to become more frequent, particularly at high elevations.[169] If humidity increases, windward areas are expected to show slight increases or no changes in precipitation, while leeward areas are projected to experience significant drying.[170] Even if rainfall does not change in the future, rising temperatures will increase drought severity and frequency because of increased evaporation. Already-dry, drought-prone leeward areas are projected to become drier and at high risk for future drought.

Rainfall patterns are strongly controlled by climate variability, including the El Niño Southern Oscillation (ENSO) which consists of two modes – El Niño and La Niña. El Niño events are typically associated with drier-than-average winter wet seasons and wetter dry seasons, whereas La Niña events often result in wetter-than-

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[166] Marra, J.J. & Kruk, M.C. (2017)
[167] Kruk, M.C., *et al.* (2015), On the state of the knowledge of rainfall extremes in the western and northern Pacific basin, *Int. J. Climatol.*, 35(3), 321–336.
[168] Elison Timm, O. (2017) Future warming rates over the Hawaiian Islands based on elevation-dependent scaling factors. *International Journal of Climatology*. 37(S1): 1093–1104. See also: Lauer, A., *et al.* (2013) Downscaling of climate change in the Hawaii region using CMIP5 results: on the choice of the forcing fields. *Journal of Climate*. 26(24): 10,006–10,030. See also: Zhang, C., *et al.* (2016) Dynamical downscaling of the climate for the Hawaiian Islands. Part II: Projection for the late 21st century. *Journal of Climate*. 29(23): 8333–8354.
[169] Longman, R.J., *et al.* (2015) Sustained increases in lower-tropospheric subsidence over the Central Tropical North Pacific drive a decline in high-elevation rainfall in Hawaii. *Journal of Climate*. 28(22): 8743–8759. See also: Zhang, C., et al. (2016) Dynamical downscaling of the climate for the Hawaiian Islands. Part II: Projection for the late 21st century. *Journal of Climate*. 29(23): 8333–8354.
[170] Elison Timm, O. (2017), Zhang, C., *et al.* (2016)

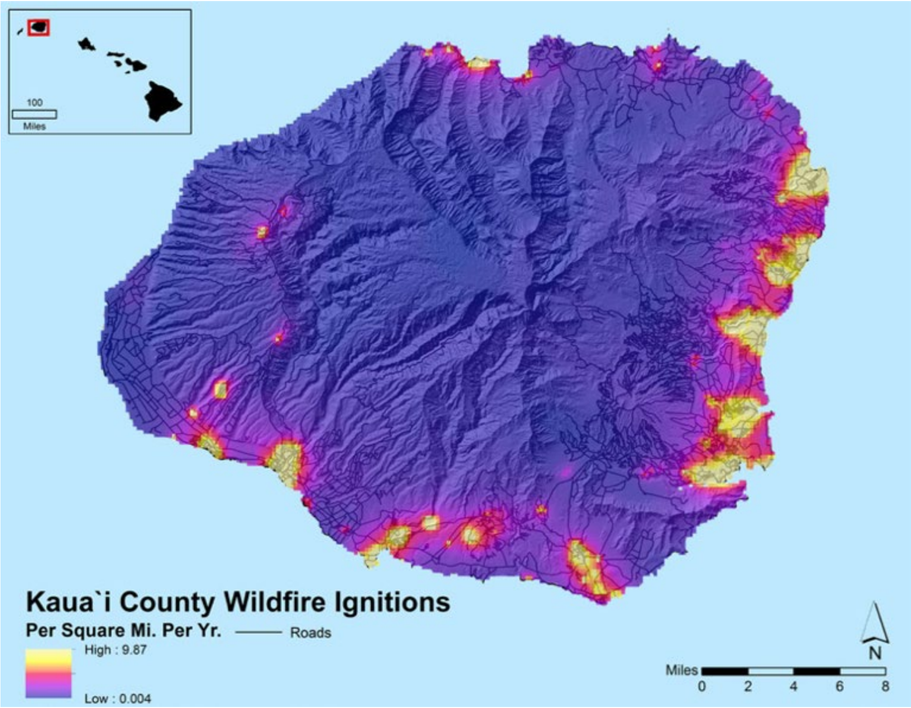
average wet seasons and drier dry seasons. The frequency of extreme El Niño events is projected to increase,[171] which will likely result in more extreme drought in the region.

2.4.8. Wildfire

Wildfire is a growing problem related to drying, invasive grasses, and human ignition.[172] Total burned area statewide has increased more than fourfold in the last century and fire propagates rapidly in dry nonnative grasslands.[173] The causes of most fires are unknown. Out of 12,000 recorded incidents statewide from 2000 to 2011, only 882, or about 7%, had a determined cause (Figure 15). Of those, 72% were accidental, which also means they're preventable.[174]

Public education on the risks of fire and how to avoid sparking a fire is an important part of the solution to wildfire. Statewide, non-native, flammable grasses and shrubland cover 25% of the total land. Effective strategy includes permanently converting flammable vegetation to something less likely to burn, such as planting trees to shade grasses out.

Figure 15. Wildfire Ignition Density



Kauaʻi County wildfire ignition density (number of ignitions per unit area) from point-based wildfire location data. The variation in ignition density over a landscape provides an illustration of where ignitions are most frequent using a straightforward, quantitative value (e.g., number of ignitions per square mile per year).
Source: Trauernicht and Lucas (2016)

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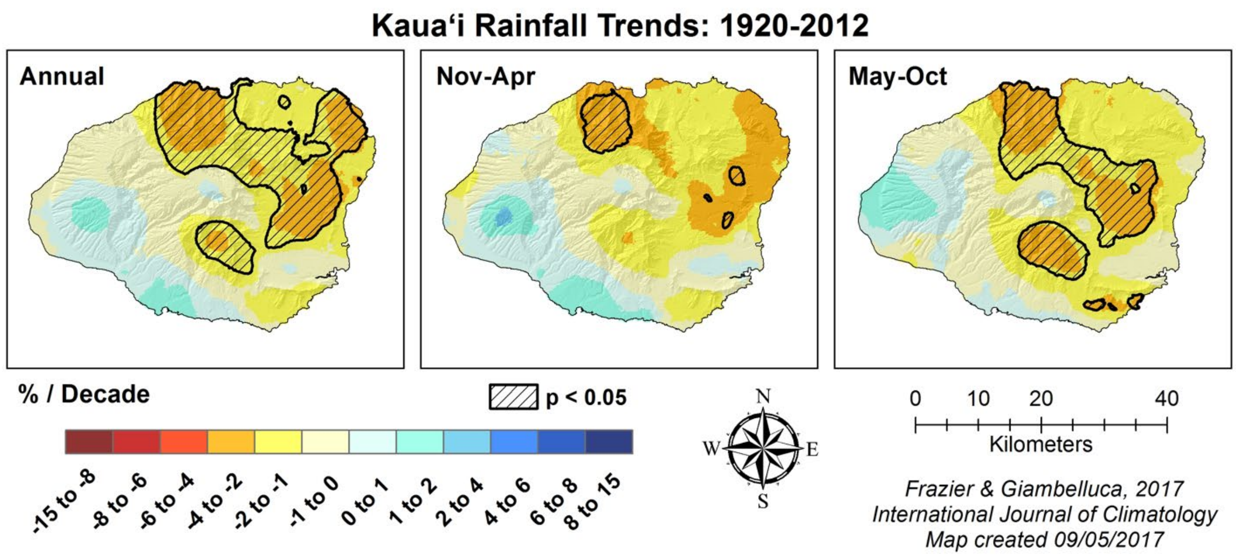
[171] Wang, G., *et al.* (2017) Continued increase of extreme El Niño frequency long after 1.5 °C warming stabilization. *Nature Climate Change*. 7(8): 568–572. See also Cai, W., *et al.* (2014) Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change*. 5(2): 1–6.
[172] Trauernicht, C., E. *et al.* (2015) The contemporary scale and context of wildfire in Hawaii. *Pacific Science* 69:427-444
[173] Trauernicht, C., *et al.* (2015) See also Trauernicht, C., & Elizabeth Pickett (2016) Pre-fire planning guide for resource managers and landowners in Hawaiʻi and Pacific Islands, Forest and Natural Resource Management, College of Tropical Agriculture and Human Resources, https://www.ctahr.hawaii.edu/oc/freepubs/pdf/RM-20.pdf.
[174] Restoration of Forest Key to Fire Control, Feb. 12 (2019) https://www.hawaiiwildfire.org/news-center/tag/Maui+%28West%29

2.4.9. Precipitation

Precipitation patterns are being disturbed on Kaua'i due to climate change. Hawai'i has seen an overall decline in rainfall (Figure 16) over the past 30 years, with a particularly dry period ensuing from 2008 to present.[175] Consecutive wet days and consecutive dry days are both increasing.[176] The heavy rainfall and drought periods have intensified, increasing runoff, erosion, flooding, and water shortages.[177] On Kaua'i there have been over 81 flood events between 2005 and 2020, with especially severe flooding occurring in 2018 and 2020.

Figure 16. Annual Average Rainfall



Average annual rainfall is declining on Kaua'i at a rate of about 1% per decade. (Scale- % change rainfall per decade). Source: Frazier, A. G., and Giambelluca, T. W. (2017)

Modeling does not necessarily do a good job of projecting high frequency flooding (e.g., 10-year floods). However, windward Kaua'i, where ridgelines capture trade wind moisture and form orographic clouds, may see an increase in wet season flooding with a changing climate (Figure 17). This trend could be detrimental to freshwater availability as intense precipitation is less effective at recharging aquifers than extended (less intense) wet weather. Drought, declining wet weather, and reduced recharge has also depleted stream flow, which indicates declining groundwater levels.

Kauai's water supply is mainly derived from groundwater.[178] Chronic water shortages may grow in probability as rainfall decreases and the water requirements of a growing population increase. On Kaua'i and across the state, extreme precipitation events are more frequent in La Niña years and less frequent in El Niño years.[179]

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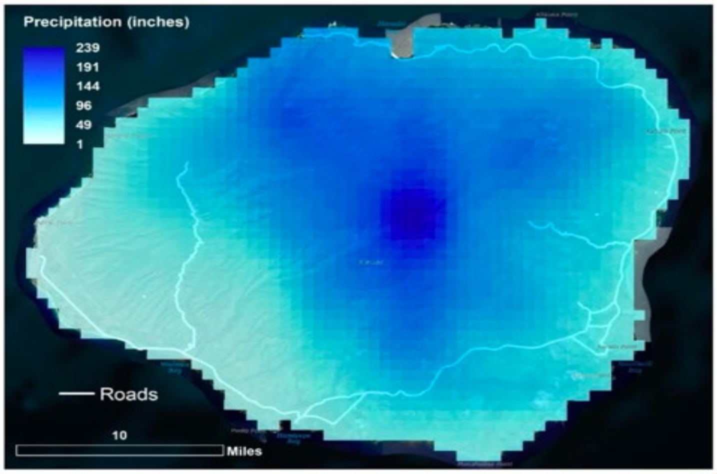
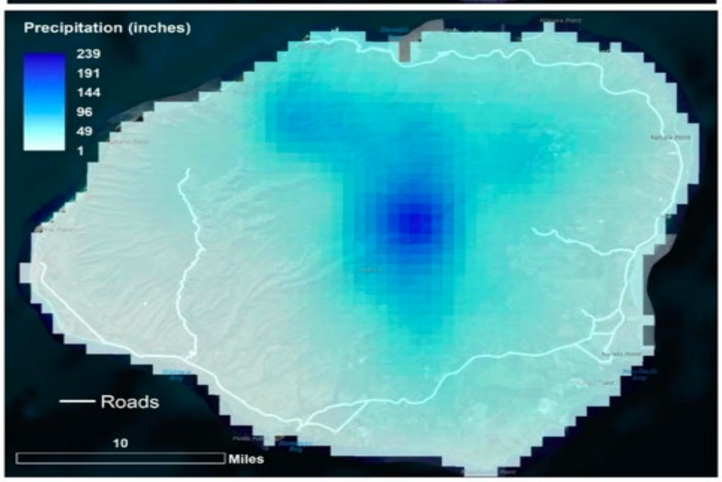
[175] Bassiouni, M., and D.S. Oki. 2013. Trends and shifts in stream flow in Hawai'i, 1913-2008. Hydrological Processes 27(10):1484-1500.
[176] Kruk, M.C., et al. (2015)
[177] Ibid.
[178] Oki, D. S., *et al.* (1999)
[179] Chen, Y. R., P.-S. Chu (2014) Trends in precipitation extremes and return levels in the Hawaiian Islands under a changing climate. *Int. J. Climatol,* 34, 3913-3925.

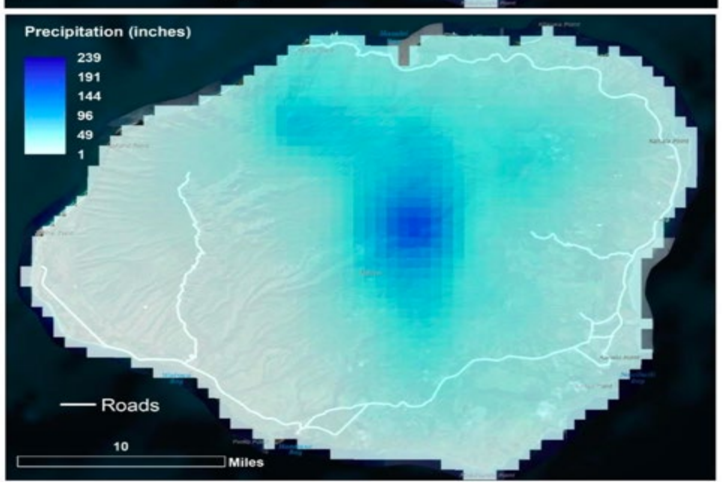
Figure 17. Wet Season Precipitation



Historical



Mid-Century



End-of-Century

Downscaled wet season ensemble mean precipitation changes (inches) using the RCP 8.5 scenario.

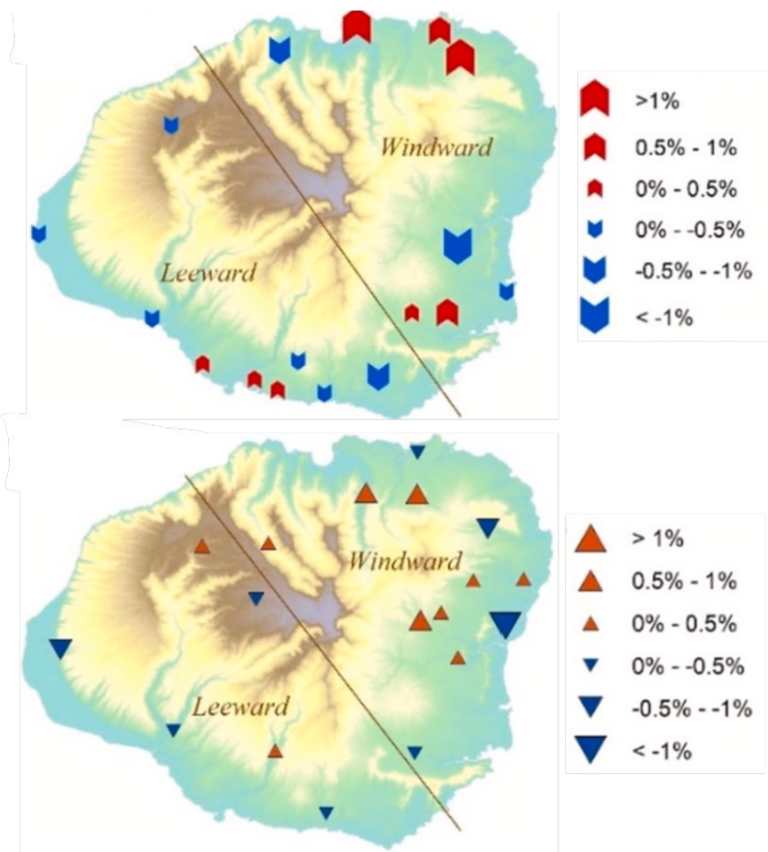
Source: Hawaii Highways, Climate Adaptation Plan, Exposure Assessments (April, 2021) based on projections by Timm, O.E. (2017)

2.4.10. Streamflow

Streamflow in Hawaiʻi has generally declined over the past century, consistent with observed decreases in rainfall.[180] Trends showing low flows becoming lower indicate declining groundwater levels. On all islands, water supply is mainly derived from groundwater.[181] If these declines continue due to further reductions in rainfall and/or increases in evaporation, groundwater availability will be impaired. Chronic water shortages are possible as rainfall decreases and both evaporation and the water requirements of a growing human population increase.

An analysis[182] of extremes in rainfall and streamflow on Kauaʻi, found that increasing trends in annual maximum daily rainfall (RFmax) were primarily located on the windward side, whereas there were no discernable differences in RFmax between leeward and windward on other Hawaiian islands. Overall (island wide), decreasing trends in RFmax dominated on Oahu, Maui, and Hawaiʻi, while no particular trend prevailed on Kauaʻi. Annual peak streamflow generally increased on the windward side of Kauaʻi, but island-wide, a decreasing trend was observed (Figure 18).

Figure 18. Trends in Precipitation and Streamflow Extremes 1970-2005

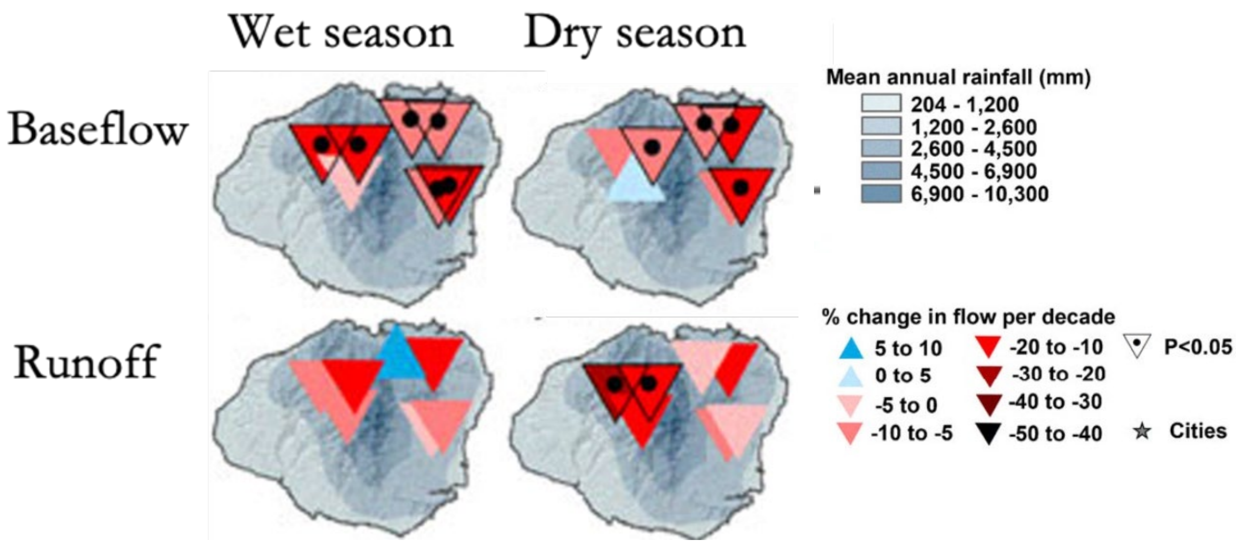


Arrows - Annual maximum daily rainfall. Triangles – Annual peak flow. Blue = decreasing trends, red = increasing trends. Brown line = physiographic division of windward (northeast) and leeward (southwest) regions. *Source: Huang, Y-F, et al. (2021)*

[180] Bassiouni, M., and D. S. Oki (2013) Trends and shifts in streamflow in Hawaiʻi, 1913–2008. *Hydrological Processes*, 27 (10), 1484–1500. doi:10.1002/hyp.9298
[181] Oki, D. S., et al. (1999)
[182] Huang, Y-F, et al. (2021) Shifting magnitude and timing of streamflow extremes and the relationship with rainfall across the Hawaiian Islands, *Journal of Hydrology*, https://doi.org/10.1016/j.jhydrol.2021.126424

Studies[183] show that streamflow has declined in association with a general drying across the islands. In particular, significant declines in low flow conditions (baseflows), were experienced in 57% of streams, compared with a significant decline in storm flow conditions for 22% of streams. Downward trends were more significant for recent decades, with an average decline in baseflow and run-off of 10.90% and 8.28% per decade, (resp.). A significant decline in dry season flows (May–October) has increased the number of no-flow days in drier areas, indicating that more streams may become intermittent. This has important implications for mauka to makai (mountain to ocean) hydrological connectivity and management of Hawai'i's native migratory freshwater fauna (Figure 19).[184]

Figure 19. Mean Annual Baseflow and Runoff Trends 1987-2016



Mean annual baseflow trends (top panels) and runoff trends (bottom panels) from 1987 to 2016 for wet season (November–April; left panels) and dry season (May–October; right panels). Trend magnitudes expressed as a percentage of the 1978–2007 reference period. Significant trends (p < 0.05) are highlighted with • *Source: Clilverd, H.M., et al. (2019)*

Climate change has fundamentally altered the water cycle in tropical islands, which is a critical driver of watershed ecologies. Natural ecosystems are the key to aquifer recharge. Indigenous vegetation that captures cloud water is responsible for nearly 40% of groundwater recharge.[185]

[183] Clilverd, H.M., et al. (2019) Long-term streamflow trends in Hawai'i and implications for native stream fauna, *Hydrological Processes*, v33(5), https://doi.org/10.1002/hyp.13356
[184] Ibid.
[185] Giambelluca, T.W., et al. (2013) Online Rainfall Atlas of Hawai'i. Bull. Amer. Meteor. Soc. 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

2.4.11. Tropical Cyclones

The global zone of tropical cyclone (TC) formation is shifting poleward. This is linked to Hadley Cell expansion.[186] Major TC's have become 15% more likely over the past 40 years.[187] Climate models project an increase in TC's near Hawai'i.[188] A global-average migration of TC activity is taking place as storms move away from the tropics at a rate of about one degree of latitude per decade.[189] With 2°C (3.6°F) of additional warming, climate models project a 10-15% increase in the average precipitation rate within 100 km of a storm.[190] As oceans warm, there is less cold, subsurface water to serve as a braking mechanism for hurricanes.[191]

Sea level rise is causing higher coastal inundation levels for TC storm surge. The proportion of TC's reaching Category 4 and 5 levels will likely increase. Hurricanes have already become bigger and more destructive in the U.S.[192] There is low confidence in the global number of future Category 4 and 5 storms, since modeling studies show decreasing global frequency of all tropical cyclones combined. The forward speed of TC's is decreasing.[193] Model simulations suggest that future global warming could lead to a significant slowing of hurricane motion.

Sea surface temperature increase has intensified in areas of TC genesis relevant to Hawai'i suggesting a connection with strengthened storminess.[194] Increased heat and evaporation contribute to a more extreme hydrological cycle and more extreme weather, in particular hurricanes. More frequent tropical cyclones are also projected for waters near Hawai'i because of the new tracks that storms will likely follow as a result of climate change.[195] There will be an increase in average cyclone intensity (Figure 20), and in the number and occurrence days of very intense category 4 and 5 storms in most basins and in tropical cyclone precipitation rates.[196]

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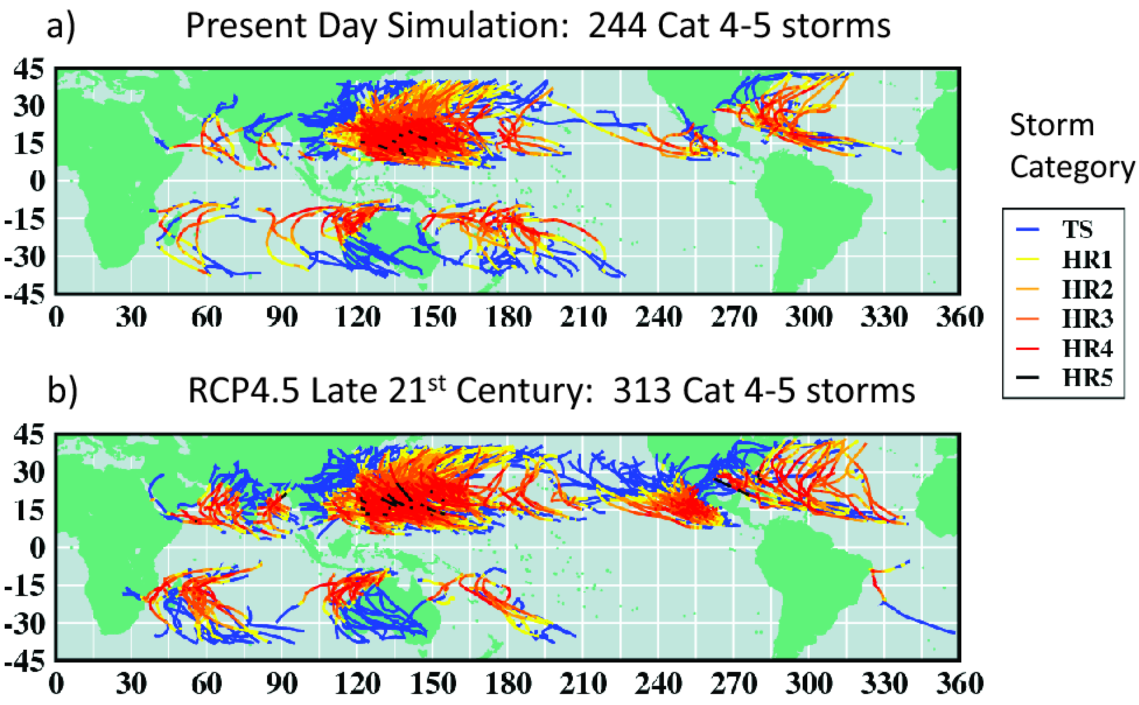
[186] Sharmila, S., and Walsh, K.J.E. (2018) Recent poleward shift of tropical cyclone formation linked to Hadley cell expansion. *Nature Clim Change* 8, 730–736. https://doi.org/10.1038/s41558-018-0227-5
[187] Kossin, J.P., *et al.* (2020) Global increase in major tropical cyclone exceedance probability over the past four decades. *PNAS*, DOI: 10.1073/pnas.1920849117
[188] Murakami, H., Wang, B., Li, T. *et al.* (2013) Projected increase in tropical cyclones near Hawaii. *Nature Clim Change* 3, 749–754. https://doi.org/10.1038/nclimate1890
[189] Kossin, J., Emanuel, K. & Vecchi, G. (2014) The poleward migration of the location of tropical cyclone maximum intensity. *Nature* 509, 349–352. https://doi.org/10.1038/nature13278
[190] Global Warming and Hurricanes, an Overview of Research Results (2020) Geophysical Fluid Dynamics Laboratory, Princeton University, NOAA: https://www.gfdl.noaa.gov/global-warming-and-hurricanes/
[191] Global Warming and Hurricanes, an Overview of Research Results (2020)
[192] Grinsted, A., *et al.* (2019) Normalized US hurricane damage estimates using area of total destruction: 1900-2018; *PNAS*: http://dx.doi.org/10.1073/pnas.1912277116
[193] Zhang, G., *et al.* (2020) Tropical Cyclone Motion in a Changing Climate, *Science Advances*, DOI: 10.1126/sciadv.aaz7610
[194] Defforge, C.L., Merlis, T.M. (2017) Observed warming trend in sea surface temperature at tropical cyclone genesis, *Geophys. Res. Lett.*, 44, 1034–1040, doi:10.1002/2016GL071045.
[195] Murakami, H., *et al.* (2013)
[196] Knutson, T., *et al.* (2020) Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Human-made Warming, *Bull. Amer. Meteor. Soc.* (2020) 101 (3): E303–E322: https://doi.org/10.1175/BAMS-D-18-0194.1

Figure 20. Simulated Cat. 4-5 Tropical Cyclone Tracks



Tracks of simulated category 4-5 tropical cyclones for (a) present-day or (b) late twenty-first century under conditions of decreasing greenhouse gas emissions in the second half of the century (RCP4.5[197]). Storm categories on the Saffir–Simpson scale are depicted by the track colors, varying from tropical storm (blue) to category 5 (black; see legend). The number and intensity of storms in Hawaiian waters significantly increases.

Source: Knutson, T.R., et al. (2015)

Tropical cyclone intensities globally will likely[198] increase. Climate models project that there will be increasing frequency and strength of El Niño[199] and La Niña[200] as a result of continued warming in the 21st Century.[201] Strong El Niño events have been associated with certain local impacts in the past: extreme rainfall and flooding, drought, high heat, extreme tides, active hurricane seasons, high sea surface temperatures and bleaching, extraordinary high waves on North-facing shores, and compound events such as intense rain at high tide which lead to urban flooding.

[197] RCP4.5 or RCP6 are more realistic modeling scenarios compared to RCP8.5 due to the accelerated deployment of renewable energy sources. See Hausfather, Z. and Peters, G.P. (2020) Emissions – the "business as usual" story is misleading. *Nature*, v577, 30 Jan., p618-620: https://doi.org/10.1038/d41586-020-00177-3

[198] The term "likely" is used to denote 66-100% likelyhood.

[199] Wang, G., *et al.* (2017) Continued increase of extreme El Niño frequency long after 1.5 °C warming stabilization. *Nature Clim Change* 7, 568–572. https://doi.org/10.1038/nclimate3351

[200] Cai, W., et al. (2015)

[201] Cai, W., et al. (2015) ENSO and greenhouse warming. *Nature Clim Change* 5, 849–859. https://doi.org/10.1038/nclimate2743

2.4.12. Sea Level Rise

Global mean sea level rise (SLR) is driven by melting of Greenland (~15.2%) and Antarctic (~9%) ice sheets, melting mountain glaciers (~19.3%), expansion of warming ocean water (~45.7%), and groundwater mining and discharge to the ocean (~10.8%).[202] Measured[203] over 28 years of global altimetry missions (1993-2021), the rate of SLR is 3.51 mm/year (1.38 in/decade). Over the past decade (2011-2021), the rate is a higher 4.43 mm/year (1.74 in/decade).

Several aspects of SLR are not widely known but should be taken into account when developing local adaptation plans:

1. Low-lying coastal areas may flood by groundwater inundation before direct marine flooding;
2. Engineered drainage systems may backflow salt water onto streets as part of SLR;
3. The first evidence of SLR is coastal erosion and high tide flooding both of which have already increased on Kaua‘i and elsewhere in Hawai‘i;
4. Hawai‘i and other tropical Pacific locations will experience amounts of SLR that are greater than the global average.

The frequency of local high tide flooding has increased from 6 to 11 days per year since the 1960’s.[204] 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.[205] Modeling the statewide impacts of 0.98 m (3.2 ft) of sea level rise indicate that 25,800 acres of land will experience chronic flooding, erosion, and/or high wave runup.[206] One-third of this land is designated for urban use, and impacts include more than $19 billion in assets.

Acceleration of SLR[207] is likely to increase with continued global warming.[208] Global mean sea level is projected[209] to rise 0.44-0.76 m (1.4-2.5 ft; SSP2-4.5) to 0.63-1.01 m (2-3.3 ft; SSP5-8.5) by the end of the century (Figure 21). However, a rise approaching 2 m (6.6 ft) by 2100 and 5 m (16.4 ft) by 2150 cannot be ruled out, as there remains deep uncertainty regarding ice sheet processes.[210] Recent findings[211] suggest that the present mass loss acceleration of the Antarctic ice sheet may mark the beginning of an ice sheet retreat period that will contribute to substantial global SLR for centuries to millennia.

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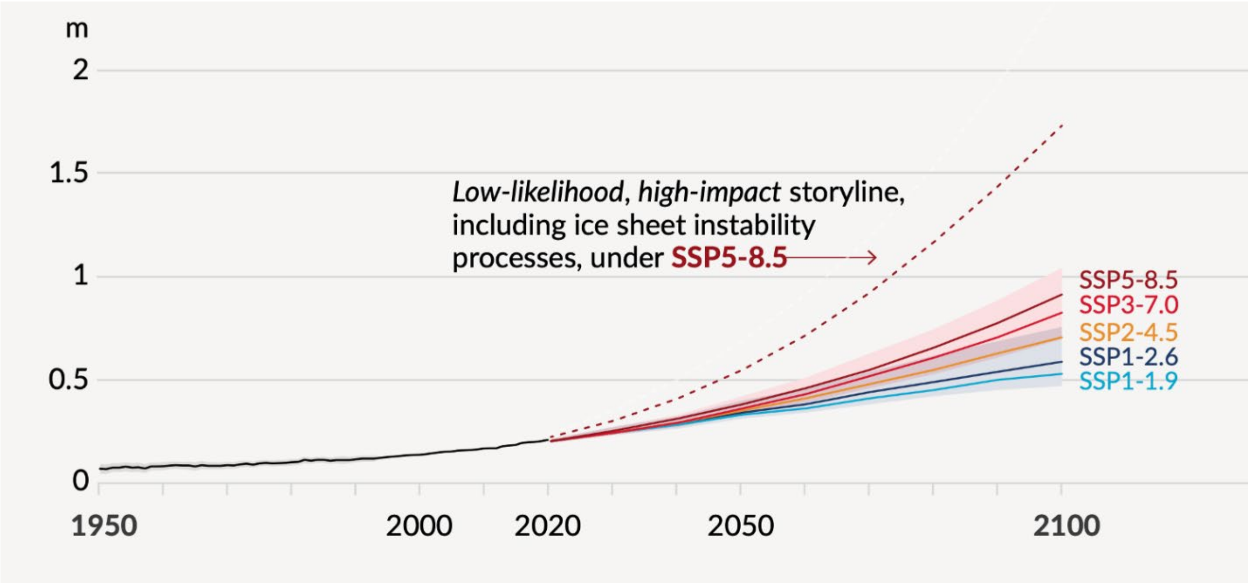
[202] Frederikse, T., *et al.* (2020) The causes of sea-level rise since 1900, *Nature* 584, 393–397, https://doi.org/10.1038/s41586-020-2591-3
[203] AVISO Satellite Altimetry Data, Mean Sea Level Products, https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/data-acces.html
[204] Marra and Kruk (2017)
[205] Sweet, W.V., *et al.* (2017) Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. NOAA/NOS Center for Operational Oceanographic Products and Services.
[206] Hawai‘i Sea Level Rise Vulnerability and Adaptation Report (2017) Tetra Tech, Inc. and the State of Hawai‘i DLNR, OCCL, DLNR Contract No: 64064.
[207] Nerem, R. S. *et al.* (2018) Climate-change–driven accelerated sea-level rise detected in the altimeter era. *PNAS*, 115, 2022–2025.
[208] Dangendorf, S., *et al.* (2019) Persistent acceleration in global sea-level rise since the 1960s. *Nat. Clim. Chang*. 9, 705–710. https://doi.org/10.1038/s41558-019-0531-8
[209] IPCC (2021) SPM
[210] Ibid.
[211] Weber, M.E., *et al*. (2021) Decadal-scale onset and termination of Antarctic ice-mass loss during the last deglaciation. *Nat Commun* 12, 6683. https://doi.org/10.1038/s41467-021-27053-6

Figure 21. IPCC-AR6 Global Mean Sea Level Change (m) Relative to 1900



Historical observations from tide gauges and altimeters. Future changes projected with ice sheet, glacier, thermal expansion and Human-made use models. Likely ranges shown for SSP1-2.6 and SSP3-7.0. Dashed curve shows 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out. *Source: IPCC (2021)*

Thwaites Glacier in West Antarctica could rapidly increase the rate of sea level rise if its floating ice shelf collapses. Several observations are especially concerning: it has doubled its outflow speed over the last 30 years, its base has eroded rapidly, new giant fractures have been observed, and researchers are concerned that part of the shelf could shatter within five years.[212] Thwaites holds enough water to raise sea level by >60 cm (2 ft) and could lead to 3 m (10 ft) of SLR if it draws surrounding glaciers with it.

Concerns that IPCC modeling focus on the low end of possible outcomes,[213] thus detracting attention from plausible high-end impacts, are consistent with observations of accelerated melting of the Greenland[214] Ice Sheet, and the West Antarctic Ice Sheet.[215] Observations[216] show accelerating ice discharge in the Amundsen Sea sector, lending further credence to concerns about multi-meter sea level rise this century.[217] Given key

[212] Giant cracks push imperiled Antarctic glacier closer to collapse (2021) https://www.nature.com/articles/d41586-021-03758-y Nature, Dec. 14.
[213] Siegert, M., et al. (2020) Twenty-first century sea-level rise could exceed IPCC projections for strong-warming futures. One Earth 3, 691–703.
[214] Aschwanden, A., et al. (2021) Brief communication: A roadmap towards credible projections of ice sheet contribution to sea-level, *The Cryosphere Discuss*. https://doi.org/10.5194/tc-2021-175
[215] DeConto, R. M., et al. (2021) The Paris Climate Agreement and future sea-level rise from Antarctica. Nature 593, 83–89.
[216] Joughin, I., et al. (2021) Ice-shelf retreat drives recent Pine Island Glacier speedup. Sci. Adv. 7.
[217] Hansen, J., et al. (2016) Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous. Atmos. Chem. Phys. 16, 3761–3812.

uncertainties[218] in ice sheet mass loss[219] and long-term responses to warming,[220] this issue continues to motivate coastal communities to engage in planning for unique and demanding scenarios[221] for which few professionals have formal training.[222]

The local expression of SLR can differ significantly from global mean SLR.[223] In addition to vertical land motion and spatially varying patterns of ocean heat storage, gravitational effects related to mass loss produce unique local and regional sea level deviations.[224] Additionally, present day 100-yr extreme sea level events are projected to occur at least once a year by the end of the century, even under only 1.5 °C of warming.[225]

For Kauaʻi, Table 3 provides estimates of local SLR at key milestones this century.[226]

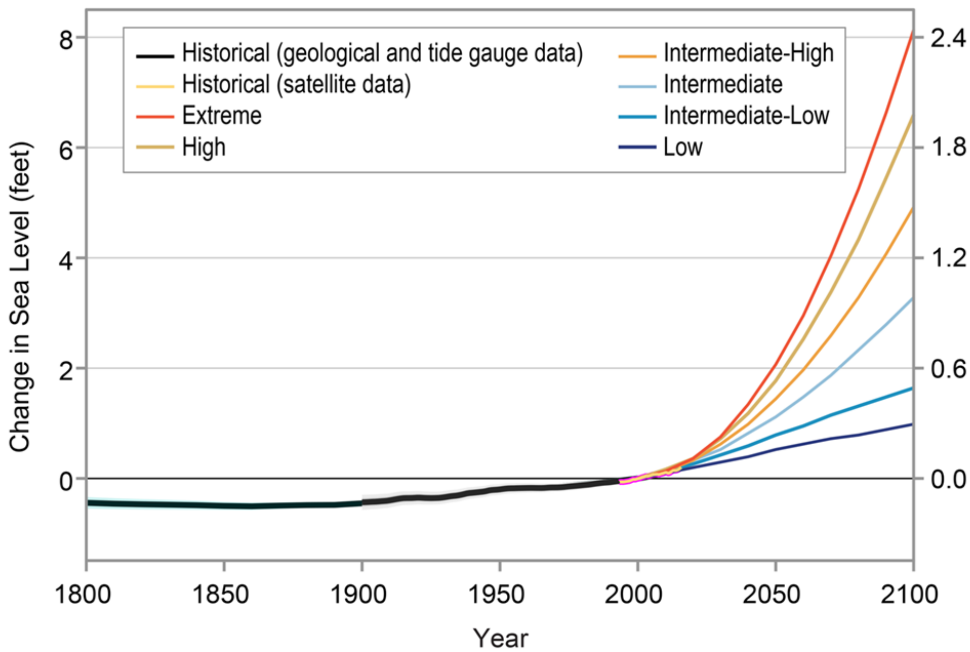
Table 3: Local SLR projections (m), Nawiliwili in the SSP5-8.5 scenario, median (17th, 83rd)

2030	2050	2090	2100
0.12 (0.08, 0.16)	0.26 (0.20, 0.35)	0.73 (0.56, 1.00)	0.89 (0.69, 1.22)

Because no single physical model accurately represents all major processes contributing to sea level rise, scenarios have been developed by NOAA for both global mean and local relative scenarios to 2100 that frame risk tolerance for use by planners (Error! Reference source not found.).[227] However, their Low and Intermediate-low scenarios are already exceeded by the observed acceleration of global SLR (0.65 ± 0.12 m).[228] Thus the Intermediate, Intermediate-high, and High relative SLR values represent more realistic scenarios for modeling impacts.

218 Choi, Y., et al. (2021) Ice dynamics remain a primary driver of Greenland ice sheet mass loss over the next century. Commun Earth Environ 2.
219 Pattyn, F. & Morlighem, M. (2020) The uncertain future of the Antarctic Ice Sheet. Science 367, 1331–1335.
220 Clark, P.U. et al. (2016) Consequences of 21st century policy for multi-millennial climate & SLR change. Nature Clim Change 6, 360–369.
221 Day, J.W., et al. (2021) Diminishing Opportunities for Sustainability of Coastal Cities in the Anthropocene: A Review. Front. Environ. Sci. 9:663275. doi: 10.3389/fenvs.2021.663275.
222 Nicholls, RJ, et al. (2021) Integrating new sea-level scenarios into coastal risk and adaptation assessments: An ongoing process. WIREs Clim Change; 12:e706. https://doi.org/10.1002/wcc.706
223 Kopp, R. E. et al. (2014) Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future 2, 383–406.
224 Adhikari, S., et al. (2019) Sea-level fingerprints emergent from GRACE mission data. Earth Syst. Sci. Data 11, 629–646.
225 Tebaldi, C., et al. (2021) Extreme sea levels at different global warming levels. Nat. Clim. Chang. 11, 746–751. https://doi.org/10.1038/s41558-021-01127-1
226 Fox-Kemper, B., et al. (2021) Ocean, Cryosphere and Sea Level Change. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the 6th Assessment Report of the IPCC [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press. In press.
227 Sweet, W.V., et al. (2017).
228 Nerem et al. (2018)

Figure 22. Representative Global Mean SLR Scenarios (ft, left, and m, right)



Six representative global mean SLR scenarios for 2100 (6 colored lines) relative to historical geological, tide gauge and satellite altimeter reconstructions from 1800–2015 (black and magenta lines).

Source: Sweet et al. (2017)[229]

Low-lying elevation areas in Hawai'i already flood during extreme tides and are projected to worsen over the next decade.[230] High water levels develop for multiple reasons, such as when eddy-like anomalies are coincident with high background sea levels.[231] Under these conditions, there is greater exposure to seasonal wave inundation,[232] coastal erosion,[233] groundwater inundation,[234] and drainage system blockage.[235] These and other impacts can be simulated by numerical modeling. The Pacific Islands Ocean Observing System (PacIOOS) Hawai'i Sea Level Rise Viewer provides users with visualizations and downloadable GIS digital files showing SLR impacts including coastal erosion, hydrostatic flooding, annual wave run-up, and potential economic loss (Figure 23).[236]

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229 Sweet, W.V. (2017) Sea level rise. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., et al. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 333-363, doi: 10.7930/J0VM49F2.

230 Thompson, P.R., et al. (2019) A Statistical Model for Frequency of Coastal Flooding in Honolulu, Hawaii, During the 21st Century. J. Geophys. Res. Oceans 124, 2787–2802. See also Thompson, P.R. et al. (2021) Rapid increases and extreme months in projections of United States high-tide flooding. Nat. Clim. Chang. 11, 584–590.

231 Firing, Y.L., and M.A. Merrifield (2004) Extreme sea level events at Hawaii: Influence of mesoscale eddies. Geophys. Res. Lett.,31, L24306, https://doi.org/10.1029/2004GL021539

232 Guiles M, et al. (2019) Forecasts of Wave-Induced Coastal Hazards in the United States Pacific Islands: Past, Present, and the Future. Front. Mar. Sci. 6:170. doi: 10.3389/fmars.2019.00170

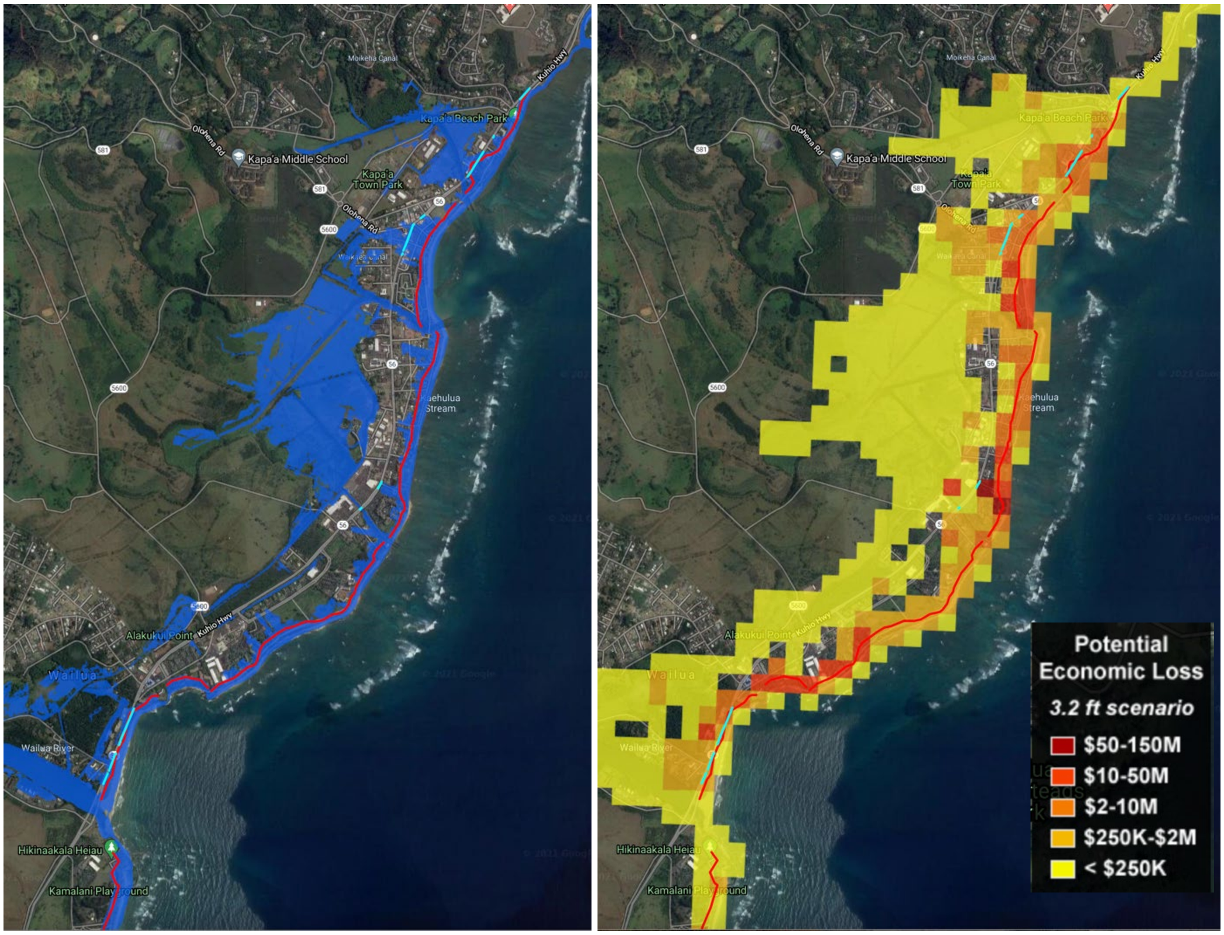
233 Anderson, T.R., (2015) Doubling of coastal erosion under rising sea level by mid-century in Hawaii. Nat Hazards 78, 75–103.

234 Habel, S., et al. (2019) Comparison of a simple hydrostatic and a data-intensive 3D numerical modeling method of simulating sea-level rise induced groundwater inundation for Honolulu, Hawai'i, USA. Environ. Res. Commun. 1, 041005.

235 Habel, S., et al. (2020) Sea-Level Rise Induced Multi-Mechanism Flooding and Contribution to Urban Infrastructure Failure. Sci Rep 10.

236 Anderson, T., et al. (2018) Modeling multiple sea level rise stresses reveals up to twice the land at risk compared to strictly passive flooding methods. Nature Scientific Reports 8: 14484 DOI:10.1038/s41598-018-32658-x

Figure 23. 3.2 ft SLR Impacts in Kapaʻa



Left – Blue = wave and hydrostatic flooding, Red = 80%ile coastal erosion. Right – Potential economic loss. According to Table 3, under the SSP5-8.5 scenario of the IPCC 6th Assessment Report, this level of flooding is projected for the final two decades of the 21st Century. However, under the NOAA High, or Intermediate High scenarios, this flooding would occur sooner. *Source: PacIOOS Hawaii SLR Viewer*

2.4.13. Disease

In September 2021, over 200 medical journals issued a joint statement[237] that the rapidly warming climate is a threat to global public health. The editorial, published in leading journals such as *The Lancet*, *The New England Journal of Medicine* and the *British Medical Journal*, urged world leaders to cut heat-trapping emissions to avoid "catastrophic harm to health that will be impossible to reverse." The editorial continued:

> *"The risks to health of increases above 1.5 °C are now well established. Indeed, no temperature rise is "safe." In the past 20 years, heat-related mortality among people over 65 years of age has increased by more than 50%. Higher temperatures have brought increased dehydration and renal function loss, dermatological malignancies, tropical infections, adverse*

[237] https://www.nejm.org/doi/full/10.1056/NEJMe2113200?query=featured_home

> *mental health outcomes, pregnancy complications, allergies, and cardiovascular and pulmonary morbidity and mortality. Harms disproportionately affect the most vulnerable, including children, older populations, ethnic minorities, poorer communities, and those with underlying health problems."*

The editorial not only identified the effects of climate change but also the consequences of global biodiversity loss.[238] Together, climate change and biodiversity loss constitute an environmental crisis with impacts that fall disproportionately on communities that are least responsible for the problem and least able to mitigate the harms. While wealthy nations may shield themselves from negative impacts, allowing the consequences to fall disproportionately on the most vulnerable will breed more conflict, food and water insecurity, forced displacement, and infectious disease — with severe implications for all countries and communities. As with the Covid-19 pandemic, we are globally as strong as our weakest member.

Because of climate change, expanding agriculture and population centers, mining, and other disruptions, only 15% of the planet's forests remain intact. The rest have been cut down, degraded or fragmented to the point that they disrupt the natural ecosystems that depend on them. As forests die, and grasslands and wetlands are also destroyed, biodiversity sharply decreases. The United Nations warns that the number of species on the planet has already dropped by 20% and that more than a million animal and plant species now face extinction.

Losing species has translated directly to a rise in infectious disease. As larger mammals suffer declines at the hands of hunters or loggers or shifting climate patterns, smaller species, including bats, rats, and other rodents, are thriving, either because they are more resilient to the degraded environment, or they are able to live better among people. It is these small animals, the ones that manage to find food in garbage cans or build nests in the eaves of buildings, that are proving most adaptable to human interference and happen to spread disease. Rodents alone accounted for more than 60% of all the diseases transmitted from animals to people, researchers have found.

Warmer temperatures and higher rainfall associated with climate change — coupled with the loss of predators — are bound to make the rodent problem worse, with calamitous implications. In 1999, for example, parts of Panama saw three times as much rainfall as usual. The rat population exploded, and so did the viruses rats carry, along with the chances those viruses would jump to people. That same year, a fatal lung disease transmitted through the saliva, feces and urine of rats and mice called hantavirus pulmonary syndrome emerged in Panama for the first time.

As the planet heats up, infectious diseases that were once confined to warmer latitudes are slowly expanding their range. In particular, the number of zoonotic diseases – diseases that spread from animals to humans – has skyrocketed. A new emerging disease surfaces five times a year. One study estimates that more than 3,200 strains of coronaviruses already exist among bats, awaiting an opportunity to jump to people. These diseases may have always been there, buried deep in wild and remote places out of reach of people.

Today, climate warming is driving a catastrophic loss in biodiversity that, when coupled with reckless deforestation and aggressive conversion of wildland for economic development, pushes farms and cities closer to the wild and opens the gates for the spread of disease. There are three ways climate influences emerging diseases.

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[238] Díaz S, Settele J, Brondízio ES, *et al.* (2019) The global assessment report on biodiversity and ecosystem services: summary for policymakers. Bonn, Germany: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (https://ipbes.net/sites/default/files/2

1) Roughly 60% of new pathogens come from animals — including those pressured by diversity loss — and roughly one-third of those can be directly attributed to deforestation and habitat loss.[239]

2) Vector-borne diseases[240] — those carried by insects like mosquitoes and ticks and transferred in the blood of infected people — are also on the rise as warming weather expands climate zones into northerly regions. Ticks and mosquitoes now thrive in places they'd never ventured before. As tropical species move northward, they are bringing dangerous pathogens with them.

3) Extreme weather events including floods, wildfire, heatwaves, and others, drives animals (and their diseases) and people together in typically unsanitary conditions.[241] Making things worse, the trauma humans experience during extreme weather events can lower immunity and open vulnerabilities to pathogenic diseases.

As the global population surges to 10 billion over the next 35 years, and the capacity to farm food is stressed further again by the warming climate, the demand for land will only get more intense. Already, more than one-third of the planet's land surface, and three-quarters of all its fresh water, go toward the cultivation of crops and raising of livestock. These are the places where infectious diseases spread most often.

How does the rising risk of disease affect Kaua'i? Climate change, rapid urbanization, deforestation, and expanding agriculture will increase the global probability of emerging diseases in coming decades (Figure 24). Disease control experts on Kaua'i need to be aware that climate change may alter the range of pathogens, allowing infections, particularly vector-borne infections, to expand to new locations. A continued uptick in global travel, trade and mobility will transport pathogens rapidly. However, increased investment in outbreak response could help mitigate the threat from future emerging infections.

A changing world requires changing science to evaluate future risks from infectious disease. More forward-looking research, to contend with possible future outcomes, is required in addition to the retroactive analyses that typically dominate the field of epidemiology. Increasing attention needs to be paid to pathogens currently circulating in both wild and domestic animal populations, especially in cases where agriculture is expanding into native species' habitats and, conversely, invasive species are moving into populous regions due to climate change. Future research needs to align with a global view of disease risk. In an increasingly connected world, the risk from infectious disease is globally shared. The COVID-19 pandemic, including the rapid global circulation of evolved strains, highlights the need for a collaborative, worldwide framework for infectious disease research and control.[242]

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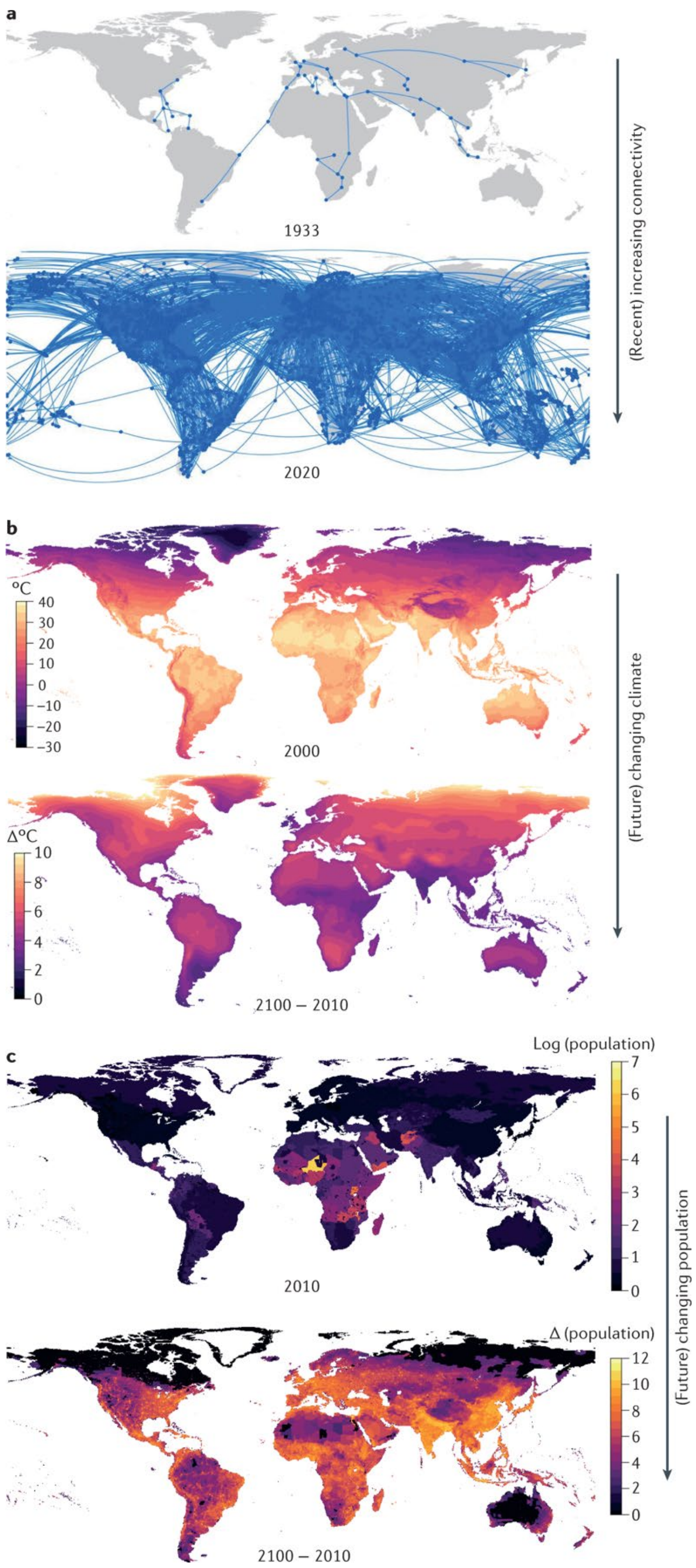
[239] Jones, K., Patel, N., Levy, M. *et al.* Global trends in emerging infectious diseases. *Nature* 451, 990–993 (2008). https://doi.org/10.1038/nature06536

[240] Ryan SJ, Carlson CJ, Mordecai EA, Johnson LR (2019) Global expansion and redistribution of *Aedes*-borne virus transmission risk with climate change. PLoS Negl Trop Dis 13(3): e0007213. https://doi.org/10.1371/journal.pntd.0007213\

[241] Garten, R., *et al.* (2018). Update: Influenza Activity in the United States During the 2017-18 Season and Composition of the 2018-19 Influenza Vaccine. *MMWR. Morbidity and mortality weekly report*, *67*(22), 634–642. https://doi.org/10.15585/mmwr.mm6722a4

[242] Baker, R.E., *et al.* (2021) Infectious disease in an era of global change. *Nat Rev Microbiol*. https://doi.org/10.1038/s41579-021-00639-z

Figure 24. Climate change and global disease transmission



Climate change and the globally connected nature of modern disease transmission. a. The global international air travel network expanded substantially from 1933 to 2020. b. Average monthly maximum temperature in 1970–2000) and difference between 2070–2100 and 1970–2000 averages (Shared Socioeconomic Pathway 3 (SSP3)). c. Population projections under SSP3 in 2010 and relative population change projected until 2100. *Source: Baker, R.E., et al. (2021)*

2.5. CONCLUSION

It is unequivocal that human influence has warmed the atmosphere, ocean, and land.[243] Hawaiʻi is one of the world's most vulnerable locations. Even under the most ambitious emissions reductions scenario, the world's oceans will continue to rise as the climate system comes into balance with the increase in atmospheric carbon dioxide concentration caused by Human-made combustion of fossil fuels. Studies show that with less than 1 m (3.3 ft) of sea level rise Kauaʻi is exposed to severe flooding,[244] environmental loss,[245] and economic damage.[246] There is no plausible emissions reduction scenario where Kauaʻi or Hawaiʻi at large can avoid the substantial cost of adapting to and protecting itself from rising seas, declining rainfall, increased exposure to tropical cyclones, expanding drought, record-setting heat, disease transmission, and marine devastation that result from the combustion of fossil fuels.[247]

[243] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of WGI to the AR6 of the IPCC [Masson-Delmotte, V., et al. (eds.)]. Cambridge Univ. Press. In Press.
[244] Habel, S., Fletcher, C., Anderson, T., & Thompson, P. 2020. Sea-Level Rise Induced Multi-Mechanism Flooding and Contribution to Urban Infrastructure Failure. Nature Scientific Reports, 10: 3796 DOI:10.1038/s41598-020-60762-4
[245] Tavares, K., Fletcher, C.H. & Anderson, T.R. 2020. Risk of shoreline hardening and associated beach loss peaks before mid-century: Oʻahu, Hawaiʻi. Nature Scientific Reports, 10: 13633. DOI:10.1038/s41598-020-70577-y
[246] Anderson, T., Fletcher, C., Barbee, M., Romine, B., & Lemmo, J. 2018. Modeling multiple sea level rise stresses reveals up to twice the land at risk compared to strictly passive flooding methods. Nature Scientific Reports 8: 14484 DOI:10.1038/s41598-018-32658-x
[247] Heede, R. (2020) Update Carbon Majors 1965-2018 [Press Release], Climate Accountability Institute (9 Dec.) https://climateaccountability.org/pdf/CAI%20PressRelease%20Dec20.pdf.

Appendix A: Human-made Global Warming Discussion

Humans burn coal, oil, and natural gas (collectively known as "fossil fuels") to make electricity, move vehicles, heat buildings, and for other uses. Fossil fuel burning releases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the air. These gases act as a partial blanket that blocks heat emitted by Earth's surface and the atmosphere, that would otherwise radiate to space. These same gases are also released by deforestation, wildfire, damming rivers, and aspects of agriculture such as manure management, soil disturbance, rice farming, livestock management, and more.

Excess heat trapped by "greenhouse gases" enhances a natural process called the "greenhouse effect."[248] Human-made pollution by greenhouse gases has raised the air temperature at Earth's surface about 1.1 to 1.3°C above the late 1800's. About 50% of the natural greenhouse effect is attributed to water vapor (H_2O), about 25% to clouds, and about 20% to CO_2.[249] Methane, nitrous oxide, other gases present in the atmosphere in small amounts also contribute to the greenhouse effect.

Water vapor and CO_2 are both powerful absorbers of heat emitted from surfaces warmed by sunlight. However, condensation and precipitation limit the residence of H_2O in the atmosphere to only 8-10 days,[250] which is too short to drive climate change. Carbon dioxide, with a longer residence time, naturally cycles between the atmosphere, the oceans, and the land biosphere. Its removal from the atmosphere involves a range of processes with different time scales.[251] About 50% of an increase in CO_2 will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years.[252] Because of its long residence time, CO_2 is considered the primary driver of climate change, responsible for about 79% of Human-made global warming.[253]

The average concentration of CO_2 in the air has risen from a natural level of 277 parts per million (ppm) to 419 ppm, the highest in human history. The rate of CO_2 accumulation in the atmosphere is accelerating; it increased from less than 1 ppm per year in the 1960's to more than 2 ppm per year averaged over the past two decades. Today's rate of CO_2 release is about ten times faster than the most rapid event of any time since

[248] The "greenhouse effect" operates as a partial blanket that blocks heat emitted by Earth's surface and the atmosphere, that would otherwise radiate to space. Much of this heat is absorbed by water vapor, including clouds, carbon dioxide and reradiated in all directions – including back to Earth, amplifying the warming already provided by the Sun. This trapped heat raises the surface temperature and warms the air. The key gases are water vapor, carbon dioxide, methane, nitrous oxide, and fluorinated gases.

[249] Schmidt, G.A., et al. (2010) Attribution of the present-day total greenhouse effect, *J. Geophys. Res.*, 115, D20106, doi:10.1029/2010JD014287.

[250] Gimeno, L., et al. (2021) The residence time of water vapor in the atmosphere. *Nat. Rev. Earth Environ.* 2, 558–569. https://doi.org/10.1038/s43017-021-00181-9

[251] Denman, K.L., et al. (2007) Couplings Between Changes in the Climate System and Biogeochemistry (p.501). In: *Climate Change 2007: The Physical Science Basis*. Contribution of WGI to AR4 of the IPCC [Solomon, S., et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.

[252] Ibid.

[253] Figure 7.6; Forster, P., et al. (2021) The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P., et al. (eds.)]. Cambridge University Press. In Press.

66 million years ago when an asteroid impact caused the extinction of the dinosaurs.[254] The last time CO_2 levels were this high, about 3 million years ago (during the Pliocene Period), Earth's climate was radically different; the global average temperature was 2 to 3°C warmer, beech trees grew near the South Pole, there was no Greenland ice sheet, no West Antarctic ice sheet, and there is evidence that global sea level was 5.6 to 19.2 meters higher than today.[255]

Because of warming, widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred. Earth's surface is reacting to the release of Human-made CO_2 much as originally calculated by Nobel Prize winning chemist Arrhenius Svante in 1896.[256] Since those early days, an extensive body of careful observations and modeling unmistakably tells us that CO_2, and the amplifying feedbacks it generates, are raising Earth's surface temperature[257] with devastating consequences that threaten human habitability.[258] Global warming risks food[259] and water[260] availability with the global land area and human population in conditions of extreme to exceptional drought more than doubling by 2100 under a scenario of continued emissions. Climate change threatens natural ecosystems that provide life-sustaining resources,[261] human security,[262] and livable conditions for human communities.[263]

[254] Zeebe, R.E., et al. (2016) Human-made carbon release rate unprecedented during the past 66 million years, Nature Geoscience, doi: 10.1038/ngeo2681
[255] Dumitru, O.A., et al. (2019) Constraints on global mean sea level during Pliocene warmth. Nature, DOI: 10.1038/s41586-019-1543-2
[256] Arrhenius, S. (1896) XXXI. On the influence of carbonic acid in the air upon the temperature of the ground, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 41:251, 237-276, DOI: 10.1080/14786449608620846
[257] Haustein, K. et al. (2017) A global warming index. Nature Scientific Reports, doi:10.1038/s41598-017-14828-5
[258] Xu, C., et al. (2020) Future of the human climate niche. PNAS May, 117 (21) 11350-11355; DOI: 10.1073/pnas.1910114117
[259] Belay, T. (2021) Impact of Climate Change on Food Availability—A Review. International Journal of Food Science and Agriculture, 5(3), 465-470. DOI: 10.26855/ijfsa.2021.09.017
[260] Pokhrel, Y., et al. (2021) Global terrestrial water storage and drought severity under climate change. Nat. Clim. Chang. 11, 226–233. https://doi.org/10.1038/s41558-020-00972-w
[261] Nolan, C., et al. (2018) Past and future global transformation of terrestrial ecosystems under climate change. SCIENCE, 31 Aug., doi: 10.1126/science.aan5360
[262] Brock, S., et al. (2021) The World Climate and Security Report 2021. Expert Group of the International Military Council on Climate and Security. Sikorsky, E. and Femia, F. (eds) Center for Climate and Security, an institute of the Council on Strategic Risks. June.
[263] Clement, V., et al. (2021) Groundswell Part 2: Acting on Internal Climate Migration. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/36248 License: CC BY 3.0 IGO.

Kaua‘i Climate Adaptation Plan

VULNERABILITY AND EQUITY ANALYSIS

Kaua‘i Climate Adaptation Plan
August 2, 2022

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Mōhala I ka wai ka maka o ka pua[1]

Unfolded by the water are the faces of flowers

Flowers thrive where there is water, as thriving people are found where living conditions are good.

[1] Pukui, Mary Kawena. ʻŌlelo Noʻeau: Hawaiian Proverbs & Poetical Sayings. Bishop Museum Press, 1983.

VULNERABILITY AND EQUITY ANALYSIS

This Vulnerability and Equity Analysis summarizes the sectors and assets that are exposed and vulnerable to climate change hazards on Kauaʻi. The analysis draws upon existing companion documents produced by County agencies, State agencies, community organizations, universities, non-profits, and research organizations. This analysis is meant to initiate a public process where more data and vulnerabilities will be assessed.

The Vulnerability and Equity Analysis identifies climate hazard exposures and vulnerabilities at the island-wide, planning area, and community scale. The findings of this document will inform the development and prioritization of adaptation measures in the Climate Adaptation Plan process.

Executive Summary

The Vulnerability and Equity Assessment delves into assets, hazard exposures, and vulnerabilities at multiple scales in detail. The Key Findings below highlight overall themes and the most pressing issues that need to be addressed based on this analysis and community input.

ES. 1. KEY FINDINGS

- **Natural Resources:** The island's native bird species are acutely impacted by warming temperatures, habitat loss/degradation, and diseases which have pushed many to the brink of extinction. In the ocean, coral reefs are experiencing bleaching events that harm the species who live there and reduce the shoreline's defenses against wave action. Beach loss is accelerating at a rapid pace, affecting coastal development, social infrastructure, and people's connection with the ocean and its resources.
- **Cultural Resources:** Native Hawaiians share a connection to ancestral, including natural, resources which are being impacted by all the climate change hazards. This may result in a significant loss of culture, identity, and ways of life.
- **Residents:** Though climate change's impacts will be felt by everyone in the county, there are some individuals and communities who will face higher risks than others with the same hazard exposure. Communities who face the most social vulnerability to climate change are located in the Līhuʻe and West Kauaʻi planning areas.
- **Economy**: Reliance on the tourism industry and the impacts of tourists themselves are two vulnerabilities community members are particularly concerned about. Lack of visitor preparedness paired with the fact that many visitor habitations and uses are exposed to hazards makes them vulnerable and puts a strain on community members.
- **Food System**: Dependence on imported food is vulnerable to interruptions from natural disasters and other disturbances. Locally grown food is also vulnerable to climate change impacts, especially the flooding of kalo and the impacts of heat, drought and pests on other crops. The food system is also a sector where practices like regenerative agriculture can help mitigate climate change.
- **Housing and Businesses**: The greatest hazard to developed areas in the county based on number of buildings that could be destroyed and cost is wildfire. Other critical issues are that many populated areas and allocated growth are in low-lying and/or coastal areas, which face flood and SLR exposure.
- **Critical Facilities:** Analysis from the Multi-Hazard Mitigation Plan finds that wildfire is expected to cause the most damage to the 798 critical facilities countywide. Though flood and sea level rise (SLR) affect fewer facilities, their impacts to roads, water and wastewater facilities, etc. will have outsize impacts.
- **Transportation**: Roads and bridges are vulnerable to flooding, sea level rise, and landslide. As demonstrated by disaster events in recent years, the transportation system in the North Shore is particularly vulnerable due to lack of redundancy in the network, which means there are no alternative routes if one section of a road or bridge is compromised during a hazard event. West Kauaʻi also has the most miles of roads exposed to climate hazards.
- **Utilities and Infrastructure**: Cesspools emerge as one of the top concerns for community members and are highly exposed to flood and SLR in West Kauaʻi's towns and other low-lying areas. The electrical system is also vulnerable to multiple hazards (flood, heat, wildfire, SLR); outages then cause cascading impacts to communications and potable water supplies.

Chapter 1: Island-Wide Climate Hazards

It is unequivocal that human influence has warmed the atmosphere, ocean, and land.[2] Hawai'i is one of the world's most vulnerable locations. Even under the most ambitious emissions reductions scenario, the world's oceans will continue to rise as the climate system comes into balance with the increase in atmospheric carbon dioxide concentration caused by anthropogenic combustion of fossil fuels. Studies show that with less than 3.2 feet of sea level rise, Hawai'i is exposed to severe flooding,[3] environmental loss,[4] and economic damage.[5] There is no plausible emissions reduction scenario where Hawai'i can avoid the substantial cost of adapting to and protecting itself from rising seas, declining rainfall, increased exposure to tropical cyclones, expanding drought, record-setting heat, and marine devastation that result from the combustion of fossil fuels.[6] These unavoidable impacts are motivation to plan and adapt to climate change to avoid greater costs in the future.

1.1 DEFINITIONS

The Intergovernmental Panel on Climate Change (IPCC) definition of a hazard is the "potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources."[7] Exposure is defined as "the presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected."[8] Not all people and assets exposed to hazards are vulnerable to them. The combination of strengths, attributes, and resources available to an individual, community, organization, or system (known as their adaptive capacity) can be used to prepare for and undertake actions to reduce adverse impacts or moderate harm from hazards.

[2] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of WGI to the AR6 of the IPCC [Masson-Delmotte, V., et al. (eds.)]. Cambridge Univ. Press. In Press.
[3] Habel, S., Fletcher, C., Anderson, T., & Thompson, P. (2020). Sea-Level Rise Induced Multi-Mechanism Flooding and Contribution to Urban Infrastructure Failure. Nature Scientific Reports, 10: 3796 DOI:10.1038/s41598-020-60762-4
[4] Tavares, K., Fletcher, C.H. & Anderson, T.R. (2020). Risk of shoreline hardening and associated beach loss peaks before mid-century: O'ahu, Hawai'i. Nature Scientific Reports, 10: 13633. DOI:10.1038/s41598-020-70577-y
[5] Anderson, T., Fletcher, C., Barbee, M., Romine, B., & Lemmo, J. (2018). Modeling multiple sea level rise stresses reveals up to twice the land at risk compared to strictly passive flooding methods. Nature Scientific Reports 8: 14484 DOI:10.1038/s41598-018-32658-x
[6] Heede, R. (2020) Update Carbon Majors 1965-2018 [Press Release], Climate Accountability Institute (9 Dec.) https://climateaccountability.org/pdf/CAI%20PressRelease%20Dec20.pdf.
[7] IPCC (2021) Summary for Policymakers. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. P. SPM-5. Contribution of WGII to the AR6 of the IPCC [Masson-Delmotte, V., et al. (eds.)]. Cambridge Univ. Press. In Press.
[8] Ibid.

1.2 LOCAL HAZARDS SUMMARY

Kauaʻi is facing unavoidable, costly, and dangerous impacts from climate change. Five hazards stand out above others as warranting special concern: increasing ambient and extreme heat, wildfire declining rainfall and expanding drought, growing storminess, and sea level rise. These represent direct challenges to long-term sustainability, public health and safety, and chronic and growing socio-economic disruption. Table 1 provides a list of key observed and projected climate change hazards and threats to Kauaʻi.

Table 1. Historical and Expected Climate Hazards on Kauaʻi

Climate Hazard	Past Trend	Future Trend	Confidence
Average Rainfall	↓ Declining (last 100 years)	↓ Decreasing wet and dry season rain	High
Heavy Rainfall Events	↑ Increasing (last 100 years)	↑ Increasing	Moderate
Drought	↑ Increasing length	↑ Increasing with changing rainfall and temperature	Moderate
Stream flow	↓ Decreasing (last 20 years)	↓ Decreasing with declining rainfall	Moderate
Wildfire	↑ Increasing (last 50 years)	↑ Increasing with changing rainfall and temperature	High
Average Temperature	↑ Increasing (last 70 years)	↑ Increasing	High
Warm Days & Nights	↑ Increasing (last 45 years)	↑ Increasing	High
Trade Winds	↓ Decreasing, turning easterly	↑ Continuing	Moderate
Sea Level Rise	↑ Increasing (last 65 years)	↑ Increasing	High
Tidal Flooding	↑ Increasing	↑ Increasing with higher SLR	High
Tropical Cyclones	↑ Increasing (last 40 years)	↑ Increasing	Moderate
Marine Heatwaves	↑ Increasing (last 40 years)	↑ Increasing	High
Global Disease	↑ Increasing (last 40 years)	↑ Increasing	High

Source: County of Kauaʻi. 2022. Climate Hazards White Paper

1.3 COASTAL FLOODING

Global mean sea level rise (SLR) is driven by melting of Greenland and Antarctic ice sheets, melting mountain glaciers, expansion of warming ocean water, and groundwater mining and discharge to the ocean.[9] From 1993-2021, the rate of SLR was 1.38 in/decade, increasing to 1.74 in/decade between 2011-2021.[10]Global mean sea level is projected to continue rising. The set of projections range from Low (1 foot; 0.3 meters), Intermediate-Low (1.6 feet; 0.5 meters), Intermediate (3.3 feet; 1 meters), Intermediate-High (4.9 feet; 1.5 meters) and High (6.6 feet; 2 meters) by 2100.[11] Sea level rise approaching 6 ft or more by 2100 and 15 ft by 2150 cannot be ruled out, as there remains deep uncertainty regarding ice sheet processes.[12]

The Sea Level Rise Exposure Area (SLR-XA) is the combined footprint of three chronic coastal flooding hazards: passive flooding, annual high wave flooding, and coastal erosion. Three exposure areas can be viewed individually or combined as the multi-hazard SLR-XA which defines the projected extent of chronic flooding due to sea level rise.[13] Each exposure area was modeled considering 0.5-, 1.1-, 2.0-, and 3.2-foot increases in sea level. The 3.2-foot projection of sea level rise was originally based on the sea level rise model for 2100 under the high greenhouse gas emissions scenario published by the Intergovernmental Panel on Climate Change (AR5, 2014).[14] Though there have been new reports published since then (IPCC AR6 and NOAA 2022 Sea Level Rise Technical Report), they still include 3.3 ft/1 m as "Intermediate" projection of global sea level rise by 2100. The main change is the timing for different rates of SLR where "there is less acceleration in the higher scenarios until about 2050 and greater acceleration toward the end of the century."[15] The Kauaʻi General Plan calls for planning for 3.2' of SLR by the latter half of the century but acknowledges that 6' or more is plausible.

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[9] Frederikse, T., et al. (2020) The causes of sea-level rise since 1900, Nature 584, 393–397, https://doi.org/10.1038/s41586-020-2591-3

[10] AVISO Satellite Altimetry Data, Mean Sea Level Products, https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/data-acces.html

[11] Sweet, W.V. et. al. (2022). Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf.

[12] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the 6th Assessment Report of the IPCC [Masson-Delmotte, V., et al. (eds.)]. In Press.

[13] The SLR-XA is an overlay of three hazards and does not account for interactive nature of these hazards as would be expected by natural processes. As with the individual exposure models, the SLR-XA maps hazard exposure on the present landscape. The modeling does not account for future (unknown) land use changes, including any adaptation measures. The SLR-XA also does not include impacts from less frequent high wave events (e.g., a 1-in-10 year event), storm surge, or tsunami. In addition, mapping errors may be found in some areas due to clipping (subsetting) of the original map layers using a shoreline (Special Management Area) boundary and possible modeling errors in the Annual High Wave Flooding model at reef and harbor channels.

[14] Romine, B.M.; Habel, S.; Lemmo, S.J.; Pap, R.A.; Owens, T.M.; Lander, M.; Anderson, T.R. (2020). Guidance for Using the Sea Level Rise Exposure Area in Local Planning and Permitting Decisions. Prepared by the University of Hawaii Sea Grant College Program with the Hawaiʻi Department of Land and Natural Resources - Office of Conservation and Coastal Lands for the Hawaiʻi Climate Change Mitigation and Adaptation Commission – Climate Ready Hawaiʻi Initiative. (Sea Grant Publication TT-20-01)

[15] Sweet, W.V. et. al. (2022). Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf.

Figure 1. Sea Level Rise Exposure Area 3.2 (2021)

Source: County of Kaua'i. 2022. Climate Hazards White Paper

While the 3.2 ft SLR is in line with the National Oceanic and Atmospheric Association's (NOAA) Intermediate projection by 2100, NOAA has mapped the areas that could be inundated if the sea level rises by 6 ft, similar to the High projection by 2100. As described by the PacIOOS Sea Level Rise Viewer tool, NOAA's passive flooding model is distinct from SLR-XA in the following ways:

> This model is different from the SLR-XA (and may be an underestimate) because it is passive flooding only and does not include annual high wave flooding or erosion. Passive flooding identifies areas below a certain sea level height (flooded by sea level rise) when raising water levels above current Mean Higher High Water (MHHW) tidal datum. In NOAA's modelling of 6' Passive Flooding, a sea level rise projection of 6 feet above a local mean higher high water (MHHW) datum is used. In other words, water levels are shown as they would appear during MHHW, or the average higher high water height of each tidal day. The

area flooded was derived by subtracting a tidal surface model from the DEM. The model does not account for waves and coastal erosion.[16]

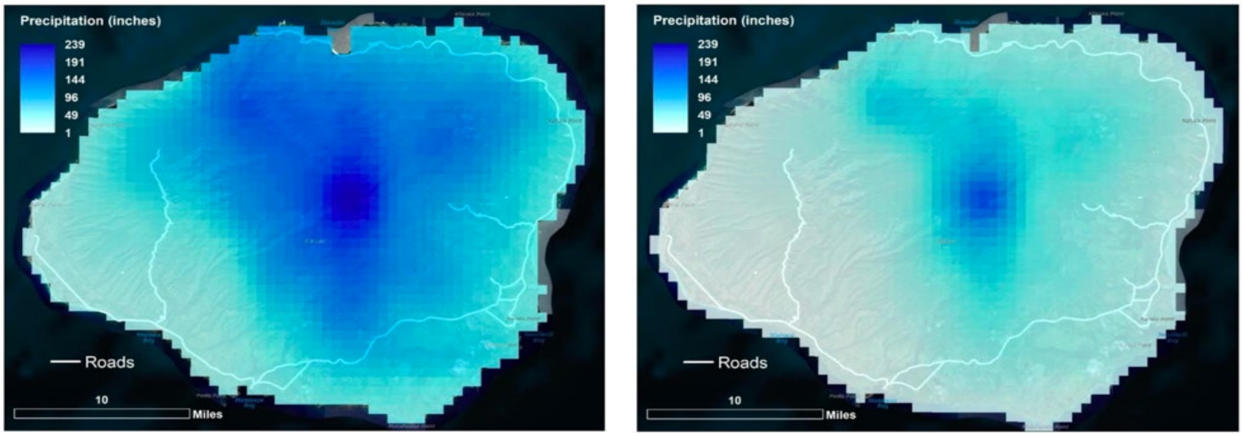
1.4. PRECIPITATION AND INLAND FLOODING

Precipitation patterns are changing on Kauaʻi due to climate change. Hawai'i has seen an overall decline in rainfall (Figure 2) over the past 30 years, with a particularly dry period ensuing from 2008 to present.[17] Consecutive wet days and consecutive dry days are both increasing.[18] The heavy rainfall and drought periods have intensified, increasing runoff, erosion, flooding, and water shortages.[19] On Kauaʻi there have been over 81 flood events between 2005 and 2020, with especially severe flooding occurring in 2018 and 2020.[20]

River flooding is measured based on the probability that a certain river flow will be equaled or exceeded in a given year. The area that is flooded by a river flow that has a 1-percent annual chance of occurrence (also called the base flood) is called the special flood hazard area. This data set does not predict future precipitation pattern with climate change but is the best data currently available.

Modeling does not necessarily do a good job of projecting high frequency flooding (e.g., 10-year floods). However, windward Kauaʻi, where ridgelines capture trade wind moisture and form orographic clouds, may see an increase in wet season flooding with a changing climate.

Figure 2. Wet Season Precipitation, Historical and 2100 (2017)



Downscaled wet season ensemble mean precipitation changes (inches) using the RCP 8.5 scenario.
Source: Hawaii Highways, Climate Adaptation Plan, Exposure Assessments (April, 2021) based on projections by Timm, O.E. (2017)

[16] PacIOOS. (2022). Sea Level Rise: State of Hawaiʻi Sea Level Rise Viewer. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/
[17] Bassiouni, M., and D.S. Oki. 2013. Trends and shifts in stream flow in Hawaiʻi, 1913-2008. Hydrological Processes 27(10):1484-1500.
[18] Kruk, M.C., et al. (2015)
[19] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 7-1
[20] Ibid.

In April 2018 a supercell thunderstorm generated heavy rain and historic flash flooding conditions on the north shore.[21] A 24-hour rainfall total of 50 inches was recorded near Hanalei. The deluge, mainly over northern Kaua‘i but also affecting east O‘ahu, damaged or destroyed farms and structures, including 532 homes. The storm downed trees and power lines, flooded homes, businesses and vehicles, and closed and damaged numerous roadways. Highway and road repairs were estimated at $35 million.

1.5. TROPICAL CYCLONE

Major tropical cyclones have become 15% more likely over the past 40 years,[22] and climate models project an increase in tropical cyclones near Hawai‘i.[23] Sea level rise is causing higher coastal inundation levels for tropical cyclone storm surge. Climate models project an increase in TC's near Hawai‘i.[24] A global-average migration of TC activity is taking place as storms move away from the tropics at a rate of about one degree of latitude per decade.[25] With 2^{o}C (3.6^{o}F) of additional warming, climate models project a 10-15% increase in the average precipitation rate within 100 km of a storm.[26] As oceans warm, there is less cold, subsurface water to serve as a braking mechanism for hurricanes.[27]

Sea level rise is causing higher coastal inundation levels for TC storm surge. The proportion of TC's reaching Category 4 and 5 levels will likely increase. Hurricanes have already become bigger and more destructive in the U.S.[28] There is low confidence in the global number of future Category 4 and 5 storms, since modeling studies show decreasing global frequency of all tropical cyclones combined. The forward speed of TC's are decreasing.[29] Model simulations suggest that future global warming could lead to a significant slowing of hurricane motion.

Sea surface temperature increase has intensified in areas of TC genesis relevant to Hawai‘i suggesting a connection with strengthened storminess.[30] Increased heat and evaporation contribute to a more extreme hydrological cycle and more extreme weather, in particular hurricanes. More frequent tropical cyclones are also projected for waters near Hawai‘i because of the new tracks that storms will likely follow as a result of climate change.[31] There will be an increase in average cyclone intensity, and in the number and occurrence days of very intense category 4 and 5 storms in most basins and in tropical cyclone precipitation rates.[32]

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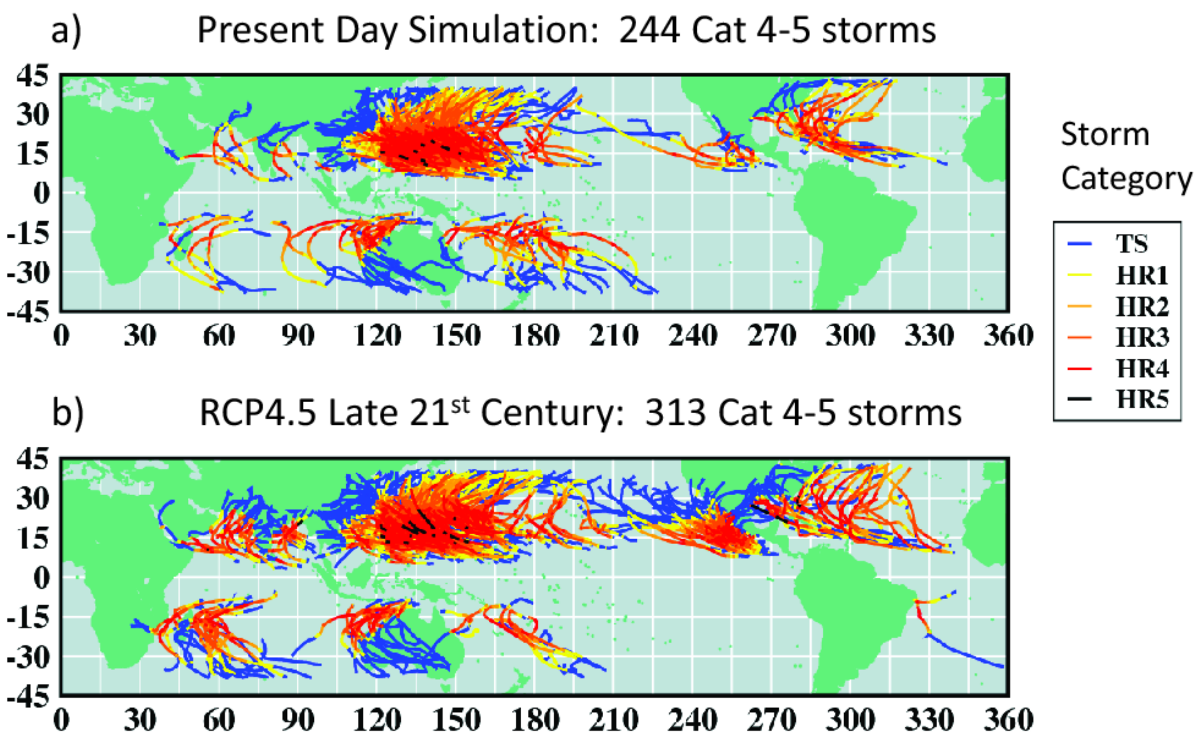
[21] Corrigan, T.J. and S. Businger. (2022). "The Anatomy of a Series of Cloud Bursts that Eclipsed the U.S. Rainfall Record. American Meteorological Society Monthly Weather Review, 753–773 DOI: https://doi.org/10.1175/MWR-D-21-0028.1
[22] Kossin, J.P., et al. (2020) Global increase in major tropical cyclone exceedance probability over the past four decades. *PNAS*, DOI: 10.1073/pnas.1920849117
[23] Murakami, H., Wang, B., Li, T. et al. (2013) Projected increase in tropical cyclones near Hawaii. Nature Clim Change 3, 749–754. https://doi.org/10.1038/nclimate1890
[24] Murakami, H., Wang, B., Li, T. *et al.* (2013) Projected increase in tropical cyclones near Hawaii. *Nature Clim Change* 3, 749–754. https://doi.org/10.1038/nclimate1890
[25] Kossin, J., Emanuel, K. & Vecchi, G. (2014) The poleward migration of the location of tropical cyclone maximum intensity. *Nature* 509, 349–352. https://doi.org/10.1038/nature13278
[26] Global Warming and Hurricanes, an Overview of Research Results (2020) Geophysical Fluid Dynamics Laboratory, Princeton University, NOAA: https://www.gfdl.noaa.gov/global-warming-and-hurricanes/
[27] Global Warming and Hurricanes, an Overview of Research Results (2020)
[28] Grinsted, A., *et al.* (2019) Normalized US hurricane damage estimates using area of total destruction: 1900-2018; *PNAS*: http://dx.doi.org/10.1073/pnas.1912277116
[29] Zhang, G., *et al.* (2020) Tropical Cyclone Motion in a Changing Climate, *Science Advances*, DOI: 10.1126/sciadv.aaz7610
[30] Defforge, C.L., Merlis, T.M. (2017) Observed warming trend in sea surface temperature at tropical cyclone genesis, *Geophys. Res. Lett.*, 44, 1034–1040, doi:10.1002/2016GL071045.
[31] Murakami, H., *et al.* (2013)
[32] Knutson, T., *et al.* (2020) Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Human-made Warming, *Bull. Amer. Meteor. Soc.* (2020) 101 (3): E303–E322: https://doi.org/10.1175/BAMS-D-18-0194.1

Figure 3. Simulated Cat. 4-5 Tropical Cyclone Tracks



Tracks of simulated category 4-5 tropical cyclones for (a) present-day or (b) late twenty-first century under conditions of decreasing greenhouse gas emissions in the second half of the century (RCP4.5[33]). Storm categories on the Saffir–Simpson scale are depicted by the track colors, varying from tropical storm (blue) to category 5 (black; see legend). The number and intensity of storms in Hawaiian waters significantly increases.

Source: Knutson, T.R., et al. (2015)

1.6. TEMPERATURE AND EXTREME HEAT

In Hawai'i, the rate of air temperature increase has accelerated in recent years.[34] At a rate of 0.3°F per decade, the air is warming four times faster than half a century ago.[35] Statewide, the average air temperature has risen by 0.75°F over the past 100 years, and 2015 and 2016 were the warmest years on record.[36]

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[33] RCP4.5 or RCP6 are more realistic modeling scenarios compared to RCP8.5 due to the accelerated deployment of renewable energy sources. See Hausfather, Z. and Peters, G.P. (2020) Emissions – the "business as usual" story is misleading. *Nature*, v577, 30 Jan., p618-620: https://doi.org/10.1038/d41586-020-00177-3

[34] Giambelluca, T.W., et al. (2008) Secular Temperature Changes in Hawai'i, Geophysical Research Letters, 35:L12702.

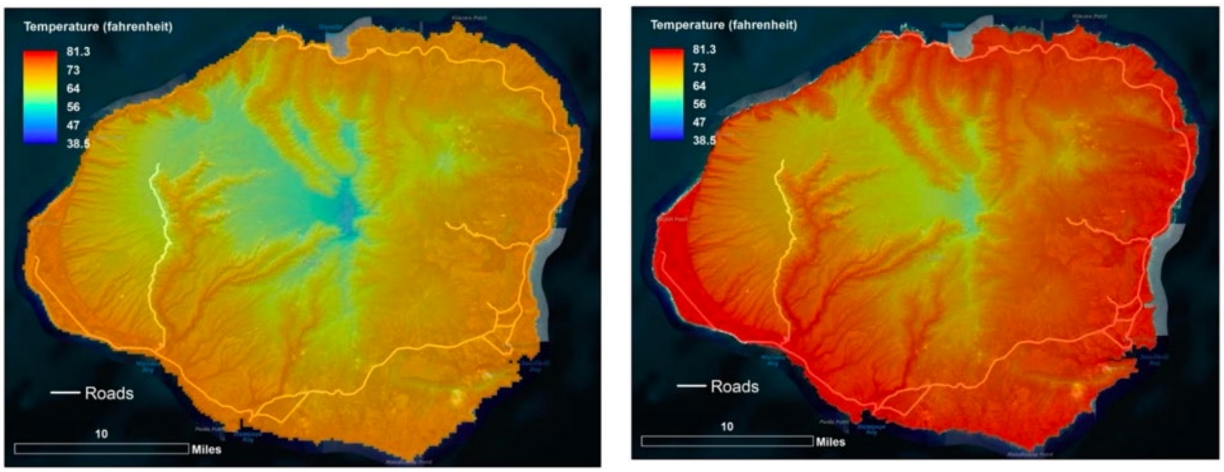
[35] Ibid.

[36] McKenzie, M.M. (2016) Regional temperature trends in Hawai'i: A century of change, 1916–2015 (MS thesis). Dept. of Geog., University of Hawai'i at Mānoa.

Rapidly increasing air temperature is detrimental to the delicate balance of Hawaii's ecosystems.[37] Modeling results suggest that for every 1.8°F temperature change projected at sea level, the high elevation zones of Kaua'i may experience 2.16°F change near 5,000 ft elevation and about 2.7°F warming at 13,000 ft elevation.[38]

All areas of Kaua'i will be exposed to some degree to extreme heat. Extreme heat is defined as temperatures that hover around 10 degrees Fahrenheit or more above the average high temperature for the region, last for prolonged periods of time, and are often accompanied by high humidity. Due to the urban heat island effect cities may be more impacted, but non-urban communities will also experience effects.

Figure 4. Mean Annual Temperature Values for Kaua'I, Historic and 2100



Downscaled 97.5th percentile ensemble mean temperature changes (°C) for RCP 8.5[39] scenario. The highest mountain elevations warm by a factor 1.5±0.2 compared to the surface temperature at sea level. In scenario RCP 8.5, high elevations above 3000 m reach up to 4–5 °C (7.2–9 °F) warmer temperatures by the late 21st century.

Source: Hawaii Highways, Climate Adaptation Plan, Exposure Assessments (April, 2021) based on projections by Timm, O.E. (2017)

[37] Fortini, L., *et al.* (2013) A Landscape-Based Assessment of Climate Change Vulnerability for all Native Hawaiian Plants. Hawai'i Cooperative Studies Unit. University of Hawai'i at Hilo. Technical Report HCSU-044

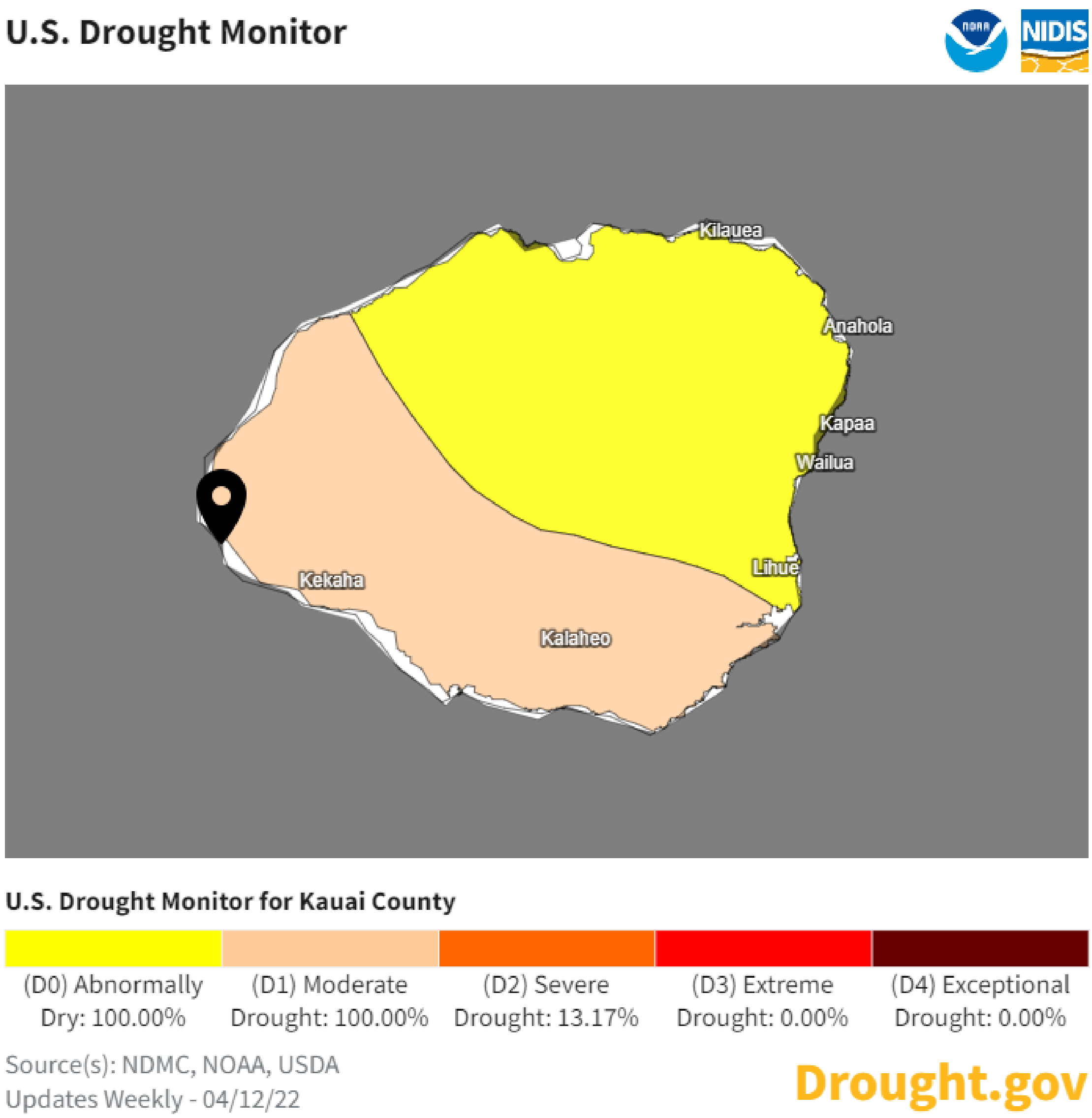
[38] Timm, O.E. (2017) Future Warming Rates over the Hawaiian Islands Based on Elevation-Dependent Scaling Factors. *Int. J. Clim*.,doi:10.1002/joc.5065.

[39] RCP or Representative Concentration Pathway, is a GHG concentration trajectory adopted by the IPCC and used in projecting future climate change. Four RCPs were modeled in the IPCC 5th Assessment Report (2014). Their use has been continued and expanded in SSP models used in the IPCC 6th Assessment Report (2021). The RCPs describe possible climate futures depending on the volume of GHGs emitted in the years to come. The RCPs – originally RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5 – are labelled after radiative forcing (net heating) values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, resp.). RCP 8.5 is now considered unlikely given the rapid deployment of renewable technologies that have replaced traditional fossil fuels, but still possible as feedbacks are not well understood.

1.7. DROUGHT

Droughts are becoming more common in Hawaiʻi and on Kauaʻi, with longer periods of drought experienced more recently. Continued changes in precipitation patterns (decline in rainfall, higher intensity events) may increase drought frequency, intensity, and duration. All areas of Kauaʻi will be exposed to drought, though the extent and severity can vary across the island with the amount of rainfall.[40] The southeastern side of the island is more vulnerable to some drought levels (Fig 5).

Figure 5. U.S. Drought Monitor (April 2022)



Source: NOAA and NIDIS, 2022

[40] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P 13-3

1.8. LANDSLIDE

Landslides are more likely to occur in areas with slopes greater than 33%; with a history of landslide activity; where there is stream or wave activity; presence of an alluvial fan; and presence of mixed impermeable and granular soils.[41] In the Multi-Hazard Mitigation and Resilience Plan analysis, moderate landslide hazard refers to slopes between 20-40% and high landslide hazard refers to slopes greater than 40%.

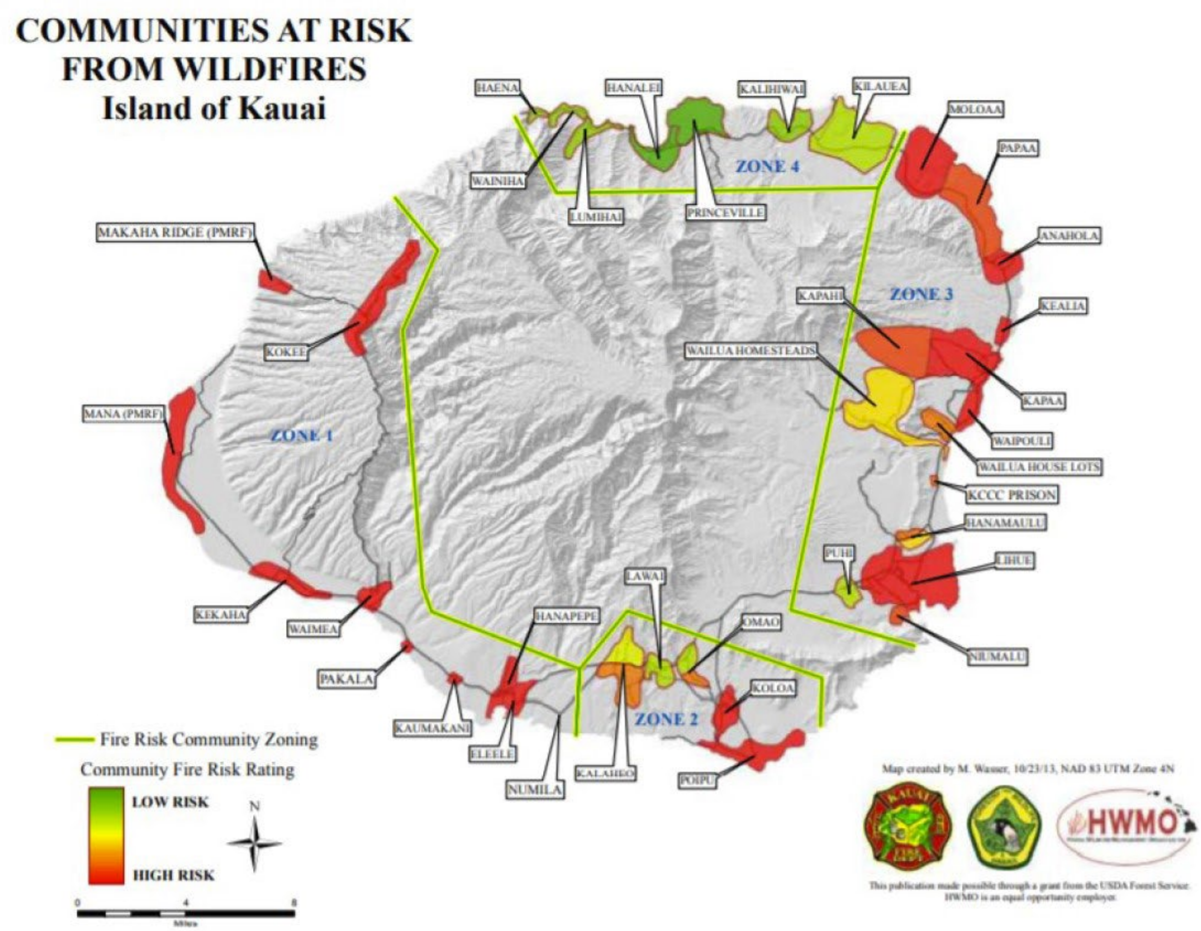
1.9. WILDFIRE

Wildfire is a growing problem related to drying, invasive grasses, and human ignition.[42] Total burned area statewide has increased more than fourfold in the last century and fire propagates rapidly in dry nonnative grasslands.[43] The causes of most fires are unknown. Out of 12,000 recorded incidents statewide from 2000 to 2011, only 882, or about 7%, had a determined cause. Of those, 72% were accidental, which also means they're preventable.[44]

The Wildland Urban Interface (WUI) – the zone where development and vegetated areas are next to each other – has the highest potential for damage to life and property. Areas at risk of wildfire are categorized into Medium and High risk according to the Communities at Risk from Wildfire (CARW) mapping[45] from the Hawai'i Wildfire Management Organization (Fig 6). The assessment qualitatively ranks 36 components related to subdivision, vegetation, building, fire environment, and fire protection characteristics of each community area on the island.[46] The resulting CARW map gives an indication of general wildfire risk for a given area based on the factors that contribute to the threat of wildfires in the WUI.

[41] Ibid. P.10-1
[42] Trauernicht, C., E. et al. (2015) The contemporary scale and context of wildfire in Hawaii. Pacific Science 69:427-444
[43] Trauernicht, C., et al. (2015) The Contemporary Scale and Context of Wildfire in Hawai'i. Pacific Science, v. 69, no 4, October, pp. 427–444. https://doi.org/10.2984/69.4.1; Trauernicht, Clay, & Elizabeth Pickett (2016) Pre-fire planning guide for resource managers and landowners in Hawai'i and Pacific Islands, Forest and Natural Resource Management, College of Tropical Agriculture and Human Resources, https://www.ctahr.hawaii.edu/oc/freepubs/pdf/RM-20.pdf.
[44] Restoration of Forest Key to Fire Control, Feb. 12 (2019) https://www.hawaiiwildfire.org/news-center/tag/Maui+%28West%29
[45] Note: Only developed community, residential, and commercial areas were assessed for wildfire hazards. Uninhabited wildland or protected areas were not assessed for hazards using the 36 components as it was specifically designed to inform the Communities at Risk mapping project.
[46] Hawaii Wildfire Management Organization. (2013). Kauai Wildfire Hazard Assessment. https://static1.squarespace.com/static/5254fbe2e4b04bbc53b57821/t/5579d2c4e4b042afe8ed2930/1434047172702/Community+Hazard+Assessments+-+County+of+Kauai+-+Cover+NEWEST.compressed.pdf

Figure 6. Communities at Risk from Wildfires



Source: Hawaii Wildfire Management Organization

Chapter 2: Kaua‘i Asset Profile and Critical Vulnerabilities

This profile highlights key existing conditions of Kaua‘i's economy, natural and cultural resources, and assets. These sectors are ones which are highly vulnerable to climate change.[47] It focuses on County assets (such as infrastructure, services, and parks that are within County jurisdiction), though county-wide assets are included. This analysis draws from a wide variety of sources including County planning documents, local/community-based planning and research, documents from state agencies, and scientific studies. Community member observations from the Climate Adaptation Plan's Open House[48] and Youth Climate Change Summit[49] events were also incorporated into this analysis. This Kaua‘i Profile is meant to supplement existing sources for the purpose of informing the final Climate Adaptation Plan.

This chapter also describes vulnerability to climate change-related hazards on an island-wide scale. The IPCC definition of vulnerability is "the propensity or predisposition to be adversely affected [and] encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."[50] This analysis draws on vulnerability assessments conducted by the County, State agencies, non-profits, universities, and the scientific community. Given the scale of analysis and available information, this chapter summarizes systems at large rather than individual locations and facilities.

This assessment is meant to be used in concert with other state, county, and region-specific vulnerability and exposure assessments. This includes assessments completed as part of the Hawai‘i Highways Climate Adaptation Action Plan (2021), Kaua‘i Multi-Hazard Mitigation and Resilience Plan (2021), and the West Kaua‘i Community Vulnerability Assessment

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[47] The Vulnerability and Equity Assessment focuses on sectors vulnerable to climate change and is not meant to be a comprehensive profile of the county.

[48] The Kauai Adaptation Plan's Open House Series #1 Summary Report summarizes the key findings from community input during the first series of open house events. This includes the Online Open House and the five In-Person Open Houses held from late March through early April 2022. The purpose of the open houses was to understand personal and local community experiences with climate hazards and adaptation measures. The Summary Report can be found here, KCAP_OpenHouse1_FINALSummary_22_0707.pdf (kauaiadaptation.com)

[49] The Kauai Adaptation Plan's Climate Change Youth Summit was held on May 7th with the aim of engaging youth in the early stages of developing the CAP. The Talk Story Summary document can be found here, KCAP_YouthSummit_Summary_062222.pdf (kauaiadaptation.com).

[50] IPCC. Introduction to WGII AR6 Factsheets. https://www.ipcc.ch/report/ar6/wg2/downloads/outreach/IPCC_AR6_WGII_IntroductionWGII.pdf

(2020). Additionally, this assessment is a companion to the online mapping platform maintained on Kauai County's GIS website.[51] The online mapping platform will incorporate new and improved data on hazards and assets when possible.

[51] Please visit the County of Kaua'i Open Hub Data for more information, GIS - Geographic Information System - Kauai.gov

2.1. NATURAL AND CULTURAL RESOURCES

Kauaʻi and its surrounding area include many important natural and cultural resources, such as rivers and streams, wetlands, forests, native flora and fauna, and Native Hawaiian cultural sites. These natural features act as landmarks establishing a strong sense of place and location within the island's communities and cultural resources, and provide significant opportunities to support biological resources in natural and urbanized areas. Kauaʻi is also a biodiversity hotspot with many threatened and endangered native species that live on the island's unique ocean, wetland, forest, stream and other habitats.

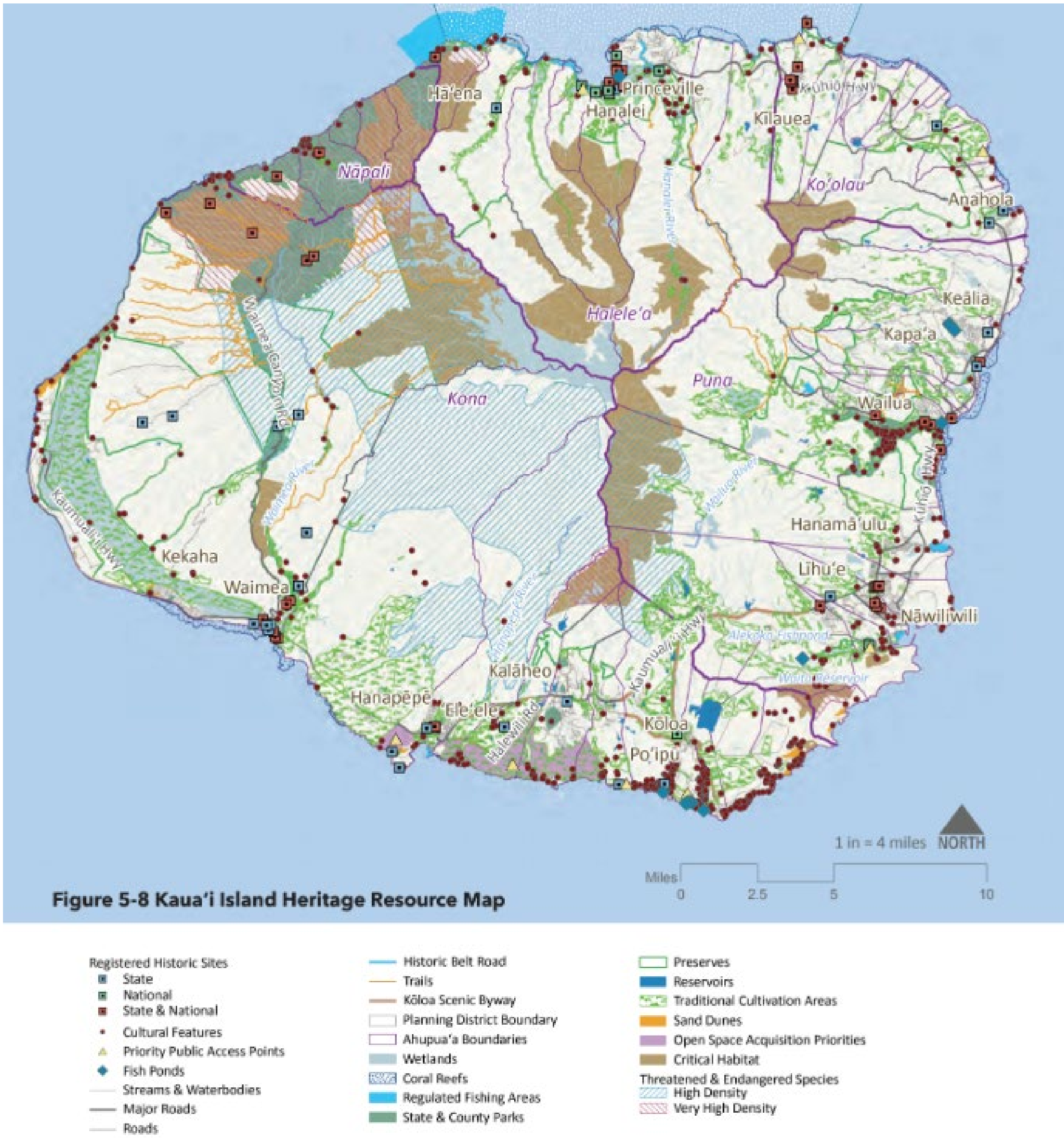
2.1.1. Asset Profile: Habitats and Resources Mauka to Makai

For many centuries, Hawaiian society thrived under the recognition that the community, forests, streams, and ocean are interconnected. A typical ahupuaʻa, or land division, follows watershed lines and extends from the highest point mauka down to the fringing reef.[52] Prior to western colonization, ʻāina could not be owned, but was rather communally accessed and cared for through local stewardship within one's moku or ahupuaʻa. A moku and ahupuaʻa are two scales in which the land was divided, and these two land divisions served as political boundaries in the pre-contact governance system. A moku is a social-ecological region in which terrestrial social-ecological zones (wao) were designated. An ahupuaʻa is a subdivision of the moku and is defined as a "social-ecological community"[53] that is "culturally appropriate, ecologically aligned, and place specific unit with access to diverse resources."[54] While wao spanned horizontally across the moku, each ahupuaʻa spanned vertically, allowing for system-based management within each ahupuaʻa as well as coordinated management of key resources between the ahupuaʻas in each respective moku[55] The ahupuaʻa subzones, listed below, is a helpful way to understand the interconnection of Kauai's ecosystems.

Figure 7 shows natural, cultural, and scenic resources island wide.[56]

[52] County of Kauaʻi. (2018). Kauaʻi Kakou Kauaʻi County General Plan." P. 97
[53] Winter, K., Beamer, K., Vaughan, M., Friedlander, A., Kido, M., Whitehead, A., Akutagawa, M., et al. (2018). The Moku System: Managing Biocultural Resources for Abundance within Social-Ecological Regions in Hawaiʻi. *Sustainability*, *10*(10), 3554. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su10103554
[54] Beamer, K. and Gonschor, L. (2014). Toward an Inventory of Ahupuaʻa in the Hawaiian Kingdon: A survey of Nineteenth- and early Twentieth-Century Cartographic and Archival Records of the Island of Hawaii. *The Hawaiian Journal of History*, *48* (48) 53-87.
[55] Winter et al (2018).
[56] Heritage Resource Maps at the Planning Area scale are available on pages 245-250 of the 2018 General Plan Update.

Figure 7. Heritage Resources



Source: County of Kaua'i, 2018

Wao Nāhele – Upper Watershed

- **Mesic and wet forests**: This habitat type exists at mid- and high-elevation sites on Kaua'i and has a forest structure ranging from high canopy cloud forests to open bogs and low stature forests.[57] They provide habitat for native flora and fauna (including endangered seabirds, waterbirds, and forest birds)

[57] Hilberg LE, Gregg RM. (2018). "Mesic and Wet Forest Habitats: Vulnerability and Adaptation Brief for Kaua'i." EcoAdapt.

as indicated by the brown "Critical Habitat" and blue and pink hatch "Threatened & Endangered Species" areas shown in Figure 3.

Kahawai – Middle Watershed

- **Streams:** This habitat type refers to streams and manmade waterways that have flowing freshwater year-round or during certain parts of the year. Forty-five of the island's 61 total streams connect to the ocean.[58] Streams are home to important native fauna including gobies, shrimp, and snails.
- **Upland wetlands**: Upland wetlands are bogs, swamps, and marshes that occur in forest openings above 1,000 ft elevations.[59] They are habitat for highly endemic and specialized mosses, grasses, and small woody plants.
- **Lowland wetlands**: Lowland wetlands contain ponded fresh water that fluctuates throughout the year.[60] It also includes irrigated agricultural fields such as those used to cultivate kalo. They contain emergent vegetation (plants that are rooted in the water but are not submerged) and are important habitat for native birds, fish, and invertebrates.
- **Estuaries and coastal wetlands**: This habitat type occurs where freshwater and saltwater come together. It includes estuaries (which connect rivers to the ocean) and tidal and salt marshes (which have intermittent connectivity to the ocean).[61] They support many types of wildlife such as migratory birds, estuarine species, and marine species.

Kahakai – Lower Watershed

- **Shorelines and coastal waters**: The island has a wide variety of shoreline typologies including rocky shoreline, sea cliffs, lava tubes and caves, sandy beach, and sand dunes.[62] It also includes coral reefs, which exist along beaches in the North Shore, West Kauaʻi, and East Kauaʻi. Shorelines provide habitat for terrestrial and aquatic invertebrates, fish, migratory shorebirds, seabirds, and turtles.[63]

Protected Lands

Lands protected by the State and County preserve important cultural practices, historic sites, and habitat.

- **State Parks and Reserves**: State parks and reserves are under the jurisdiction of the Department of Land and Natural Resources Division of State Parks. There are nine state parks in total on the island that protect biologically and culturally significant resources.[64] Five of the parks also contain historic sites. There are other state-managed lands such as forest reserves and natural area reserves, which may be outside the boundaries of state parks.
- **County Parks:** The Kauaʻi Department of Parks and Recreation operate and maintain 67 parks totaling 487 acres across the entire island.[65] County parks provide recreational opportunities and preserve open space. A subset of these are beach parks, which focus on water-based recreation and passive

[58] Reynier WA, Gregg RM. (2018). "Stream Habitats: Vulnerability and Adaptation Brief for Kaua'i." EcoAdapt.
[59] Reynier WA, Gregg RM. (2018). "Upland Wetland Habitats: Vulnerability and Adaptation Brief for Kaua'i." EcoAdapt
[60] Reynier WA, Gregg RM. (2018). "Lowland Wetland Habitats: Vulnerability and Adaptation Brief for Kaua'i." EcoAdapt.
[61] Reynier WA, Gregg RM. (2018). "Estuarine and Coastal Wetland Habitats: Vulnerability and Adaptation Brief for Kaua'i." EcoAdapt.
[62] Hilberg LE, et al. (2018). "Shoreline Habitats: A Habitat Climate Change Vulnerability Assessment Synthesis for Kauaʻi." EcoAdapt.
[63] Ibid.
[64] Department of Land and Natural Resources. (2021) "Island of Kauai". https://dlnr.hawaii.gov/dsp/parks/kauai/
[65] "Facilities." Kauai.gov. Accessed April 2022. https://www.kauai.gov/Government/Departments-Agencies/Parks-Recreation/Facilities

activities.[66] There are 21 beach parks on the island totaling approximately 133 acres of developed park land and 162 acres of undeveloped park land.

- **Hawaiian Home Lands:** Hawaiian Home Lands are residential, pastoral, and agricultural lands which are leased to native Hawaiian beneficiaries and under the jurisdiction of the Department of Hawaiian Homelands.[67] There are Hawaiian Home Lands in Waimea, Kekaha, Hanapēpē, Wailua, Kapaʻa, Anahola/Kamalomaloʻo, and Moloaʻa.[68] As of June 2020, there are 697 residential, 46 agricultural, and 1 pastoral Hawaiian homestead leases on the island.[69] A majority (over two-thirds) of the homesteads are in Anahola, which is one of the Department of Hawaiian Home Lands' priority areas to develop large master-planned communities for people of Native Hawaiian ancestry.

2.1.2. Key Vulnerabilities and Planning Issues

Native Hawaiian Cultural Resources

While a concern for all people, climate change will disproportionately impact all native peoples, including direct threats associated with health and livelihoods, as well as relationships with cultural and natural resources. Since Native Hawaiians share a connection to ancestral resources, loss of land may result in a significant loss of culture, identity, and ways of life.

About 550 Hawaiian cultural sites are exposed to chronic flooding with a sea level rise of 3.2 ft.[70] Sea level rise impacts fishpond maintenance, cultivation of salt, crop cultivation, and gathering from nearshore fisheries: all traditional and culturally significant practices.[71] Detachment from traditional land and practice interferes with indigenous ways of living and harms both the spiritual and mental health of the people.[72] Climate change impacts such as reduced streamflow, sea level rise, ocean acidification, saltwater intrusion, long periods of drought, and pollution all interfere with the livelihood and security of Pacific communities.[73] Significant and harmful effects on the Native Hawaiian community and their traditional and customary rights and practices area also likely.[74]

Materials for Physical and Spiritual Customs

Hawaiians considered the uplands the realm of the gods or "wao akua" due to its importance in the ecosystem and for being a source of physical and spiritual nourishment.[75] With the rapid decline of Hawaiʻi's native forests, Hawaiʻi's native species have also perished and this "both limits the perpetuation of cultural

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[66] County of Kauai. (2013). "Kauai Parks & Recreation Master Plan." P. 2-7. https://www.dropbox.com/s/r83poce5ioy1jff/MASTER_PLAN_Kauai_Parks.pdf?dl=0

[67] Department of Hawaiian Home Lands. (2004). "Kauai Island Plan." https://dhhl.hawaii.gov/wp-content/uploads/2012/05/Island_Plan_Kauai_2004.pdf

[68] Ibid.

[69] Department of Hawaiian Home Lands. (2020). "2020 Hawaiian Homelands Annual Report." https://dhhl.hawaii.gov/wp-content/uploads/2021/03/DHHL-Annual-Report-FY-20.pdf

[70] Hawaiʻi Climate Change Mitigation and Adaptation Commission (2017).

[71] Sproat, D. K. (2016) An Indigenous People's Right to Environmental Self-Determination: Native Hawaiians and the Struggle Against Climate Change Devastation. Stanford Environmental Law Journal, 35.

[72] Akutagawa, M., et al. (2016) Health Impact Assessment of the Proposed Moʻomomi Community-Based Subsistence Fishing Area (Report). The Kohala Center.

[73] Gillett, R., et al. (2001) Tuna: a key economic resource in the Pacific Islands. Pacific studies series. Manila, Philippines: Asian Development Bank.

[74] See generally D. Kapua'ala Sproat, An Indigenous People's Right to Environmental Self-Determination: Native Hawaiians and the Struggle against Climate Change Devastation, 35 STAN. EVNTL. L. J. 157 (2016) (discussing Native Hawaiian responses to the impacts of climate change and how native peoples claim and realize an indigenous right to environmental self-determination).

[75] Id. at 174. "Forests are a vital system for the continuum of life cycles in Hawai'i, capturing fresh water in the form of mist and rain, and absorbing and releasing it into streams and aquifers78 which eventually feed nearshore marine areas, the ocean, and communities. Trees house the seeds necessary for regeneration, acting as a food source for insects, birds, animals, and others." Id.

knowledge across generations and severs the connection between [Hawaiians] and natural and cultural resources."[76] Hawaiian practices in the upland that will be affected by climate change also include the collection of timber and medicinal plants, and collection related to traditional hula and hulu work (featherwork).[77] Although cultural practitioners continue to collect these materials, "it is now difficult to find the necessary resources."[78]

Agricultural Practices

In the "wao kanaka," or the realm of man, traditional Hawaiian agriculture practices is at high risk of becoming unsustainable in the future due to climate change.[79] Changing rainfall, diminished streamflow, rising temperatures, and rising sea levels causing saltwater intrusion threaten Hawaiian farming practices and food security.[80]

Increased soil temperatures and impacts to water quality and/or supply (i.e. drought, cyclones and storms) will lead to the loss and damage of crops to Kaua'i's food and fiber systems. Culturally significant crops including kalo cultivated in lowland areas will likely be impacted by sea level rise and tidal flooding, which may cause coastal wetlands to become brackish and face saltwater intrusion.[81]

Practices on the Coastline

Climate change also poses significant chances of disrupting or preventing numerous traditional and customary Hawaiian practices at the coastline and in nearshore areas. Climate change has the potential to impact the practice of burying and the already buried Hawaiian remains in soft sand dunes, cultivating and collecting sea salt, gathering marine life, using and maintaining fishponds,[82] fishing, and paddling and sailing in the open ocean.[83]

Native Hawaiian iwi kupuna (ancestral burials) are highly valued and carefully protected by Hawaiian families. Iwi kūpuna in Kaua'i have a moderate-high vulnerability level to climate change impacts and non-climate stressors. Coastal erosion associated with SLR is likely to remove sand deposits and disturb or destroy iwi.[84] The Nohili sand dunes on the Mānā shoreline in West Kaua'i are a site where iwi kūpuna are threatened or already affected by annual high wave flooding with both near- and long-term SLR.[85] The decision of what to do about the exposure of iwi must be made carefully according to the unique needs of each family.

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[76] Id. at 174 (discussing the loss of Hawai'i's endemic birds).
[77] Id. at 175. "Healthy forests are essential to the perpetuation of this sacred art that has preserved history through oral tradition since ancient times and holds invaluable significance in contemporary Hawai'i." Id.
[78] Id.
[79] Id. at 176-677. "Sea level rise will further aggravate this problem by reducing the area available for farming and increasing the salinity of groundwater resources, which provide more than 90 percent of drinking water and about half of the water used for agricultural irrigation on O'ahu, where nearly 70 percent of Hawai'i's population currently resides." Id. at 177.
[80] Id. "Maoli communities relied and continue to rely on streams and springs to satisfy many needs, primarily for distributing flow sufficient to cultivate the staple crop kalo and to gather native stream life." Id. at 177-78.
[81] Hilberg, LE, Reynier, WA, Kershner, JM, & Gregg, RM. (2018). "Food and Fiber: An Ecosystem Service Climate Change Adaptation Summary for Kaua'i. EcoAdapt.
[82] "Ancient Hawaiian fishponds are another ecologically and culturally significant resource that are vulnerable to climate change's impacts, including sea level rise, increasing surface water runoff, and saltwater intrusion into springs. These changes are interrupting the delicate balance between salt and fresh water as well as the indigenous management system that fishpond practitioners carefully designed." Id. at 180; See also Dillon Ancheta, As climate change takes shape fears over its threat to cultural resources grow, HAWAII NEWS NOW (Aug. 28, 2017), https://www.hawaiinewsnow.com/story/36018757/as-climate-change-takes-shape-fears-over-its-threatstoculturalresourcesgrow/#:~:text=cultural%20resources%20grow,As%20climate%20change%20takes%20shape%2C%20fears%20over,threat%20to%20cultural%20resources%20grow&text=And%20for%20those%20fearing%20the,the%20Nature%20Conservancy%20of%20Hawaii..
[83] Id. at 178-80.
[84] Hilberg LE, et al. (2018). "Cultural Coastal Habitats: A Habitat Climate Change Vulnerability Assessment Synthesis for Kaua'i." EcoAdapt.
[85] Spirandelli et al. (2020) "West Kaua'i Community Vulnerability Assessment" P. 54

The Lo‘i pa‘akai of Ukula (Hanapēpē salt ponds) have a moderate-high vulnerability level to climate change impacts and non-climate stressors.[86] Potential SLR-related impacts to the ponds are flooding shortening (or even completely preventing) the times salt can be harvested, and inundation of the salt ponds (with SLR >6.5 ft).[87] The impacts of increased temperatures, drought, and changing precipitation patterns may change the salt season length and harvest amount. Warmer, drier conditions may have a positive effect by speeding up evaporation of water from the salt ponds, while increased precipitation would likely have a negative effect.[88]

Loko i'a (fishponds) in Kaua‘i are moderately vulnerable (high confidence) to climate change impacts and non-climate stressors. SLR may inundate fishponds and alter their size, abundance, and distribution. Inundation will also increase the fishponds' salinity directly and through saltwater intrusion into springs.[89] Fishpond depth and water quality will be negatively impacted by both drought conditions and high streamflow.

Native Species and Biodiversity

Pacific island ecosystems have high percentages of species found only in the region. Unfortunately, endemic and endangered flora and fauna are highly vulnerable to climate change and are already displaying shifting habitats.[90] Increases in the frequency of events such as wildfires, tropical cyclones, drought periods, hurricanes –all exacerbated by climate change– threaten the balance of Hawaii's delicate ecosystems. These climate shocks and stressors promote the spread of invasive species of plants and animals; for instance, Kaua‘i's mesic and wet forest habitat are vulnerable to the establishment of flammable grasses, ungulates, pathogens/parasites, and social insects after parts of the forest are disturbed by storms and wildfire.[91] Habitat loss is another threat, for example one community member observed that the Alaka‘i swamp is drying up in the past ten years, and there are new pests there.[92] Community members also acknowledged that many of these species were already threatened and vulnerable to development and other human activities.[93]

Native Birds

The predicted negative consequences of warming temperatures to Hawaiian forest birds would first be seen on Kaua‘i. These consequences include loss/degradation of habitat, the invasion of non-native species into habitat, and the distribution of diseases (avian malaria and avian poxvirus in particular).[94]

"Future projections of climate-based habitat suggest that nearly all of the current climatic space of native forest birds on Kaua‘i will be lost by 2100."[95] In the past four decades, "all of Kaua‘i's native forest birds have had their range contract… ranging from 57-70% for the most range-restructed and 27-66% for those with broader ranges."[96] Even moderate warming will cause 10 of 21 existing native forest bird species to lose over 50% of their range by the year 2100.[97] Three others are projected to lose more than 90% of their range, making them a high concern for extinction. Climate change will also facilitate the movement of diseases to higher elevations over time. Warmer temperatures bring mosquito-borne diseases to previously safe upland

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86 Hilberg LE, et al. (2018). "Cultural Coastal Habitats: A Habitat Climate Change Vulnerability Assessment Synthesis for Kaua‘i." EcoAdapt.
87 Ibid. P. 4
88 Ibid. P. 7
89 Hilberg LE, et al. (2018). "Cultural Coastal Habitats: A Habitat Climate Change Vulnerability Assessment Synthesis for Kaua‘i." EcoAdapt.
90 Jacobi, J.D., et al. (2017) Baseline land cover. In Selmants, P.C., et al., eds., USGS, http://pubs.er.usgs.gov/publication/pp1834.
91 Hilberg LE, et al. (2018) "Mesic and Wet Forest Habitats: A Habitat Climate Change Vulnerability Assessment Synthesis for Kaua‘i." EcoAdapt.
92 County of Kaua‘i. (2022). "Talk Story Summary."
93 County of Kaua‘i. (2022). "Open House Series #1 Summary Document."
94 Paxton, E.H., et al. (2016) Collapsing avian community on a Hawaiian island. P. 1. Science Advances, 2, e1600029.
95 Ibid. P.1
96 Ibid. P. 1
97 Fortini, L., et al. (2015). Large-Scale Range Collapse of Hawaiian Forest Birds under Climate Change and the Need 21st Century Conservation Options. PLoS ONE 10(10): e0140389. doi:10.1371/journal.pone.0140389

forests, which further drives native bird species towards extinction.[98] Studies of avian malaria presence on the Alakaʻi Plateau, which has some of the island's core high-elevation forests, have found a correlation between disease/vector prevalence with warming and drought.[99] Figure 8 illustrates the modeled range and habitat of bird species given climate shifts and disease-driven changes.

Figure 8. Projected Change in Native Forest Bird Richness (Now to End-of-Century)

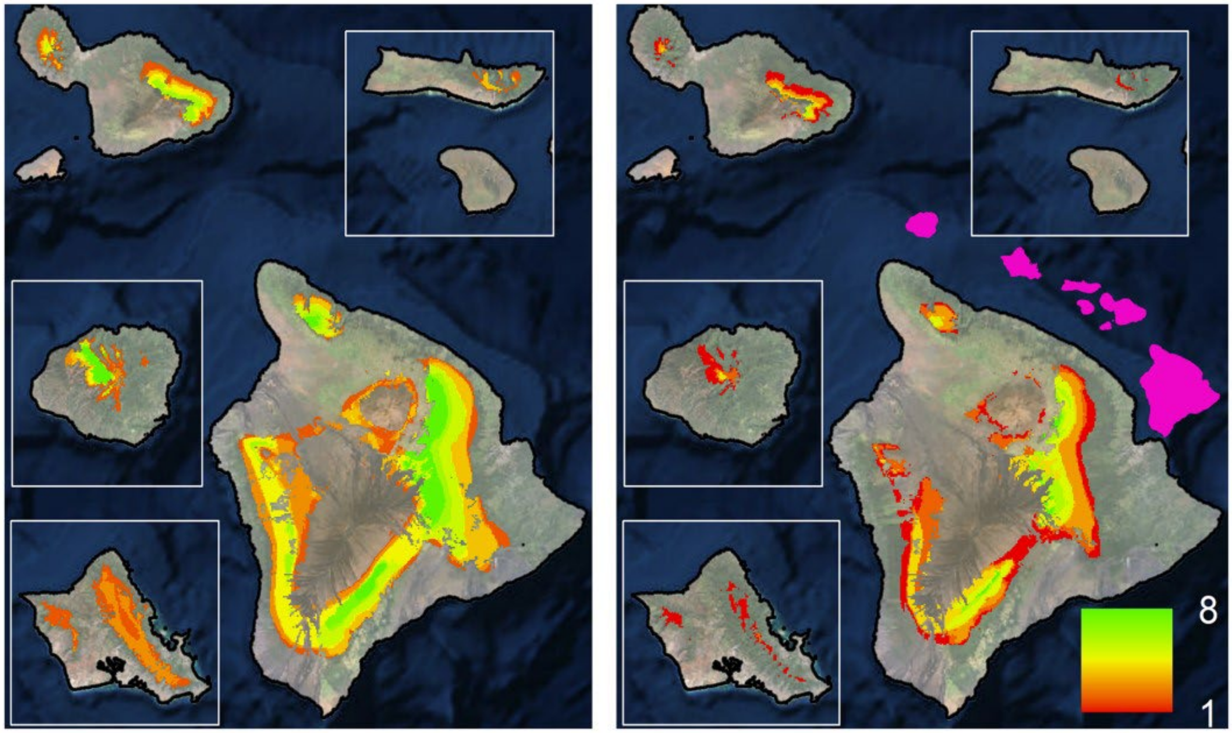

Fig 3. Current (left) and future (right) forest bird number of species based on modeled range and available primary habitat of all extant species. The pink overlay shows the spatial configuration of the main Hawaiian Islands.

Source: Fortini et al. (2015)

Native Marine Species

Coastal habitats contain native fish, sea creatures, and vegetation. Nesting seabirds, honu (green sea turtles) and seals, and coastal plants in low-lying areas are expected to experience the most severe impacts of sea level rise due to direct inundation, large waves, and saltwater intrusion.[100] Fisheries, coral reefs, and the livelihoods they support are threatened by higher ocean temperatures, ocean deoxygenation, and ocean acidification.[101] As indicated by Figure 9, widespread coral reef bleaching and mortality have been occurring more frequently. By mid-century bleaching events are projected to occur annually, threatening extinction of many coral species and reef ecology in general.

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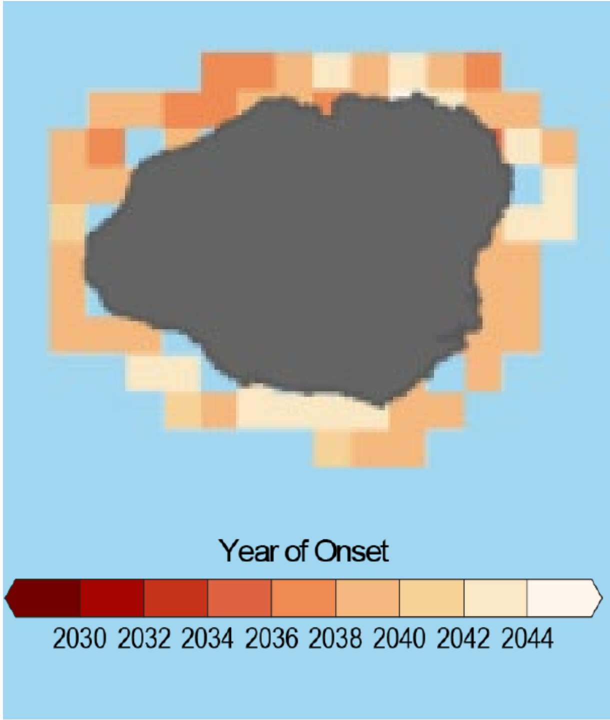
[98] Paxton, E.H., et al. (2016) Collapsing avian community on a Hawaiian island. Science Advances, 2, e1600029.
[99] Ibid. P. 1
[100] US Global Change Research Program. (2018) "Chapter 27: Hawaii and US-Affiliated Pacific Islands." *Fourth National Climate Assessment*. https://nca2018.globalchange.gov/chapter/27/
[101] Keener, V., et al. (2018)

Figure 9. Projected Year of Onset of Coral Bleaching



Source: US Global Change Research Program, 2018

One community member explained their observations of a warming ocean and expressed concern for the species that rely on healthy estuaries and nearshore ocean ecosystems as part of its life cycle.[102] Cages to collect limu must now be placed further out into the ocean because the nearshore water is too warm. In addition, they have observed an increase of a seaweed species that is contributing to the calcium loss of the ocean, indicating a change in nearshore water chemistry.[103] They have also observed an increase in coral bleaching. Other community members also shared that they have observed an increase in coral bleaching and disease, such as "a lot of bleached/ dead coral on Kauai- how much is affected by temp changes?"[104].,

Under projected warming of approximately 0.5ºF per decade (RCP 8.5), severe coral bleaching is projected to occur annually in Kauaʻi starting as early as the mid-2030's. Reefs on the North Shore are projected to experience impacts first on the island, though all nearshore coral reefs in the region will experience annual bleaching before 2050. Coral reef cover in the Hawaiian Archipelago as a whole is projected to decline to 11% in 2050 to 1% by 2100.[105] Bleaching and acidification will result in loss of reef structure. Reef collapse leads to lower fisheries yields and loss of coastal protection and habitat.[106] Fishery productivity is projected to decline to 15% and 50% of current levels by mid-century and 2100, respectively, under a high greenhouse gas emission scenario.[107] In addition to being an enourmous component of Kauaʻi'ecosystem biodiversity, the decline of healthy coral reef reduces natural storm protection on the coastline.

In the open ocean, warming is projected to reduce the mixing of deep nutrients into the surface zone. With continued emissions increasing temperatures and declining nutrients are projected to reduce tuna and billfish species' richness and abundance in the central and western Pacific Ocean, resulting in declines in maximum fisheries yields by 2%–5% per decade. Climate change is also projected to result in overall smaller fish sizes, further adding to the fishing impact.

Tuna habitat in the equatorial region is projected to shift eastward with changing temperatures, so that by the end of the century the availability of skipjack tuna in the Western Pacific will likely be 10%–40% lower than

[102] County of Kauaʻi. (2022). "Talk Story Summary."
[103] Ibid.
[104] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."
[105] US Global Change Research Program. (2018) "Chapter 27: Hawaii and US-Affiliated Pacific Islands." *Fourth National Climate Assessment*. https://nca2018.globalchange.gov/chapter/27/
[106] Yates, K. K., Zawada, D. G., Smiley, N. A., and Tiling-Range, G. (2017) Divergence of seafloor elevation and sea level rise in coral reef ecosystems, Biogeosciences, 14, 1739-1772, https://doi.org/10.5194/bg-14-1739-2017.
[107] Keener, V., et al. (2018)

current levels. On low-lying shores, sea level rise is projected to result in the loss of resting and nesting habitat for sea birds and sea turtles and the loss of beach and pupping habitat for Hawaiian monk seals.

Beaches

Sandy beaches and sand dune habitats are highly vulnerable to climate change (high confidence).[108] Studies of historical shoreline change report that 71% of beaches on Kauaʻi are eroding.[109] On average shorelines retreated over 36 feet over the past century, and nearly 4 miles of beach have been completely lost.[110] Over three quarters of the beaches on the north and east coasts and about one third of beaches on the south and west coasts are undergoing erosion.[111] But when projections include accelerated SLR, the average shoreline recession by 2050 is nearly twice the historical extrapolation, and nearly 2.5 times by 2100.[112]

The loss of beaches is a critical issue to the built environment (including housing) and infrastructure along the coast. Beaches physically help control coastal flooding and erosion. Without them, homes, property and infrastructure face increased flooding and land loss during high waves, storm surges, and tsunamis. This could lead to increased economic vulnerability for the community as a portion of the County's revenue stems from property taxes. Additionally, many members of the county's houseless population live at the beach parks. One service provider representative pointed out that as beaches shrink or disappear, houseless individuals may be pushed into conflict with private property when selecting a place to live.

Community members have emphasized concern about the inability for beach ecosystems to migrate landward due to privitization and hardening of the shoreline to protect development.[113] These ecosystems are also important parts of people's livelihoods and are critical access for surfing, fishing, limu gathering, and other activities. Community members expressed how privitization and sea level rise impacts make it difficult to traverse to fishing grounds. As sea level rises, the space between the ocean and property line narrows, which affects how fisherpeople access their sites, how they can fish, and where they can fish. Seawalls change the fishing dynamics. One community member explained that limu (seaweed) gathering has changed over the years due to changing ecosystem conditions that are partly due to human actions as well as climate change. They explained that the area where the limu growing cages are typically placed are now experiencing larger swells, which result in the cages rolling around and a small limu harvest.

The loss of beaches also impact Kauaʻi's social infrastructure and community fabric because they are everyday places where people experience the outdoors, play, and socialize.[114] Several community members shared their concerns of losing recreational and social gathering areas, in which families can picnic, from rising sea levels.[115] One community member noted that coastal erosion has already destroyed facilities such as the Waipouli Pavilion. [116] Drainage issues (primarily due to rain events) are already being observed in the coastal parks and parking lots that provide access to the shoreline.

[108] Hilberg LE, et al. (2018). "Shoreline Habitats: A Habitat Climate Change Vulnerability Assessment Synthesis for Kauaʻi." EcoAdapt.
[109]Spirandelli, D. J., Pap, R., Summers, A. K., and Braich, E. (2020) West Kaua`i Community Vulnerability Assessment. University of Hawai`i Sea Grant College Program. Honolulu, HI. UNIHI-SEAGRANT-TT-18-10. https://eos.ucs.uri.edu/seagrant_Linked_Documents/hawau/TT-13-08.pdf
[110] Ibid.
[111] Transects of historical erosion rates and related information can be viewed at https://www.soest.hawaii.edu/coasts/index.php/resources/hawaii-shoreline-study-web-map/
[112] Anderson, T.R., Fletcher, C.H., Barbee, M.M. et al. (2015). Doubling of coastal erosion under rising sea level by mid-century in Hawaii. *Nat Hazards* 78, 75–103 https://doi.org/10.1007/s11069-015-1698-6
[113] County of Kauai. (2022). "Talkstory Summary"
[114] County of Kauaʻi. (2013). "Kauaʻi Parks & Recreation Master Plan." https://www.dropbox.com/s/r83poce5ioy1jff/MASTER_PLAN_Kauaʻi_Parks.pdf?dl=0
[115] County of Kauaʻi. (2021). "Talk Story Summary."
[116] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."

2.2. RESIDENTS

2.2.1. Profile

As of May 2022, data from the 2020 ACS 5-year Estimates is available for the county and provide information on residents' demographics. Some key characteristics from the Census summary of Kauaʻi County are below:

- Total population is 73,298;
- There are 23,331 total households;
- Median household income is $82,818, which is just below the state median
- Median age is 42.3 years, which is three years higher than the state median. 20% of the population is older than 65 years old and 21.7% is under 18 years old
- 9.7% of residents are disabled, which is under the state average. The most prevalent type of disability are independent living difficulty and ambulatory difficulty
- The employment rate is 62.8%, a little bit higher than the state rate.[117]

2.2.2. Key Vulnerabilities and Planning Issues

Though climate change's impacts will be felt by everyone in the county, there are some individuals and communities who will face higher risks than others with the same hazard exposure. In the context of climate change, social vulnerability refers to the inherent characteristics of a population or system that makes them more susceptible to and less able to withstand adverse impacts.[118] Social inequities such as limited English-speaking abilities, lower incomes, and education level can affect people's access to resources and social safety nets which are crucial for responding to and recovering from climate shocks and stressors. These inequities, shaped by colonial legacies and the resulting distribution of resources and power, are also a critical social equity factor for Kauaʻi'ʻs Native Hawaiian communities. Community members noted that Native Hawaiians and other BIPOC (black, indigenous, and people of color) would be the most drastically impacted by climate change. Also, former plantation camp families, some of whom may be low-income, were another group community members also identified as vulnerable.[119] Individuals' characteristics, such as age and disability status, can affect people's physical susceptibility to harm from adverse environmental conditions.

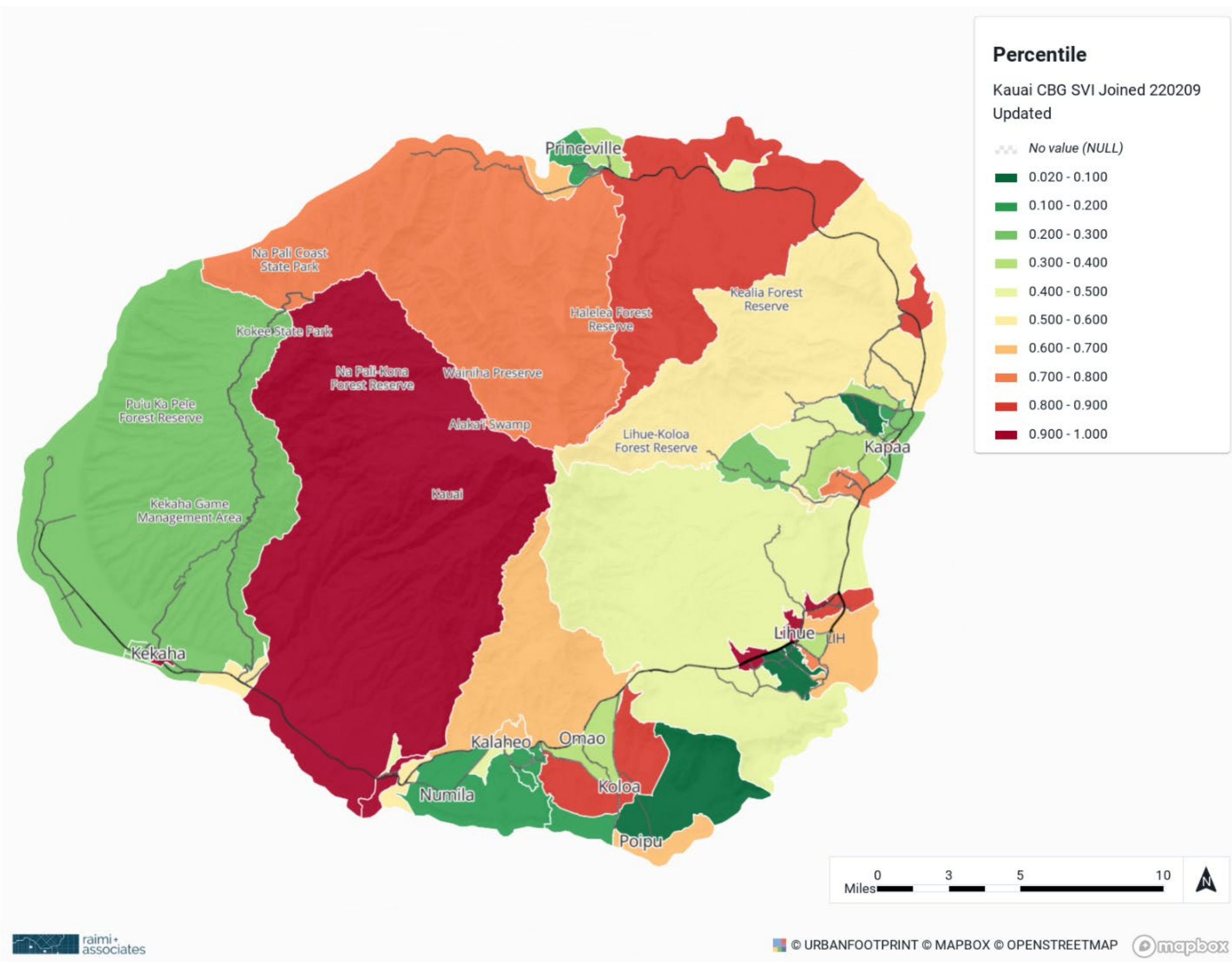
One community member noted the complexity of assessing social vulnerability due to changing demographics and the migration of residents to areas that are more or less exposed to climate change hazards. For instance, while landowners living in coastal or rural areas may be exposed to more climate change hazards, these areas are becoming less populated by Native Hawaiians due to high housing costs and the legacy of land dispossession. This results in vulnerable populations who move to areas which are less exposed to climate change hazards, yet they are still vulnerable to the consequences of climate change due to other factors, such as househould characteristics, socioeconomic status, race and ethnicity, and physical conditions.[120] It is important to keep this complexity in mind while assessing social vulnerability.

[117] US Census Bureau. Kauai County, Hawaii. Accessed May 2022. https://data.census.gov/cedsci/profile?g=0500000US15007
[118] US EPA. (2021). "Appendix B. Climate Change and Social Vulnerability." *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*. P. B-1.
[119] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."
[120] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."

Figure 10 shows communities' social vulnerability to climate change based on an analysis of 13 indicators representing household characteristics, socioeconomic status, race and ethnicity, and physical conditions (see Appendix A for the full SVI methodology). Having high social vulnerability to climate change means that residents of these communities may experience greater impacts others experiencing the same hazard. For instance, a person who rents their home does not have direct control to make changes to the property that could help them withstand extreme heat, flooding, etc. Having low social vulnerability to climate change means that people in these communities are better able to withstand shocks and stressors. This might include having enough money to make improvements to their residence or having better access to information due to technology and English proficiency.

Using the geographic scale of the census block group, the SVI score provides a system to compare the vulnerability of all the communities within the county. Those in higher percentiles are considered more vulnerable; for example, a block group in the 95th percentile has a higher score than 95% of the other block groups in the county.

Figure 10. Social Vulnerability Index Percentiles



Source: Raimi + Associates, 2022

Block groups with the lowest scores (least social vulnerability) are spread around the county. The least socially vulnerable block group is located in Kapa'a's residential area, and most of the town has low scores. The other lowest scoring block groups somewhat align with the county's visitor destination areas in North Shore, Līhuʻe, and South Kauaʻi planning areas. The Līhuʻe and West Kauaʻi planning areas contain the highest number of highly socially vulnerable census block groups in the county. Block groups with high SVI scores are indicated in red:

- The block group with the highest SVI score (1) is located in Hanamāulu in the Līhuʻe planning area. The planning area has two other block groups at or above the 90th percentile in Līhuʻe (0.92) and Puhi (0.90), and one above the 80th percentile (also in Hanamāulu, with a score of 0.86).
- The West Kauaʻi planning area also has communities with some of the highest SVI scores in the county. Three block groups are above the 90th percentile, located in the area covering Pakala Village and Kaumakani (0.98), Hanapēpē (0.96), and central Kekaha (0.94).
- Other block groups with high scores (above the 80th percentile) are located around Kōloa (two block groups with scores of 0.82 and 0.88), Anahola (0.82), and the outskirts of Kilauea (0.80).

While conducting a quantitative assessment of social vulnerability using the geographic scale of the census block groups provides a broad screening level assessment of communities that are socially vulnerable to climate change hazards, it is important to also acknowledge that social vulnerability can be further understood on a more localized scale with the incorporation of qualitative knowledge. For instance, one community member pointed out that while Anahola census block group had an overall high social vulnerability score (0.82), the social vulnerability of Anahola can be further understood by knowing that the northern portion of Anahola typically houses residents of higher income, whereas the mid-to-southern end of Anahola includes Native Hawaiian residents who live in Hawaiian Homelands.[121] Throughout the Climate Adaptation Plan process, qualitative information should validate and enrich quantitative social vulnerability results.

The hazard exposures in each census block group scoring High (80-90th percentile) or Very High (90-100th percentile) are detailed in Table 2. The acres were reached through geospatial analysis that overlayed the footprint of each hazard with each block group's area and represent the total area within the tract exposed to the hazard. All the acres where the two overlap are counted. Six of these block groups are exposed to every or almost every hazard analyzed: wildfire, flood, landslide, near-term SLR and coastal hazards, long term SLR and coastal hazards, and 6' of passive flooding. This means that the communities experience many impacts of climate change but may have the least capacity to adapt.

[121] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."

Table 2. Acres Exposed to Hazards in Top SVI Census Block Groups

Census Block Group (CBG)	Planning Area, Approx. Location	SVI Score Percentile	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	SLRXA-3.2	6 ft SLR Passive Flooding (NOAA)	Number of Hazards Exposed To
Block Group 5, Census Tract 404	Līhuʻe (portion of Hanamāulu)	100%	129 (M)	3	4	-	-	-	3
Block Group 1, Census Tract 408	West Kauaʻi (large area covering Pakala Village and Kaumakani)	98%	439 (H)	1,180	38,768	142	215	1,356	6
Block Group 3, Census Tract 408	West Kauaʻi (Hanapēpē)	96%	320 (H)	509	8	46	90	423	6
Block Group 5, Census Tract 409	West Kauaʻi (central Kekaha)	94%	95 (H)	111	-	13	26	40	5
Block Group 3, Census Tract 405	Līhuʻe	92%	278 (H)	10	-	-	-	-	2
Block Group 4, Census Tract 404	Līhuʻe (Puhi)	90%	1 (H) 300 (L)	-	3	-	-	-	2
Block Group 3, Census Tract 406.03	South Kauaʻi (around Kōloa)	88%	424 (H)	493	518	-	-	-	3
Block Group 3, Census Tract 404	Lihuʻe (portion of Hanamāulu)	86%	301 (M)	201	37	12	31	248	6
Block Group 2, Census Tract 9400	East Kauaʻi (Anahola)	84%	801 (H)	347	20	70	118	-	5
Block Group 2, Census Tract 406.04	South Kauaʻi (around Kōloa)	82%	145 (H) 173 (M)	126	173	-	-	-	3
Block Group 1, Census Tract 401.03	North Shore (large area between Princeville and Moloaʻa but excluding Kilauea)	80%	291 (H) 3,312 (L)	1,862	6,273	172	257	2,501	6
Total Acres Exposed	-	-	2,793(H) 430 (M) 3,784 (L)	4,840	45,810	454	738	5,068	-

1. *The acres reflect the area within the census block group that is actually exposed to the specific hazard.*
2. *"Number of Hazards Exposed to" column totals all the hazards each block group is exposed to (the cells highlighted in light purple for each row). Numbers that are red simply indicate that the block group is exposed to many hazards (i.e. 6 out of the 6 analyzed).*

Source: County of Kauaʻi, Raimi + Associates

2.3. ECONOMY

Kauai's economy is heavily reliant on tourists who come to see the island's beautiful environment, peaceful small towns, cultural activities, and outdoor recreation. Other anchor industries include healthcare, education, construction, and government.[122] Over the long term, average annual job growth is projected at 1.12%, equating to 34,900 civilian wage and salary jobs by 2035. While all sectors of the economy are exposed to climate change, tourism and agriculture are explored in greater detail below.

2.3.1. Tourism

Asset Profile

Tourism has remained the primary economic driver in Kauaʻi and across all the Hawaiian Islands and serves as an important local revenue source. Resort, hotel properties, and vacation rentals account for 41% of the County's real property tax collected,[123] which equals 29% of total property tax revenues.[124] Additionally in 2019, over 1.3 million visitors traveled to Kauaʻi and spent $1.9 billion (which also contributes to sales tax revenue).[125] On any given day that year, visitors made up 28% of all people on the island.[126] Tourism hotspots on the island include (but are not limited to) Polihale State Park, Kokeʻe and Waimea Canyon, Nāpali and Kalalau Trail, Salt Pond Beach Park, and the towns and beaches on the North Shore.

According to data from the Hawaii Department of Business, Economic Development & Tourism, in 2019 there was an annual average of 10,500 people employed in the Leisure and Hospitality industry in Kauaʻi County,[127] making up 38% of the county's jobs.[128] Data from 2020 indicates that the number of people employed in the sector dropped to less than half of that following the onset of the COVID-19 pandemic;[129] accommodations jobs accounted for 70% of all jobs lost in the second quarter of 2020, and food and beverage jobs accounted for 42%.

Tourist-serving uses like resorts and hotels are allowed in areas with the County's Resort designation, which is limited to visitor destination areas (VDA). The primary VDAs are located in Princeville, Līhuʻe, and Poʻipū (Figure 11). There are also two smaller VDAs around Waimea and Coconut Coast. The most recent General Plan Update reduced the island's total resort acreage, turning unentitled land in Resort designations to agriculture or provisional uses.[130] Transient vacation rentals are only allowed in visitor destinations as well, though there are nonconforming units outside their boundaries pursuant to County approval of a Nonconforming Use Certificate. County data indicates there are 602 non-conforming TVRs on the island, about 60% of which are located on the North Shore.

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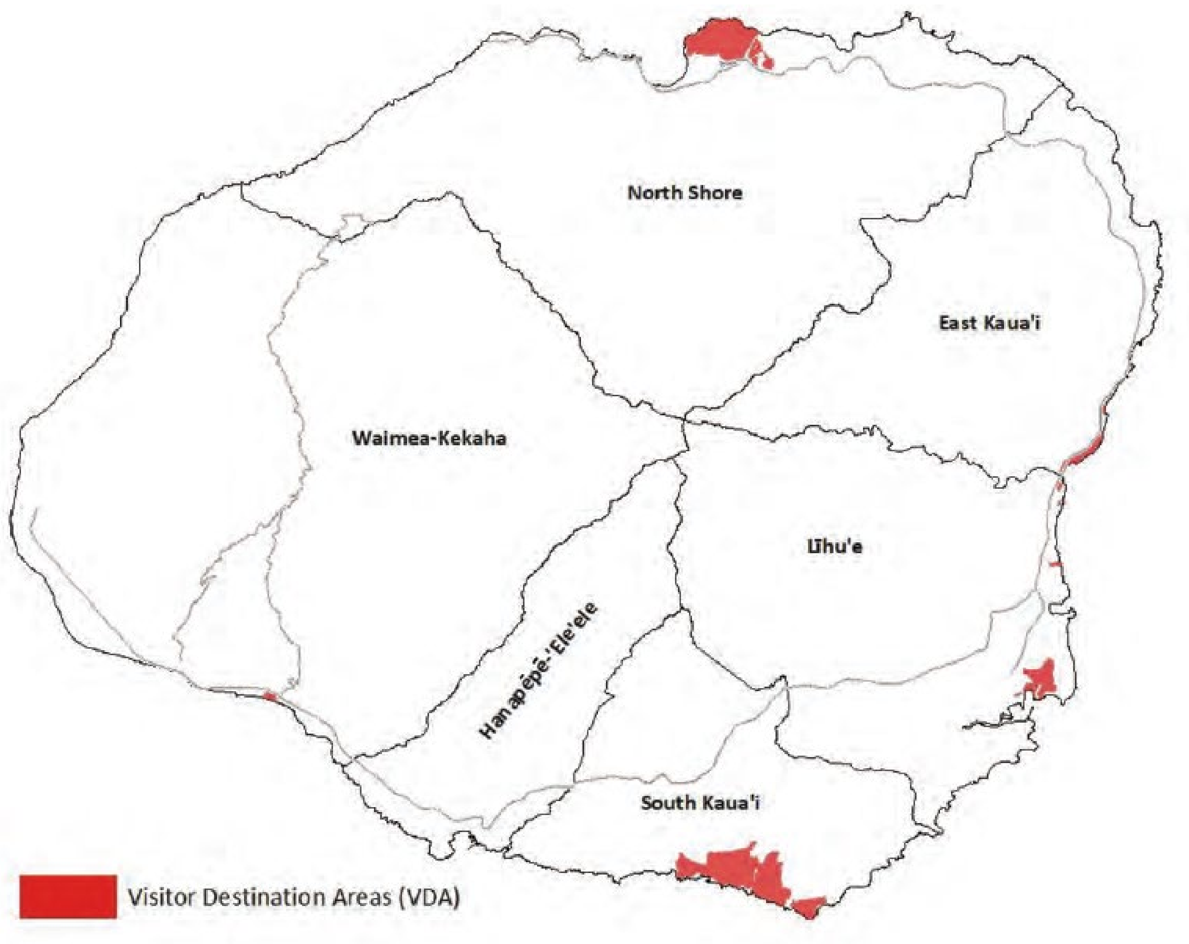
[122] County of Kauaʻi. (2018). "Kauaʻi Kakou Kauaʻi County General Plan"
[123] Zachary, Diane. (2018). "Kauaʻi Tourism Strategic Plan 2019-2021." P. IX.
[124] County of Kauai. (2021). "FY 2022 Operating Budget." https://www.kauai.gov/Portals/0/Finance_Acct/FY2021-2022_Operating_Budget.pdf?ver=2021-06-03-112020-223
[125] Hawaii Tourism Authority. (2021). "Kauaʻi Destination Management Plan 2021-2023." P. 7
[126] Ibid.
[127] Hawaii Department of Business, Economic Development & Tourism. (2019)."Job County by Industry (CES) – Not Seasonally Adjusted Monthly Data (2019)." http://dbedt.hawaii.gov/economic/job-count-by-industry/
[128] Ibid.
[129] Hawaii Department of Business, Economic Development & Tourism. (2020). "Job County by Industry (CES) – Not Seasonally Adjusted Monthly Data (2020)." http://dbedt.hawaii.gov/economic/job-count-by-industry/
[130] County of Kauaʻi. (2018). Kauaʻi Kakou Kauaʻi County General Plan" P. 87

Figure 11. Visitor Destination Areas



Source: County of Kauaʻi, 2018

Key Vulnerabilities and Planning Issues

The rural and natural areas that make the island unique have historically been main draw for Kauaʻi's tourism industry but are being affected by climate change. This includes beaches and coastal trails, which are subject to SLR, coastal erosion, and high tides. Marine-based tourist activities like snorkeling and scuba diving will be reduced as ocean acidification and warming harm corals and the ocean coastal environment at large.[131] Access to trails can also affected by storms, flooding, and landslides; for example, in December 2021 the Hawaii Division of State Parks posted on its website that the Hanakāpiʻai and Kalalau Trail at Hāʻena and Nāpali Coast remain closed due to flash flooding and inclement weather.[132]

Many visitor-serving assets like hotels, resorts, and other attractions are located along shorelines. While some hotels and resorts (in VDAs) are expected to be directly affected in the various SLR scenarios, all coastal visitor uses rely on water, wastewater, and road infrastructure which, as discussed in Section 2.4 "Community

[131] Cristini, L. et al. (2013). "Climate Change and the Visitor Industry: People, Place, Culture, and the Hawaiʻi Experience." UH Sea Grant. https://seagrant.soest.hawaii.edu/wp-content/uploads/2021/06/HTA-climatechange-visitorindustry_0.pdf
[132] Division of State Parks. https://dlnr.hawaii.gov/dsp/

Assets," face problems related to SLR as well. In relation to future climate change responses, community members have expressed the need to prioritize supporting community needs over tourism.[133]

Community members expressed concern that dependence on tourism limits the community's adaptive capacity.[134] Tourists, especially those staying in transient vacation rentals (TVRs), are typically not prepared for climate change-related disasters. TVRs lack disaster "go-bags," emergency contact information, information of evacuation routes or procedures, and a general lack of responsibility on the part of vacation property managers/owners.[135] The large number of tourists also produce indirect, long-term impacts related to resilience and adaptation such as stress on the transportation system, utilities, and community social capacity.

The issue of tourism, disaster, and community social capacity is particularly acute in the North Shore. The Hanalei Hāʻena Disaster Resilience Plan states that the daily visitor-to-resident ratio is 22:1 (10,000 visitors to 450 residents).[136] Community research from the plan finds that "a transition from long-term affordable residential housing to high-cost homes, rentals and TVRs… appears to have fractured the sense of community and social networks that prove critical during disasters."[137] Experience has made some North Shore residents feel that visitors are a burden on them and their resources even during common floods,[138] let alone a major event such as the 2018 floods that devastated the area. Unfortunately flooding will continue to be a risk for visitors, as 206 out of the 363 non-conforming TVRs in the North Shore are in the 1% chance annual floodplain.

Table 3. Transient Vacation Rentals Hazard Exposure

Planning Area	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	Passive Coastal Flooding	High Wave Flooding	Coastal Erosion	SLRXA-3.2	Passive Coastal Flooding	High Wave Flooding	Coastal Erosion	6 ft SLR Passive Flooding
North Shore	313 (L)	206	5	23	2	16	2	76	4	64	21	66
East Kauaʻi	59 (H) 7 (M)	21	1	13	0	2	15	27	0	24	18	22
Līhuʻe	2 (H)	2	0	0	0	0	0	0	0	0	0	2
South Kauaʻi	60 (H) 1 (M) 1 (L)	54	1	4	0	2	0	2	1	1	0	7
West Kauaʻi	55 (H)	30	0	14	0	2	1	30	0	19	22	6

Source: County of Kauaʻi, 2022

133 County of Kauaʻi. (2022). "Talk Story Summary."
134 County of Kauaʻi. (2022). "Talk Story Summary."
135 County of Kauaʻi. (2021). "Stakeholder Interview Summary."
136 Disaster Resilience LLC. (2021). "Hanalei to Haena Community Disaster Resilience Plan: 2021 Update." Hanalei to Haena Community Disaster Resilience Committee.
137 Ibid. P. 14
138 Ibid.

2.3.2. Agriculture and Subsistence Activities

Asset Profile

Agriculture is another key economic driver on Kauaʻi. According to the 2017 USDA Agricultural Census, there are 733 farm operations in the county. A majority are small farms (under 10 acres), with a median size of five acres.[139] In 2017, the estimated market value of agricultural products sold per farm was approximately $79,000 and $61 million in total.[140] Kauaʻi's agricultural lands, however, are owned and managed by a small number of large landowners, particularly on the south and west sides of the island.[141] The North Shore is home to a large portion of the island's diversified agriculture operations, particularly around Moloaʻa and Kīlauea.

As of 2020, there are 23,191 acres of cropped area[142] on the island and 42,345 acres of pasture,[143] with over 37,000 acres of land are designated as Important Agricultural Lands by the State Land Use Commission. Seed production has the largest footprint (comprising 61% of Kauaʻi's cropped area), coffee is the second largest crop, and commercial forestry is the third. Taro[144] is cultivated on only 546 acres (2% of cropped area), but that is an increase of over 100 acres since 2015.[145] There is one active Agricultural Park in Kekaha totaling 160 acres that is used primarily for shrimp aquaculture.[146]

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[139] USDA National Agricultural Statistics Service. (2017). "2017 Census of Agriculture - County Summary Highlights." https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Hawaii/st15_2_0001_0001.pdf

[140] Ibid.

[141] County of Kauaʻi. (2018). Kauaʻi Kakou Kauaʻi County General Plan" P. 167.

[142] Includes land used for aquaculture, banana, coffee, commercial forestry, diversified crop, flowers/foliage/landscape, seed production, taro, and tropical fruits.

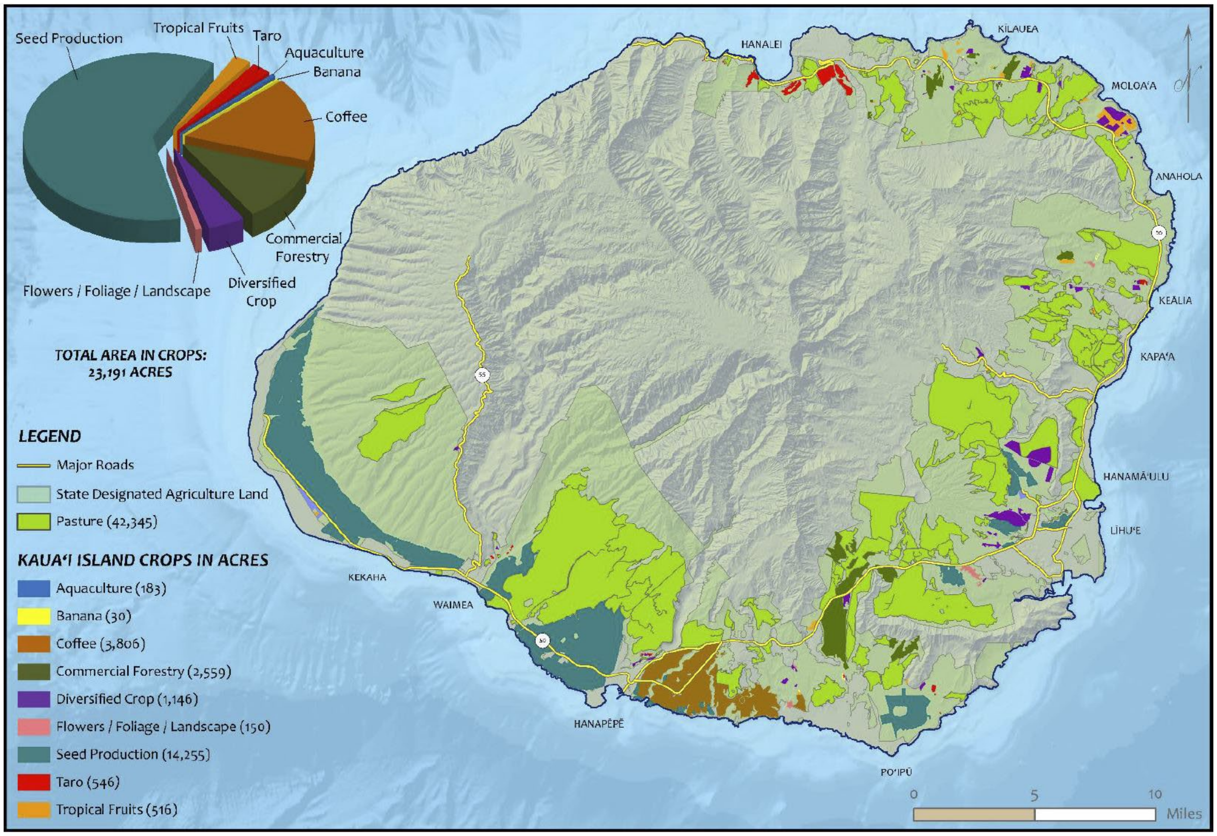
[143] UH Hilo Spatial Data Analysis & Visualization Research Laboratory. (2021). "2020 Update to the Hawaii Statewide Agricultural Land Baseline: Oahu, Hawaii Island, and Kauaʻi." P. 24. https://hdoa.hawaii.gov/wp-content/uploads/2021/04/2020_Update_Ag_Baseline_Oahu_Hawaii_Kauaʻi_v3.pdf

[144] The terms taro and kalo are used interchangeably in the document

[145] Ibid. P. 24

[146] Ibid. P. 29-30

Figure 12. Agricultural Land by Type



Source: UH Hilo, 2020

Key Vulnerabilities and Planning Issues

Hawaiʻi is exposed to significant food insecurity due to its geographically isolated nature.[147] The closest port is in Oakland, California, categorizing the Hawaiian population as one of the most food import-dependent in the world.[148] The state of Hawaiʻi imports approximately 90% of its food and over 73% of its energy.[149] Hawaii's 1.4 million residents and 10 million annual visitors are uniquely vulnerable to food distribution interruptions due to natural disasters (which are exacerbated by climate change), and other economic and social disturbances.[150] Surpassing the 2.7°F (1.5 C) warming threshold established by the Paris Agreement threatens global food security.[151] Crop failure due to drought, flood, or damaging events in the course of a growing season increases disproportionately between 2.7 and 3.6°F. Limiting global warming to 2.7°F would reduce the risk of crop failure for food resources such as maize, wheat, and soybean by 26%, 28%, and 19% respectively.[152]

Participants in County talk stories detail the ways that climate change hazards are a significant threat to Kauaʻi's agricultural system. Kauaʻi's best agriculture lands tend to be low-lying and along stream banks where

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[147] Miles, A. (2020) If we get food right, we get everything right: rethinking the food system in post-COVID-19 Hawai'i, Position Paper: http://hdl.handle.net/10790/5248
[148] Ibid.
[149] Gaupp, F, et al. (2019) Increasing risks of multiple breadbasket failure un 1.5 and 2°C global warming, Agricultural Systems, v. 175, p. 34-45,
[150] Ibid.
[151] Ibid.
[152] Ibid.

there are alluvial soils. These areas are the most prone to flooding. It erodes the topsoil and soil recovery takes a long time.[153] Repeated events may force farmers to move to higher ground, which would result in increased need for inputs and in higher production costs. Floods and winds greatly impact infrastructure on a farm and are costly. Agricultural irrigation systems are vulnerable to severe flooding, especially the plantation ditch systems and diversions along streams that provide agricultural water.[154]

The 2018 flooding demonstrated these impacts. The floodwaters brought mud and silt to the kalo patches in the Waioli Valley, which turned the crop watery and spongy, reduced yields, and devastated farmers' land and facilities.[155] Many farmers lost their entire crop of kalo, lost equipment and livestock, and sustained damage to their irrigation ditches.[156] The kalo industry statewide experienced skyrocketing prices and shortages.[157] Locals experienced a shortage of the staple food poi and exports impacted, as companies were not able to sell their typical amount of poi to big box and supermarket chains across the state.[158]

Community members have noticed that agriculture is harmed by climate stressors including drought, heat, and other changes in the ecosystem. Drier conditions have already been observed by farmers and they expressed concern regarding the water table being sufficiently refilled to sustain farming practices.[159] Crops that are under increased stress are more vulnerable to different pathogens and pests. The proliferation of invasive species is an issue for farmers. Lastly, it is important to note that industrial agriculture practices further threaten food supply by leading to a loss of pollinators and biodiversity.[160]

In addition to drought, a primary climate stressor to agriculture in West Kauaʻi's Mānā Plain is SLR. Prior to its draining by the sugar industry, this area was a large brackish wetland. This area is low-lying, and as a result, much of it is threatened by SLR induced passive flooding in the near-term. SLR could lead to passive flooding and saltwater intrusion. Saltwater intrusion impacts crop yield or can kill crops all together. This could lead to loss of farming jobs and reduce opportunities for local food production. Although there are no crops in the area dedicated to food production, some community members expressed the desire to increase local food production. The plants or crops that are currently planted in the area are not salt-water tolerant. Flooding could also impact the existing infrastructure, namely drainage and roads, and reduce access to these lands, which in turn could lead to isolation and economic loss.[161] Severe rainfall flooding is also a primary climate stressor to agriculture in this area.[162]

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153 County of Kauaʻi. (2022). "Talk Story Summary."
154 Ibid.
155 Associated Press. (27 May 2018)."Shortage expected after floods smother Hawaii staple crop." The Garden Island. https://www.thegardenisland.com/2018/05/27/hawaii-news/shortage-expected-after-floods-smother-hawaii-staple-crop/
156 Harangody et al. (2021). "Halana Ka Manaʻo Reflections from Kauaʻi of the 2018 Floods." UH Manoa.
157 Ibid.
158 Associated Press. (27 May 2018). "Shortage expected after floods smother Hawaii staple crop." The Garden Island. https://www.thegardenisland.com/2018/05/27/hawaii-news/shortage-expected-after-floods-smother-hawaii-staple-crop/
159 County of Kauaʻi. (2022). "Talk Story Summary."
160 Ibid.
161 Spirandelli, D. J., Pap, R., Summers, A. K., and Braich, E. (2020) West Kaua`i Community Vulnerability Assessment. University of Hawai`i Sea Grant College Program. Honolulu, HI. UNIHI-SEAGRANT-TT-18-10. https://eos.ucs.uri.edu/seagrant_Linked_Documents/hawau/TT-13-08.pdf
162 Gomez, Basil (pers. Comm.)

2.4. COMMUNITY ASSETS

Community assets described in the following sections are the built systems that serve critical functions such as housing, transportation, and utility infrastructure.

2.4.1. Critical Facilities

Asset Profile

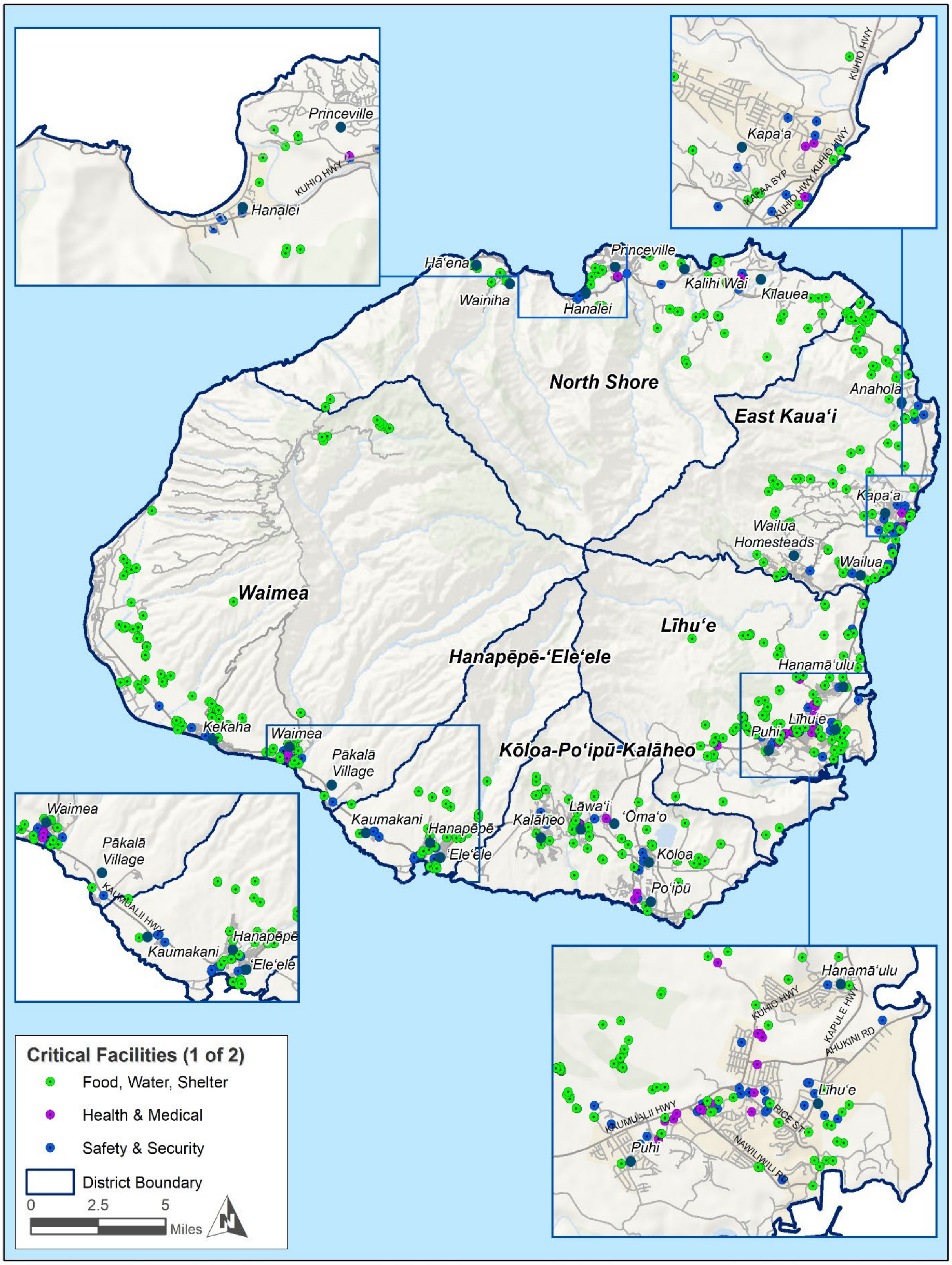
Critical facilities include structures and infrastructure from which essential services and functions for victim survival, continuation of public safety actions, and disaster recovery are performed or provided.[163] The 798 critical facilities identified in the county are broken into the following categories:[164,165]

- 565 **food, water and sheltering facilities**: includes food banks, wastewater pump stations, wastewater treatment plants, water pumps, water tanks, and wells.
- 100 **safety and security facilities**: includes civic buildings, neighborhood centers, County parks and beach parks, fire and police stations, waste facilities, and schools.
- 67 **transportation facilities**: includes bridges, airports, and boat harbors.
- 30 **health and medical facilities**: includes hospitals, emergency medical services, community health care, urgent care, and other related facilities.
- 17 **communications facilities**: includes banks, communications distribution hubs, KEMA communications sites, and radio/tv facilities.
- 13 **energy facilities**: includes fuel stations, petroleum bulk terminals, power grid facilities, and LNG storage[166]
- 6 **hazardous materials facilities**: includes plantation facilities and laboratories.

The locations of these critical facilities are illustrated in Figure 13 and Figure 14.

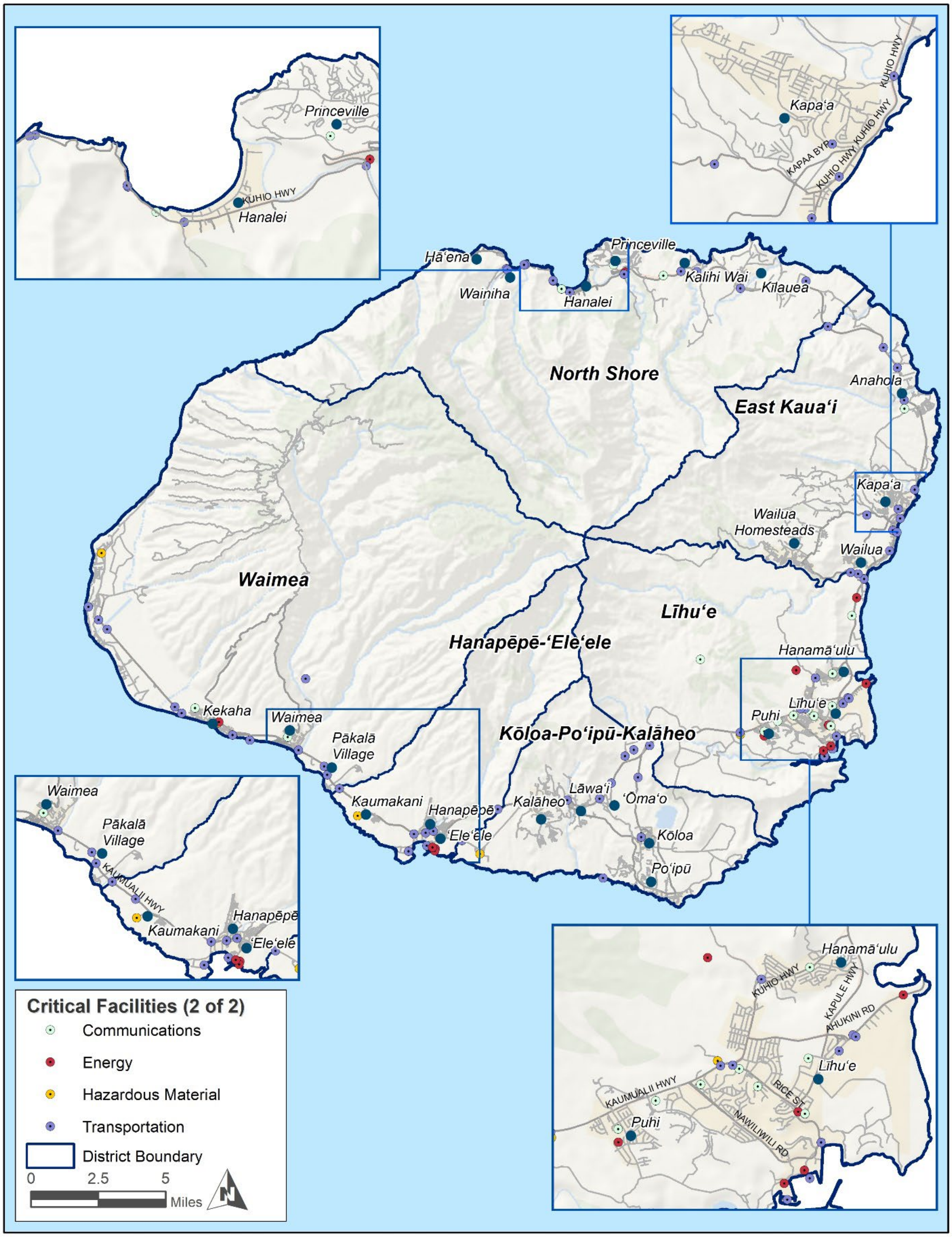
[163] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 2-7
[164] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 2-8
[165] TetraTech. (2020). "Critical Facilities Kauaʻi County."
[166] KIUC's hydroelectric plants and solar energy projects are not included in this count of energy facilities. See Section 2.4.4. Utilities and Infrastructure for more information on electrical infrastructure.

Figure 13. Critical Facilities (1 of 2)



Source: County of Kaua'i, 2021

Figure 14. Critical Facilities (2 of 2)



Source: County of Kaua'i, 2021

Key Exposures and Planning Issues

The Multi-Hazard Mitigation and Resilience Plan completed a detailed analysis of the critical facilities exposed to specific hazards. Key highlights are broadly described below, with more detail included in Chapter 3 Planning Areas Exposures. Tables of selected critical facilities' hazard exposures can be found in Appendix B.

- **Coastal Flooding:** In the scenario where sea level rises 3.2 ft (SLR-XA 3.2), 4% of the population (2,690 people) is exposed.[167] Countywide, 1,255 buildings worth an estimated $494.7 million in structures and their content are exposed to coastal flooding hazard.
- **Inland flooding:** Approximately 12% (95) of Kaua'i's total critical facilities are exposed to 1-percent annual flood hazard. Over a third of transportation facilities, and a fifth of safety and security facilities are exposed.[168]
- **Storm surge and tropical cyclone:** Nearly 30% of transportation facilities, 17% of safety and security facilities, and 9% of food, water, and shelter facilities are exposed to Category 4 storm surge inundation.[169] Potential impacts of high winds storm surge inundation include long-term power outages and loss of water utility systems, cutting off of transportation lifelines due to fallen objects, and cascading impacts to resources and tourism.
- **Wildfire:** Approximately 41% (330) of the county's critical infrastructure and facilities are located in the Medium and High CARW zones. This includes a majority of the health and medical, safety and security, energy, hazardous materials, and communication facilities in the county. It also includes 40% of transportation facilities and 32% of food, water, and sheltering facilities.[170] Most infrastructure is expected to avoid damage, but power lines have the highest potential of being damaged because they are made of wood. There is also the possibility that hazardous materials at facilities within the Medium and High CARW zones could rupture. All natural areas within the mapped wildfire risk areas are exposed to the hazard as well.
- **Landslide:** A quarter of food, water, and shelter facilities and about 12% of transportation facilities are exposed to the medium or high landslide hazard. On State roads, landslides have historically occurred on Kuhio Highway in the North Shore. Community members have observed an increase in landslides on the North Shore due to intense and more frequent rain events.[171]

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[167] County of Kaua'i. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 6-3
[168] Ibid. P. 7-6
[169] Ibid.
[170] Ibid. P. 5-3
[171] County of Kaua'i. (2022). "Open House Series #1 Summary Document."; County of Kaua'i. (2022). "Talk Story Summary." County of Kaua'i. (2022). "Youth Climate Change Summary Report."

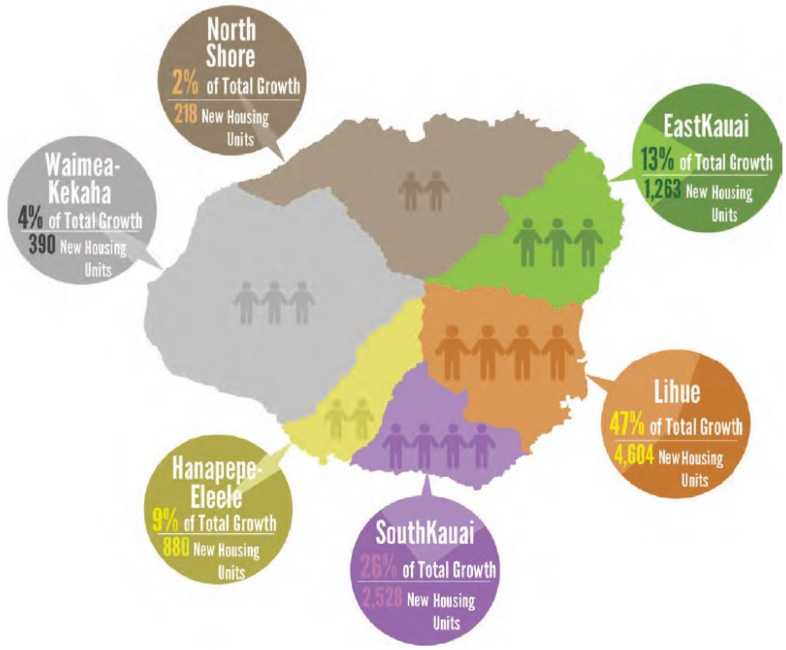
2.4.2. Housing and Business

Asset Profile

The county's urban development is concentrated near the coast and ranges in size from large towns (clusters of neighborhoods that support a larger, mixed-use environment) to rural crossroads (small locally serving retail and services locate at rural road intersections).[172] The most populous, urbanized communities are Līhuʻe and Kapaʻa.

According to data from 2019, there are 34,695 buildings in the county, 94% of which are residential. A majority of housing units (71%) are detached single-family dwellings and 21% are multifamily (3 or more units).[173] Sixty-three percent of Kauaʻi's housing units are owner occupied and 37% are renter occupied.[174] There are 36 affordable housing developments totaling 1,735 units in the county.[175] Almost all of the affordable housing developments are located in the Līhuʻe, West Kauaʻi, and South Kauaʻi planning areas.

Figure 15. County Growth Allocation



Source: County of Kauaʻi, 2018

Kauaʻi's total population was 73,298 in 2020[176] and is anticipated to increase to 88,013 in 2035.[177] Assuming a stable household size, the 2035 total housing unit forecast is 39,676. The County's Future Land Use strategy focuses development, uses, and density within existing towns to preserve agricultural land and open space. Growth is directed to Urban Center, Residential Community, Neighborhood Center, and Neighborhood General Plan land uses. As indicated in Figure 15, close to half of the County's total growth is allocated to Līhuʻe, followed by South Kauaʻi (a quarter of total growth). The North Shore, Waimea-Kekaha, and Hanapēpē-ʻEleʻele are only allocated enough growth to account for natural population increase by 2035.[178] Community members also

[172] County of Kauaʻi. (2018). Kauaʻi Kakou Kauaʻi County General Plan" P. 62
[173] US Census Bureau. "ACS 5-Year Estimates 2015-19 Table DP04: Selected Housing Characteristics." Accessed 15 December 2021.
[174] Ibid.
[175] Data provided by County of Kauai
[176] US Census Bureau. "2020 DEC Redistricting Data (PL 94-171) Table P1: Race" Accessed 24 January 2022.
[177] County of Kauaʻi. (2018). Kauaʻi Kakou Kauaʻi County General Plan" P. 26
[178] The population growth rate has been declining and the island wide population is currently below the figures projected in the 2018 General Plan. As of Spring 2022, population growth is nominal.

identified near-term concerns about displacement and gentrification pressures associated with population growth during the COVID-19 pandemic.[179]

Jobs are expected to grow only 0.7% annually between 2020 and 2030 across the county, which is much less than population growth. The Līhuʻe planning area is the county's largest center of employment. It is forecasted to make up 47% of all jobs in the county in 2030 and 2035 and have the highest average annual job growth rate out of all planning areas.[180] The Līhuʻe planning area has larger shares of non-visitor jobs than the other districts, including in the retail trade; transportation, warehousing and utilities; and finance, insurance and real estate.

Employment growth has been impacted by the COVID-19 pandemic. The COVID-19 pandemic resulted in a decline in economic activity with variation across sectors and demographic groups. For example, employment in service sector fell significantly with businesses in leisure and hospitality, recovering more slowly than other sectors.

Key Vulnerabilities and Planning Issues

The Multi-Hazard Mitigation and Resilience Plan completed a detailed analysis of the populations and buildings exposed to specific hazards. Key highlights are broadly described below, with more detail included in Chapter 3 Planning Areas Exposures.

- **Sea level rise**: In the scenario where sea level rises 3.2 ft (SLR-XA 3.2), 4% of the population (2,690 people) is exposed.[181] Countywide, 1,255 buildings worth an estimated $494.7 million in structures and their content are exposed to coastal flooding hazard. A County representative mentioned that when coastal properties are threatened by coastal hazards, the common response of oceanfront homeowners was to protect their property by armoring the shoreline, which is the practice of using a physical structure, such as a seawall to protect lands from flooding or wave overwash. While temporarily effective at protecting upland, shoreline armoring ultimatly will accelerate eorsion on neighboring lands (known as "flanking"); therefore, increasing the vulnerability of neighboring properties.
- **Inland flooding:** The inland flood hazard, analyzed using the 1-percent annual chance flood zone, covers 3% of the entire county (7,358 acres) and affects approximately 10% of the population (6,796 people). The districts with the greatest area of mapped floodplain are Waimea, North Shore, and East Kauaʻi. However, Waimea and Kōloa-Poʻipū-Kalāheo have the highest number of buildings exposed (both count for a third of the total buildings exposed in the county). Almost half of Waimea's population is exposed to the inland flood hazard. The North Shore as a whole (which includes Princeville and Kilauea) has relatively few buildings and people exposed to inland flooding compared to the other planning districts (only 413 buildings and 479 people) but the FEMA flood studies have not been updated for Hanalei since 2005. A County representative and community member expressed concern about public housing's vulnerability to extreme rain events, with one community member relaying that heavy rain can enter the ground floor of some public housing.[182]

[179] County of Kauaʻi. (2022). "Talk Story Summary."
[180] County of Kauaʻi. (2014). "Kauaʻi General Plan Update: Socioeconomic Analysis and Forecasts"
[181] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 6-3
[182] County of Kauaʻi. (2022). "Talk Story Summary."

- **Storm surge and cyclones**: In the event of a Category 4 hurricane, all people and buildings in all areas of the island will be exposed to wind impacts.[183] In an event tracking south-southwest by northeast,[184] the Kōloa-Poʻipū-Kalāheo district will experience the highest wind speeds.[185] Storm surge inundation is a related impact because strong winds can lead to high surf. Twelve percent of the population (8,081 people) is potentially exposed to storm surge.[186] Waimea will be particularly hard hit, with about half of its population and half the areas total building value exposed.[187] East Kauaʻi and Hanapēpē-Eleʻele population and structures are also exposed to storm surge, but at a much lesser degree.
- **Extreme heat:** Individuals with physical, cognitive, and/or economic constraints, pre-existing medical conditions, and those who are experiencing houselessness are more vulnerable to the impacts of extreme heat. Extreme heat's effect on buildings is indirect, for example damaging heating, ventilation, and cooling systems.
- **Drought**: County residents are not anticipated to experience significant life or health impacts due to drought; however, drought can indirectly impact public health. An indirect threat is that drought depletes the urban and rural drinking water systems that communities depend on. This threatens food security and farmers' livelihoods if people lose their crops or livestock. Structures will not be directly affected by drought, but they may become more vulnerable to wildfires and their landscaping will be impacted. Immediate, short-term effects of drought on the environment include damage to plants, animals, habitat, and air and water quality. It also contributes to wildfire risk, which is harmful to human and ecosystem health. In the long-term, drought can permanently degrade landscape quality and cause permanent loss of biological productivity.
- **Wildfire**: An estimated $13.3 billion in structures and their contents are exposed to wildfire, the highest of all the hazards.[188] Seventy-seven percent of Kauaʻi's population (53,329 people) live in an area at Medium or High wildfire hazard (13% in Medium and 64% in High).[189] An estimated 96% of Hanapēpē-Eleʻele population and 91% of Waimea population is exposed to High wildfire risk rating. All county residents and visitors will potentially experience indirect effects such as smoke exposure.
- **Landslide**: About 4% of the population (2,917 people) are exposed to the landslide hazard.[190] Though the population exposed to High landslide hazard is minimal, it is most prevalent in Waimea and Kōloa-Poʻipū-Kalāheo (0.9% and 0.8% of their population exposed respectively). Hanapēpē-Eleʻele has the largest portion of its population exposed to Moderate landslide hazard (6.4%), but Kōloa-Poʻipū-Kalāheo has the highest dollar value of structure and contents exposed (over $177 mil).[191]

Community members have noticed that the lack of affordable housing and the island's high cost of living decreases the island's adaptive capacity and resiliency to climate impacts. Related concerns also include the unaffordability of home hazard insurance.[192] Talk story participants stressed the issue of gentrification and the feeling that housing and resources are being taken away from locals and Native Hawaiians.[193] One concern is that extreme weather changes outside the islands compels more people to move to Kauaʻi, which then takes

[183] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. M-4
[184] For the Multi-Hazard Mitigation and Resilience Plan risk assessment, Kauaʻi County determined that a Category 4 event with a storm track south-southwest by northeast, following the path of Iniki, was the scenario likely to have the greatest impact on the planning area.
[185] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 4-1
[186] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 4-6
[187] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. M-2
[188] County of Kauaʻi. (2021). "Multi-Hazard Mitigation and Resilience Plan." P. 5-2
[189] Ibid. P. M-11
[190] Ibid. P. M-28
[191] Ibid. P. M-28
[192] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."
[193] County of Kauaʻi. (2021). "Talk Story Summary."

resources/housing away from locals. Others notice that more people are relocating and teleworking in Hawaiʻi since the start of the pandemic.

The General Plan's allocation of future growth in existing towns helps reduce greenhouse gas emissions because it avoids conversion of natural land and keeps people closer to goods and services. However, many of these towns were developed in low-lying areas and highly exposed to climate change impacts.[194]

Key vulnerabilities and planning issues related to housing and businesses are further described in the Planning Area Hazard Exposures section.

Table 4. Countywide Hazard Exposure Table

Hazard	Population Exposed (#)	Housing + Business (#)	Housing + Business ($)
Chronic Sea Level Rise (SLR-XA 3.2)	2,690	1,255	494.7 million
Inland Flooding	6,796	3,608	2 billion
Tropical Cyclone	8,081	3,712	1.6 billion
Extreme Heat	All	All	Not quantified
Drought	All	All	Not quantified
Wildfire (High)	44,244	20,346	11.9 billion
Wildfire (Medium)	9,085	3,978	1.4 billion
Landslide (High)	355	175	64.8 million
Landslide (Moderate)	2,562	1,295	503.1 million

1. *Dollar value of Housing + Business is the value of exposed structures and their contents*
2. *Extreme heat and drought affect all people, property and environments but do not have direct impacts on critical facilities. Impacts to the value of housing and businesses is also indirect*

Source: County of Kauaʻi, 2021

[194] For more details on these towns, see Section 2.4 of the General Plan. Waimea, Kekaha, Poipu, Kōloa, Kapaʻa, and Hanalei are all low lying.

2.4.3. Transportation

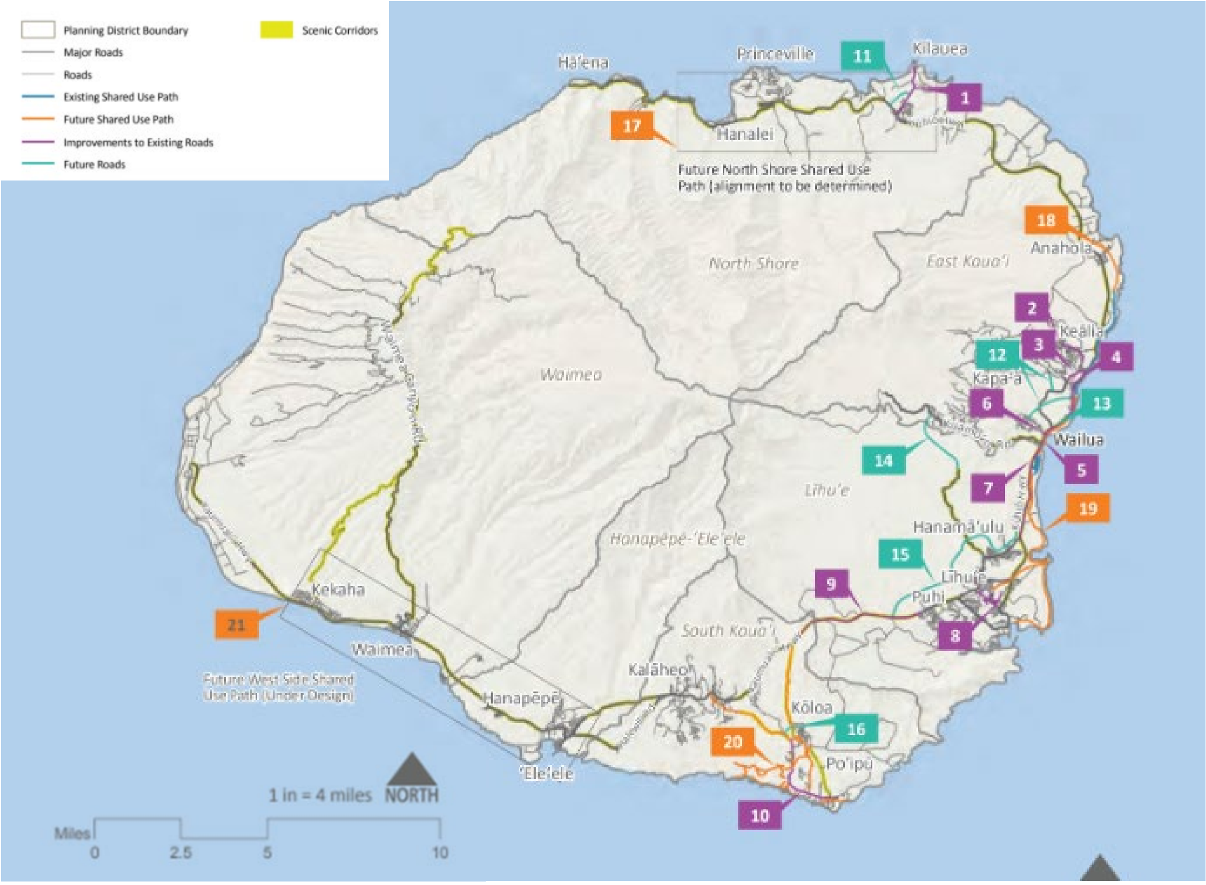
The island relies on ground, air, and water transportation via its roads and highways, airports, and boat harbors. Air travel is essential for inter- and extra-island travel, tourism, and air cargo. Water transportation is a key source of cargo and can be a means of personal transportation during an emergency.

State Highways and Local Roads

Asset Profile

Kūhiō Highway and Kaumualiʻi Highways are the two main routes on the island. The Hawaiʻi Department of Transportation (HDOT) is responsible for these belt highways as well as the major roads leading to the airport and Nāwiliwili Harbor.[195] Local roads include the County roadways and bridges. The County also has shared use paths, which promote active transportation. These are paths (often located within a linear park) that are separated from roads to provide a safe environment for pedestrians and cyclists.[196] The Ke Ala Hele Makalae runs 8 miles along the East Kauaʻi Coast, and others are planned for the North Shore, South Kauaʻi, and Waimea-Kekaha.

Figure 16. Island-Wide Transportation



Source: County of Kauaʻi, 2018

[195] County of Kauaʻi. (2018). Kauaʻi Kakou Kauaʻi County General Plan" P. 128
[196] Ibid. P. 154

Key Vulnerabilities and Planning Issues

The island's roads and highways are highly exposed to multiple climate change-related hazards. The impacts are magnified due to the lack of redundancy in the transportation system, which means there are no alternative routes if one section of road or bridge is compromised during a hazard event.

In Kauaʻi, portions of the Kūhiō Highway between Hanalei and Wainiha, the Kaumualiʻi Highway in Kekaha/Waimea, and the Kūhiō Highway over Wailua River and through Kapaʻa are exposed to coastal erosion, SLR marine flooding, annual high wave flooding, and storm surge from Category 1-4 hurricanes.[197] A state road section that community members identified as particularly vulnerable is the Kūhō Highway backing Wailua Beach.[198] Table 5 indicates the miles of state roads and the number of other transportation assets that could be impacted by coastal hazards due to sea level rise.

Table 5. State Transportation Asset Coastal Hazards

Hazard	Road (mi)	Bridges (#)	Culverts (#)	Tunnels (#)
Coastal Erosion	4.4	5	1	0
Passive Flooding (Marine)	1	25	1	0
Annual High Wave Flooding	6.4	14	0	0

Source: HDOT, 2018

Community members are concerned about Kauaʻi's local roads being threatened by sea level rise, heavy rain and storm events. They identified the road down by Anini Beach, Lawai Road, Kealia Road, Hauaʻala Road, and the road along Hanalei River as particularly vulnerable local road segments.[199] Community members also identified low-lying bridges and culverts in the Kalapaki Bay area and Niumalu as vulnerable. One comment mentioned that Hanapēpē Swinging Bridge is highly vulnerable to wind.[200] Table 6 shows miles of County and local roads exposed to various hazards in each planning area.

Table 6. Miles of State and Local Roads Exposed to Hazards

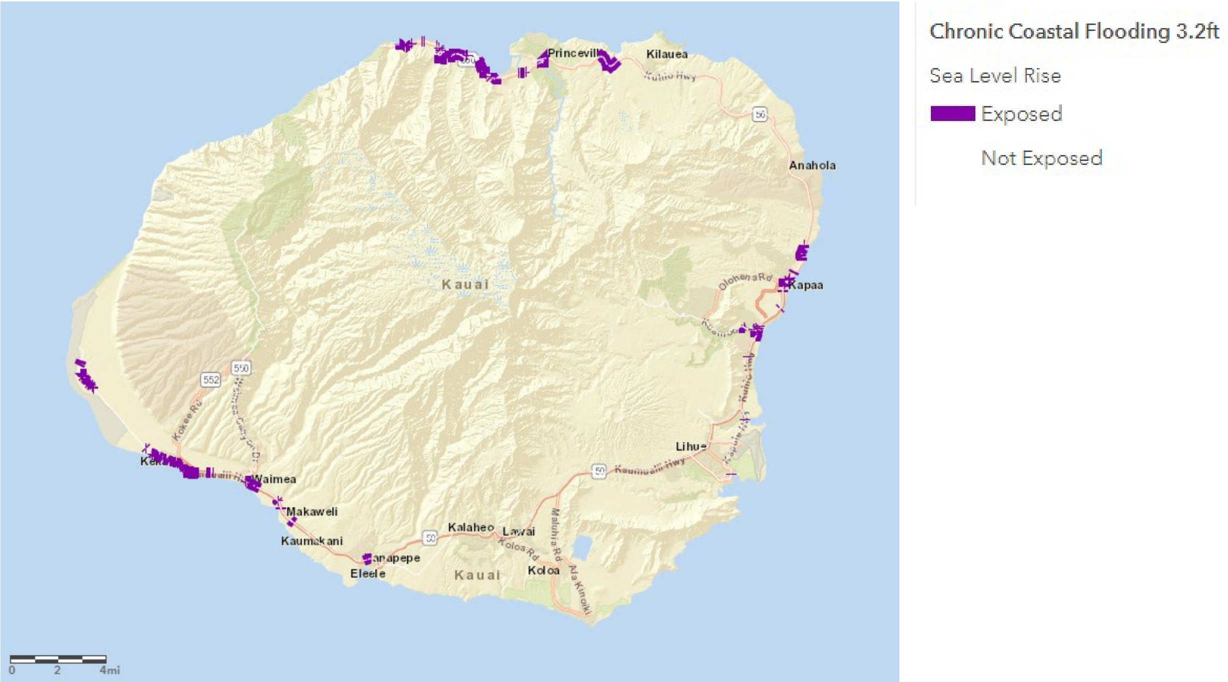
Planning Area	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	SLRXA-3.2	6 ft SLR Passive Flooding (NOAA)
North Shore	1.2 (H), 57 (L)	13.6	1.9	2.4	4.6	4.7
East Kauaʻi	85.9 (H), 26.7 (M)	9.9	1.5	1	4.6	9.1
Līhuʻe	48.7 (H), 10.2 (M), 11.9 (L)	2.5	1.1	0	0.3	2.2
South Kauaʻi	41.4 (H), 9.7 (M), 9.1 (L)	6.4	0.6	0.3	0.7	0.9
West Kauaʻi	76.9 (H), 1 (M)	34.2	5.8	4.6	11.1	13.3

Source: County of Kauaʻi, Raimi + Associates

[197] Hawaii Department of Transportation. (2018) "Climate Adaptation Action Plan" P. 6
[198] County of Kauaʻi. (2021). "Talk Story Summary."
[199] County of Kauaʻi. (2021). "Talk Story Summary."; County of Kauaʻi. (2022). "Open House Series #1 Summary Document."
[200] County of Kauaʻi. (2022). "Open House Series #1 Summary Document."

Kauaʻi's highways are affected by extreme precipitation, rockfall, landslide, debris flows, and inland flooding. For example, in the 2018 floods Kūhiō Highway in North Shore had to be reconstructed and stabilized after being damaged by heavy precipitation. All the communities west of Hanalei were isolated for more than a year. In 2012 and 2018 a Kuhio Highway stream crossing in Kalihiwai was re-routed because of high water flow.[201] A County representative also noted drainage infrastructure for roads as a concern, with older roads being identified as not dealing with runoff well. Community members identified specific roads and areas with poor drainage, such as Hanapēpē Heights, Puna Road, Lopaka Paipa Road, Kōloa Elementary School, and Kūhiō Highway (north of Princeville).[202]

Figure 17. State Highway Chronic Coastal Flooding Exposure



Source: HDOT, 2018

Figure 18 highlights the sections of the State highways that are susceptible to landslide. There are areas of very high and high landslide susceptibility along Kūhiō Highway near Wainiha, Kokeʻe Road, and Kaumualiʻi Highway near Eleʻele. In January 2022, a landslide in Waimea blocked a portion of Menuhune Road (County Road) and damaged the swinging bridge, isolating approximately 60 people and 20 homes.[203] In recent years, Kūhiō Highway from Hanalei to Hāʻena has been severely damaged due to landslides and access has been limited affecting causing hardship to these isolated communities. Traffic is also current issue and the vulnerability of the State and County roads to sea level rise, heavy rain, and storm events will further lead to delays.[204] Extreme precipitation in conjunction with wildfire burn scars can lead to landslides that cut off road access. Wildfires remove soil-stabilizing vegetation and change soil chemistry, which can cause a major landslide with just a small amount of runoff.

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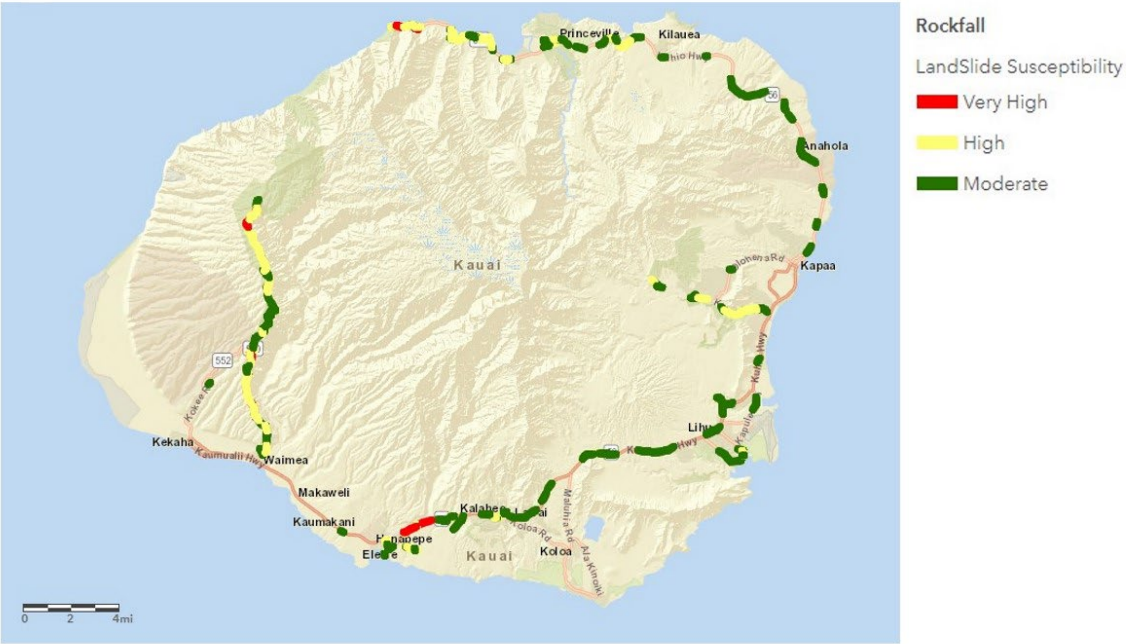
201 Ibid. P. 12

202 County of Kauaʻi. (2022). "Open House Series #1 Summary Document."

203 Fujimoto, D. (6 Jan 2022). "Families reel with Waimea landslide blocking a portion of Menehune Road." The Garden Island. https://www.thegardenisland.com/2022/01/06/hawaii-news/families-reel-with-waimea-landslide-blocking-a-portion-of-menehune-road/

204 County of Kauaʻi. (2021). "Talk Story Summary."

Figure 18. State Highway Landslide Risk



Source: HDOT, 2018

Figure 19 highlights the sections of State highways at risk of wildfire. Portions of Kūhiō Highway in the Līhuʻe and Kapaʻa areas are vulnerable to wildfire based on the metric that more than one ignition occurred within 0.4 mi^2 between 2000 and 2012.[205]

Figure 19. State Highway Wildfire Risk

Source: HDOT, 2018

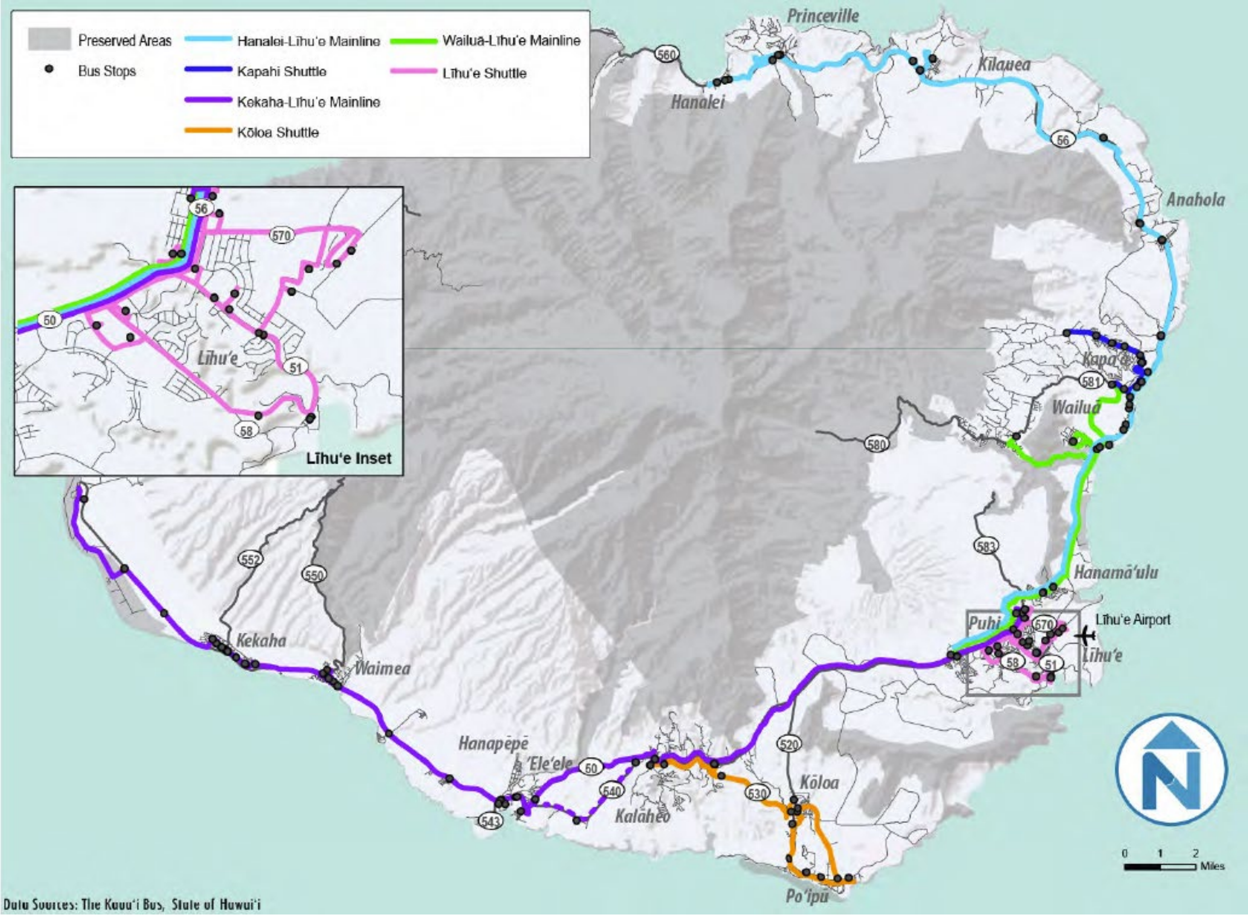
[205] Ibid P. 7

Public Transportation

Asset Profile

Public transportation services use the State, County, and local roadway systems to serve residents and visitors. The Kaua‘i Bus operates six fixed routes and paratransit bus service from Hanalei to Kekaha daily as shown in Figure 20.[206] The Mainline is composed of three routes that run along the perimeter of the island Hanalei to Kekaha, and a commuter line offering limited trips between Wailua and Līhu‘e. The other lines are the Kapahi, Kōloa, and Līhu‘e Shuttles.

Figure 20. Existing Bus Network



Source: Kaua‘i Bus, 2015

Key Vulnerabilities and Planning Issues

Kaua‘i’s public transportation runs on the roads and highways that are vulnerable to multiple climate hazards. The Hanalei Mainline Route and the Wailua Mainline Route operate primarily on the Kuhio Highway, including the portions that are vulnerable to coastal erosion, SLR marine flooding, annual high wave flooding, storm surge, and landslide.[207] The Kekaha Mainline Route primarily operates on the portions of the Kaumuali‘i Highway that are exposed to coastal hazards as well. A County representative also noted that the County’s coastal bike path on the East side has had problems with coastal erosion.

[206] County of Kaua‘i Transportation Agency. “Transportation Agency.” Accessed 2 December 2021. https://www.Kaua‘i.gov/Transportation
[207] Landslide only affects the Hanalei route

The main hazard affecting the bus stops is wildfire. About 90% of the bus stops in all planning areas except the North Shore are exposed to either High or Medium wildfire risk. Half of West Kauaʻi's bus stops are also exposed to flooding. Only bus stops in East and West Kauaʻi are exposed to near- and long-term SLR and coastal hazards.

Table 7. Bus Stop Hazard Exposures

Planning Area	Fire Risk	FEMA 1% Chance Annual Flood	SLRXA-3.2	Passive Coastal Flooding	High Wave Flooding	Coastal Erosion	NOAA 6 ft SLR
North Shore	0	3	0	0	0	0	0
East Kauaʻi	28 (H) 1 (M)	6	4	0	1	2	6
Līhuʻe	20 (H) 4 (M)	0	0	0	0	0	0
South Kauaʻi	14 (H)	1	0	0	0	0	0
West Kauaʻi	30 (H)	17	5	0	4	0	5

1. No bus stops are exposed to landslide or SLRXA-1.1

Source: County of Kauaʻi, Raimi + Associates

In addition to the physical infrastructure, many households, with and without a vehicle, rely on public transportation to access basic goods and services, get to work and school, and connect with their social networks. These households may experience detrimental economic, health, and social effects if they become isolated during and after a hazard event due to reduced mobility. Census block groups in Līhuʻe and Puhi have the highest rate of households without a vehicle (23% and 16% respectively).[208] However, these residents may not be as isolated since Līhuʻe has the highest concentration of jobs and other assets that people ride the bus to. Other communities around the island including Kekaha, Poʻipū , Anahola, and Wainiha also have 11 to 15% of households without a vehicle. On-board surveying of bus riders found that a majority of riders (57%) commute to Līhuʻe for work, school, or errands and the largest portions of riders are from the West and East sides (both represent 27% of riders).[209]

[208] US Census Bureau. (2019). ACS 15-19, Table B25044

[209] County of Kauaʻi. (2018). Kauaʻi Short-Range Transit Plan. P. 6-8. https://kauai.gov/Portals/0/Transportation/Kaua'i%20SRTP%20Final%20Report%202018.pdf?ver=2019-09-11-143326-030

2.4.4. Utilities and Infrastructure

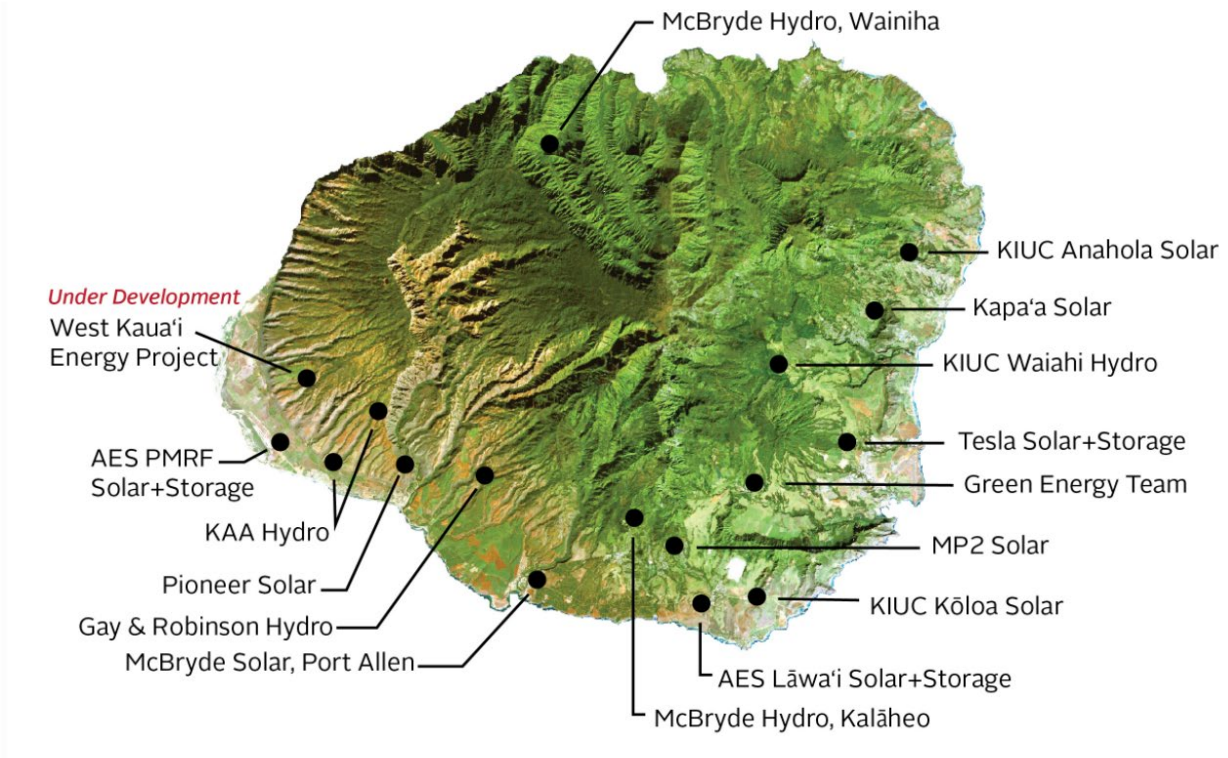
Electricity

Asset Profile

Kauaʻi Island Utility Cooperative (KIUC) is the island's ratepayer-owned electric utility. The co-op owns and maintains 1,500 miles of transmission and distribution lines.[210] Sixty seven percent of its electricity comes from renewable energy, generated by 15 active renewable energy projects (solar, hydroelectric, and biomass).[211] As indicated in Figure 21, three of KIUC's renewable facilities are paired with battery storage. The grid routinely runs on 100% renewable for 6-8 hours per day.[212] KIUC has one additional power generation project in the pipeline.

Though there is not data available for this, households also have rooftop solar, off-grid electricity systems, and propane which help increase resiliency to power outages.

Figure 21. KIUC Renewable Projects



Source: Kauaʻi Island Utility Cooperative, 2021

Key Vulnerabilities and Planning Issues

Electrical infrastructure is vulnerable to direct damage during storms, high winds, landslides, and wildfires. Power poles themselves can be toppled, and wind, trees, or other debris can damage transmission lines in an

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[210] For safety and security reasons, utility company infrastructure is not mapped.
[211] Kauaʻi Island Utility Cooperative. (2021). "Powering Through A Pandemic." https://kiuc.coop/sites/default/files/documents/presentations/2021-0721-AnnualMeeting.pdf
[212] Ibid.

extreme event. Power lines, substations, and underground electricity assets will also likely be more vulnerable to inundation with 3.2 feet of SLR (many of these facilities are already vulnerable to a major storm event).

Although some energy transmission data area included in the critical facilities analysis (2.4.1), a detailed analysis of the electric system was not conducted due to data availability and security considerations.

Power Outages

Regardless of the cause, power outages can be life-threatening for people who are medically dependent on electricity and inhibit disaster recovery and response. Not having electricity for a long period of time can also have larger social ramifications such as community experiencing frustration. All of the hazards described above can cause power outages from direct and indirect damage:

- During a wildfire, wooden power poles can ignite and cause a community to lose power. On the other hand, malfunctioning power equipment can also ignite wildfires (which are more extreme due to climate-change related conditions like invasive grasses and drier-than-normal vegetation).
- High tide nuisance flooding (an impact of SLR) will result in water ponding and wetting of power poles and underground infrastructure.[213] Major flooding and permanent inundation of critical electricity assets from the groundwater rising could result in complete loss of power to the community.[214]
- High winds from a hurricane can bring down power lines, trees, and potentially impact solar panels. The invasive Albizia tree in particular is vulnerable to strong winds and has been found to be a major disruptor and cause of damages in Hawaiʻi.[215]
- Extreme heat can cause damage to the power system indirectly. Periods of extreme heat stress the power grid as people use air conditioning, potentially leading to power outages.

Since Hurricane Iniki, significant efforts to increase the resilience of the electricity infrastructure have been implemented, including hardening and “micro-gridding” the infrastructure. Unfortunately, Kauaʻi communities can still be greatly impacted by power issues as seen during the 2018 floods. Twelve power outages were reported along the North Shore and lightning strikes cut power in other areas of the north and west sides.[216]

Additional impacts from power outrages include:

- **Communications**: Impacts to electrical infrastructure cascade to other critical systems like communications. Community members express particular concern over cell towers, since most use cell phones as a primary means of communication rather than landlines or radios.[217] For example, when the 2018 floods struck, there was no cell phone service in the affected area for at least 24 hours.[218]
- **Potable Water Supply**: The loss of electricity impacts water pumps at deep well sites, as well as homes and pump stations that rely upon energy to pump water from their source along the pipe network.[219] Though the Department of Water has various emergency response measures, prolonged power outages could slow down recovery efforts and result in loss of water access to residents and the community over a longer period of time.

[213] Spirandelli et al. (2020). “West Kauaʻi Community Vulnerability Assessment” P. 87
[214] Ibid.
[215] Ibid.
[216] Harangody et al. (2021). “Halana Ka Manaʻo Reflections from Kauaʻi of the 2018 Floods.” UH Manoa.
[217] Spirandelli et al. (2020). “West Kauaʻi Community Vulnerability Assessment” P. 87
[218] Harangody et al. (2021). “Halana Ka Manaʻo Reflections from Kauaʻi of the 2018 Floods.” UH Manoa.
[219] Spirandelli et al. (2020). “West Kauaʻi Community Vulnerability Assessment” P. 92

Water and Wastewater

Asset Profile

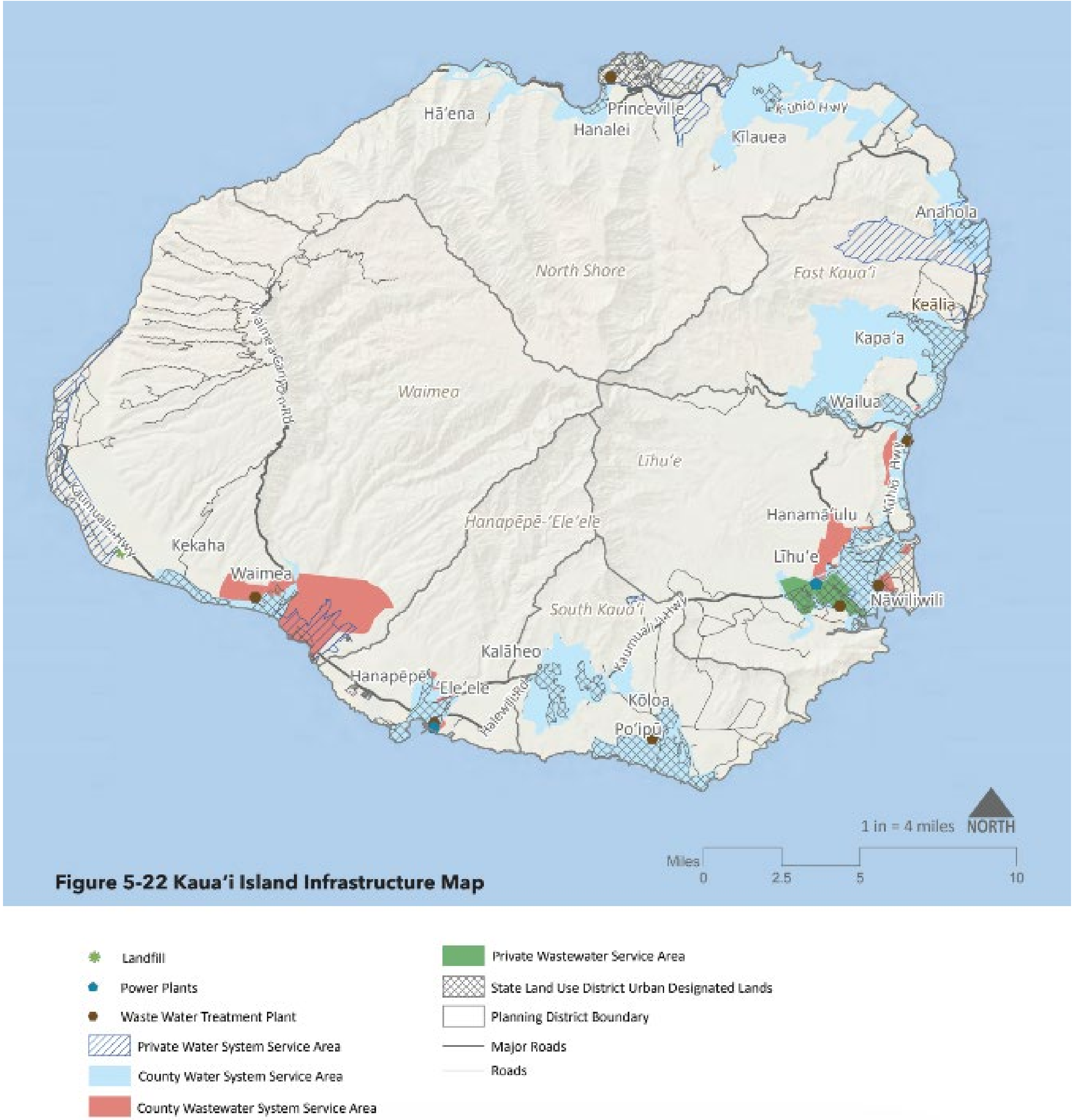
Most domestic fresh water in Kaua'i is groundwater from the island's aquifer. The Commission on Water Resources Management determined that an estimated 312 million gallons per day is a sustainable yield. The aquifers rely on continual recharge from rainfall and streamflows, and they can be negatively affected by drought, withdrawals, and contamination.[220]

Kaua'i's wastewater treatment and disposal is a combination of County and private systems. Treated effluent is disposed of via injection well and ocean outfall or is recycled for irrigation.[221] The County's wastewater treatment plants are located at Waimea, Ele'ele, Līhu'e, and Wailua, but there are also over 35 privately owned wastewater treatment plants for various developments and small beach resorts.[222]

Cesspools are holes in the ground that discharge raw, untreated human waste. The waste is not treated in any way, and under certain circumstances, can contaminate groundwater, drinking water, streams, and the ocean.[223] There were 13,688 cesspools and 5,300 septic and aerobic units on the island in 2016.[224] In 2017, State legislation was passed requiring the replacement of all cesspools by 2050.[225] The Kapa'a/Wailua area and the Po'ipū/Kōloa area are a priority for replacement due to potential impacts to drinking water wells, and the Hanalei Bay area is a priority due to impacts to sensitive water bodies used for recreation and that have coral reefs.[226]

[220] County of Kaua'i. (2018). Kaua'i Kakou Kaua'i County General Plan" P. 101
[221] County of Kaua'i. (2018). Kaua'i Kakou Kaua'i County General Plan" P. 142
[222] Ibid.
[223] Hawaii Department of Health. "Cesspools in Hawaii." Accessed December 2021. https://health.hawaii.gov/wastewater/cesspools/
[224] Ibid.
[225] Ibid.
[226] Hawaii Department of Health. (2017). Report to the Twenty-Ninth Legislature Relating to Cesspools and Prioritization for Replacement." Environmental Management Division. https://health.hawaii.gov/opppd/files/2017/12/Act-125-HB1244-HD1-SD3-CD1-29th-Legislature-Cesspool-Report.pdf

Figure 22. Water and Wastewater Infrastructure



Source: County of Kaua'i, 2018

Key Vulnerabilities and Planning Issues

Potable water systems, sanitary sewer systems, and cesspools are vulnerable to climate change, particularly precipitation extremes. Rising seas and flooding can directly damage equipment and impair water quality. Likewise, drought conditions cause declines in water quantity and quality impacting the availability of water for communities and natural resources.

Potable water: Climate change has fundamentally altered the water cycle on tropical islands which is a critical driver of freshwater ecosystems and water resource renewal.[227] Long-term decreases in precipitation result in negative impacts to water resources, stream discharge, watershed and coastal ecosystems, and mauka to makai watershed connectivity. Streamflow has declined with increasing numbers of perennial streams running dry between direct rain events.[228] Kauai's water supply is mainly derived from groundwater.[229] The probability of chronic water shortages may grow as rainfall decreases and the water requirements of a growing population increase. Furthermore, a County representative relayed that high rain events are not leading to groundwater recharge.

Potable water supply faces threats both from rising groundwater and saltwater intrusion. SLR increases the water table, which will eventually cause groundwater to come up to the land's surface (groundwater inundation or expression).[230] This can cause problems such as aquifer salinization and flooding of facilities.[231] However, it is important to note that many of Kaua'i's water wells are located at higher elevations away from saltwater intrusion risk. Related to water infrastructure, the Department of Water also pointed out that storm events have realigned the rivers, which resulted in issues maintaining the wells and watermains that traverse along these riverbanks.

Potable water infrastructure are also vulnerable to flooding and SLR impacts. Countywide, potable water infrastructure (wells, water tanks, and water pumps) is most exposed to wildfire (192), landslide (41), 1% chance annual flooding (34). Two water infrastructure components in East Kaua'i and three in West Kaua'i are exposed to near-term SLRXA-1.1. In the long term, eight components of water infrastructure are exposed to SLRXA-3.2 and 24 are exposed to flooding in the NOAA 6' ft SLR scenario. For example, during the 2018 floods, the Department of Water pump station that served water to Hanalei, Wainiha, and Ha'ena was temporarily down due to a mainline break.[232] Flooding can directly damage equipment, especially since Department of Water documented that up to 23% of their pipes island wide were built prior to 1960 and needing upgrade and repair.[233] The resilience of pipes depends upon their material and age; some pipes are built out of cast iron, some galvanized steel, some built with asbestos cement. More current pipes are ductile iron, which is the industry standard, unless the pipes are near the coast in which case they should be polyvinyl chloride (PVC). The Department of Water maintains an active pipe replacement program. The water system is also dependent upon constant electricity to pump water from deep wells. The Department of Water maintains generators at its Līhu'e base yard, which can be mobilized to remote sites, and also has permanent generators located at key deep well sites to ensure power can be provided as reliably as possible.

A County representative also mentioned that Department of water staff are also relient on the transportation system to ensure that staff can make repairs to continue service. For instance, if there are impacts to critical roads or bridges, this could potentially isolate communities from receiving service.

Wastewater infrastructure. Flooding from extreme storms and coastal flooding will impact wastewater systems and stormwater infrastructure. It can also cause blockages that lead to releases of untreated wastewater. A County representative mentioned that intense storm flows can directly impact wastewater treatment plants,

[227] Leta, O.T., *et al.* (2018) Impact of climate change on daily streamflow and its extreme values in Pacific Island watersheds, *Sustainability*, 10, 2057, doi:10.3390/su10062057
[228] Bassiouni, M., and D. S. Oki (2013) Trends and shifts in streamflow in Hawai'i, 1913–2008. *Hydrological Processes*, 27 (10), 1484–1500. doi:10.1002/hyp.9298
[229] Oki, D. S., *et al.* (1999) Hawaii. *Ground Water Atlas of the United States*, Segment 13, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. Miller, J. A., et al., Eds., U.S. Geological Survey, Reston, VA, N12–N22, N36.
[230] UH Sea Grant College Program. (2014) "Kaua'i Climate Change and Coastal Hazards Assessment." https://eos.ucs.uri.edu/seagrant_Linked_Documents/hawau/TT-13-08.pdf
[231] Ibid.
[232] Harangody et al. (2021). "Halana Ka Mana'o Reflections from Kaua'i of the 2018 Floods." UH Manoa.
[233] Kauai Department of Water. (2001). WaterPlan 2020. http://www.kauaiwater.org/ce_waterplan2020app.asp

such as the wastewater infrastructure in Waimea and Wailua, which can lead to spills. Countywide, GIS analysis found that wastewater infrastructure (wastewater pumps and wastewater treatment plants)[234] are most exposed to wildfire (29) and 1% annual chance flooding (14). One piece of wastewater infrastructure in East Kauaʻi is exposed to SLRXA-1.1 and one in West Kauaʻi is exposed to SLRXA-3.2. However, in the 6' SLR scenario, a total of thirteen infrastructure assets are exposed in East Kauaʻi, West Kauaʻi, and Līhuʻe.

Cesspools: There are many cesspools and injection wells that are close to the shoreline and the inundation of cesspools are already occurring in some areas.[235] Low-lying communities without municipal sewer system are threatened by sea level inundating cesspools, in areas including Hanalei, Haēna, Waimea, and Kekaha. One community member has noticed that some people are building illegal systems.[236] High water level could potentially cause surface flows of effluent, contamination above ground, and/or backing up into the house.[237] This was the case in the North Shore during the 2018 floods, where overflowing cesspools and septic tanks spread bacteria through low lying areas (including an elementary school yard) and into the ocean.[238] One community member said that they have a cesspool on the property they grew up on, which is located next to a stream, and the effluent is getting into the water system.[239]

Analysis of cesspools' exposure to hazards by planning area are included in Chapter 3: Planning Area Hazard Exposures.

Solid Waste

Asset Profile

The County oversees numerous programs and policies that allow the solid waste management system to function. The County's existing solid waste management system includes the following main components: solid waste collection; source reduction; recycling and bioconversion; special waste management; household hazardous waste and electronic waste (eWaste) management; refuse transfer stations (RTSs); Kauaʻi Resource Center (KRC); and Kekaha Municipal Solid Waste Landfill (Kekaha Landfill).[240] Locations of solid waste facilities by type are shown in Figure 23.

Refuse Transfer Stations accept municipal solid waste from residential collection trucks and transfer it to the landfill, but residents and small businesses also bring waste directly. There are stations in Hanapēpē, Līhuʻe, Kapaʻa, and Hanalei. The Kekaha Municipal Solid Waste Landfill collects residential and commercial refuse and is the only operating landfill facility of its kind on Kauaʻi. It was expected to reach capacity in 2019, but the landfill was expanded and as of 2020 has over 619,000 cubic yards of airspace.[241] The Integrated Solid Waste Management Plan estimates that the landfill will now reach capacity in June 2027; however, the County is planning a vertical expansion which will extend its remaining life to 2030.[242]

Key Vulnerabilities and Planning Issues

Regardless of climate change impacts, the island's solid waste system is vulnerable there is no redundancy in it. All of the waste goes to a single facility which is already at capacity. Though the Kekaha Landfill is not

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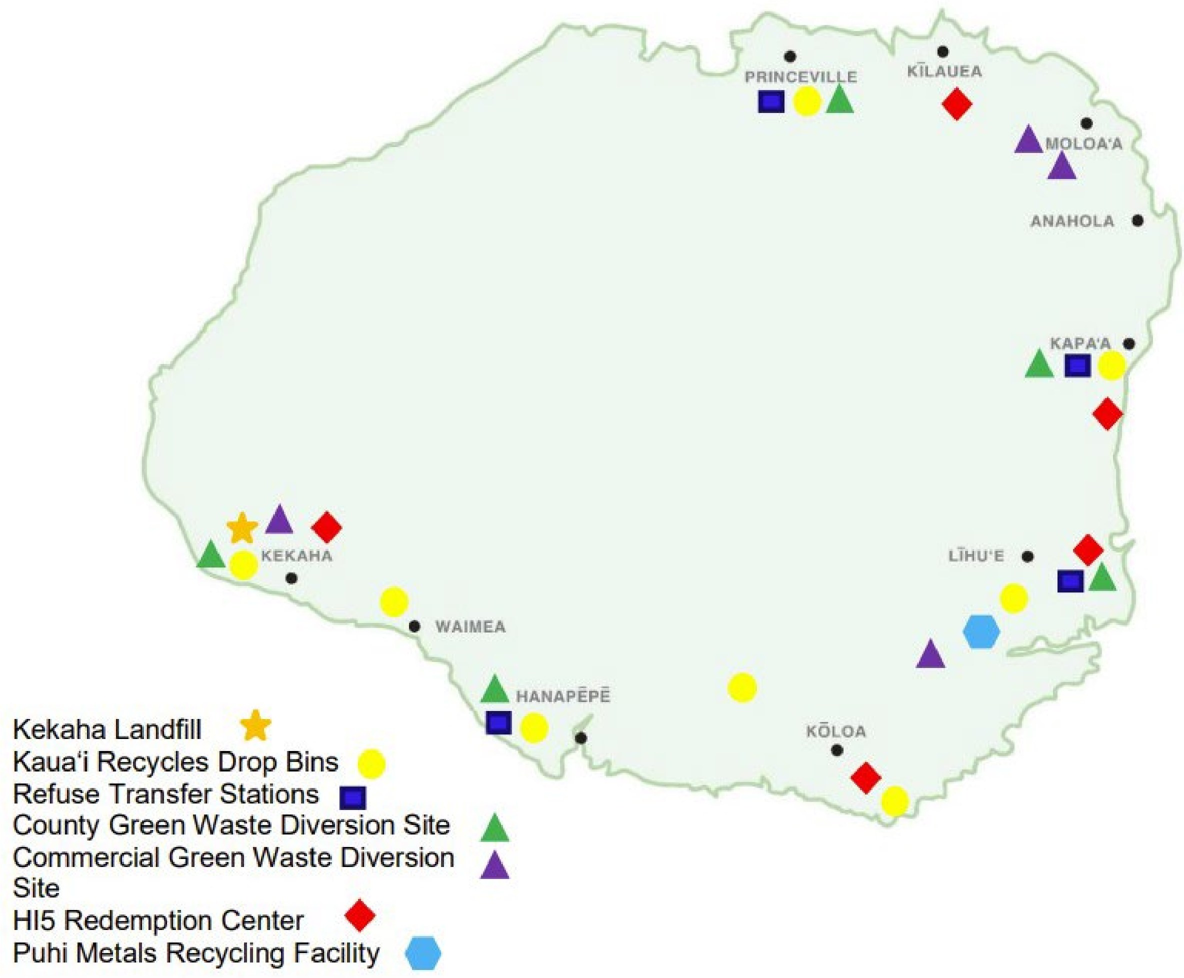
[234] Does not include cesspools (on-site disposal systems)
[235] County of Kauai. (2022). "Talk Story Summary."
[236] Ibid.
[237] Spirandelli et al.. (2020) "West Kauaʻi Community Vulnerability Assessment" P. 77
[238] Harangody et al. (2021). "Halana Ka Manaʻo Reflections from Kauaʻi of the 2018 Floods." UH Manoa.
[239] County of Kauai. (2022). "Talk Story Summary."
[240] Kauaʻi Department of Public Works, Solid Waste Division. (2021). "Integrated Solid Waste Management Plan Update." https://www.Kauaʻi.gov/Portals/0/PW_SolidWaste/ISWMP_DOCUMENTS/PROOF%20v2__Kauaʻi Co_ISWMP_Update_Draft5_Final%20211103.pdf
[241] Ibid.
[242] Ibid.

directly exposed to any of the hazards analyzed in the Planning Area Hazard Exposures analysis, there would be consequences for solid waste island wide if the roads and bridges around it are compromised by flood or SLR. County staff have also identified the vulnerability of the Kekaha Landfill's leachate system, which is currently full of liquid (it is supposed to be dry) which could overflow during a storm. A County representative also relayed that the 2018 floods were an 'intense experience' where staff still had to operate while they needed a temporary debris station that had to be quickly sited and staffed. Similarly, flooding occurred at the waste facility in Kapaʻa during the 2020 flood event. Lack of staff was noted as a challenge, as well as the fact that the design of the landfill was not in anticipation for climate change impacts.

Figure 23. Solid Waste Facilities



Source: County of Kauaʻi, 2021

Chapter 3: Planning Area Hazard Exposures

The following section is a screening level assessment of hazard exposures for each of the five planning areas. The first component of the analysis is a map of the planning area's hazard exposures and selected assets. The maps illustrate how the hazards overlay with each other and where areas for potential concern are. This is followed by a table which summarizes key people, natural and cultural,[243] community, transportation, and utility assets exposed to hazards by community (Census Designated Places). It also highlights some places where high social vulnerability overlaps with those hazard exposures using findings from the Social Vulnerability Index (SVI) developed for this project.[244] The third component is a table quantifying all the assets in the planning area which are exposed to the hazards listed below in Methodology. All together, this planning area hazard exposure analysis will help identify which adaptation strategies need to be applied in which places throughout the CAP development.

PURPOSE AND METHODOLOGY

This assessment is meant to be used in concert with other state, county, and region-specific vulnerability and exposure assessments. This includes assessments completed as part of the Hawaiʻi Highways Climate Adaptation Action Plan (2021), Kauaʻi Multi-Hazard Mitigation and Resilience Plan (2021), and the West Kauaʻi Community Vulnerability Assessment (2020). Additionally, this assessment is a companion to the online mapping platform maintained on Kauai County's GIS website. The online mapping platform will incorporate new and improved data on hazards and assets when possible.

The maps and tables in the following sections summarize assets' exposure to the following hazards:

- Wildfire[245]
- 1% chance annual flooding
- Landslide
- Near-term SLR and coastal hazards (SLRXA-1.1 and its component parts – passive flooding, high wave flooding, and coastal erosion)
- Long-term SLR and coastal hazards (SLRXA-3.2 and its component parts – passive flooding, high wave flooding, and coastal erosion)

[243] In the tables, cultural sites' types and locations are not described due to their sensitive nature. The County does not have a complete spatial dataset of culturally significant resources and sites, and some cultural data points are intended to be representational and not precise. Therefore, the total number of cultural sites exposed to hazards is likely to be underrepresented.

[244] Social Vulnerability is discussed in greater detail in Section 2.1: Residents and in Appendix A: Social Vulnerability Index Methodology

[245] The Communities at Risk of Wildfire designations of Low, High, and Medium Risk account for the characteristics of the area's subdivision, vegetation, building, environment, and fire protection capability.

- Passive coastal flooding that may occur with 6 feet of sea level rise as modelled by NOAA.

For a more detailed explanation of the methodology, refer to Section B.1 Methodology in Appendix B: Detailed Hazard Exposures of Select Critical Facilities.

NORTH SHORE

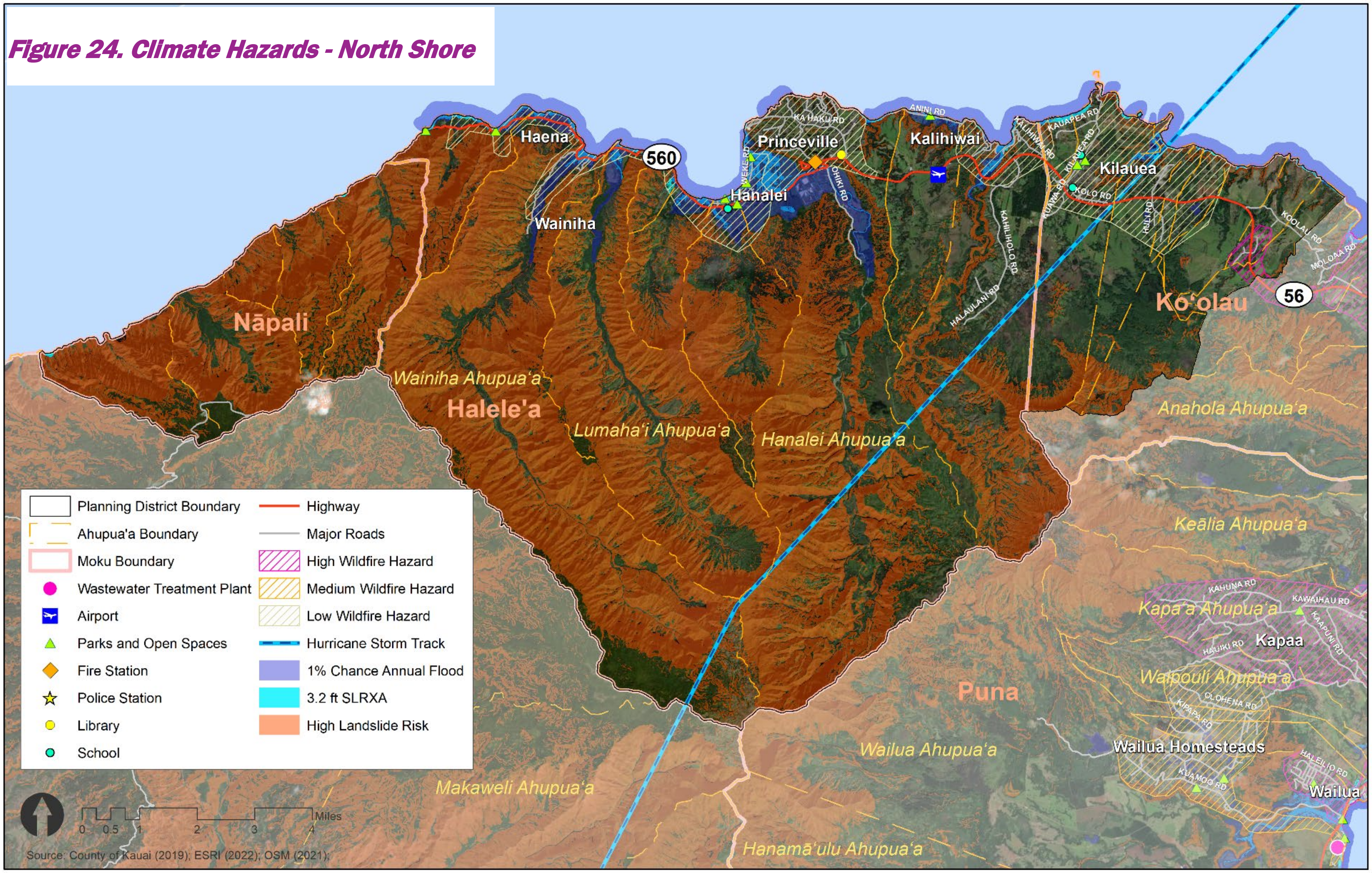


Figure 24. Climate Hazards - North Shore

Table 8. North Shore Hazard Exposures by Census Place

Community	Hazard Exposures
Kīlauea	• **Residents**: The most densely urbanized neighborhood of Kīlauea is exposed to low wildfire hazard. The area has a low-moderate SVI score (40-50th percentile) and includes one affordable housing development with 12 units. • **Natural and Cultural Resources**: There are two cultural features exposed to SLRXA 1.1, SLRXA 3.2, passive flooding with 6' of SLR, and flood. The entirety of Kauapea Beach is exposed to SLR. • **Community Assets**: The area directly adjacent to Kīlauea stream is exposed to flooding, SLR, and some landslide. It is also in the tropical storm path modeled in the MHMP that follows Hurricane Iniki. However, the area is mostly undeveloped.
Kalihiwai	• **Residents**: The town has a high SVI score (80th percentile). • **Natural and Cultural Resources**: Kalihiwai Beach and stream are exposed to SLR and flooding. • **Community Assets**: Anini is exposed to flooding and SLR. The area exposed to flood is directly adjacent to areas with high landslide risk. • **Transportation**: Sections of Kalihiwai Road are within the SLRXA 3.2. Kalihiwai Bridge is exposed to flooding but it should not be impacted due to its high elevation over the stream. Anini Road is within the SLR-XA 3.2, and there are some residences that may be within the flood and landslide area. • **Utilities and Infrastructure:** 49 (37%) of cesspools are exposed to flood, 8 (6%) to SLRXA 1.1, 21 (16%) to SLRXA 3.2, and 44 (33%) to passive flooding with 6' SLR.
Princeville	• **Natural and Cultural Resources**: There are two cultural features exposed to SLRXA 1.1, SLRXA 3.2, passive flooding with 6' SLR, and flooding. The traditional cultivation area on the banks of the Puukumu Stream are exposed to flood. Mauka critical habitat areas are exposed to High Landslide Risk. • **Community Assets:** All development in Princeville (primarily residential and visitor uses) is completely within the low wildfire hazard area. This includes one affordable housing development with 44 units. Critical facilities in the area include fire station, post office, police station, and the KKCR Radio facility. • **Utilities and Infrastructure:** 10 (67%) of cesspools are exposed to flood.

Continued on next page

Community	Hazard Exposures

Hanalei	• **Residents:** The more developed portion of the town has a moderate-high SVI score (60-70th percentile), and the agricultural areas have a moderate-high score (70-80th percentile)
	• **Natural and Cultural Resources:** Hanalei has a wealth of registered historic sites, cultural features, and a fishpond surrounding the bay. Almost all are exposed to flooding, and some are also exposed to passive flooding with 6' SLR. The traditional cultivation areas where lo'i is still cultivated today are vulnerable to flood, as demonstrated by flood events in recent years. Mauka critical habitat areas and wetlands are exposed to High Landslide Risk.
	• **Community Assets:** The entire town (developed with residential, commercial, and agricultural uses) is exposed to flooding between the Wai'oli Stream and Hanalei River. The areas of flooding are immediately adjacent to high landslide risk, including at multiple points along Kuhio Highway.
	  o Development along the bay and the Hanalei River are also exposed to SLRXA 3.2.
	  o Residential and agricultural lands from Black Pot Beach to Kuhio Highway are exposed to SLR. 190 (72%) cesspools are exposed to flood, 11 (4%) to SLRXA 1.1, 33 (13%) to SLRXA 3.2, and 45 (33%) to passive flooding with 6' SLR.
	• **Transportation**: The Hanalei Bridge is exposed to multiple hazards: low wildfire risk, 1% chance annual flood, landslide, SLRXA-1.1 (passive flooding), SLRXA 3.2 (passive flooding), and passive floosing with 6' SLR.
	• **Critical Facilities:** The elementary school, post office, and neighborhood center are exposed to low wildfire hazard and flood.

Hā'ena	• **Residents**: It has a moderate-high SVI score (70-80th percentile). The entire town (primarily residential development) is exposed to flooding. • **Natural and Cultural Resources**: The town's entire coast is exposed to SLRXA 3.2, but it is most prevalent around the YMCA camp and at Wainiha Beach Park. Five cultural features in Ha'ena are exposed to flood and three of those are exposed to SLRXA 1.1 or 3.2. The traditional cultivation area on the banks of the Wainiha River are also exposed to flood. • **Transportation**: Kuhio Highway is exposed to landslide, SLR, and flooding between Wainiha Bay Park and Beach Park. • **Utilities and Infrastructure:** 207 (81%) of cesspools are exposed to flood, 24 (10%) to SLRXA 1.1, 67 (28%) to SLRXA 3.2, and 21 (9%) to passive flooding with 6' SLR.

Table 9. Summary of Assets Exposed to Hazard in North Shore

Asset	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	Passive Coastal Flooding (1.1 ft)	High Wave Flooding (1.1 ft)	Coastal Erosion (1.1 ft)	SLRXA-3.2	Passive Coastal Flooding (3.2 ft)	High Wave Flooding (3.2 ft)	Coastal Erosion (3.2 ft)	6 ft SLR Passive Flooding (NOAA)
Point Features												
Critical Facilities	4 (H); 57 (L)	16	11	2	2	0	0	8	4	5	0	9
Buildings	116 (H); 4,513 (L)	1,038	64	75	1	54	10	279	20	216	83	280
Affordable Housing Developments	2 (L)	0	0	0	0	0	0	0	0	0	0	0
Cesspools	18 (H); 1409 (L)	514	34	49	3	37	17	143	14	14	41	134
Bridges	13 (L)	10	0	7	5	1	0	9	9	5	1	10
Bus Stops	8 (L)	3	0	0	0	0	0	0	0	0	0	0
Hotels and Rentals	90 (L)	35	2	3	0	2	1	11	1	11	2	8
Cultural Features[1]	2 (H); 47 (L)	37	43	7	4	5	1	8	4	6	3	10
Fish Ponds	1 (L)	1	0	0	0	0	0	0	0	0	0	1
Linear Features (in miles)												
Roads & Hwys	1.2 (H); 57 (L)	13.6	1.9	2.4	-	-	-	4.6	-	-	-	4.7
Acres												
Coral Reefs[2]	0	1,004	0	0	-	-	-	392	-	-	-	996
Parks	0	0	0	0	-	-	-	0	-	-	-	0
Agricultural LU	213 (L)	192	2,295	5	-	-	-	5	-	-	-	146

1. *The County does not have a complete spatial dataset of culturally significant resources and sites, and some cultural data points are intended to be representational and not precise. Therefore, the total number of cultural sites exposed to hazards is likely to be underrepresented*
2. *For coral reefs and parks, acres reflect the entire area of a polygon regardless of how much of it is exposed to the hazard. For Hawaiian Homelands, only the acres which are exposed to a composite layer (fire, flood, landslide, the SLRXA-1.1 and -3.2, and passive flooding with 6' SLR) are counted. Hawaiian Homelands in the subarea are Waimea and Kekaha Hawaiian Homelands.*

Source: County of Kaua'i, Raimi + Associates

EAST KAUA‘I

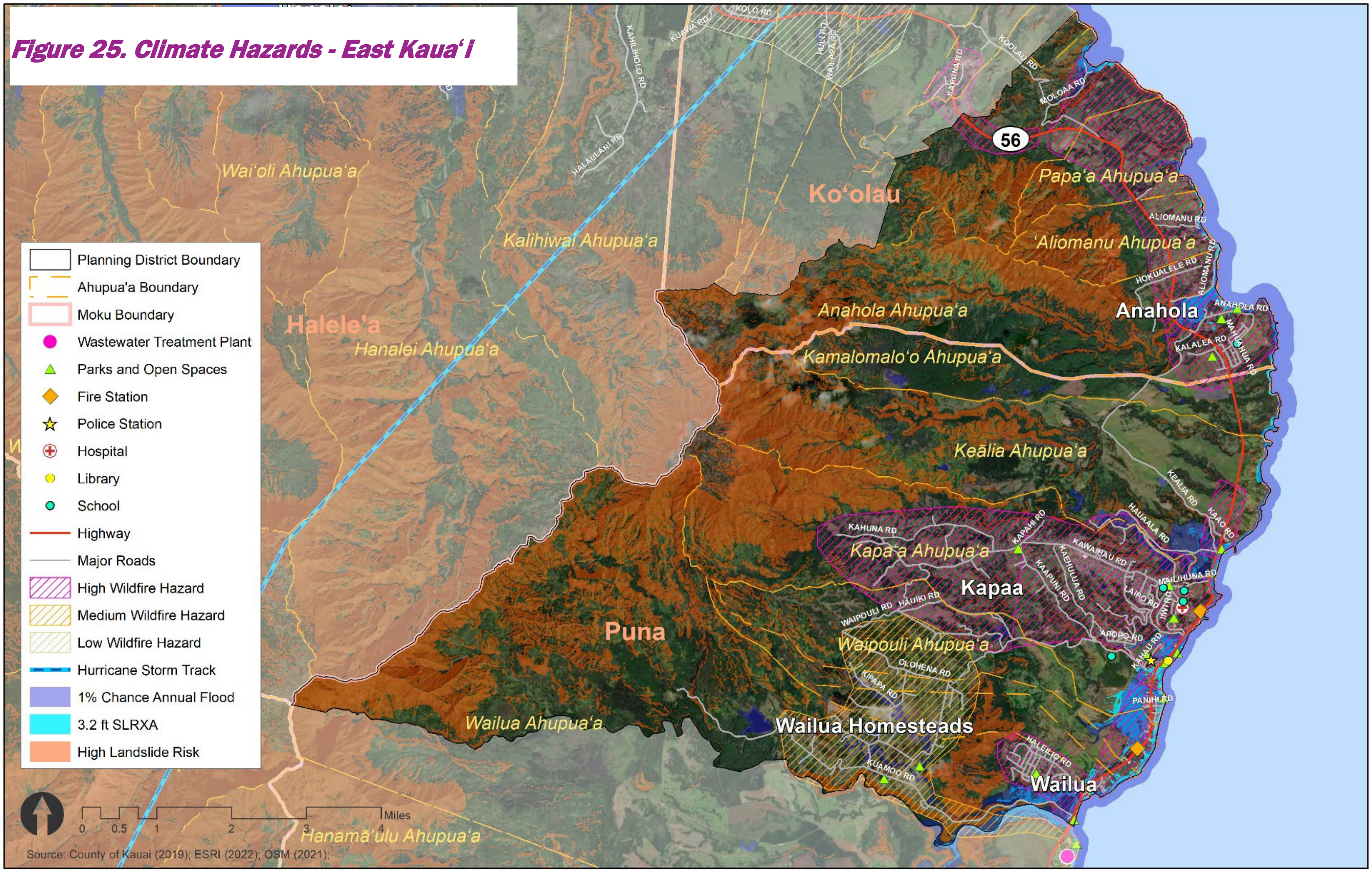


Figure 25. Climate Hazards - East Kaua‘i

Table 10. East Kauaʻi Hazard Exposures by Census Place

Community	Hazard Exposures
Anahola Town Center	• **Residents**: The census block group mauka of the highway has a moderate SVI score (around 60th percentile) while the block group makai has a high score (80-90th percentile). • **Natural and Cultural Resources**: Moloaʻa is exposed to SLR and flooding around the beach and stream. • **Tourism**: The area from Anahola Beach to Kuhio Highway has several homes and vacation rentals exposed to flooding and SLR. Moloaʻa is exposed to SLR and includes several homes and vacation rentals. • **Critical facilities:** All land mauka of Kuhio Highway from Anahola to Moloaʻa is at high wildfire risk. Critical facilities in this area include two county parks, the Anahola Post office, a communications facility, and the Kanuikapono Charter School. • **Transportation**: The area from Anahola Beach to Kuhio Highway is exposed to flooding and SLR. • **Utilities and Infrastructure**: 52 (12%) OSDS are exposed to flood, 14 (3%) to SLRXA 1.1, 32 (8%) to SLRXA 3.2, and 85 (20%) to passive flooding with 6' SLR.
Kapaʻa	• **Residents**: Kapaʻa has low SVI scores everywhere except the block group that contains Pono Kai and the residences mauka of Kuhio Highway (70-80th percentile). • **Natural and Cultural Resources:** There is one each of wetland, cultural feature, State Historic Site, and State and National Historic Site exposed to SLRXA 3.2. • **Community Assets**: Kapaʻa is the most populous town in the planning area. High wildfire risk covers the entire town, including the denser residential development around Kawaihau Road and the more rural residential on its outskirts. There are three affordable housing developments in this area with a total of 79 units. • **Critical facilities:** Critical facilities exposed to wildfire include the Mahelona Medical Center and the Kaiakea Fire Station. The Kapaʻa police station and AMR emergency medic are exposed to multiple hazards: high wildfire, flood, SLRXA-3.2 (AMR only), and passive flooding with 6' SLR. • **Transportation**: Segments of Kuhio Highway here are extremely close to the shore and are within both the flood zone and SLR-XA. Waipouli commercial and residential corridor is exposed to flooding and SLR from both sides of Kuhio Highway, which would essentially isolate the area as a peninsula. It is also completely within the high wildfire risk zone. • **Utilities and Infrastructure**: 118 (4%) of OSDS are exposed to flood, 24 (3%) to SLRXA 1.1, 93 (4%) to SLRXA 3.2, and 156 (6%) to passive flooding with 6' SLR.

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Community	Hazard Exposures
Wailua	• **Residents**: The area scores medium-high on the SVI (70-80th percentile). • **Natural and Cultural Resources:** The banks of the Wailua River "lived queens and kings, heroes and heroines, dragons and sharks, and many magical beings whose legends reflect a thousand years of history."[246] Cultural features, and State and National Historic Sites in Wailua are exposed to SLRXA 3.2 and flooding. Wailua Beach and the reservoir there are also vulnerable to sea level rise and erosion. • **Housing and Businesses**: Nounou, also known as Sleeping Giant, is an area of high landslide risk. It abuts the residential neighborhood which is at high wildfire risk. • **Tourism**: The resort area are exposed at high wildfire risk. • **Utilities and Infrastructure**: 37 (6%) OSDS are exposed to flood and 20 (3%) are exposed to passive flooding with 6' of SLR. • **Transportation**: Kūhiō Highway (directly adjacent to the beach) is vulnerable to erosion, flooding, and storms. This is the only access to points east and north, and if the highway or Wailua Bridge were to be lost these communities would be isolated. There is high wildfire risk, flood exposure, and SLR-XA at the bridge over the Wailua River and Beach Park.
Waliua Homesteads	• **Housing and Businesses** The entire town (primarily residential development) is at medium wildfire risk. This includes one affordable housing development with a total of six units. Areas around Kalama and Opaekaʻa Stream are exposed to flood hazard, including areas that contain development. • **Transportation:** Kuamoʻo Road, one of two roads in and out of the neighborhood, is exposed to wildfire risk, landslide risk, and flood hazard where it is adjacent to Wailua River and Opaekaʻa Stream. • **Utilities and Infrastructure**: 88 (6%) OSDS are exposed to flood. None are exposed to SLR impacts.

[246] Kauai Nui Kuapapa. (2014). "Wailua." Accessed May 2022 from https://kauainuikuapapa.com/ahupuaa/wailua

Table 11. Summary of Assets Exposed to Hazard in East Kaua'i

Asset	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	Passive Coastal Flooding (1.1 ft)	High Wave Flooding (1.1 ft)	Coastal Erosion (1.1 ft)	SLRXA-3.2	Passive Coastal Flooding (3.2 ft)	High Wave Flooding (3.2 ft)	Coastal Erosion (3.2 ft)	6 ft SLR Passive Flooding (NOAA)
Point Features												
Critical Facilities	105 (H); 12 (M)	26	14	7	3	4	1	7	4	4	3	21
Buildings	7,642 (H); 941(M)	693	93	69	4	9	25	332	32	239	132	658
Affordable Housing Developments	3 (H), 1 (M)	0	0	0	0	0	0	0	0	0	0	0
OSDS	3711 (H); 1576 (M)	343	87	36	7	5	6	156	28	28	61	249
Bridges	12 (H); 3 (M)	11	1	5	5	3	0	5	5	4	1	8
Bus Stops	28 (H); 1 (M)	6	0	0	0	0	0	4	0	1	2	6
Hotels and Rentals	34 (H)	7	0	1	0	0	0	5	0	5	0	7
Cultural Features[1]	18 (H); 6 (M)	16	6	6	1	2	0	6	1	4	1	8
Fish Ponds	4 (H)	4	0	1	1	0	0	1	1	1	0	1
Linear Features (in miles)												
Roads & Hwys	85.9 (H); 26.7 (M)	9.9	1.5	1	-	-	-	4.6	-	-	-	9.1
Acres												
Coral Reefs[2]	0	828	0	0	-	-	-	929	-	-	-	948
Parks	22 (H); 17 (M)	17	17	7	-	-	-	7	-	-	-	7
Agricultural LU	143 (H); 62 (L)	1	2,349	1	-	-	-	1	-	-	-	1
Hawaiian Homelands	1,274 (H); 77 (M)	191	327	40	-	-	-	96	-	-	-	184

1. *The County does not have a complete spatial dataset of culturally significant resources and sites, and some cultural data points are intended to be representational and not precise. Therefore, the total number of cultural sites exposed to hazards is likely to be underrepresented*
2. *For coral reefs and parks, acres reflect the entire area of a polygon regardless of how much of it is exposed to the hazard. For Hawaiian Homelands, only the acres which are exposed to a composite layer (fire, flood, landslide, the SLRXA-1.1 and -3.2, and passive flooding with 6' SLR) are counted. Hawaiian Homelands in the subarea are Waimea and Kekaha Hawaiian Homelands*

Source: County of Kaua'i, Raimi + Associates

LĪHUʻE

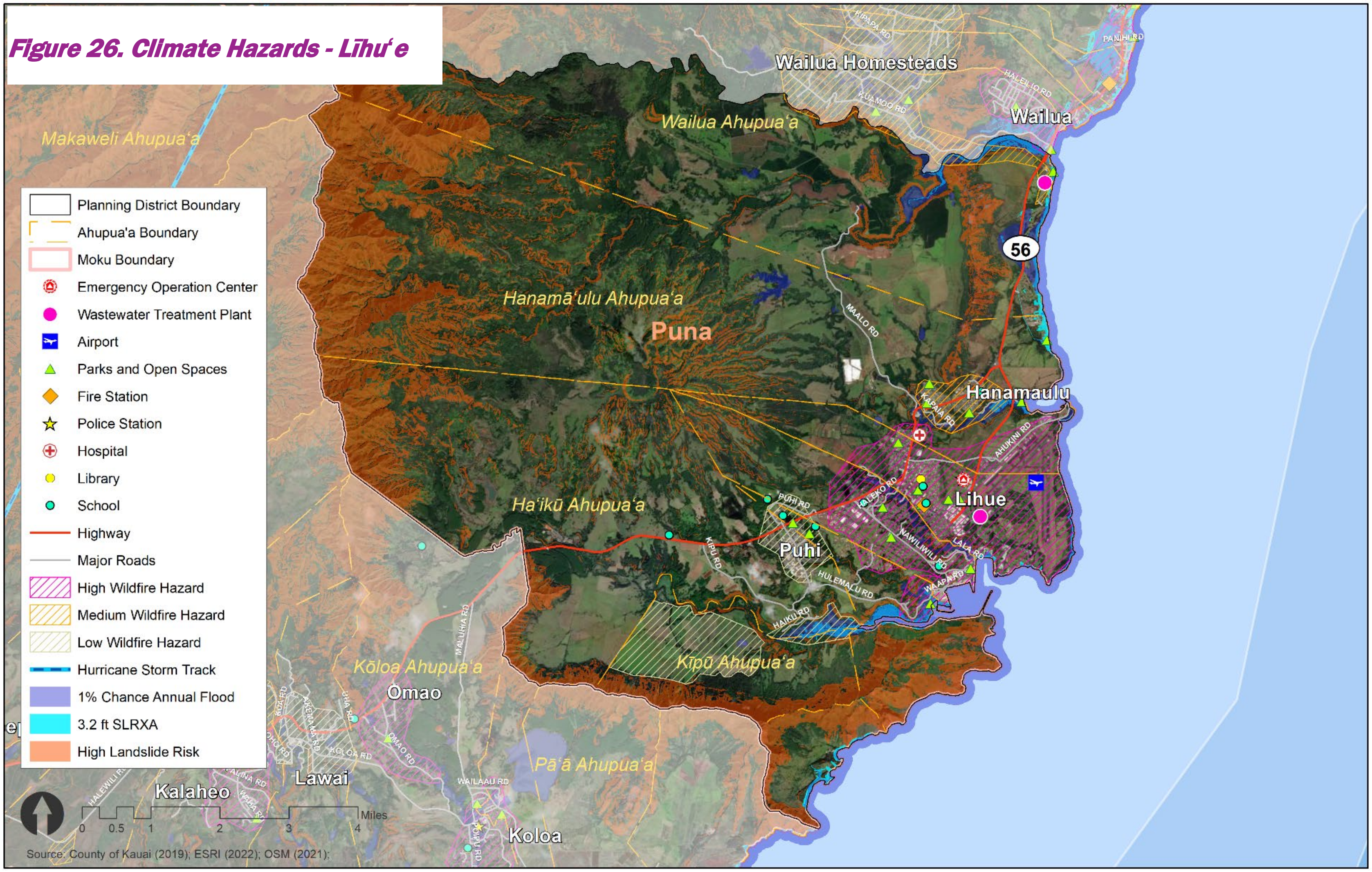

Figure 26. Climate Hazards - Līhuʻe

Table 12. Līhuʻe Hazard Exposures by Census Place

Community	Hazard Exposures
Puhi	• **Residents:** The town has a high SVI score (90th percentile). • **Critical Facilities:** Puhi is only exposed to low wildfire hazard. It covers six critical facilities including the food bank, the KFMN radio tower, Kaua'i Community College, the county park, a well pump, and a fuel station. • **Utilities and Infrastructure:** None of Puhi's OSDS are exposed to flooding or SLR hazards.

Līhuʻe	• **Residents**: Social vulnerability varies within the city. The block group mauka of Kūhiō Highway near the civic center has an SVI score in the 90-100th percentile. On the other hand, block groups containing Ulu Mahi, Ulu Ko, and Niumalu have some of the lowest scores in the county.
	• **Natural and Cultural Resources**: Four cultural features are exposed to flooding, and one of those is also exposed to SLRXA 3.2 and passive flooding with 6' SLR. There are numerous State and National Historic Sites (including historic buildings and Grove Farm) in Līhuʻe which are encompassed by the High Wildfire Risk covering the city.
	• **Housing and Businesses**: The entire town of Līhuʻe, which contains residential, commercial, and civic uses, is at high wildfire risk. Every affordable housing development in the city is exposed to high wildfire hazard. They total 390 units. Some development around Nāwiliwili Stream is exposed to flood, but the area is mostly undeveloped where it runs through Līhuʻe.
	• **Critical Facilities**: Critical facilities exposed to wildfire hazard:
	  ◦ The emergency operations center, fire station, police station, Līhuʻe Airport, and Wilcox Medical Center.
	  ◦ Lihue Wastewater Treatment Plant (Wailua Wastewater Treatment Plant is only exposed to medium).
	  ◦ All the County operations buildings.
	• **Transportation**: Roads within the high wildfire risk area include portions of Kaumuali'i Highway, Kuhio Highway, Ahukini Road, Rice Street, and Nāwiliwili Road.
	• **Utilities and Infrastructure**: 47 (7%) OSDS are exposed to flood. Less than 1% are exposed to any of the SLR hazards.

Nāwiliwili	• **Natural and Cultural Resources:** The Hulēʻia Valley, which includes Alakoko Fishpond and Hulēʻia Wildlife Refuge, is exposed to SLR, flood, and landslide. • **Community Assets:** Nāwiliwili Harbor and Nāwiliwili Small Boat Harbor are exposed to wildfire, flood, SLRXA 1.1 (passive flooding), SLRXA 3.2 (passive flooding) and passive flooding with 6' of SLR. Niumalu Beach Park, and the residences along Hulemalu Road are exposed to SLR and flooding around Puali and Hulēʻia Streams in addition to wildfire.

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Community	Hazard Exposures
Hanamāʻulu	• **Residents**: The block group north of Kūhiō Highway has the highest SVI score on the island, and the block group covering the rest of the town is also high (80-90th percentile). • **Natural and Cultural Resources:** The area around the beach and stream is exposed to SLR and flooding, which is problematic because it has some of the highest bacteria counts on the island. There is one cultural feature exposed to flood, SLRXA 3.2, and passive flooding with 6' SLR. • **Housing and Businesses**: The half of the town that contains residential development (makai of Kapule Highway) is at medium wildfire risk. This includes three affordable housing developments with a total of 258 units. • **Transportation**: The area around the beach and stream is exposed to SLR and flooding; however, the highway bridge is elevated very high. • **Critical Facilities:** Critical facilities exposed to medium wildfire risk in the area are a Time Warner Cable hub and the King Kaumualiʻi Elementary School.

Table 13. Summary of Assets Exposed to Hazard in Līhuʻe

Asset	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	Passive Coastal Flooding (1.1 ft)	High Wave Flooding (1.1 ft)	Coastal Erosion (1.1 ft)	SLRXA-3.2	Passive Coastal Flooding (3.2 ft)	High Wave Flooding (3.2 ft)	Coastal Erosion (3.2 ft)	6 ft SLR Passive Flooding (NOAA)
Point Features												
Critical Facilities	82 (H); 9 (M); 7 (L)	12	2	4	4	1	0	4	4	1	0	10
Buildings	3,291 (H); 114 (M); 1,032 (L)	238	38	8	2	0	0	36	18	2	12	173
Affordable Housing Developments	8 (H); 3 (M)	0	0	0	0	0	0	0	0	0	0	0
Cesspool/OSDS	735 (H); 16 (M); 277 (L)	90	23	3	2	0	0	6	5	5	1	38
Bridges	6 (H)	9	0	2	4	0	0	4	4	2	0	5
Bus Stops	20 (H); 4 (M); 3 (L)	0	0	0	0	0	0	0	0	0	0	0
Hotels and Rentals	7 (H)	1	0	0	0	0	0	0	0	0	0	3
Cultural Features[1]	23 (H); 11 (M); 2 (L)	37	14	5	3	0	2	10	7	2	2	14
Fish Ponds	1 (L)	1	0	0	0	0	0	0	0	0	0	0
Linear Features (in miles)												
Roads & Hwys	48.7 (H); 10.2 M); 11.9 (L)	2.5	1.1	0	-	-	-	0.3	-	-	-	2.2
Acres												
Coral Reefs[2]	0	0	0	0	-	-	-	0	-	-	-	0
Parks	24 (H); 4 (L)	0	0	0	-	-	-	0	-	-	-	0
Agricultural LU	0	3	13,498	2	-	-	-	2	-	-	-	3

1. *The County does not have a complete spatial dataset of culturally significant resources and sites, and some cultural data points are intended to be representational and not precise. Therefore, the total number of cultural sites exposed to hazards is likely to be underrepresented*
2. *For coral reefs and parks, acres reflect the entire area of a polygon regardless of how much of it is exposed to the hazard. For Hawaiian Homelands, only the acres which are exposed to a composite layer (fire, flood, landslide, the SLRXA-1.1 and -3.2, and passive flooding with 6' SLR) are counted. Hawaiian Homelands in the subarea are Waimea and Kekaha Hawaiian Homelands.*

Source: County of Kauaʻi, Raimi + Associates

SOUTH KAUA'I

Figure 27. Climate Hazards - South Kaua'i

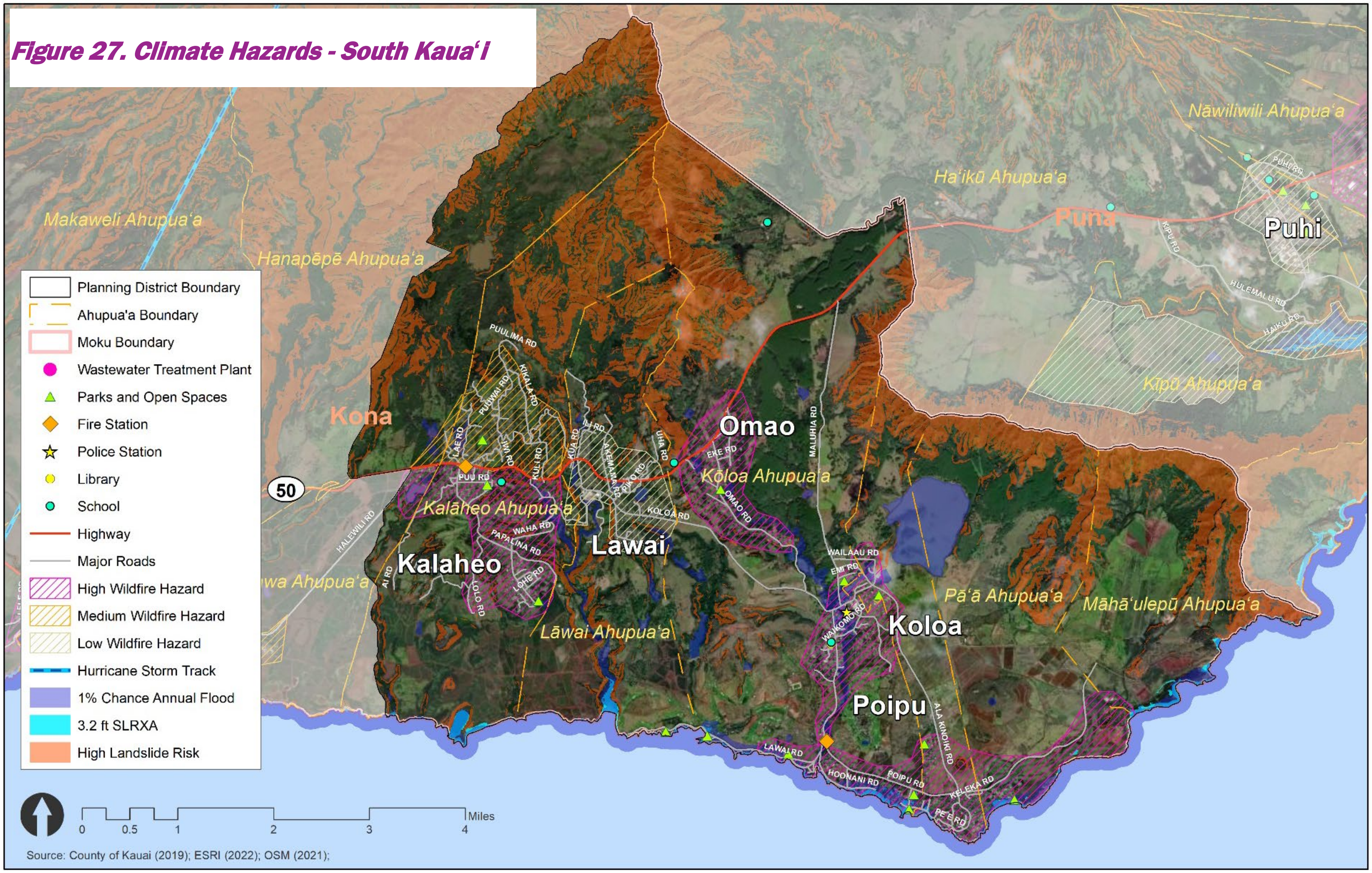

Table 14. South Kauaʻi Hazard Exposures by Census Place

Community	Hazard Exposures
Poʻipū	• **Residents**: This block group has a moderate SVI score (60th percentile). • **Natural and Cultural Resources**: Poʻipū has a very high concentration of cultural features along the coast and extending mauka. 18 cultural features are exposed to flooding, and about half of those are also exposed to SLRXA 1.1, SLRXA 3.2, and passive flooding with 6' SLR. • **Tourism**: All hotels and rentals in the subarea are located in Poʻipū and are exposed to high wildfire hazard. All development (primarily resort and other tourist-focused uses) makai of Poipu Road are exposed to high wildfire hazard. Poipu Beach Park, one of the island's most popular tourist areas, is exposed to SLR and erosion. • **Critical Facilities**: The Kōloa Fire Station and the AMR Medic emergency medical services are both exposed to flood and high wildfire hazard. • **Transportation**: Poʻipū Road is exposed to wildfire hazard and is exposed to flood around the Poipu Roundabout. • **Utilities and Infrastructure**: The Poʻipū Water Reclamation Facility is exposed to high wildfire hazard.78 (15%) OSDS are exposed to flood. Less than 2% are exposed to any of the SLR hazards.
Kukuiʻula	• **Natural and Cultural Resources:** Traditional cultivation area, cultural features and two registered historic sites are exposed to SLRXA 3.2 and flooding. • **Housing and Businesses**: All residences makai are exposed to flooding and SLR. • **Critical Facilities**: Kukuiʻula boat harbor is exposed to 1% chance annual flood, SLRXA-1.1 (passive flooding and high wave flooding), SLRXA-3.2 (passive flooding and high wave flooding), and passive flooding with 6' SLR. Kukuiula Small Boat Harbor is exposed to flood, SLRXA 1.1 and 3.2 (passive flooding and high wave flooding) and passive flooding with 6' SLR. • **Transportation**: Lawaʻi Road from Waikomo Stream to the boat harbor is exposed to flooding.
Kōloa	• **Residents**: Kōloa's SVI score is high (80-90th percentile). • **Natural and Cultural Resources:** The west side of the town is exposed to flood hazard. Some of the exposed area is developed and some is natural, as it is a traditional cultivation area. • **Housing and Businesses**: All development in the town (primarily residential) is exposed to high wildfire hazard and inland flooding. This includes six affordable housing developments with a total of 311 units. • **Critical Facilities**: All seven critical facilities identified by the MHMP in Koloa are exposed to high wildfire hazard (including the elementary school, County park, and neighborhood center). The police station, post office, and bridge over Waialana Stream also exposed to 1% chance annual flood. • **Utilities and Infrastructure**: 85 (19%) OSDS are exposed to flood, but none are exposed to any SLR hazards.

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Community	Hazard Exposures

Lawa'i	• **Residents**: The portion of the town makai of Kaumualiʻi Highway has a high SVI score (80th percentile)
	• **Natural and Cultural Resources:** Lawa'i watershed is exposed to SLR, flooding, and landslide hazard.
	• **Critical Facilities**: Critical facilities exposed to low wildfire hazard:
	  ◦ The bridge over Lawai Stream. Though it is elevated it is surrounded by vegetation.
	  ◦ 13 pieces of water infrastructure (wells, pumps, tanks).
	  ◦ Lawai Post Office
	• **Utilities and Infrastructure**: The Hanini and Huinawai reservoirs are exposed to flood. 16 (2%) cesspools are exposed to flood.

ʻŌmaʻo	• **Housing and Businesses**: All development in the town (primarily residential) is exposed to wildfire hazard. Housing on the east side of ʻŌmaʻo Road is also exposed to flood hazard. • **Critical Facilities**: Critical facilities exposed to high wildfire hazard: three water tanks, one bridge, and the Hale Kupuna Heritage Home extended care facility.
Kalāheo	• **Natural and Cultural Resources:** Nomilo Fishpond and Palama Beach are exposed to flooding and SLR. Traditional cultivation area makai of Kaumualiʻi Highway is exposed to high wildfire risk. • **Housing and Businesses**: The development makai of Kaumualiʻi Highway is exposed to high wildfire risk. This includes two affordable housing developments with a total of 34 units. • **Critical Facilities**: Critical facilities exposed to high wildfire hazard include: the fire station, the neighborhood center the post office, and the elementary school.

Table 15. Summary of Assets Exposed to Hazard in South Kaua'i

Asset	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	Passive Coastal Flooding (1.1 ft)	High Wave Flooding (1.1 ft)	Coastal Erosion (1.1 ft)	SLRXA-3.2	Passive Coastal Flooding (3.2 ft)	High Wave Flooding (3.2 ft)	Coastal Erosion (3.2 ft)	6 ft SLR Passive Flooding (NOAA)
Point Features												
Critical Facilities	27 (H); 5 (M); 16 (L)	12	6	2	2	2	0	2	2	2	0	2
Buildings	3,917 (H) 881 (M); 895 (L)	478	57	7	0	1	0	24	0	9	9	26
Affordable Housing Developments	9 (H)	0	0	0	0	0	0	0	0	0	0	0
OSDS	2,187 (H) 478 (M); 569 (L)	216	38	7	1	6	1	10	1	1	5	8
Bridges	5 (H); 2 (L)	6	0	0	0	0	0	0	0	0	0	0
Bus Stops	14 (H); 3 (L)	1	0	0	0	0	0	0	0	0	0	0
Hotels and Rentals	35 (H)	10	0	0	0	0	0	3	0	1	1	1
Cultural Features[1]	175 (H)	44	22	15	9	14	3	19	10	12	4	18
Fish Ponds	5 (H)	5	0	0	0	0	0	2	1	0	1	4
Linear Features (in miles)												
Roads & Hwys	41.4 (H; 9.7 (M); 9.1 (L)	6.4	0.6	0.3	-	-	-	0.7	-	-	-	0.9
Acres												
Coral Reefs[2]	0	6	0	0	-	-	-	6	-	-	-	6
Parks	7 (H); 21 (M)	7	0	0	-	-	-	0	-	-	-	0
Agricultural LU	2,564 (H) 5 (M); 15 (L)	20	2,517	0	-	-	-	0	-	-	-	0

1. *The County does not have a complete spatial dataset of culturally significant resources and sites, and some cultural data points are intended to be representational and not precise. Therefore, the total number of cultural sites exposed to hazards is likely to be underrepresented*
2. *For coral reefs and parks, acres reflect the entire area of a polygon regardless of how much of it is exposed to the hazard. For Hawaiian Homelands, only the acres which are exposed to a composite layer (fire, flood, landslide, the SLRXA-1.1 and -3.2, and passive flooding with 6' SLR) are counted. Hawaiian Homelands in the subarea are Waimea and Kekaha Hawaiian Homelands.*

Source: County of Kaua'i, Raimi + Associates

WEST KAUA‘I

Figure 28. Climate Hazards - West Kaua‘i

Table 16. West Kaua'i Hazard Exposures by Census Place

Community	Hazard Exposures

Kekaha	• **Residents**: Almost the entire town has a low SVI score (20th percentile), except for the portion directly west of the old sugar mill (90-100th percentile).
	• **Natural and Cultural Resources:** Portions of the Mānā Plain, which stretches from Polihale to Waimea, are exposed to SLRXA 3.2 and flooding.
	• **Housing and Business**: Nearly all development in the town (primarily residential) is exposed to flood and high wildfire hazard. This area contains two affordable housing developments with a total of 114 units.
	• **Critical Facilities**: All 13 critical facilities identified in the MHMP are exposed to high wildfire risk; eight of those are also exposed to 1% chance annual flood. Both bridges are exposed to even more hazards:
	  ◦ The bridge where Kaumuali'i Highway crosses drainage canal 4 (next to Kekaha Beach Park) is exposed to high wildfire hazard, 2050 SLRXA-1.1 (passive and high wave flooding), 2100 SLRXA-3.2 (passive and high wave flooding), and NOAA 6 ft SLR projected coastal flooding.
	  ◦ The bridge where Kaumuali'i Highway crosses drainage canal 3 is exposed to high wildfire hazard, 1% chance annual flooding, and 2100 SLRXA-3.2 (coastal erosion).
	• **Transportation**: Kaumuali'i Highway between Kekaha and PMRF will become increasingly vulnerable to SLR by mid-to-late century given its location along the coast and low-lying position.
	• **Utilities and Infrastructure:** Groundwater inundation is expected to become an increasing concern, especially to onsite disposal systems (OSDS) and underground infrastructure. At 3.2 feet of SLR, areas east of the town will passively flood and groundwater will break the land surface. 504 (54%) OSDS are exposed to flood, 24 (3%) to SLRXA 1.1, 82 (9%) to SLRXA 3.2, and 64 (7%) to passive flooding with 6' SLR. Rising groundwater is expected to render underground infrastructure vulnerable first in the form of wetting with occasional nuisance flooding, then with higher sea levels, permanent inundation impacting cesspools, an electrical substation and underground electrical assets in Kekaha leading to possible power outages. The Kekaha Landfill (the only one on the island) is not directly within hazard exposure areas, but land mauka and makai are exposed to SLR, flooding, and wildfire.

Continued on the next page

Community	Hazard Exposures
PMRF	• **Transportation**: Kaumualiʻi Highway between Kekaha and PMRF will become increasingly vulnerable to SLR by mid-to-late century given its location along the coast and low-lying position. Facilities makai of Kaumualiʻi Highway (including Barking Sands Airport) are at high wildfire risk. Portions of runway at Barking Sands Airport are exposed to flood, SLRXA 1.1 (high wave flooding and erosion), and SLRXA 3.2 (high wave flooding and erosion). • **Natural and Cultural Resources**: Barking Sands Beach is exposed to SLRXA 3.2, particularly coastal erosion and high wave flooding. Iwi kupuna in the sand dunes are currently being affected by coastal erosion and sea level rise. The Mānā Plain is exposed to SLR and flooding.
Waimea	• **Residents**: The town has moderate SVI scores (50-60th percentile). • **Natural and Cultural Resources:** Waimea has a high concentration of cultural features and registered historic sites. 13 cultural features are exposed to flooding, and about a third of those are also exposed to SLR 3.2 (specifically high wave flooding). • **Housing and Business**: All development in the town (residential and commercial development) is at high wildfire risk. 91% of the town's population is exposed per the MHMP. Waimea's coastal neighborhoods will become more and more vulnerable to erosion. While much of the area east of Kikiaola Harbor in front of Waimea Town is accreting, the SLR exposure data shows that by the latter half of the century the beach will become more and more erosional, threatening the first block of homes. The majority of the neighborhood makai of the highway is impacted by the SLRXA 3.2, as well as many businesses within the town core. With passive flooding 6ft of sea level rise, the homes adjacent to the revetment are impacted. • **Critical Facilities**: Both the Waimea Fire Station and Police Substation would be exposed to annual high wave flooding under the 3.2' SLR scenario and to passive flooding under a 6' scenario. • **Transportation**: Downtown Waimea, especially makai of the highway and west of the levee, will become increasingly exposed to SLR by the latter half of the century. Kaumualiʻi Highway and County Roads in Waimea will be increasingly vulnerable to annual high wave flooding or storm surge. Waimea Valley roads are also vulnerable due to problems that arise between the drainage ditch and its exit point through the Waimea River levee. The entire length of Waimea Canyon drive is exposed to landslide risk. The impacts of groundwater inundation on drainage systems will likely be an increasing concern for the town, especially makai of the highway • **Utilities and Infrastructure:** Waimea Wastewater Treatment Plant is exposed to 1% chance annual flood and passive flooding with 6' SLR. 95 (62%) OSDS are exposed to flood, 5 (3%) to SLRXA 1.1, and 18 (12%) to SLRXA 3.2.
Kaumakani	• **Residents**: It also has a very high SVI score (90-100th percentile). • **Housing and Business**: The entire town is exposed to high wildfire risk. This includes three critical facilities: the neighborhood center, post office, and County park.

Continued on the next page

Community	Hazard Exposures
Numila	• **Residents**: Numila is relatively free from hazard exposure. It also has one of the lowest SVI scores in the county.
Hanapēpē-‘Ele‘ele	• **Residents**: SVI scores vary in the area. The block group surrounding the Hanapēpē River has a very high score (90-100th percentile), while the rest has moderate scores (50-60th percentile). • **Natural and Cultural Resources**: Four cultural features in the area are exposed to flood, and three of those are also exposed to passive flooding with 6’ SLR. Traditional cultivation area and two registered historic sites are exposed to flood around the Hanapēpē River. The Salt Pond (the beach and ponds) and the part of the runway of Port Allen Airport are exposed to SLR. • **Housing and Business**: All development in the town (primarily residential development) is at high wildfire risk. 96% of the town’s population is exposed per the MHMP. This includes four of the five affordable housing developments in ‘Ele‘ele (130 units combined). Development around the mouth of the Hanapēpē River and directly adjacent to it is exposed to flood; the area east of the river mouth (the swath that includes homes and businesses along Hanapēpē Road all the way to the ocean) is exposed to 3.2 SLRXA and passive flooding with 6’ SLR • **Agriculture**: Large storms that lead to flooding could wash away the topsoil of small-scale river valley farms. This would destroy crops, increase the amount and distribution of invasive species, and lead to a long recovery time for farmers and families • **Critical Facilities**: The Hanapēpē Fire Station and neighborhood center are exposed to wildfire and flood hazards. and Hanapēpē Health Center is exposed to wildfire. • **Transportation**: Kaumuali‘i Highway Bridge is sensitive to large storm events due to its low-lying location and that it could ‘act as a dam’ during a large rainstorm event by catching heavy debris that is carried down the fast-moving river. SLR could compound the situation and possibly overwhelm the bridge. For air travel, part of the runway of Port Allen Airport is exposed to SLR. • **Utilities and Infrastructure:** ‘Ele‘ele Wastewater Treatment Plant is exposed to high wildfire hazard. 48 (13%) OSDS in Hanapēpē are exposed to flood, 5 (1%) to SLRXA 3.2, and 17 (5%) to passive flooding with 6’ SLR. None of the cesspools in ‘Ele‘ele are exposed to flood or SLR hazards.

Table 17. Summary of Assets Exposed to Hazard in West Kauaʻi

Asset	Fire Risk (H-High, M-Med, L-Low)	FEMA 1% Chance Annual Flood	Landslide	SLRXA-1.1	Passive Coastal Flooding (1.1 ft SLR)	High Wave Flooding (1.1 ft SLR)	Coastal Erosion (1.1 ft SLR)	SLRXA-3.2	Passive Coastal Flooding (3.2 SLR)	High Wave Flooding (3.2 ft SLR)	Coastal Erosion (3.2 ft SLR)	6 ft SLR Passive Flooding (NOAA)
Point Features												
Critical Facilities	85 (H); 1 (M)	45	9	11	6	5	4	18	9	13	6	32
Buildings	5,769 (H); 98(M)	2,224	45	96	0	22	20	456	48	269	142	779
Affordable Housing Developments	8 (H)	3	0	0	0	0	0	0	0	0	0	0
OSDS	1,678 (H)	650	24	29	1	4	6	105	5	5	56	83
Bridges	8 (H)	8	8	0	9	9	3	0	9	9	5	1
Bus Stops	30 (H)	17	0	0	0	0	0	5	0	4	0	5
Hotels and Rentals	8 (H); 90 (L)	7	0	0	0	0	0	0	0	0	0	1
Cultural Features[1]	45 (H)	50	15	18	3	11	6	35	3	26	10	12
Fish Ponds	0	0	0	0	0	0	0	0	0	0	0	0
Linear Features (in miles)												
Roads & Hwys	76.9 (H); 1 (M)	34.2	5.8	4.6	-	-	-	11.1	-	-	-	13.3
Acres												
Coral Reefs[2]	0	678	0	0	-	-	-	893	-	-	-	893
Parks	42 (H)	28	0	0	-	-	-	0	-	-	-	28
Agricultural LU	2,765 (H) 1,486 (M)	884	32,321	0	-	-	-	0	-	-	-	9
Hawaiian Homelands	112 (H)	38	5,380	2	-	-	-	7	-	-	-	0

1. *The County does not have a complete spatial dataset of culturally significant resources and sites, and some cultural data points are intended to be representational and not precise. Therefore, the total number of cultural sites exposed to hazards is likely to be underrepresented*
2. *For coral reefs and parks, acres reflect the entire area of a polygon regardless of how much of it is exposed to the hazard. For Hawaiian Homelands, only the acres which are exposed to a composite layer (fire, flood, landslide, the SLRXA-1.1 and -3.2, and passive flooding with 6' SLR) are counted. Hawaiian Homelands in the subarea are Waimea and Kekaha Hawaiian Homelands.*

Source: County of Kauaʻi, Raimi + Associates

Appendix A: Social Vulnerability Index Methodology

A.1. INTRODUCTION

Understanding how place, demographics, and socioeconomic status contribute to climate change vulnerability may help identify avenues for policy and/or programmatic interventions. This assessment draws on existing literature on the subject to illustrate the geographic distribution of vulnerability in the County of Kauaʻi. It includes a series of variables to include in the assessment and defines a methodology for combining them.

A.2. LITERATURE REVIEW

Overall, there are many social, economic, and environmental factors that influence community and individual vulnerability to climate impacts and their ability to adapt to climate change.

For example, outdoor workers are at greater risk of heat stroke and related illnesses from extreme heat events, lower income residents have fewer resources to repair flood or fire damage and may live in poor housing conditions, and people with limited English language proficiency are less likely to access programs that could help during or after an extreme weather event. Moreover, individual biological factors, such as age or health status, can amplify a population's sensitivity to climate change.

Racism is a key factor influencing climate vulnerability. Communities of color are often burdened with multiple, overlapping factors that cumulatively impact their ability to adapt or respond to climate change. Structural and institutional racism in economic, government, and social systems has resulted and continues to result in the disproportionate distribution of climate burdens and exposures. In addition, a growing body of social epidemiological research has found that repeated experiences of racism become biologically embedded in the body and results in "weathering" or premature physiological deterioration, which in turn increases a population's sensitivity to climate hazards. Given the specific context of Kauaʻi (a majority of the population identifies as a race/ethnicity other than White alone, not Hispanic or Latino) the index considers the percent of Native Hawaiian or Other Pacific Islander identifying people as one of the Race and Ethnicity indicators. This gives weight to the burdens faced by Native Hawaiian communities as a result of colonization and the subsequent effects of structural and institutional racism.

A.2.1. Model Indices

As part of the literature review, three indices that measure social vulnerability and disadvantage were assessed to inform the County of Kaua'i Social Vulnerability Index. All three indices are publicly available and utilize data from several verified sources of information.

CDC Social Vulnerability Index

The Social Vulnerability Index was developed by the Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) to help public health officials and local planners better prepare for and respond to emergency events like hurricanes, disease outbreaks, or exposure to dangerous chemicals. This index includes fifteen indicators from the U.S. American Community Survey, and they are organized into four domains: socioeconomic status, household composition, race/ethnicity/language, and housing/transportation. Overall index scores are calculated on a percentile rank basis by ranking census tracts in comparison to all other census tracts in the state and in the nation. The index is commonly used to identify communities that will most likely need support before, during, or after natural disasters and public health emergencies.

Climate Change and Health Vulnerability Indicators (CCHVIs)

The CCHVIs is a data visualization platform developed by the Climate Change and Health Equity Section at the California Department of Public Health (CDPH). The platform provides data on nineteen climate change and health indicators, which are organized into three domains: environmental exposures, population sensitivity, and adaptive capacity. Although CCHVIs is not itself an index, it provides information to better understand the people and places in California that are more susceptible to adverse health impacts associated with climate change, specifically extreme heat, wildfire, sea level rise, drought, and poor air quality.

CalEnviroScreen

In California, disadvantaged communities are often identified through the California Environmental Health Screening Tool (CalEnviroScreen), which is a statewide index developed by the Office of Environmental Health Hazards Assessment (OEHHA) and California's Environmental Protection Agency (CalEPA). In 2021, OEHHA and CalEPA released version 4.0 of the tool, which includes data on twenty-one indicators at the census tract level that are organized into four categories: pollution exposures, environmental effects, sensitive populations, and socioeconomic factors. CalEnviroScreen's overall index scores are calculated relative to all census tracts in California and are not on an absolute numeric basis. Based on guidance from the Governor's Office of Planning and Research, disadvantaged communities are identified as the top 25% scoring census tracts in comparison to all other census tracts in the state. Overall, CalEnviroScreen helps jurisdictions to identify communities disproportionately burdened by multiple sources of pollution.

A.3. VARIABLES AND METHODOLOGY

Based on the results of the literature review, Raimi + Associates compiled a list of social, economic, and physical/neighborhood indicators commonly associated with climate change vulnerability. This preliminary list was further refined by prioritizing cross-cutting variables that applied to at least two distinct hazards. Variables were then sorted into five distinct categories: demographic characteristics, socioeconomic status, race and ethnicity, housing conditions, and neighborhood conditions. Table A-1 lists the categories, vulnerability factors, geographic scales, and data sources of the datasets included in the analysis.

As shown in Table 1, two units of geography are used for the social vulnerability analysis:

- Census Tract: A statistical subdivision of a county designated by the U.S. Census Bureau. A census tract generally has a population size between 1,200 and 8,000 people, with an optimum size of 4,000 people. Census tracts are often used in demographic analysis because their optimum size allows for community-level data with low margins of error.
- Census Block Group: A small statistical subdivision of county designated by the U.S. Census Bureau. A block group generally has a population size between 600 and 3,000 people. Every census tract has at least one block group, and block groups are uniquely numbered within a census tract.

Table A - 1. Social Vulnerability Characteristics

Category	Indicator	Geographic Scale	Data Source[247]
Household Characteristics	Percent Age 65 or older	Block Group	ACS 15-19, Table B01001
	Percent Age 17 or younger	Block Group	ACS 15-19, Table B01001
	Percent with Any Disability	Census Tract	ACS 15-19, Table B18101
Socioeconomic Status	Percent Age 25 or older with less than a Bachelor's degree	Block Group	ACS 15-19, Table B15003
	Percent of Households with income below $75,000[248]	Block Group	ACS 15-19, Table B19013
	Percent Outdoor workers	Census Tract	ACS 15-19, Table C24050
Race and Ethnicity	Percent Population identifying as Native Hawaiian or Pacific Islander	Block Group	ACS 15-19, Table B03002
	Percent Linguistic Isolation (speak English less than well)	Census Tract	ACS 15-19, Table C16001
Physical Conditions	Percent Renter-Occupied Housing Units	Block Group	ACS 15-19, Table B25032
	Percent Rent-Burdened Households	Block Group	ACS 15-19, Table B25106

[247] ACS 15-19 5-Year Estimates are the most recent data available for the selected variables. Data from the 2020 Decennial Census has not been released by the US Census Bureau as of the writing of this document.
[248] $75,000 is the ALICE Annual Survival Budget in Kauaʻi for a household of two adults and two school age children. This figure differs based on household type (ranging from $30,000 for a single adult household to $90,000 for a household of two adults and two children with childcare). For more information visit https://www.unitedforalice.org/household-budgets-mobile/hawaii

	Percent Pre-1970 Housing	Block Group	ACS 15-19, Table B25034
	Percent Mobile Homes	Block Group	ACS 15-19, Table B25024
	Percent No Vehicle Households	Block Group	ACS 15-19, Table B25044

A.3.1. Index Standardization

All indicators were standardized into z-scores, which maintains the relative difference in scores across census tracts while allowing for calculations across indicators. This data transformation is needed to appropriately compare each variable along a relative range. To perform this normalization, the following equation is used:

$$Z = \frac{(x - \mu)}{(\sigma)}$$

where, Z = standard score

x = observed value

μ = mean of the sample

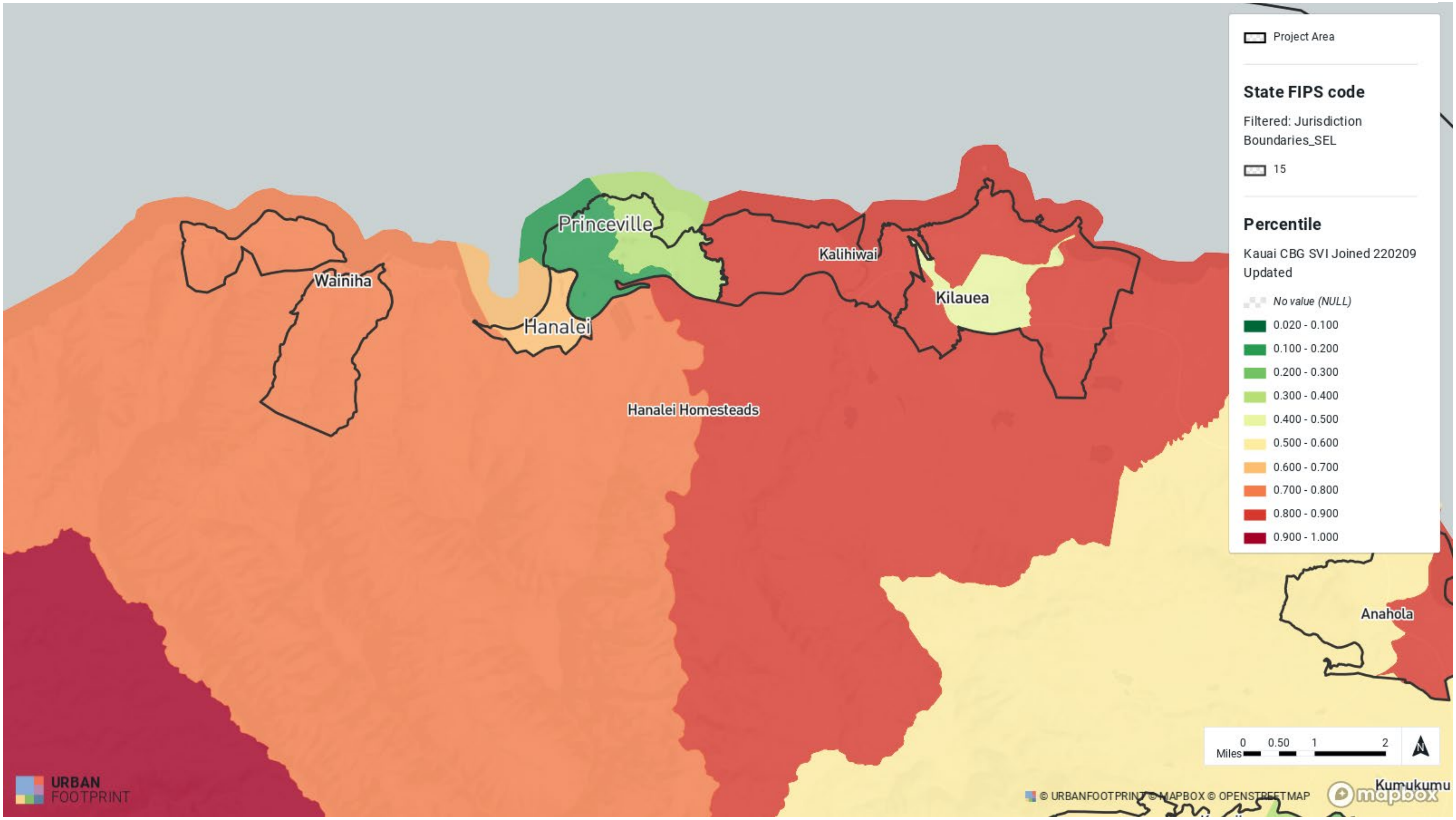
σ = standard deviation of the sample

For each census block group, the z-scores for all indicators are averaged into a total z-score. Four block groups were excluded from the analysis because they were unpopulated. A social vulnerability index (SVI) was then constructed by indexing those total z-scores into a percentile rank format. Values range between 0% and 100% with higher values corresponding to greater vulnerability.

A.3.2. Detailed SVI Maps

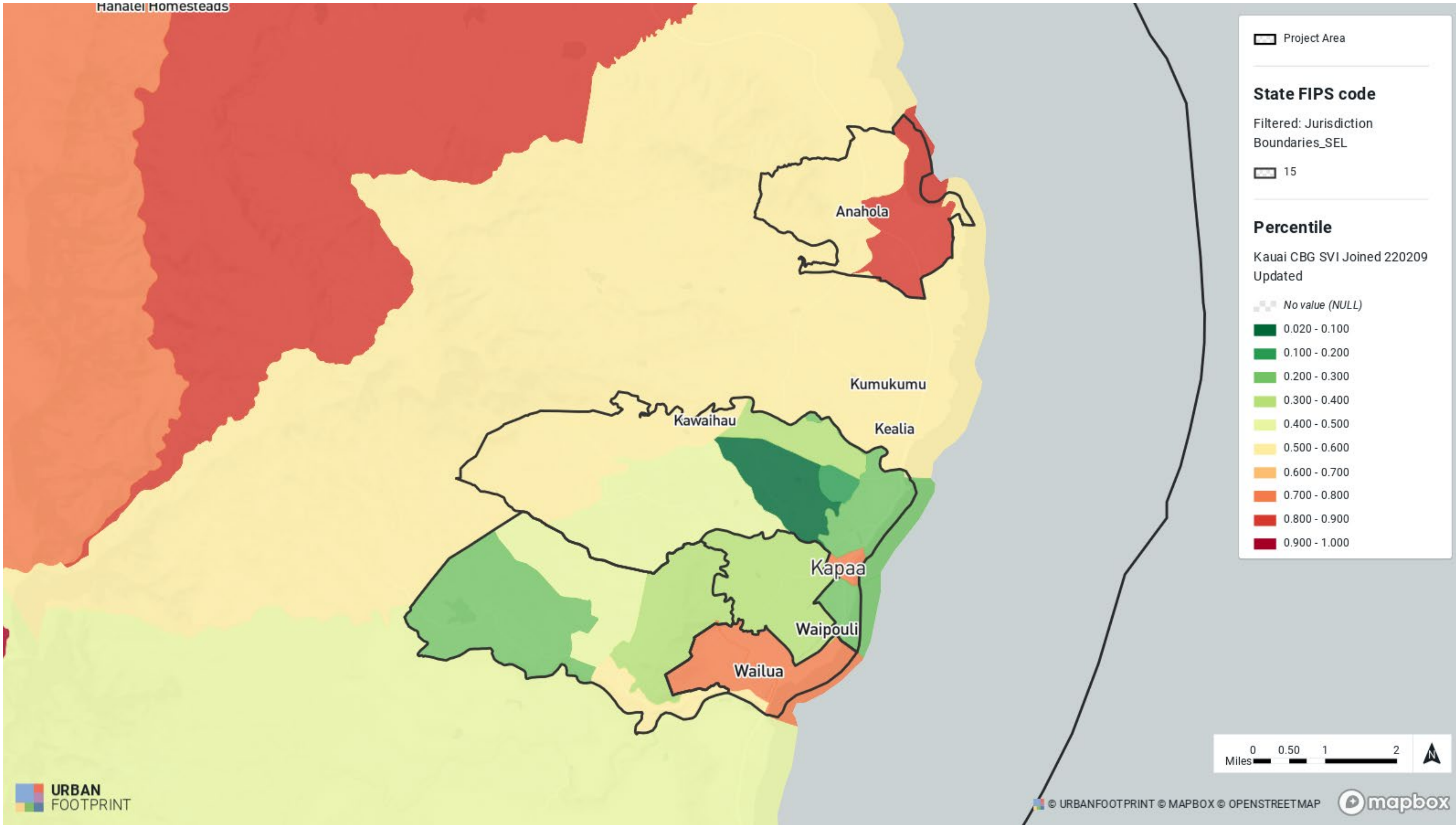
The following maps are details from the overall SVI map that focus primarily on parts of the planning areas with major communities (designated census places).

Figure A - 1. North Shore SVI (Detail)



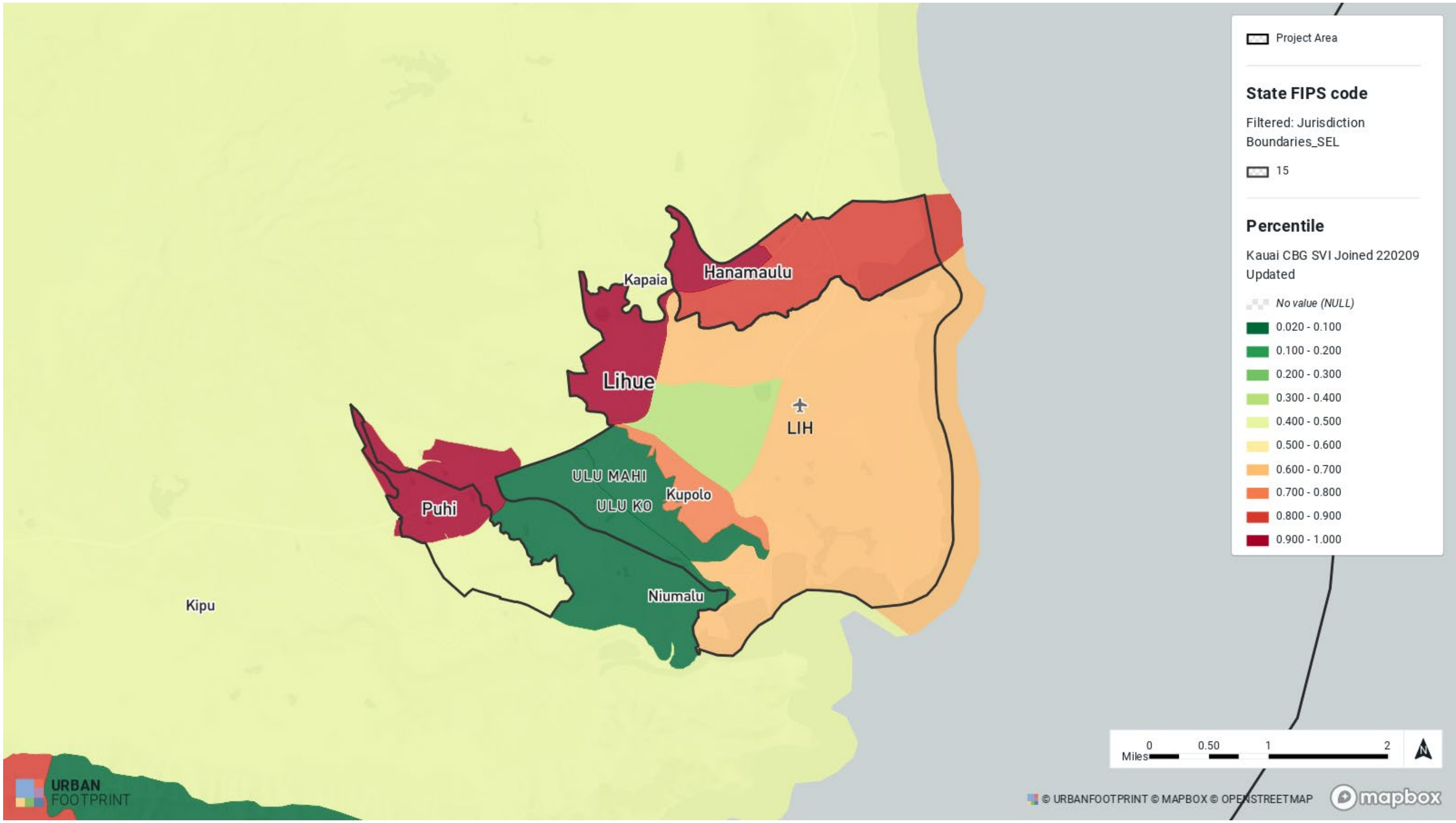
Source: Raimi + Associates, 2022

Figure A - 2. East Kaua'i SVI (Detail)



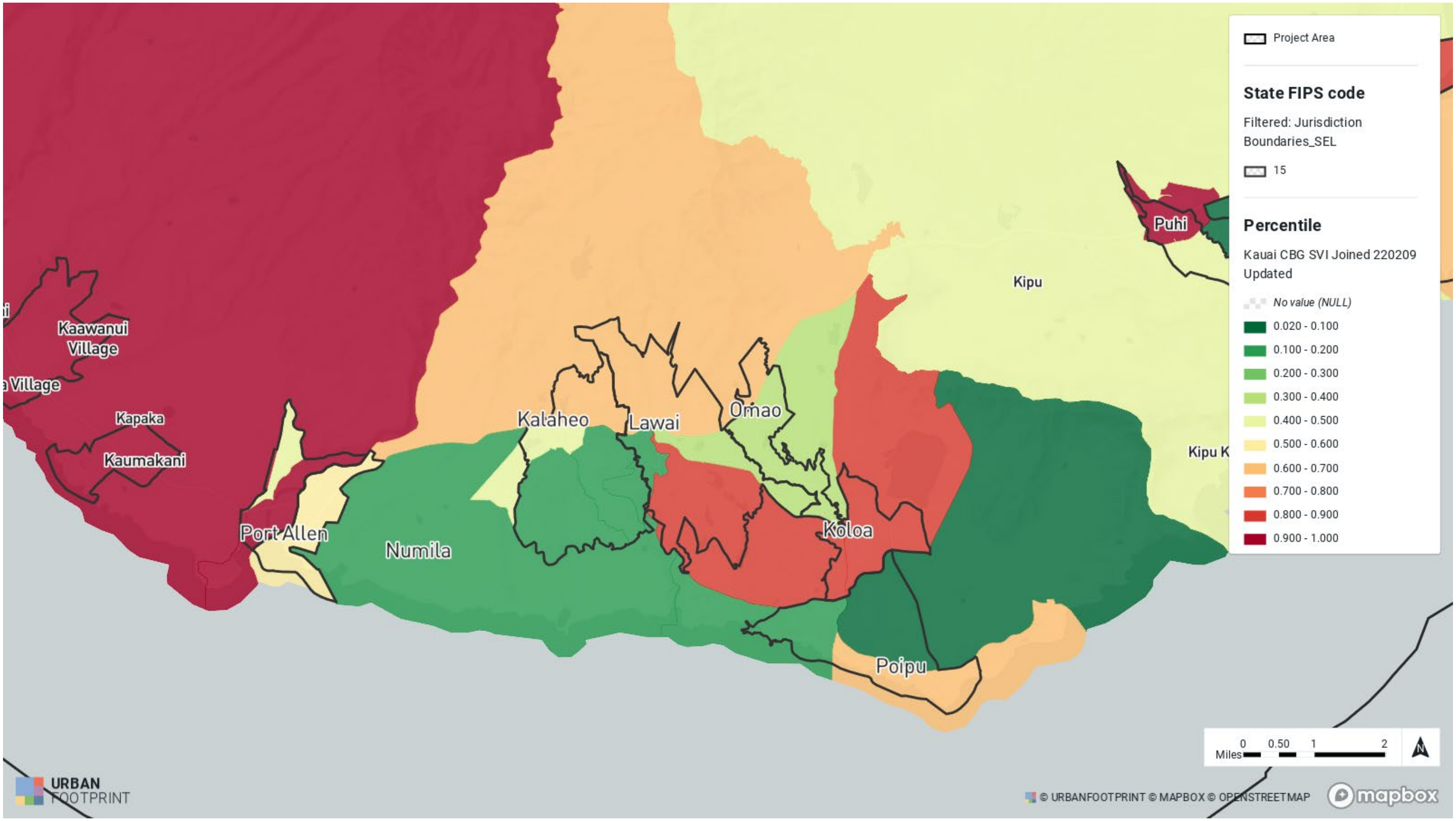
Source: Raimi + Associates, 2022

Figure A - 3. Līhuʻe SVI (Detail)



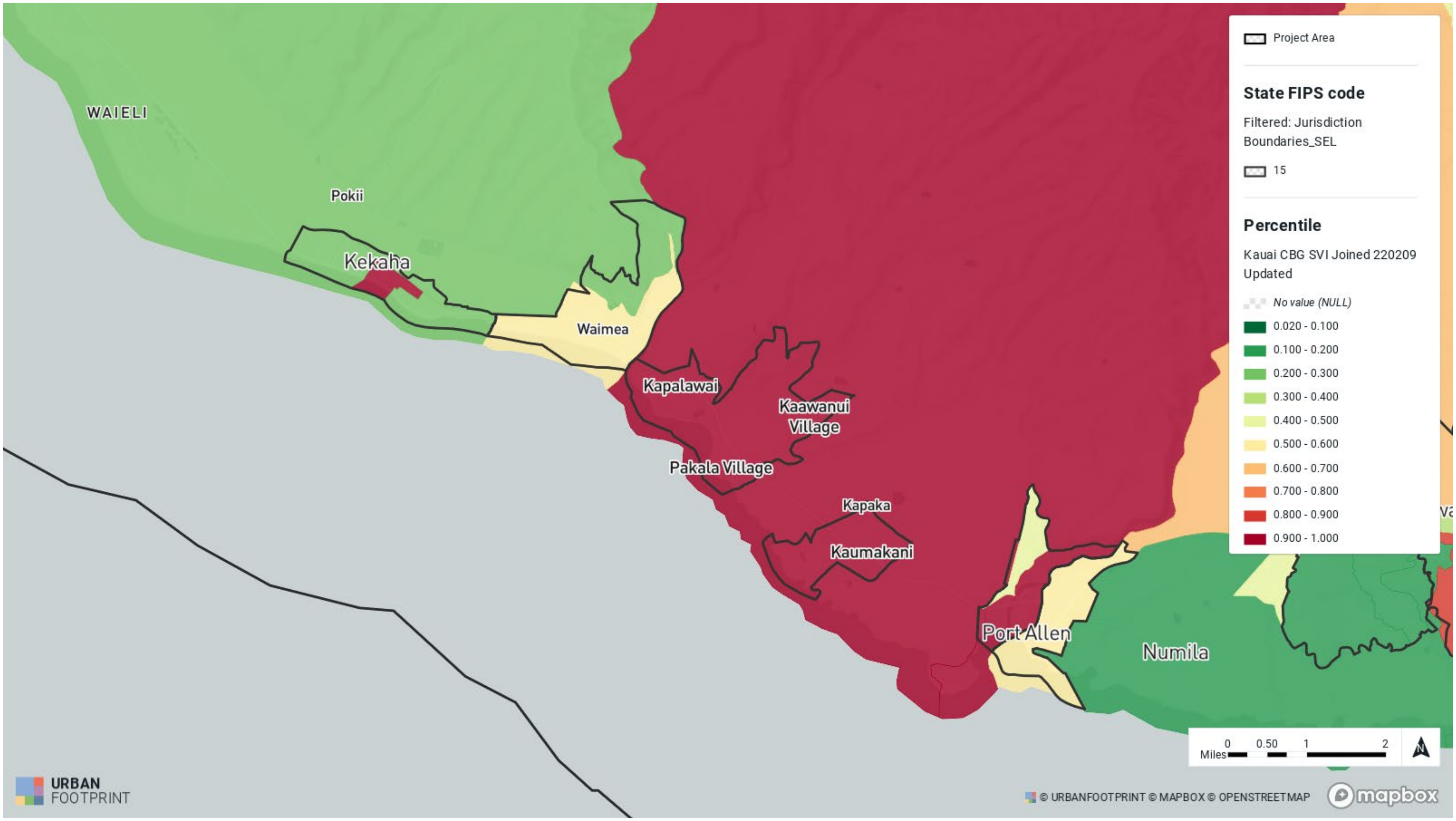
Source: Raimi + Associates, 2022

Figure A - 4. South Kaua'i SVI (Detail)



Source: Raimi + Associates, 2022

Figure A - 5. West Kaua'i SVI (Detail)



Source: Raimi + Associates, 2022

Appendix B: Detailed Hazard Exposures of Select Critical Facilities

The following spreadsheets present raw data showing the hazard exposures of selected critical facilities. The spreadsheets are a product of GIS analysis and the data is presented with minimal formatting. This assessment is meant to be used in concert with other state, county, and region-specific vulnerability and exposure assessments. This includes assessments completed as part of the Hawai‘i Highways Climate Adaptation Action Plan (2021), Kaua‘i Multi-Hazard Mitigation and Resilience Plan (2021), and the West Kaua‘i Community Vulnerability Assessment (2020). Additionally, this assessment is a companion to the online mapping platform maintained on Kauai County's GIS website. The online mapping platform will incorporate new and improved data on hazards and assets when possible.

B.1. METHODOLOGY

The methodology to identify assets exposed to hazards was as follows:

- Asset data used was in point, polygon, and polyline geometries depending on the type. For ease of data processing, some data (such as buildings) were converted from polygon to point (centroid).
- For each type of asset, a series of spatial joins were performed to mark whether it intersected with any hazard geospatial layers
  - If an asset is exposed to a certain hazard the cell is marked with "1," meaning "Yes."
  - If an asset is exposed to wildfire, the cell has the CARW risk rating it is exposed to (Low, Medium, or High). If a facility is not exposed to a certain hazard, it is blank.
  - For assets with polygon and polyline geometries, the analysis also calculated the area or length of the asset exposed to hazard
- Results were exported as spreadsheets. For the Summary of Assets Exposed to Hazard in each planning area (Chapter 3), pivot tables were generated to add up the how many assets in each category were exposed to each hazard in all five planning areas
- In the following tables, the pink highlight simply demarcates the two SLRXA columns for consistency with the tables in Chapter 3. If there is no "1" in the cell the asset is **not** exposed.

TRANSPORTATION Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
NĀWILIWILI SMALL BOAT HARBOR	Boat Harbor	Lihue	Lihue		1		1	1			1	1			1
NĀWILIWILI HARBOR	Boat Harbor	Lihue	Lihue		1		1	1			1	1			1
KIKIAOLA SMALL BOAT HARBOR	Boat Harbor	West Kauai	Waimea		1		1	1			1	1			1
KUKUIULA SMALL BOAT HARBOR	Boat Harbor	South Kauai			1		1	1	1		1	1	1		1
PORT ALLEN SMALL BOAT HARBOR	Boat Harbor	West Kauai	Ele'ele		1		1	1			1	1			1
PORT ALLEN LARGE HARBOR	Boat Harbor	West Kauai	Ele'ele												
BARKING SANDS PMRF AIRPORT (MIL ONLY)	Airport	West Kauai		High	1		1		1	1	1		1	1	
PRINCEVILLE AIRPORT	Airport	North Shore													
PORT ALLEN AIRPORT	Airport	West Kauai			1		1	1	1	1	1	1	1	1	1
Lihu'e Airport Terminal (Gen 2)	Airport	Lihue	Lihue	High											
Lihu'e Airport Terminal (Gen 1)	Airport	Lihue	Lihue	High											
Lihu'e Airport - Maintenance Base Yard	Airport	Lihue	Lihue	High											
Bridge ID 007005600500670	Bridge	North Shore	Wainiha	Low	1						1		1		1
Bridge ID 007005600500396	Bridge	North Shore		Low	1						1		1		1
Bridge ID 007000500002511	Bridge	West Kauai	Kekaha	High	1						1			1	
Bridge ID 007000500300570	Bridge	West Kauai	Kekaha	High			1	1	1		1	1	1		1
Bridge ID 007000560400572	Bridge	Lihue	Wailua	High	1		1	1	1		1	1	1		1
Bridge ID 007056000400161	Bridge	East Kauai	Kapaa	High	1		1	1	1		1	1	1		1
Bridge ID 007000500301039	Bridge	West Kauai			1		1	1	1		1	1	1		1
Bridge ID 007000560400804	Bridge	East Kauai	Kapaa	High	1		1	1			1	1	1		1
Bridge ID 007000500300178	Bridge	West Kauai			1		1				1	1	1		1
Bridge ID 007000500300135	Bridge	West Kauai			1						1	1	1		

TRANSPORTATION

Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
Bridge ID 007005600500427	Bridge	North Shore		Low	1						1	1	1		1
Bridge ID 007000560300985	Bridge	East Kauai	Kapaa		1		1	1	1	1	1	1	1	1	1
Bridge ID 007005600500343	Bridge	North Shore	Hanalei	Low	1		1	1			1	1			1
Bridge ID 007005600500123	Bridge	North Shore			1		1	1			1	1			1
Bridge ID 007005800600062	Bridge	Lihue			1		1	1			1	1			1
Bridge ID 007000500300535	Bridge	West Kauai			1		1	1			1	1			
Bridge ID 007005600500593	Bridge	North Shore		Low	1						1	1			
Bridge ID 007000500302465	Bridge	South Kauai	Omao	High											
Bridge ID 007000500302806	Bridge	Lihue													
Bridge ID 007000500303031	Bridge	Lihue													
Bridge ID 007430200743001	Bridge	East Kauai													
Bridge ID 007005400500077	Bridge	West Kauai													
Bridge ID 007380021138001	Bridge	West Kauai													
Bridge ID 007000500301972	Bridge	West Kauai													
Bridge ID 007000501101343	Bridge	West Kauai													
Bridge ID 007000500301258	Bridge	West Kauai													
Bridge ID 007280500728001	Bridge	South Kauai													
Bridge ID 007000500302613	Bridge	South Kauai													
Bridge ID 007000500302671	Bridge	South Kauai													
Bridge ID 007000500300700	Bridge	South Kauai													
Bridge ID 007000560301844	Bridge	East Kauai		High											
Bridge ID 007000560301581	Bridge	East Kauai		High											
Bridge ID 007280500728003	Bridge	South Kauai	Kōloa	High	1										
Bridge ID 007000510400023	Bridge	Lihue	Lihue	High	1										
Bridge ID 007000500403271	Bridge	Lihue	Lihue	High	1										
Bridge ID 007000560400859	Bridge	East Kauai	Kapaa	High	1										1
Bridge ID 007005600500673	Bridge	North Shore	Wainiha	Low	1										

TRANSPORTATION **Facility Name**	**FacType**	**SubArea**	**CensusPl**	**FireRiskRa**	**1% Flood**	**LandslRisk**	**1.1SLRXA**	**1.1 PassFl**	**1.1 HighWave**	**1.1 Erosion**	**3.2 SLRXA**	**3.2 PassFl**	**3.2 HighWave**	**3.2 Erosion**	**6ftNOAASLR**
Bridge ID 007000560302286	Bridge	North Shore	Kilauea	Low											
Bridge ID 007000560302024	Bridge	North Shore		Low											
Bridge ID 007000500302388	Bridge	South Kauai		High	1										
Bridge ID 007000560400123	Bridge	Lihue	Hanamāulu	Medium											
Bridge ID 007000500301190	Bridge	West Kauai	Pakala Village												
Bridge ID 007000500301157	Bridge	West Kauai	Pakala Village												
Bridge ID 007000560400727	Bridge	East Kauai		High											1
Bridge ID 007000500302249	Bridge	South Kauai	Lawai	Low	1										
Bridge ID 007000560302485	Bridge	North Shore	Kalihiwai	Low	1										
Bridge ID 007000500301631	Bridge	West Kauai	Hanapēpē	High	1										1
Bridge ID 007000560400573	Bridge	East Kauai	Wailua		1										1
Bridge ID 007000560302497	Bridge	North Shore		Low	1										1
Bridge ID 007005600500644	Bridge	North Shore		Low	1										1
Bridge ID 007000500300100	Bridge	Lihue	Lihue	High											
Bridge ID 007000560301489	Bridge	East Kauai	Anahola	High											
Bridge ID 007000560301359	Bridge	East Kauai	Anahola	High											
Bridge ID 007056000400279	Bridge	East Kauai	Kapaa	High											
Bridge ID 007000500301595	Bridge	West Kauai	Hanapēpē	High											
Bridge ID 007000500301668	Bridge	West Kauai	Hanapēpē	High											

1. Bridge ID numbers are unique numbers in the National Bridge Inventory Item and can be viewed at https://geoportal.hawaii.gov/datasets/HiStateGIS::national-bridge-inventory/about

SAFETY & SECURITY

Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
KEKAHA LANDFILL	Landfill	West Kauai													
HANALEI TRANSFER ST	Transfer St	North Shore													
LIHUE REFUSE TRANSFER ST	Transfer St	Lihue	Lihue	High											
KAPAA TRANSFER ST	Transfer St	East Kauai	Kapaa	High											
HANAPĒPĒ TRANSFER ST	Transfer St	West Kauai	Hanapēpē	High											
KALĀHEO FIRE STATION	Fire	South Kauai	Kalāheo	High											
KŌLOA FIRE STATION	Fire	South Kauai	Poipu	High	1										
WAIMEA FIRE STATION	Fire	West Kauai	Waimea	High	1						1		1		1
HANAPĒPĒ FIRE STATION	Fire	West Kauai	Hanapēpē	High	1										1
HANALEI FIRE STATION	Fire	North Shore	Princeville	Low											
KAPAA FIRE STATION	Fire	East Kauai		High											1
LIHUE FIRE STATION	Fire	Lihue	Lihue	High											
Airport ARFF STATION	Fire	Lihue	Lihue	High											
KAIAKEA FIRE STATION	Fire	East Kauai	Kapaa	High											
WAIMEA SUB-STATION	Police	West Kauai	Waimea	High	1						1		1		
KŌLOA SUB-STATION	Police	South Kauai	Kōloa	High	1										
HANALEI POLICE STATION	Police	North Shore	Princeville	Low											
KAPAA SUB-STATION	Police	East Kauai	Kapaa	High	1										1
LIHUE POLICE STATION (POLICE DEPT HQ)	Police	Lihue	Lihue	High											
KAPAA NEIGHBORHOOD CENTER	Neighborhood Center	East Kauai	Kapaa	High	1		1				1			1	
KŌLOA NEIGHBORHOOD CENTER	Neighborhood Center	South Kauai	Kōloa	High											

SAFETY & SECURITY Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
KALĀHEO NEIGHBORHOOD CENTER	Neighborhood Center	South Kauai	Kalāheo	High											
WAIMEA NEIGHBORHOOD CENTER	Neighborhood Center	West Kauai	Waimea	High											
HANAPĒPĒ NEIGHBORHOOD CENTER	Neighborhood Center	West Kauai	Hanapēpē	High	1										
KILAUEA NEIGHBORHOOD CENTER	Neighborhood Center	North Shore	Kilauea	Low											
HANALEI NEIGHBORHOOD CENTER	Neighborhood Center	North Shore	Hanalei	Low	1										
LIHUE NEIGHBORHOOD CENTER	Neighborhood Center	Lihue	Lihue	High											
KEKAHA NEIGHBORHOOD CENTER	Neighborhood Center	West Kauai	Kekaha	High											
KAUMAKANI NEIGHBORHOOD CENTER	Neighborhood Center	West Kauai	Kaumakani	High											
ELE'ELE ELEMENTARY SCHOOL	School	West Kauai	Ele'ele	High											
KŌLOA ELEMENTARY SCHOOL	School	South Kauai	Kōloa	High											
KALĀHEO ELEMENTARY SCHOOL	School	South Kauai	Kalāheo	High											
WAIMEA HIGH SCHOOL	School	West Kauai	Waimea	High											
WAIMEA CANYON MIDDLE SCHOOL	School	West Kauai	Waimea	High											
KAWAIKINI PUBLIC CHARTER SCHOOL	School	Lihue													
ISLAND SCHOOL	School	Lihue													
CHIEFESS KAMAKAHELEI MIDDLE SCHOOL	School	Lihue													
KAPAA MIDDLE SCHOOL	School	East Kauai													
ALAKAI O KAUAI CHARTER SCHOOL	School	South Kauai													
KANAKA PUBLIC CHARTER SCHOOL	School	West Kauai	Kekaha	High	1										
KAUAI CHRISTIAN ACADEMY	School	North Shore	Kilauea	Low											

SAFETY & SECURITY

Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
KILAUEA ELEMENTARY SCHOOL	School	North Shore	Kilauea	Low											
KAUAI COMMUNITY COLLEGE	School	Lihue	Puhi	Low											
KING KAUMUALII ELEMENTARY SCHOOL	School	Lihue	Hanamāulu	Medium											
KAHILI ADVENTIST SCHOOL	School	South Kauai				1									
HANALEI ELEMENTARY SCHOOL	School	North Shore	Hanalei	Low	1										
KEKAHA ELEMENTARY SCHOOL	School	West Kauai	Kekaha	High	1										
KE KULA NIIHAU O KEKAHA	School	West Kauai	Kekaha	High	1										
HAWAII TECHNOLOGY ACADEMY	School	Lihue	Lihue	High											
OLELO CHRISTIAN ACADEMY	School	Lihue	Lihue	High											
WILCOX ELEMENTARY SCHOOL	School	Lihue	Lihue	High											
KAUAI HIGH SCHOOL	School	Lihue	Lihue	High											
KANUIKAPONO CHARTER SCHOOL	School	East Kauai	Anahola	High											
KAPAA HIGH SCHOOL	School	East Kauai	Kapaa	High											
KAPAA ELEMENTARY SCHOOL	School	East Kauai	Kapaa	High											
ST. CATHERINE SCHOOL	School	East Kauai	Kapaa	High											
ST. TERESA SCHOOL	School	West Kauai	Kekaha	High											

HEALTH & MEDICAL

Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
WEST KAUAI MED CTR / KAUAI VETS MEM HOSP	Hospital	West Kauai	Waimea	High											
WILCOX MEDICAL CTR / WILCOX MEM HOSPITAL	Hospital	Lihue	Lihue	High											
MAHELONA MED CTR / S. MAHELONA MEM HOSP	Hospital	East Kauai	Kapaa	High											
AMR Medic 20	Emergency Medical Services	West Kauai	Waimea	High											
AMR Medic 24	Emergency Medical Services	South Kauai	Poipu	High	1										
AMR Medic 22	Emergency Medical Services	North Shore	Kilauea	Low											
AMR Medic 23	Emergency Medical Services	East Kauai	Kapaa	High	1						1				1
AMR Medic 21	Emergency Medical Services	Lihue	Lihue	High											
Makana North Shore Urgent Care	Urgent Care Centers	North Shore	Princeville	Low											
Hale Lea Medicine & Urgent Care	Urgent Care Centers	North Shore	Kilauea	Low											
Urgent Care at Poipu	Urgent Care Centers	South Kauai	Poipu												
Kauai Urgent Care	Urgent Care Centers	Lihue	Lihue	High											

WASTEWATER **Facility Name**	**FacType**	**SubArea**	**CensusPl**	**FireRiskRa**	**1% Flood**	**LandslRisk**	**1.1SLRXA**	**1.1 PassFl**	**1.1 HighWave**	**1.1 Erosion**	**3.2 SLRXA**	**3.2 PassFl**	**3.2 HighWave**	**3.2 Erosion**	**6ftNOAASLR**
Poipu Water Reclamation Facility	WWTP	South Kauai	Poipu	High											
WAILUA WWTP	WWTP	Lihue		Medium											
WAIMEA WWTP	WWTP	West Kauai	Waimea		1										1
LIHUE WWTP	WWTP	Lihue	Lihue	High											
ELE'ELE WWTP	WWTP	West Kauai	Ele'ele	High											
Waimea Id #2 (SPS "C" Captain Cook)	WW Pump St	West Kauai	Waimea	High	1						1		1		1
Wailua Id #14	WW Pump St	West Kauai	Ele'ele	High											
Wailua Id #1	WW Pump St	East Kauai	Wailua	High	1										
Anchor Cove WWPS	WW Pump St	Lihue	Lihue	High	1										
Waimea Id #4	WW Pump St	West Kauai	Waimea	High	1										1
Ele'ele Id #13	WW Pump St	West Kauai	Hanapēpē	High	1										1
Waimea Id #3	WW Pump St	West Kauai	Waimea	High	1										1
Wailua Id #13	WW Pump St	West Kauai	Hanapēpē	High	1										1
Harbor Mall WWPS	WW Pump St	Lihue	Lihue	High	1										1
Waimea Id #1	WW Pump St	West Kauai	Waimea		1										
Wailua Id #7	WW Pump St	Lihue		Medium											
Hanamāulu WWPS	WW Pump St	Lihue	Hanamāulu	Medium											
Waimea Id #5	WW Pump St	West Kauai	Waimea												
Kapaia WWPS	WW Pump St	Lihue	Lihue												
Wailua Id #6	WW Pump St	East Kauai	Kapaa	High											1
Wailua Id #0	WW Pump St	East Kauai	Wailua	High											1
Wailua Id #12	WW Pump St	West Kauai	Hanapēpē	High	1										1
Ele'ele Id #12 (Hanapēpē WWPS)	WW Pump St	West Kauai	Hanapēpē	High	1										1
Wailua Id #8	WW Pump St	Lihue			1										1
Wailua Id #4	WW Pump St	East Kauai	Kapaa	High	1		1		1						1

WASTEWATER Facility Name	FacType	SubArea	CensusPl	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
Sun Condos WWPS	WW Pump St	Lihue	Lihue	High											
Airport WWPS	WW Pump St	Lihue	Lihue	High											
Nāwiliwili WWPS	WW Pump St	Lihue	Lihue	High											
Haleko WWPS	WW Pump St	Lihue	Lihue	High											
Industrial WWPS	WW Pump St	Lihue	Lihue	High											
Wailua Id #0	WW Pump St	East Kauai	Wailua	High											
Wailua Id #19	WW Pump St	East Kauai	Wailua	High											
Wailua Id #3 (Wailua SPS #6 (Arzadon))	WW Pump St	East Kauai	Kapaa	High											
Ele‘ele Id #14	WW Pump St	West Kauai	Ele‘ele	High											

WATER *note: wells that were not exposed to any of the hazards were omitted **Facility Name**	**FacType**	**SubArea**	**CensusPlac**	**FireRiskRa**	**1% Flood**	**LandslRisk**	**1.1SLRXA**	**1.1 PassFl**	**1.1 HighWave**	**1.1 Erosion**	**3.2 SLRXA**	**3.2 PassFl**	**3.2 HighWave**	**3.2 Erosion**	**6ftNOAASLR**
SUNKISS SHRIMP (5844-06)	Well	West Kauai		High	1		1		1	1	1		1	1	
KEKAHA-SUNKISS (5844-01)	Well	West Kauai		High	1		1			1	1		1	1	
PAKALA (5639-01)	Well	West Kauai	Pakala Village		1		1				1		1	1	1
HANALEI FISHPOND (1229-01)	Well	North Shore	Hanalei	Low	1						1		1		1
HANALEI FISHPOND (1229-02)	Well	North Shore	Hanalei	Low	1						1		1		1
MOLOAA-KAAUMOANA (1120-12)	Well	East Kauai		High	1		1				1			1	
MOLOAA-YOSHIOKA (1120-05)	Well	East Kauai		High	1		1		1		1	1	1		1
SAKI MANA KS16 (0345-02)	Well	West Kauai									1	1			1
NONOU 9-1C (0321-01)	Well	East Kauai	Wailua	High											
WAILUA (0320-02)	Well	East Kauai	Wailua	High											
KALĀHEO (5531-01)	Well	South Kauai	Kalāheo	High											
WAIMEA B (5840-02)	Well	West Kauai	Waimea	High											
WAIMEA (5740-01)	Well	West Kauai	Waimea	High											
WAIMEA A (5840-01)	Well	West Kauai	Waimea	High											
HI-BRED #2 (5844-03)	Well	West Kauai		High											
HI-BRED #3 (5844-04)	Well	West Kauai		High											
PORT ALLEN NO. 4 (5435-05)	Well	West Kauai		High											
HI-BRED #1 (5844-02)	Well	West Kauai		High											
BARKING SANDS 1 (0046-01)	Well	West Kauai		High											
PAPAA BAY RANCH (1019-08)	Well	East Kauai		High											
MOLOAA BAY VIEW (1120-23)	Well	East Kauai		High											
MONTGOMERY (1120-24)	Well	East Kauai		High											
MOLAA-SPARKS 1 (1120-11)	Well	East Kauai		High											
MOLOAA-SPARKS 2 (1120-13)	Well	East Kauai		High											
ALIOMANU (1019-04)	Well	East Kauai		High											

Facility Name	FacType	SubArea	CensusPlac	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
MOLOAA TUNNEL (1120-01)	Well	East Kauai		High											
KAPAA HMSTDS 2 (0622-02)	Well	East Kauai		High											
PAPAA RANCH (1019-03)	Well	East Kauai		High											
GARLINGHOUSE OBS (5823-03)	Well	Lihue		High											
POIPU-HYATT (5226-01)	Well	South Kauai	Poipu	High											
MOLOAA-MAE (1120-09)	Well	East Kauai		High	1										
KEALIA 6 (0618-06)	Well	East Kauai		High	1										
KEALIA 5 (0618-07)	Well	East Kauai		High	1										
KEALIA 3 (0618-04)	Well	East Kauai		High	1										
KEALIA 7 (0618-05)	Well	East Kauai		High	1										
KEALIA 1 (0618-02)	Well	East Kauai		High	1										
KEALIA 4 (0618-03)	Well	East Kauai		High	1										
POIPU (5227-01)	Well	South Kauai	Poipu	High	1										
KEALIA 2 (0618-01)	Well	East Kauai		High	1										
KEKEHA K59 (5842-01)	Well	West Kauai	Kekaha	High	1										
FERN GROTTO 2 (0221-02)	Well	Lihue			1										
KALIHIWAI TUNNEL (1225-01)	Well	North Shore	Kalihiwai	Low		1									
LAWAI CANNERY (5530-01)	Well	South Kauai	Lawai		1										
KUKUIULA-A & B (5428-01)	Well	South Kauai	Omao		1										
HANAPEPE PUMP 1 (5534-02)	Well	West Kauai	Eleele		1										
KA LAE MANA (1120-28)	Well	East Kauai		High	1										1
MOLOAA-MATTSON (1120-07)	Well	East Kauai		High	1										1
SAKI MANA KS18 (0346-02)	Well	West Kauai													1
MOLOAA-LAWHEAD (1120-03)	Well	East Kauai		High	1										1
MANA FIELD 238 (0146-02)	Well	West Kauai													1
SAKI MANA KS15 (0345-01)	Well	West Kauai													1
CAMP 3 KS14 (0145-03)	Well	West Kauai													1

Facility Name	FacType	SubArea	CensusPlac	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
MANA FIELD 235 (0146-01)	Well	West Kauai													1
KAUNELEWA KS7 (0044-13)	Well	West Kauai													1
KAUNALEWA KS8 (0044-14)	Well	West Kauai													1
LAGOON SUPPLY (0020-02)	Well	Lihue													1
KAUNALEWA KS10 (0044-11)	Well	West Kauai													1
HI-BRED #4 (5844-05)	Well	West Kauai			1										
HANALEI (1329-01)	Well	North Shore	Princeville	Low											
ECDC EFFL T H (1329-02)	Well	North Shore	Princeville	Low											
KILAUEA-KPGI III (1225-03)	Well	North Shore	Kilauea	Low											
HANALEI (1123-01)	Well	North Shore	Kilauea	Low											
HERMITAGE (1123-02)	Well	North Shore	Kilauea	Low											
EARHART (1325-03)	Well	North Shore	Kalihiwai	Low											
KALIHIWAI (1325-01)	Well	North Shore	Kalihiwai	Low											
EARHART (1325-02)	Well	North Shore	Kalihiwai	Low											
WAINIHA 1 (1232-01)	Well	North Shore	Wainiha	Low		1									
WAINIHA 2 (1232-02)	Well	North Shore	Wainiha	Low		1									
KIPU (5625-01)	Well	Lihue		Low											
HAENA (1333-01)	Well	North Shore		Low											
LAWAI NO. 2 (5530-04)	Well	South Kauai	Lawai	Low											
LAWAI A (5529-03)	Well	South Kauai	Lawai	Low											
LAWAI 1 (5530-03)	Well	South Kauai	Lawai	Low											
HUINAWAI RESVR (5529-01)	Well	South Kauai	Lawai	Low											
KALAWAI T H 5 (5529-02)	Well	South Kauai	Lawai	Low											
MOLOAA-ALTEMUS (1120-04)	Well	East Kauai		High	1										1
SAKI MANA KS17 (0345-03)	Well	West Kauai													1
KALEPA RIDGE (5921-01)	Well	Lihue		Medium											
WAILUA HMSTD 1 (0421-01)	Well	East Kauai	Wailua Homesteads	Medium											

Facility Name	FacType	SubArea	CensusPlac	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
WAILUA HMSTD B (0421-02)	Well	East Kauai	Wailua Homesteads	Medium											
WAILUA-SMITH (0323-01)	Well	East Kauai	Wailua Homesteads	Medium											
KILAUEA-KPGI (1225-02)	Well	North Shore	Kilauea												
KŌLOA B (5427-02)	Well	South Kauai				1									
KŌLOA E (5427-03)	Well	South Kauai				1									
KŌLOA A (5427-01)	Well	South Kauai				1									
HULUHULUNUI SHFT (5842-03)	Well	West Kauai				1									
HANAPEPE TOWN (5534-03)	Well	West Kauai				1									
MAHINAULI SHAFT (5638-01)	Well	West Kauai				1									
KAWAIKOI STR DH6 (0836-02)	Well	West Kauai				1									
MOLOAA-ANDERSON (1120-20)	Well	East Kauai				1									
MOLOAA RANCH 1 (1120-30)	Well	East Kauai				1									
ALIOMANU (1019-02)	Well	East Kauai				1									
MOLOAA 2 (1020-03)	Well	East Kauai				1									
KALIHIWAI (1327-02)	Well	North Shore	Kalihiwai			1									
FISCHER (1326-02)	Well	North Shore	Kalihiwai			1									
ANINI TUNNEL (1327-01)	Well	North Shore	Kalihiwai			1									
KAUNALEWA KS11 (0044-12)	Well	West Kauai													1
MAHELONA HOSP (0518-04)	Well	East Kauai	Kapaa	High		1									
MAHELONA HOSP (0518-05)	Well	East Kauai	Kapaa	High		1									
MAHELONA HOSP (0518-03)	Well	East Kauai	Kapaa	High		1									
MOLOAA-DONNA (1120-08)	Well	East Kauai		High	1										1
LAWAI PUMP 6 SH (5330-01)	Well	South Kauai			1										
HOG FARM (0045-02)	Well	West Kauai			1										1
NONOU 9-1B (0320-03)	Well	East Kauai	Wailua	High		1									
HANAPEPE PUMP 2 (5534-04)	Well	West Kauai	Eleele	High		1									
NONOU 9-1A (0320-01)	Well	East Kauai	Wailua	High		1									

Facility Name	FacType	SubArea	CensusPlac	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
ANDERTON (0919-04)	Well	East Kauai	Anahola	High											
ALIOMANU (0919-01)	Well	East Kauai	Anahola	High											
ANAHOLA (0919-02)	Well	East Kauai	Anahola	High											
AINA ANAHOLA (0818-04)	Well	East Kauai	Anahola	High											
ALIOMANU (0918-01)	Well	East Kauai	Anahola	High											
ANAHOLA 2 (0818-02)	Well	East Kauai	Anahola	High											
ANAHOLA 3 (0818-03)	Well	East Kauai	Anahola	High											
ANAHOLA 1 (0818-01)	Well	East Kauai	Anahola	High											
LIHUE GRAM SCH (5822-02)	Well	Lihue	Lihue	High											
WESTIN KAUAI #5 (5821-06)	Well	Lihue	Lihue	High											
SUGAR MILL (5822-01)	Well	Lihue	Lihue	High											
WESTIN KAUAI #2 (5821-04)	Well	Lihue	Lihue	High											
WESTIN KAUAI #4 (5821-05)	Well	Lihue	Lihue	High											
KAUAI INN TANK (5821-02)	Well	Lihue	Lihue	High											
WESTIN KAUAI #1 (5821-03)	Well	Lihue	Lihue	High											
WESTIN KAUAI #3 (5820-01)	Well	Lihue	Lihue	High											
LIHUE STP (5821-01)	Well	Lihue	Lihue	High											
WESTIN KAUAI (5721-01)	Well	Lihue	Lihue	High											
MAKALEHA TH (0623-03)	Well	East Kauai	Kapaa	High											
KAPAA HMSTDS 1 (0623-04)	Well	East Kauai	Kapaa	High											
KAPAA CANNERY (0620-01)	Well	East Kauai	Kapaa	High											
AKULIKULI TUN (0622-01)	Well	East Kauai	Kapaa	High											
MAHELONA HOSP (0518-02)	Well	East Kauai	Kapaa	High											
KAPAA (0519-01)	Well	East Kauai	Kapaa	High											
KAPAA CANNERY (0419-01)	Well	East Kauai	Kapaa	High											
MAHELONA HOSP (0518-01)	Well	East Kauai	Kapaa	High											
PORT ALLEN NO. 3 (5435-03)	Well	West Kauai	Eleele	High											

Facility Name	FacType	SubArea	CensusPlac	FireRiskRa	1% Flood	LandslRisk	1.1SLRXA	1.1 PassFl	1.1 HighWave	1.1 Erosion	3.2 SLRXA	3.2 PassFl	3.2 HighWave	3.2 Erosion	6ftNOAASLR
HANAPEPE (5435-04)	Well	West Kauai	Eleele	High											
PORT ALLEN NO. 1 (5435-01)	Well	West Kauai	Eleele	High											
PORT ALLEN NO. 2 (5435-02)	Well	West Kauai	Eleele	High											