Tsunami

Tsunamis are a single wave or a series of waves that are caused by earthquakes, landslides, or other disturbances in or near large bodies of water like seas and oceans. Tsunami waves can travel at hundreds of miles per hour and create waves as tall as 100 feet when they reach shore. Statistics below are based on the Great Aleutian Tsunami scenario.

CHANGES SINCE 2018

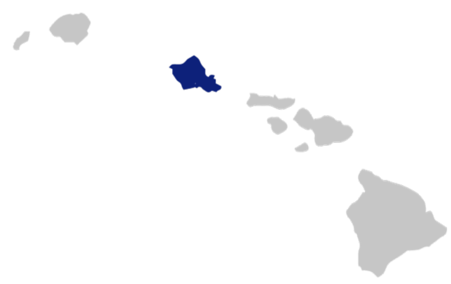
+0

Declared Disasters

+9

Tsunami Events

COUNTIES MOST VULNERABLE



SOCIALLY VULNERABLE POPULATION

2.8%

Of Total Population

37,701

Persons

HAZARD RANKING

COMMUNITY LIFELINES

386

Total

Food, Water, Shelter

Greatest

CLIMATE PROJECTIONS

Higher sea levels will exacerbate the extent of coastal inundation from a tsunami.

Tsunami activity stimulated by potentially increased earthquakes may occur

1,204

State Buildings

SQUARE MILES

42

Environmental Resources

4

Hawaiian Home Lands

20.5

Cultural Resources

146

Miles of State Road

CONTENTS

TABLES

FIGURES

SECTION 4. RISK ASSESSMENT

4.13 TSUNAMI

2023 SHMP Update Changes

- Tsunami events that occurred in Hawai'i from January 1, 2018, through December 31, 2022, were researched for this 2023 SHMP Update.
- New and updated figures from federal and state agencies were incorporated.
- The School of Ocean & Earth Science & Technology (SOEST) and American Society of Civil Engineers (ASCE) inundation areas were added to assess exposure and vulnerability.
- This section now includes a discussion of how the tsunami hazard impacts socially vulnerable populations and community lifelines.
- In Environmental Resources, reefs (both artificial and coral) were analyzed in their own category.
- Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) were added to the vulnerability assessment.

4.13.1 HAZARD PROFILE

HAZARD DESCRIPTION

Tsunami Terms Defined

Distant-Source Tsunami – Originating from a faraway source that may arrive in more than three hours

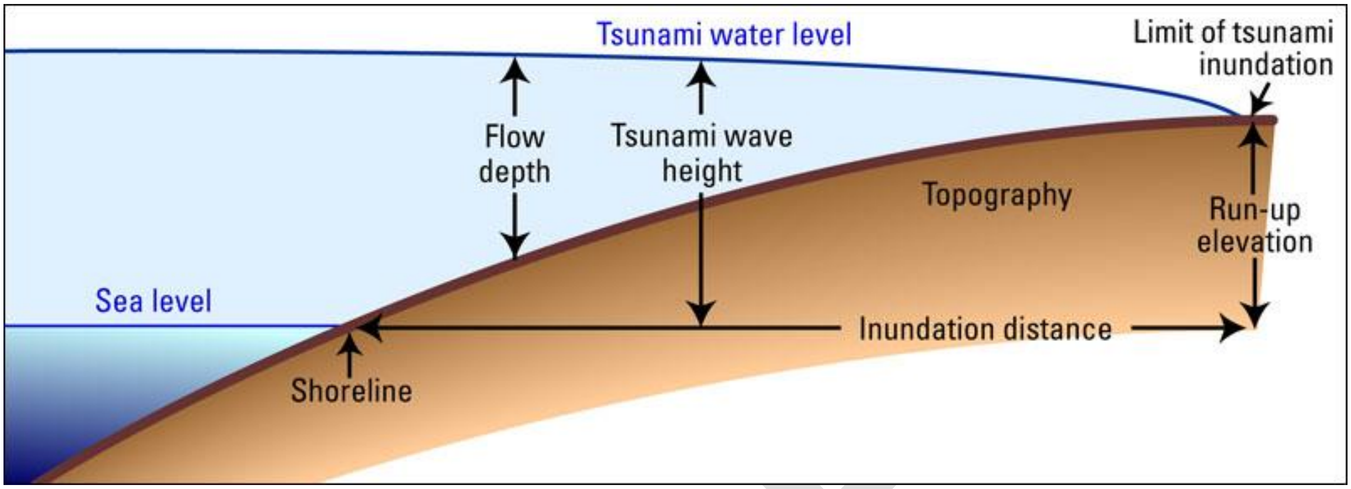
Inundation – The limit of flooding, measured horizontally from the shoreline

Local-Source Tsunami – Originating nearby that may arrive in less than one hour

Run-up – The maximum elevation water reaches onshore, measured from sea level

Tsunamis are a series of enormous waves created by an underwater disturbance such as an earthquake, landslide, volcanic eruption, or meteorite impact. The most common cause is earthquakes (Pacific Tsunami Museum 2022). A tsunami can move hundreds of miles per hour in the open ocean and smash into land with waves as high as 100 feet or more. From the area where the tsunami originates, waves travel outward in all directions. Once the wave approaches the shoreline, it builds in height. The topography of the ocean floor will influence the size of the wave. Figure 4.13-1 illustrates the makeup of a tsunami and associated terminology.

Figure 4.13-1. Illustration of Tsunami Terminology



Source: (U.S. Geological Survey n.d.)

Areas at greatest risk are those less than 25 feet above sea level and within a mile of the shoreline. The most common cause of death associated with tsunamis is drowning. Other hazards associated with tsunamis include flooding, contamination of drinking water, and fires from gas lines or ruptured tanks (International Tsunami Information Center 2023).

Earthquakes generate tsunamis when the sea floor abruptly deforms and displaces the overlying water from its equilibrium position. Waves are formed as the displaced water mass, acting under the influence of gravity, attempts to regain its equilibrium.

The main factor that determines the initial size of a tsunami is the amount of vertical sea floor deformation resulting from subduction zone earthquakes. The earthquake's magnitude, depth, fault characteristics, and coincident slumping of sediments or secondary faulting control the size of the tsunami (National Tsunami Warning Center n.d.). Refer to Section 4.5 (Earthquake) for details on the earthquake hazard.

Tsunamis are characterized as shallow-water waves; the ratio between the water depth and its wave length gets very small. Shallow-water waves are different from wind-generated surf waves. Wind-generated waves usually have a period (time between two successional waves) of 5 to 20 seconds and a wavelength (distance between two successional waves) of about 300 to 600 feet. A tsunami wave can have a period in the range of five minutes to two hours and an open ocean wavelength in excess of 300 miles. It is because of their long wavelengths that tsunamis behave as shallow-water waves. From the area where the tsunami originates, waves travel outward in all directions. Once the wave approaches the shore, it builds height (National Tsunami Warning Center n.d.).

When a tsunami finally reaches the shore, it typically appears as a rapidly rising or falling tide, or as a change in sea level marked by a series of breaking waves. Tsunamis generally appear as an advancing tide without a developed wave face and produce rapid flooding of low-lying coastal areas. Reefs, bays, entrances to rivers, undersea features and the slope of the beach all help to modify the tsunami as it approaches the shore. Because the long-period wave can bend around obstacles, the tsunami can enter bays and gulfs having the most intricate shapes. Unlike storm waves, tsunami waves may be very large in coastal bays, actually experiencing amplification in long funnel-shaped bays. Shorelines protected by reefs typically do not sustain extensive damage from tsunamis as the reefs reflect the wave energy. Low coral islands may experience reduced runup as the tsunami waves may reflect off the steep slopes around them.

LOCATION

All of the Hawaiian Islands can be impacted by tsunami events triggered by local sources or generated along the Pacific Ring of Fire surrounding the state (International Tsunami Information Center 2023). Tsunamis are a threat to life and property for all those living along or near the coastline. They can strike anywhere along the coastline of the State of Hawaiʻi. At sea level on the coast, there is no safe place during a tsunami. On low-lying shorelines, such as in the river and stream valleys that characterize so much of Hawaiʻi, a tsunami may occur as a rapidly growing high tide that rises over several minutes and inundates low coastal regions. The return of these flood waters to the sea causes much damage. At headlands, the refractive focusing of the wave crest leads to energy concentration and high-magnitude runup.

A worst-case scenario for the state is a magnitude 9+ earthquake in the eastern Aleutian Islands. The tsunami from such an earthquake would produce extensive flooding of lowlands throughout the entire State of Hawaiʻi. This extreme tsunami was modeled to understand potential impacts on the state and is called the Great Aleutian Tsunami (GAT). The expected recurrence interval for a GAT is 1,500 years.

The GAT as well as SOEST and ASCE inundation data were provided by the Pacific Disaster Center (PDC) for analysis in the 2023 SHMP Update. **Error! Reference source not found.** shows the inundation areas in square miles and the percent of the total area by county. In general, the inundation areas are larger than the coastal flood inundation area depicted on FEMA FIRMs (discussed in Section 4.6 Flood). The City and County of Honolulu has the largest area that may be inundated (almost 77 square miles), followed by the County of Hawaiʻi.

Table 4.13-1. GAT, SOEST, and ASCE Inundation Areas by County

	Area (in square miles)						
County	Total Area	GAT Hazard Area	GAT Hazard Area as Percent of Total Area	SOEST Hazard Area	SOEST Hazard Area as Percent of Total Area	ASCE Hazard Area	ASCE Hazard Area as Percent of Total Area
County of Kauaʻi	624.29	28.75	4.61%	21.04	3.37%	31.78	5.09%
City and County of Honolulu	598.57	55.18	9.22%	20.37	3.40%	76.67	12.81%
County of Maui	1,176.28	16.63	1.41%	11.66	0.99%	24.02	2.04%
County of Hawaiʻi	4,039.64	18.98	0.47%	7.38	0.18%	38.35	0.95%
Total	**6,438.78**	**119.54**	**1.86%**	**60.45**	**0.94%**	**170.82**	**2.65%**

Source: Tetra Tech Requested Data from Doug Bausch 2022

Figure 4.13-2. Great Aleutian Tsunami Inundation Area in the County of Kaua'i

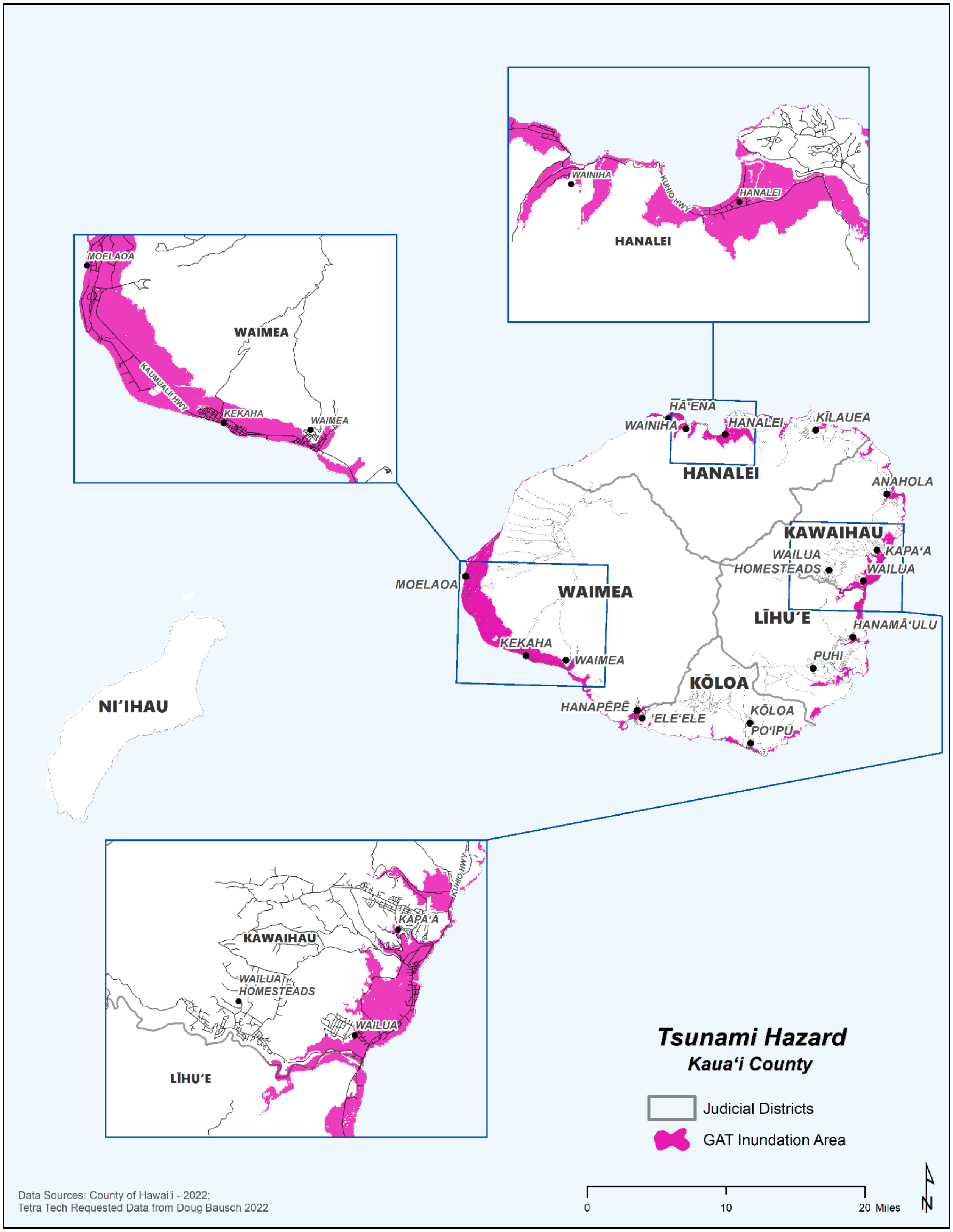


Figure 4.13-3. Great Aleutian Tsunami Inundation Area in the City and County of Honolulu

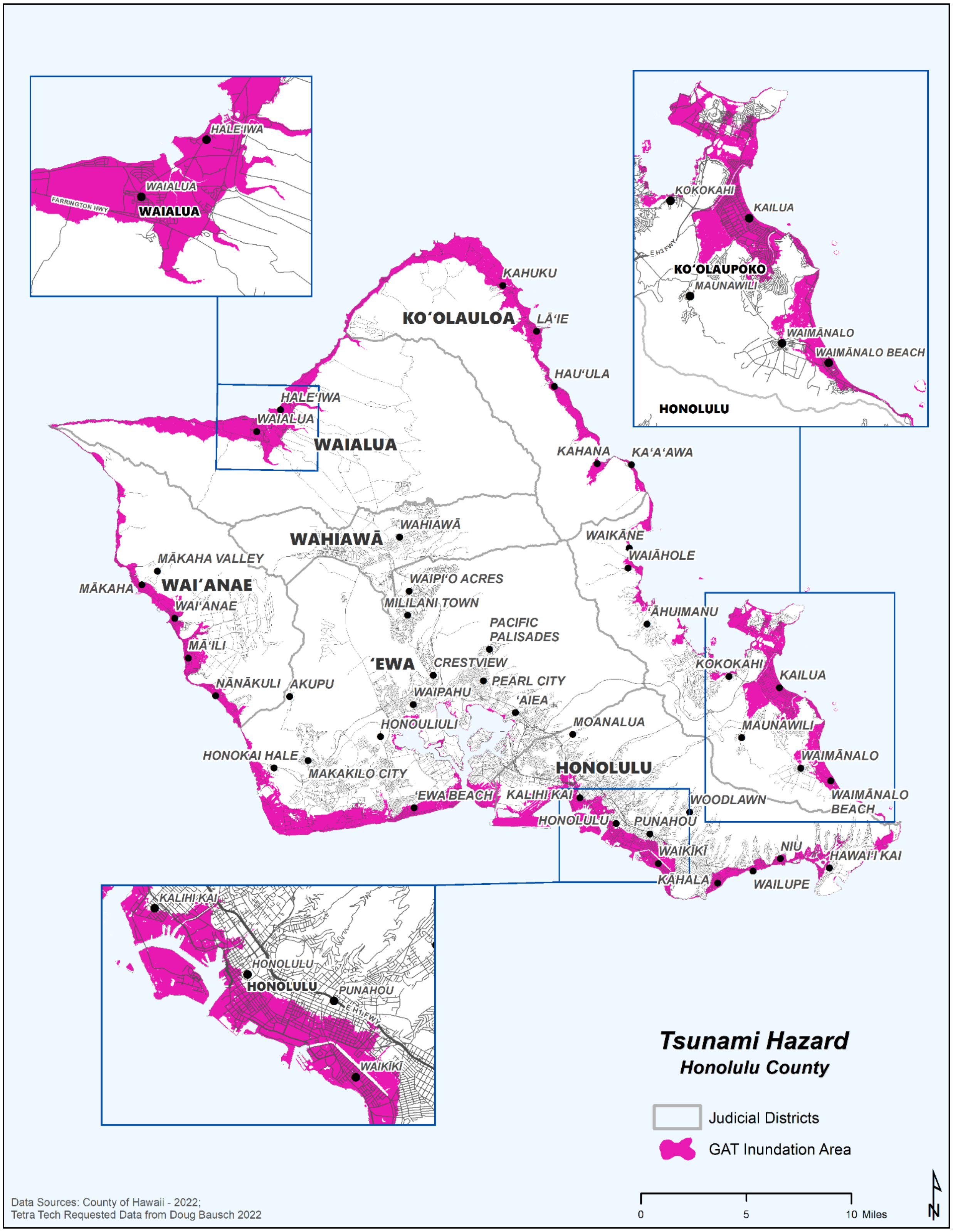


Figure 4.13-4. Great Aleutian Tsunami Inundation Area in the County of Maui

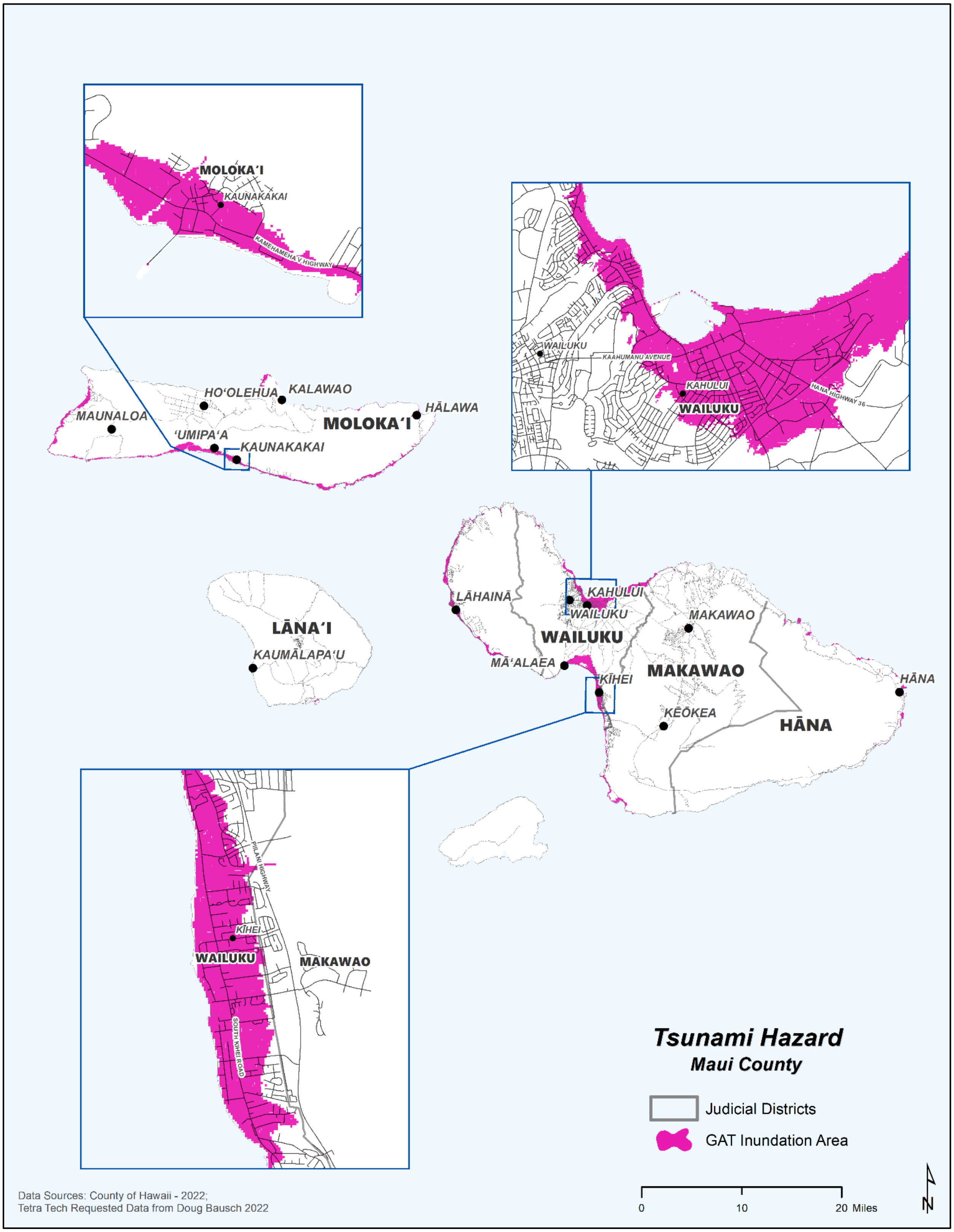
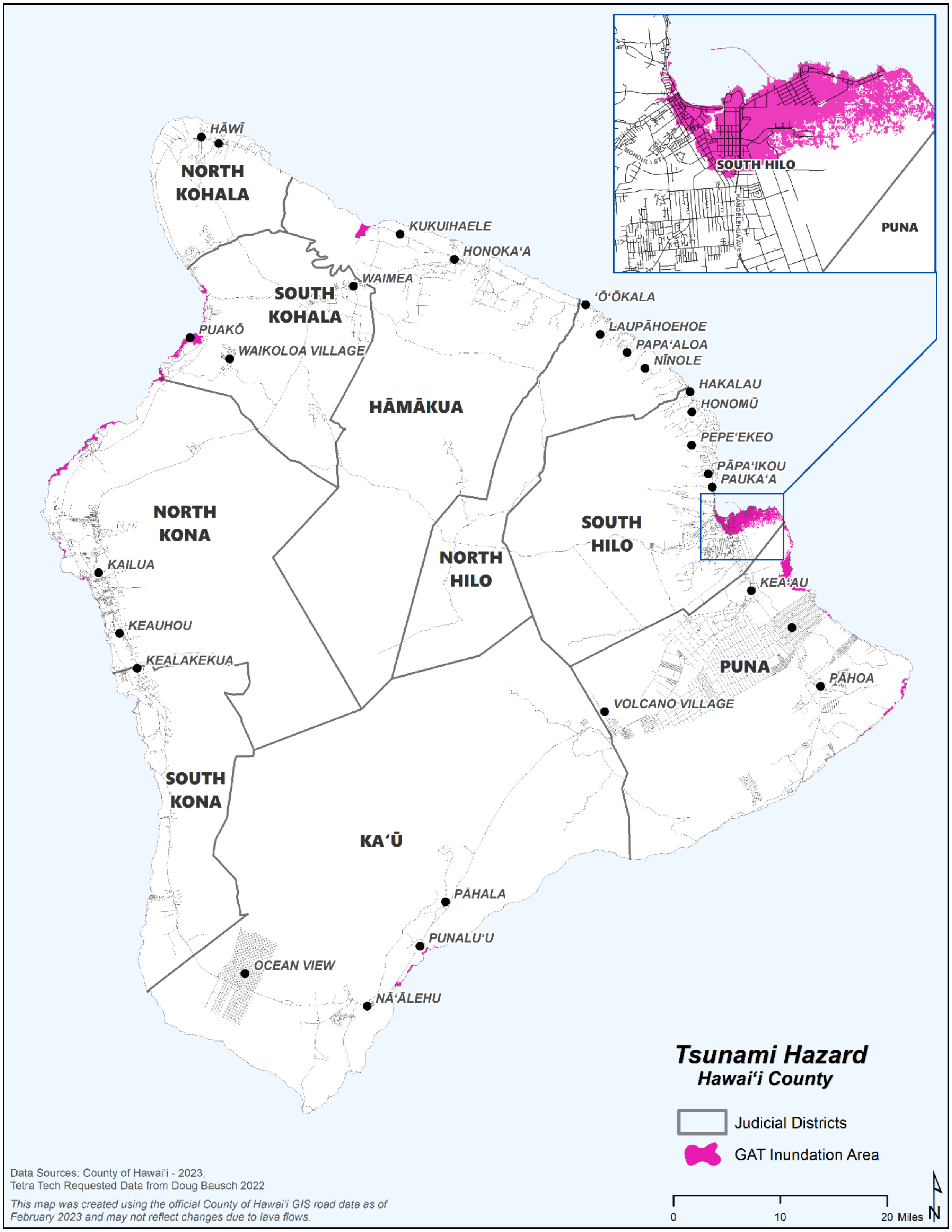


Figure 4.13-5. Great Aleutian Tsunami Inundation Area in the County of Hawaiʻi



EXTENT

A tsunami's effect at the shoreline is measured in terms of runup height and inundation (Figure 4.13-1). Runup and inundation can vary considerably over short distances. Runup tends to be highest at steep shorelines, while inundation is greatest along low-lying coastal plains.

When a tsunami reaches the shore, the water level can rise many feet. In extreme cases, the water level can rise to more than 50 feet for tsunamis of distant origin, and over 100 feet for tsunamis generated near the earthquake's epicenter. The first wave may not be the largest in the series of waves. One coastal area may see no damaging wave activity, while in another area destructive waves can be large and violent. Flooding tsunami waves can carry loose objects and people out to sea when they retreat (Pacific Tsunami Museum 2022). **Error! Reference source not found.** shows the effects after a flooding tsunami wave has receded.

Figure 4.13-6. Tsunami Wave Receding After Flooding the Pier and Aliʻi Drive in Kailua-Kona, 2011

Source: Pacific Tsunami Museum 2022

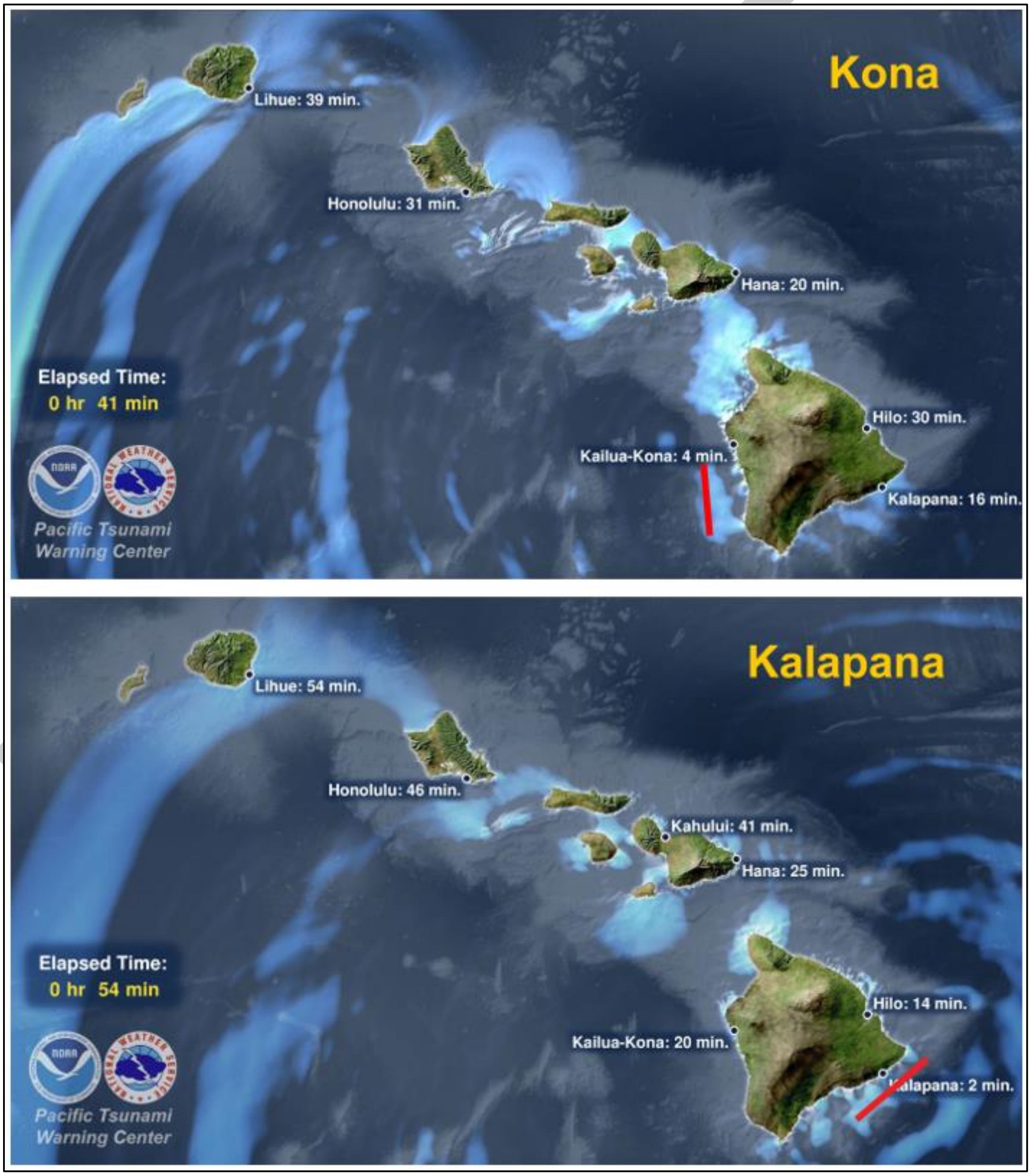
Warning Time

Tsunamis affecting the State of Hawaiʻi may be generated locally or may come from across the ocean. Local tsunamis may be generated by volcanic eruptions, earthquakes, large-scale subsidence or sub-aerial and submarine landslides.

Local-Source Events

Local-source events are most likely to be generated near the County of Hawai'i, primarily from earthquakes and large-scale subsidence along the south flank of Kīlauea, or the west flank of Mauna Loa. The local tsunami could reach the coastlines of most major Hawaiian Islands in less than one hour (International Tsunami Information Center 2023). **Error! Reference source not found.** shows the travel times of tsunamis originated from earthquakes within the Hawaiian Islands.

Figure 4.13-7. Approximate Travel Time of Tsunamis Generated in Hawai'i



Source: International Tsunami Information Center 2023

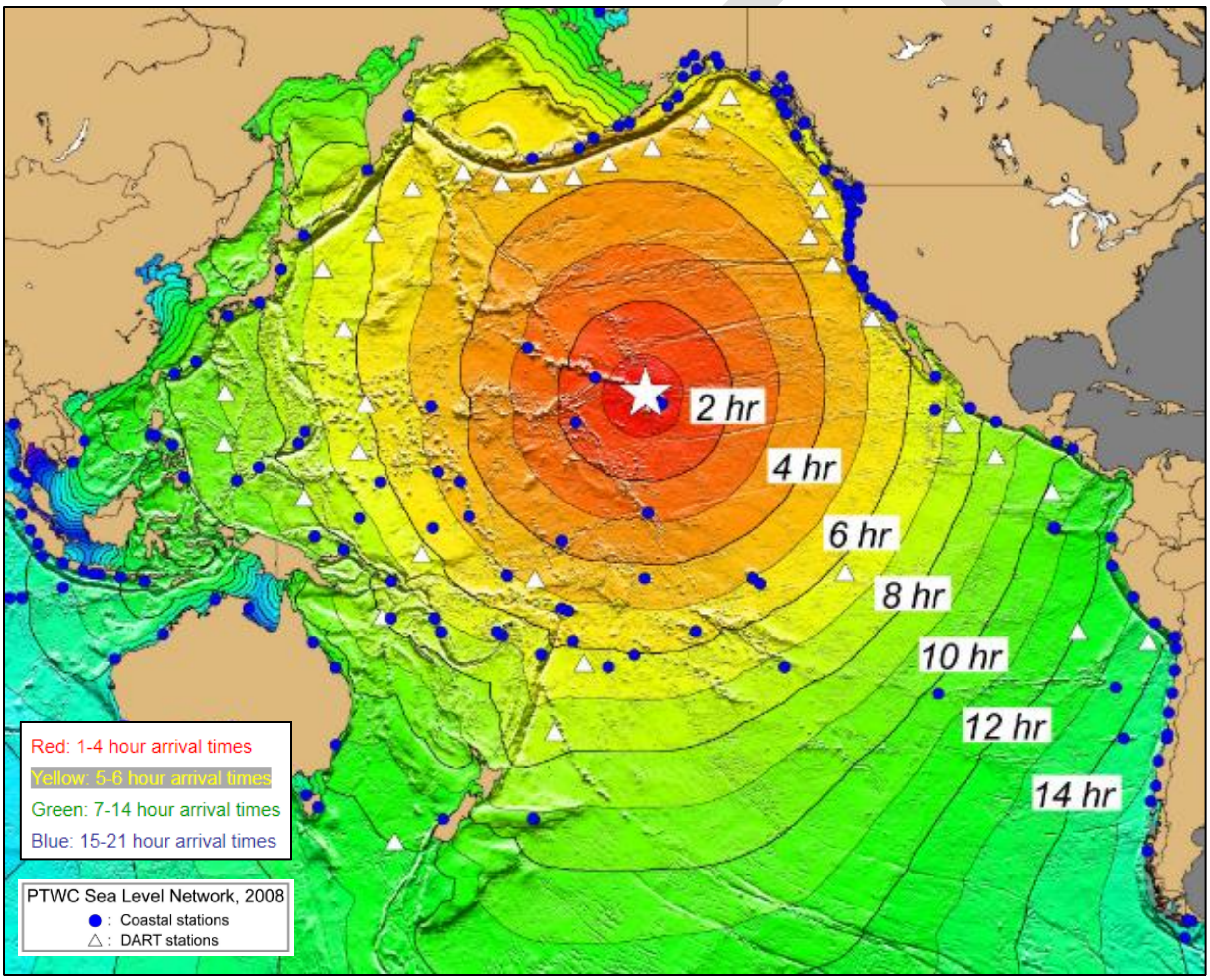
Distant-Source Events

Distant-source tsunamis originate from a faraway source, generally more than 600 miles or more than three hours tsunami travel time from its source. The State of Hawai'i is exposed to these types of tsunamis as well. In particular, areas with subduction fault lines, such as the coasts of the State of Alaska's mainland and Aleutian Islands, the States of Washington, Oregon, and California, the countries of Chile and Japan, and Russia's Kamchatka Peninsula, are common places of earthquakes that generate tsunamis that have affected Hawai'i in the past.

Although these tsunamis originate from earthquakes with epicenters far away from Hawai'i, they lose little energy on the open ocean and can cause large devastation when they reach the Hawaiian Islands' coasts. For tsunamis from distant sources, the time for the waves to reach the islands is measured in hours. Source: International Tsunami Information Center 2023

shows the travel times of tsunamis originated from earthquakes in the Pacific Rim.

Figure 4.13-8. Tsunami Travel Times to Hawai'i



Source: International Tsunami Information Center 2023

Evacuation Plans and Warning Systems

An effective early warning system is essential in protecting life and property. In the 20th century, an estimated 221 people have been killed by tsunamis in Hawaiʻi (U.S. Geological Survey n.d.). Tsunamis reaching the Hawaiian Islands have exhibited tremendous variability in terms of their runup heights, inundation distances, and the damage they have inflicted.

Improving techniques and understanding of the tsunami hazard, in particular identifying areas most likely to be flooded, is a continuous effort. Scientists found that a M9.2 earthquake in the eastern Aleutian Islands would generate a tsunami inundation area exceeding flooding observed from past historical events. In response to these findings, additional evacuation maps (Tier 2) were developed for Kauaʻi, Honolulu, and Maui Counties. The Tier 2 evacuation maps represent an unlikely worst-case scenario and do not replace the Tier 1 evacuation maps that are based on historical tsunamis (International Tsunami Information Center 2023).

Tsunami Warning Centers

Tsunami warning centers have been established around the world as part of an international warning system. In the United States, NOAA has two tsunami warning centers that are staffed 24 hours a day, 7 days a week. Their mission is to provide early tsunami warnings on potentially destructive tsunamis and help protect life and property from them. The warning centers monitor for tsunamis and the earthquakes that may cause them, forecast tsunami impacts, and prepare and issue tsunami messages (National Oceanic and Atmospheric Administration 2022). The Pacific Tsunami Warning Center (PTWC) provides the official tsunami warnings for the State of Hawaiʻi. The PTWC's products include: warnings, watches, advisories, information statements, seismic information statements, and warning cancelations (Source: National Oceanic and Atmospheric Administration 2022

). Operational warning sirens for these warnings exist on the most densely populated coastal areas of all islands. When the PTWC issues a tsunami warning, a steady three-minute siren tone is the attention alert signal (International Strategy for Disaster Reduction n.d.).

Figure 4.13-9. Tsunami Alerts

Source: National Oceanic and Atmospheric Administration 2022

- A **Tsunami Warning** is issued when a potential tsunami with significant widespread inundation is imminent or expected. Generally, this means that the tsunami is expected to run up more than one meter above sea level somewhere in the state. Warnings alert the public that widespread, dangerous coastal flooding accompanied by powerful currents is possible and may continue for several hours after arrival of the initial wave. Warnings also alert emergency management officials to take action for the entire tsunami hazard zone. Appropriate actions to be taken by local officials may include the evacuation of low-lying coastal areas and the repositioning of ships to deep waters when there is time to safely do so. Warnings may be updated, adjusted geographically, downgraded, or canceled. To provide the earliest possible alert, initial warnings are normally based only on seismic information. The warning includes an estimate (usually good to within a few minutes) of when the first tsunami wave will arrive.

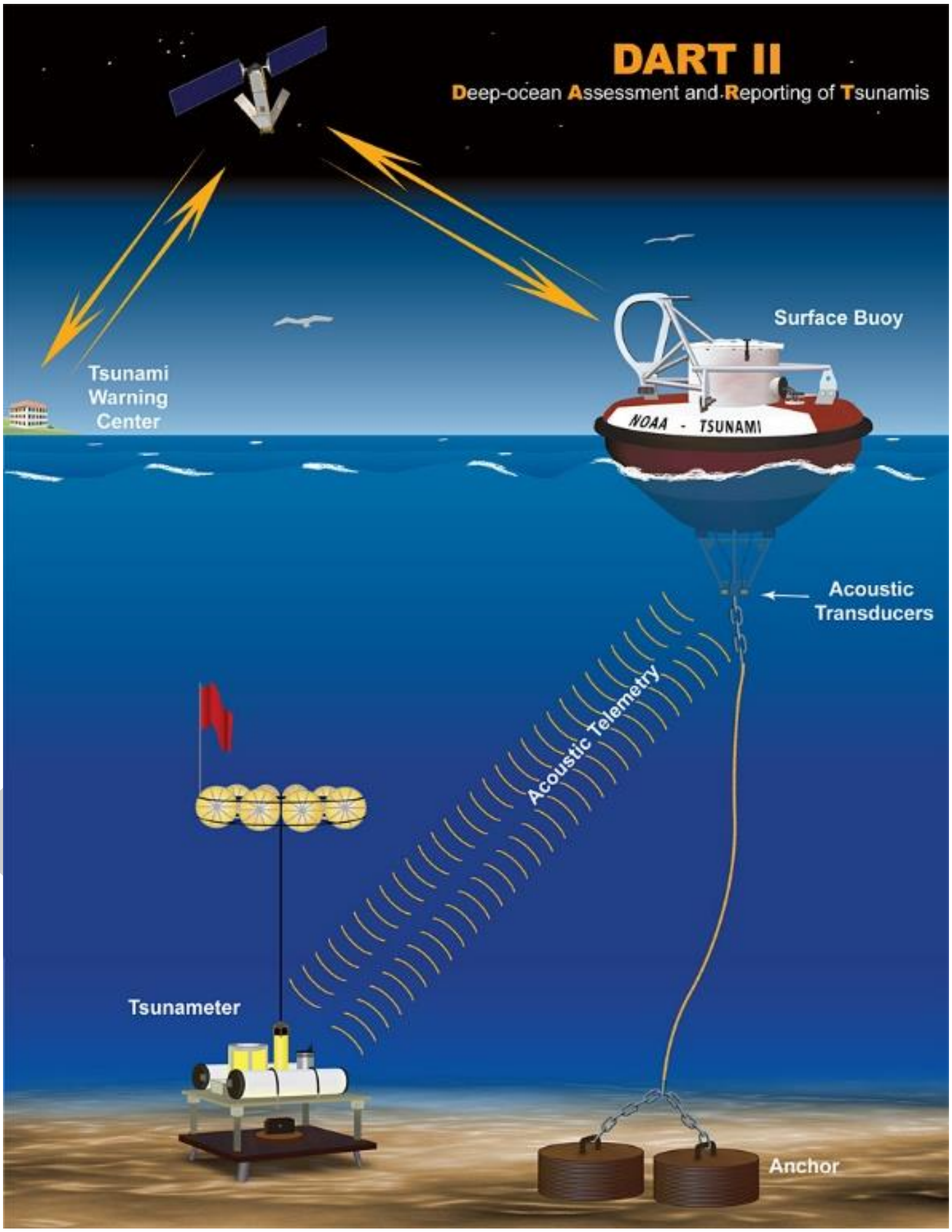
- A **Tsunami Advisory** is issued when the tsunami will be too small to require evacuation but is expected to be large enough to make beaches and near shore waters dangerous. Generally, this means that tsunami runup is expected to exceed 0.3 meters somewhere in the state but will not exceed 1.0 meters anywhere. A tsunami advisory means there is threat of a potential tsunami which may produce strong currents or waves dangerous to those in or near the water. Coastal regions historically prone to damage due to strong currents induced by tsunamis are at the greatest risk. The threat may continue for several hours after the arrival of the initial wave, but significant widespread inundation is not expected for areas under an advisory. Appropriate actions to be taken by local officials may include closing beaches, evacuating harbors and marinas, and the repositioning of ships to deep waters when there is time to safely do so. Advisories are normally updated to continue the advisory, expand/contract affected areas, upgrade to a warning, or cancel the advisory.
- A **Tsunami Watch** is issued to alert emergency management officials and the public of a tsunami which may later impact the watch area. A tsunami watch will always be either upgraded to a warning or advisory—or canceled—based on updated information and analysis. Therefore, emergency management officials and the public should prepare to take action. Watches are normally issued based on seismic information before confirmation that a destructive tsunami has been generated. A tsunami watch is only issued if any potential tsunami is more than three hours away; if the potential tsunami will arrive within three hours a tsunami warning is issued instead.
- A **Tsunami Information Statement** is issued to inform emergency management officials and the public that an earthquake has occurred, but there is no threat of a destructive tsunami in Hawaiʻi. For earthquakes within the state, information statements are issued to prevent unnecessary evacuations as the earthquake may have been felt. An information statement may, in appropriate situations, caution about the possibility of minor wave activity. Information statements may be re-issued with additional information, though normally these messages are not updated. However, a watch, advisory or warning may be issued for the area, if necessary, after analysis and/or updated information becomes available.
- A **Tsunami Warning Cancelation** is the final product indicating the end of the damaging tsunami threat. A cancelation is usually issued after an evaluation of sea level data confirms that a destructive tsunami will not impact the warned area. In the event of a damaging tsunami, the cancelation is issued after coastal tide gauges show that waves have fallen below the danger level and no further damaging waves are expected (National Tsunami Warning System 2023).

Deep-ocean Assessment and Reporting of Tsunami (DART®)

To detect tsunamis in real time as they travel across the open ocean, NOAA developed a tsunami measurement system called Deep-ocean Assessment and Reporting of Tsunami (DART®). Source: National Weather Service n.d.

depicts the operation of the DART® system.

Figure 4.13-10. DART II System



Source: National Weather Service n.d.

The information collected by a network of DART® systems positioned at strategic locations throughout the ocean plays a critical role in tsunami forecasting. There are 60 systems located throughout the world, with a majority of them located in the Pacific Ocean. There is one DART® system located west of Kailua-Kona.

When a tsunami occurs, the first information available, from the worldwide network of seismometers, is about the earthquake source. That is enough to send out an initial warning message. As the tsunami wave propagates across the ocean and reaches coastal tide gauges or the DART® systems, sea level measurements are reported back to the Tsunami Warning Centers – National Tsunami Warning Center in Palmer, Alaska, and PTWC in Honolulu, Hawaiʻi. The information from the DART® systems are processed at the warning centers to produce a new and more refined estimated of the tsunami source. The result is an increasingly accurate forecast of the tsunami that can be used to issue refine watches and warnings (National Oceanic and Atmospheric Administartion n.d.).

Tsunami Warning Sirens

Each county in Hawaiʻi is responsible for tsunami evacuations and issuing the all-clear. For distant-source tsunamis, the HI-EMA coordinates the statewide sounding of the first tsunami warning siren. Subsequent siren soundings are the responsibility of each county. If evacuation is necessary, the sirens will be activated. The sirens exist on the most densely populated coastal areas of all Hawaiian Islands. They are tested monthly. When the PTWC issues a warning, a steady three-minute siren tone is the attention alert signal (International Strategy for Disaster Reduction n.d., International Strategy for Disaster Reduction n.d.).

Runup Detector System

PTWC measures tsunamis within Hawaiʻi at 12 tide gauges throughout the state as well as at the DART® off Kailua-Kona (National Centers for Environmental Information 2022). For a local-source tsunami, these data are not available fast enough to issue a useful warning, so in the early 2000s, a new runup detector system was installed close to potential sources on the Island of Hawaiʻi. Each sensor is a device on land, within 50 yards of the ocean, which sounds an alarm at PTWC if it gets wet. Six of these sensors are distributed along the southwest and southeast shorelines of Hawaiʻi Island. If two adjacent sensors are flooded within a few minutes of each other, regardless of whether or not there is an earthquake, PTWC will issue the appropriate local tsunami warning. In the event of an earthquake, PTWC will issue a warning within three minutes, several minutes before the tsunami reaches land. The runup detectors then serve simply to corroborate the warning since the warning will already have been issued. But if there is no earthquake, as in the case of a tsunami generated by a spontaneous landslide, the runup sensors allow a warning to be issued for the adjacent coast. The runup sensors therefore serve as a “fail safe” system.

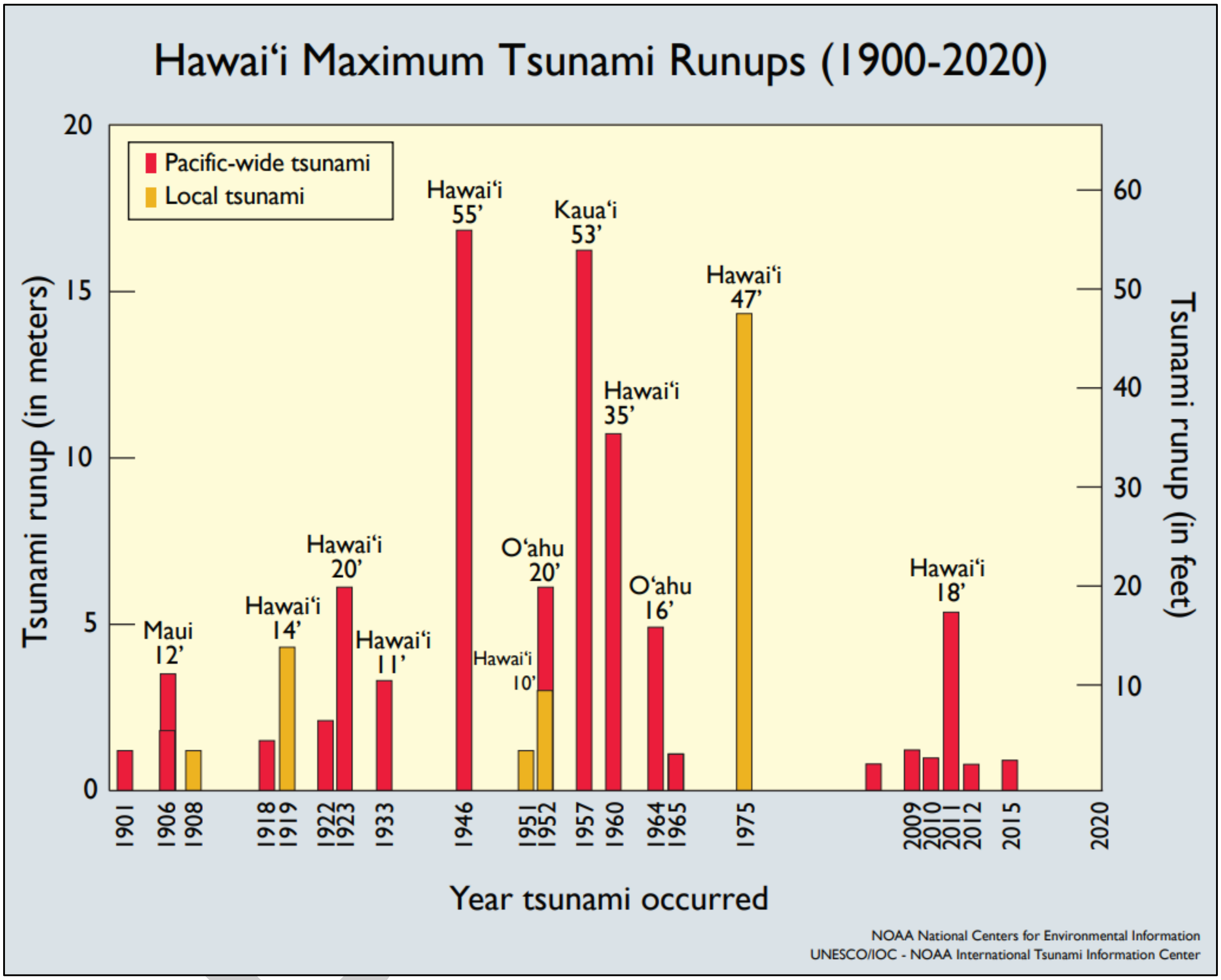
Previous Occurrences and Losses

The earliest historical account of a Hawaiʻi tsunami was from a 16th century Hawaiian chant that described a huge wave that struck the coast of Molokaʻi. The earliest written record of a tsunami in the state was on December 21, 1812, when a wave from southern California was observed at Hoʻokena on the west coast of the Island of Hawaiʻi. Since 1812, there have been more than 160 confirmed tsunamis in the state, resulting in over 2,000 runup observations. Nine of the confirmed tsunamis caused 293 deaths and damages, totaling over $625 million (International Tsunami Information Center 2023).

From 1812 to December 2022, eight tsunamis had significant damaging effects in the state, based on number of deaths, injuries, and damages (National Centers for Environmental Information 2022).

In the 120 years between 1900 and 2020, 12 tsunamis in Hawai‘i have had runups of 10 feet or more (Figure 4.13-11).

Figure 4.13-11. Hawai‘i Tsunami Runups, 1900-2020



Source: International Tsunami Information Center 2023

Many sources provided tsunami information regarding previous occurrences and losses associated with these events throughout the State of Hawai‘i. The 2018 Plan discussed specific tsunami events that impacted Hawai‘i through 2017. For this 2023 SHMP Update, tsunami events and associated runups were summarized between January 1, 2018, and December 31, 2022. According to the NOAA National Centers for Environmental Information database, between 2018 and 2022, there have been no recorded tsunamis that originated in Hawai‘i. However, Hawai‘i has experienced impacts of recent tsunami events in the form of runups.

Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to the tsunami hazard have been issued for Hawaiʻi:

- **Federal disaster (DR) or emergency (EM) declarations, 1955 – 2022**: 1 event, classified as tsunami
- **Hawaiʻi State Emergency Proclamations, 2018 – 2022**: none
- **USDA agricultural disaster declarations, 2012 – 2022**: none

Table 4.13-2 includes details of tsunami and runup events that occurred in the state between 2018 and 2022. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement). Based on all sources researched, the State of Hawaiʻi was not included in any FEMA tsunami-related declarations between 2018 and 2022. For details regarding all declared disasters, refer to Section 4.1 (Overview) and Appendix D (Map Atlas).

Table 4.13-2. Tsunami Events in Hawaiʻi, 2018 to 2022

Date(s) of Event	Event Type	Counties Affected	Description
January 23, 2018	Tsunami Runup	Kauaʻi, Honolulu, Maui, Hawaiʻi	The source of the tsunami was in Kodiak Island, Alaska. The maximum runup (elevation water reached onshore) of this tsunami near the source was 0.25 meters. Runup was measured in all counties: • Honolulu (Honolulu) had a maximum water height of 0.03 meters • Kahului (Maui) had a maximum water height of 0.12 meters • Hanalei (Kauaʻi) had a maximum water height of 0.13 meters • Nāwiliwili (Kauaʻi) had a maximum water height of 0.03 meters • Mokuoloʻe-Coconut Island (Honolulu) had a maximum water height of 0.03 meters • Makapuʻu Point (Honolulu) had a maximum water height of 0.14 meters • Kawaihae (Hawaiʻi) had a maximum water height of 0.07 meters • Honokōhau (Hawaiʻi) had a maximum water height of 0.04 meters • Hilo (Hawaiʻi) had a maximum water height of 0.18 meters
May 4, 2018	Tsunami Runup	Kauaʻi, Honolulu, Maui, Hawaiʻi	The source of the tsunami was in Hawaiʻi from the magnitude 6.9 earthquake, part of the Kīlauea volcanic eruption sequence. The maximum near-source runup of this tsunami was 0.4 meters. Runup was measured in all counties: • Kawaihae (Hawaiʻi) had a maximum water height of 0.16 meters • Honuʻapo (Hawaiʻi) had a maximum water height of 0.15 meters • Kahului (Maui) had a maximum water height of 0.15 meters • Hilo (Hawaiʻi) had a maximum water height of 0.2 meters • Kapoho (Hawaiʻi) had a maximum water height of 0.4 meters • Honolulu (Honolulu) had a maximum water height of 0.03 meters • Nāwiliwili (Kauaʻi) had a maximum water height of 0.04 meters
December 5, 2018	Tsunami Runup	Honolulu, Hawaiʻi	The source of the tsunami was in the Loyalty Islands, New Caledonia. The maximum runup of this tsunami near the source was 2.0 meters. Runup was measured in Honolulu and Hawaiʻi counties: Kawaihae (Hawaiʻi) had a maximum water height of 0.05 meters Honolulu (Honolulu) had a maximum water height of 0.03 meters
March 25, 2020	Tsunami Runup	Honolulu, Maui, Hawaiʻi	The source of the tsunami was in the North Kuril Islands, Russia. The maximum runup of this tsunami near the source was 0.5 meters. Runup was measured in Honolulu, Maui, and Hawaiʻi counties: • Hilo (Hawaiʻi) had a maximum water height of 0.07 meters • Kahului (Maui) had a maximum water height of 0.08 meters

Date(s) of Event	Event Type	Counties Affected	Description
			• Haleʻiwa (Honolulu) had a maximum water height of 0.05 meters
October 19, 2020	Tsunami Runup	Kauaʻi, Honolulu, Maui, Hawaiʻi	The source of the tsunami was in the Shumagin Islands, Alaska. The maximum runup of this tsunami near the source was 0.76 meters. Runup was measured in all counties: • Kahului (Maui) had a maximum water height of 0.13 meters • Hanalei (Kauaʻi) had a maximum water height of 0.26 meters • Haleʻiwa (Honolulu) had a maximum water height of 0.19 meters • Kawaihae (Hawaiʻi) had a maximum water height of 0.05 meters • Hilo (Hawaiʻi) had a maximum water height of 0.28 meters • Mokuoloʻe-Coconut Island (Honolulu) had a maximum water height of 0.02 meters • Nāwiliwili (Kauaʻi) had a maximum water height of 0.09 meters
March 4, 2021	Tsunami Runup	Kauaʻi, Honolulu, Maui, Hawaiʻi	The source of the tsunami was in the Kermadec Islands, New Zealand. The maximum runup of the tsunami near the source was not recorded due to power and communication outages. Runup was measured in all counties: • Nāwiliwili (Kauaʻi) had a maximum water height of 0.06 meters • Honolulu (Honolulu) had a maximum water height of 0.08 meters • Waimānalo (Honolulu) had a maximum water height of 0.1 meters • Kahului (Maui) had a maximum water height of 0.18 meters • Kawaihae (Hawaiʻi) had a maximum water height of 0.07 meters • Barbers Point (Honolulu) had a maximum water height of 0.01 meters • Haleʻiwa (Honolulu) had a maximum water height of 0.05 meters • Hilo (Hawaiʻi) had a maximum water height of 0.09 meters
July 29, 2021	Tsunami Runup	Maui, Hawaiʻi	The source of the tsunami was in Kodiak Island, Alaska. The maximum runup of this tsunami near the source was 0.42 meters. Runup was measured in Maui and Hawaiʻi Counties: • Hilo (Hawaiʻi) had a maximum water height of 0.12 meters • Kahului (Maui) had a maximum water height of 0.13 meters
August 12, 2021	Tsunami Runup	Kauaʻi, Honolulu, Maui, Hawaiʻi	The source of the tsunami was in the Southern Atlantic Ocean. Runup was measured in all counties: • Honokōhau (Hawaiʻi) had a maximum water height of 0.06 meters • Honuʻapo (Hawaiʻi) had a maximum water height of 0.02 meters • Honolulu (Honolulu) had a maximum water height of 0.04 meters • Hilo (Hawaiʻi) had a maximum water height of 0.17 meters • Kahului (Maui) had a maximum water height of 0.17 meters • Kawaihae (Hawaiʻi) had a maximum water height of 0.09 meters • Haleʻiwa (Honolulu) had a maximum water height of 0.04 meters • Nāwiliwili (Kauaʻi) had a maximum water height of 0.06 meters
January 15, 2022	Tsunami Runup	Kauaʻi, Honolulu, Maui, Hawaiʻi	The source of the tsunami was the volcanic eruption of Hunga Tonga-Hunga Haʻapai Volcano in Tonga. The maximum runup of this tsunami near the source was 22.0 meters. Honolulu County sustained $3.32 million in damages and Hawaiʻi County had $75,000 in damages. Runup was measured in all counties: • Haleʻiwa (Honolulu) had a maximum water height of 0.69 meters • D51407 BPR (Honolulu) had a maximum water height of 0.05 meters Makapuʻu Point (Honolulu) had a maximum water height of 0.86 meters • Honokōhau (Hawaiʻi) had a maximum water height of 0.34 meters • Honolulu (Honolulu) had a maximum water height of 0.12 meters • Kahului (Maui) had a maximum water height of 0.83 meters • Barbers Point (Honolulu) had a maximum water height of 0.19 meters

Date(s) of Event	Event Type	Counties Affected	Description
			• Kawaihae (Hawaiʻi) had a maximum water height of 0.37 meters • Hawaiʻi County (all) had a maximum water height of 1.0 meters • Nāwiliwili (Kauaʻi) had a maximum water height of 0.31 meters • Waimānalo (Honolulu) had a maximum water height of 0.28 meters • Hanalei (Kauaʻi) had a maximum water height of 0.82 meters

Source: (National Centers for Environmental Information 2022)
Note: Please note that not all sources may have been identified in order to be researched for this 2023 SHMP Update. Additionally, loss and impact information for many events could vary depending on the source. Therefore, ***Error! Reference source not found.*** *may not include all events that have occurred in or impacted the state and the accuracy of monetary figures discussed is based only on the available information identified during research for this 2023 SHMP Update.*

Probability of Future Hazard Events

Overall Probability

Tsunamis are caused by earthquakes, landslides, and volcanic eruptions, so the frequency of tsunamis depends on these other geological events. Generally, four to five tsunamis occur every year in the Pacific Basin, though these are usually hazardous only close to the source. Every five years or so, a tsunami is generated which is large enough to threaten coastlines on the far side of the ocean from its source. Based on information from the National Centers for Environmental Information, since 1812, 61 tsunamis have produced a runup of greater than 0.3 meters (the threshold for issuing a tsunami advisory) somewhere in the State of Hawaiʻi. Of these, 35 produced a runup greater than one meter (the threshold for coastal flooding and, therefore, the threshold for issuing a tsunami warning). Based on these data, the State of Hawaiʻi should expect a potentially damaging tsunami, one requiring coastal evacuation, approximately once every six years. The State of Hawaiʻi has roughly a 17 percent chance of a damaging tsunami occurring in any given year.

The probability of advisory-level tsunamis, those for which evacuation is unnecessary but which may create dangerous coastal currents, is at least double that of the larger, warning-level tsunamis; the historical record for these smaller events is likely incomplete before about 1910. Very roughly, the State of Hawaiʻi should expect a tsunami advisory once every three years, or about a 34% chance in any year.

Climate Change Impacts

The warming of the atmosphere and the oceans and melting of ice sheets and glaciers is causing the global mean sea level to rise. Higher sea levels will exacerbate the extent of coastal inundation from a tsunami. The Intergovernmental Panel on Climate Change 6th Assessment Report predicts up to 7.89 feet of sea level rise for the Pacific Islands by 2100 (NASA 2022). This would have devastating impacts on the State of Hawaiʻi. Rising sea levels will increase the extent of coastal flooding from tsunamis as they create waves that flood low-lying coastal areas (Hawaiʻi Climate Change Mitigation and Adaptation Commission 2017). What rising sea level means for tsunami preparedness is that the evacuation maps should be reassessed periodically, probably once a decade.

4.13.2 VULNERABILITY ASSESSMENT

Tsunami Hazard Area Scenarios

Spatial data, provided by the Pacific Disaster Center, were used to assess exposure and potential loss to the tsunami hazard using the following three scenarios:

- Great Aleutian Tsunami (GAT) (1,500-year)
- School of Ocean & Earth Science & Technology (SOEST) Historic (200-year)
- American Society of Civil Engineers (ASCE) Design Inundation Mapping (3,500-year probabilistic event based on aggregated sources)

A statewide tsunami analysis was conducted based on best available data for the State of Hawaiʻi. The GAT, SOEST, and ASCE inundation areas and Hazus reports were provided by the PDC including building damage and loss, displaced population and potential casualties for each county, for use in the 2023 SHMP Update.

Assessment of State Vulnerability and Potential Losses

This section discusses statewide vulnerability of areas susceptible to the tsunami hazard and potential losses to state assets (state-owned or state-leased buildings), state roads and critical facilities.

State Assets

The spatial analysis determined there are 1,204 state buildings located in the GAT inundation area. Of these buildings, the greatest number are located in the City and County of Honolulu (801 buildings with a replacement cost value of $3.384 billion); the majority of these buildings are occupied by the Department of Education and University of Hawaiʻi. Table 4.13-3 and Table 4.13-6 summarize the state buildings located in the GAT inundation area by county and state agency, respectively.

The spatial analysis determined there are 420 state buildings located in the SOEST inundation area. Of these buildings, the greatest number are located in the City and County of Honolulu (231 buildings with a replacement cost value of $994 million); the majority of these buildings are occupied by the Department of Education and University of Hawaiʻi. Table 4.13-4 and Table 4.13-7 summarize the state buildings located in the SOEST inundation area by county and state agency, respectively.

The spatial analysis determined there are 1,474 state buildings located in the ASCE inundation area. Of these buildings, the greatest number are located in the City and County of Honolulu (989 buildings with a replacement cost value of $4.683 billion); the majority of these buildings are occupied by the Department of Education and University of Hawaiʻi. Table 4.13-5 and Table 4.13-8 summarize the State buildings located in the ASCE inundation area by county and state agency, respectively.

Table 4.13-3. State Buildings Exposure to the GAT Inundation Area by County

County	Total Number of State Buildings	Total Replacement Cost Value	State Buildings in the Tsunami Hazard Area			
			Number	Percent (%) of Total	Total Replacement Cost Value	Percent (%) of Total
County of Kaua'i	531	$990,850,824	110	20.72%	$243,280,131	24.55%
City and County of Honolulu	3,472	$17,393,945,915	801	23.07%	$3,384,627,763	19.46%
County of Maui	831	$3,097,491,689	161	19.37%	$595,279,795	19.22%
Count of Hawai'i	1,261	$4,638,567,141	132	10.47%	$576,473,135	12.43%
Total	**6,095**	**$26,120,855,568**	**1,204**	**19.75%**	**$4,799,660,824**	**18.37%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Risk Management Office 2017

Table 4.13-4. State Buildings Exposure to the SOEST Inundation Area by County

County	Total Number of State Buildings	Total Replacement Cost Value	State Buildings in the Tsunami Hazard Area			
			Number	Percent (%) of Total	Total Replacement Cost Value	Percent (%) of Total
County of Kaua'i	531	$990,850,824	48	9.04%	$157,173,901	15.86%
City and County of Honolulu	3,472	$17,393,945,915	231	6.65%	$994,231,118	5.72%
County of Maui	831	$3,097,491,689	66	7.94%	$258,541,414	8.35%
Count of Hawai'i	1,261	$4,638,567,141	75	5.95%	$127,144,842	2.74%
Total	**6,095**	**$26,120,855,568**	**420**	**6.89%**	**$1,537,091,275**	**5.88%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Risk Management Office 2017

Table 4.13-5. State Buildings Exposure to the ASCE Inundation Area by County

County	Total Number of State Buildings	Total Replacement Cost Value	State Buildings in the Tsunami Hazard Area			
			Number	Percent (%) of Total	Total Replacement Cost Value	Percent (%) of Total
County of Kaua'i	531	$990,850,824	89	16.76%	$186,412,528	18.81%
City and County of Honolulu	3,472	$17,393,945,915	989	28.49%	$4,683,551,419	26.93%
County of Maui	831	$3,097,491,689	254	30.57%	$640,976,500	20.69%
Count of Hawai'i	1,261	$4,638,567,141	142	11.26%	$499,902,903	10.78%
Total	**6,095**	**$26,120,855,568**	**1,474**	**24.18%**	**$6,010,843,350**	**23.01%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Risk Management Office 2017

Table 4.13-6. State Buildings Exposure to the GAT Inundation Area by State Agency

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Dept of Accounting & General Services	66	$953,963,738	17	25.76%	$225,705,367	23.66%
Dept of Agriculture	70	$147,607,399	25	35.71%	$47,526,939	32.20%
Dept of Attorney General	15	$108,425,480	6	40.00%	$34,366,693	31.70%
Dept of Budget & Finance	16	$28,968,679	6	37.50%	$22,172,194	76.54%
Dept of Business, Economic Development and Tourism	25	$645,480,379	6	24.00%	$560,518,082	86.84%
Dept of Commerce & Consumer Affairs	2	$40,197,360	1	50.00%	$35,605,036	88.58%
Dept of Defense	69	$267,352,836	12	17.39%	$38,237,951	14.30%
Dept of Education	4,090	$10,598,205,739	774	18.92%	$1,738,645,173	16.41%
Dept of Hawaiian Home Lands	12	$110,427,352	2	16.67%	$7,414,080	6.71%
Dept of Health	44	$387,068,440	7	15.91%	$11,154,835	2.88%
Dept of Human Resources Development	1	$5,973,872	0	0.00%	$0	0.00%
Dept of Human Services	130	$480,212,294	46	35.38%	$274,328,048	57.13%
Dept of Labor and Industrial Relations	22	$90,076,209	6	27.27%	$62,294,284	69.16%
Dept of Land and Natural Resources	90	$101,441,821	36	40.00%	$21,054,311	20.76%
Dept of Public Safety	154	$440,774,415	27	17.53%	$66,868,409	15.17%
Dept of Taxation	1	$7,174,162	1	100.00%	$7,174,162	100.00%
Dept of Transportation	68	$2,935,208,214	42	61.76%	$478,935,460	16.32%
Hawaiʻi State Ethics Commission	1	$984,533	0	0.00%	$0	0.00%
Hawaiʻi Health Systems Corporation	106	$1,230,852,871	1	0.94%	$936,734	0.08%

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Hawai'i Housing Finance & Development Corporation	86	$360,851,671	16	18.60%	$156,215,306	43.29%
Hawai'i Public Housing Authority	273	$982,981,701	44	16.12%	$107,913,043	10.98%
Hawai'i State Legislature	2	$48,555,381	0	0.00%	$0	0.00%
Hawai'i State Public Library System	53	$525,584,082	17	32.08%	$49,960,772	9.51%
Judiciary	41	$534,877,354	12	29.27%	$165,922,633	31.02%
Legislative Reference Bureau	1	$2,996,162	0	0.00%	$0	0.00%
Office of Hawaiian Affairs	11	$54,125,645	7	63.64%	$43,813,415	80.95%
Office of the Auditor	2	$1,921,180	0	0.00%	$0	0.00%
Office of the Governor	1	$2,996,162	0	0.00%	$0	0.00%
Office of the Lieutenant Governor	2	$4,588,849	0	0.00%	$0	0.00%
Office of the Ombudsman	1	$1,818,060	0	0.00%	$0	0.00%
Research Corporation of the University of Hawai'i	3	$4,189,026	0	0.00%	$0	0.00%
University of Hawai'i	637	$5,014,974,503	92	14.44%	$641,913,366	12.80%
Total	**6,095**	**$26,120,855,568**	**1,203**	**19.74%**	**$4,798,676,291**	**18.37%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Risk Management Office 2017

Table 4.13-7. State Buildings Exposure to the SOEST Inundation Area by State Agency

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Dept of Accounting & General Services	66	$953,963,738	5	7.58%	$34,904,592	3.66%
Dept of Agriculture	70	$147,607,399	7	10.00%	$17,187,559	11.64%
Dept of Attorney General	15	$108,425,480	2	13.33%	$17,236,498	15.90%
Dept of Budget & Finance	16	$28,968,679	1	6.25%	$4,806,631	16.59%

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Dept of Business, Economic Development and Tourism	25	$645,480,379	3	12.00%	$546,896,699	84.73%
Dept of Commerce & Consumer Affairs	2	$40,197,360	0	0.00%	$0	0.00%
Dept of Defense	69	$267,352,836	9	13.04%	$29,801,107	11.15%
Dept of Education	4,090	$10,598,205,739	255	6.23%	$390,999,952	3.69%
Dept of Hawaiian Home Lands	12	$110,427,352	1	8.33%	$1,925,000	1.74%
Dept of Health	44	$387,068,440	5	11.36%	$9,934,532	2.57%
Dept of Human Resources Development	1	$5,973,872	0	0.00%	$0	0.00%
Dept of Human Services	130	$480,212,294	18	13.85%	$28,959,968	6.03%
Dept of Labor and Industrial Relations	22	$90,076,209	2	9.09%	$2,790,797	3.10%
Dept of Land and Natural Resources	90	$101,441,821	22	24.44%	$12,073,274	11.90%
Dept of Public Safety	154	$440,774,415	3	1.95%	$27,866,012	6.32%
Dept of Taxation	1	$7,174,162	0	0.00%	$0	0.00%
Dept of Transportation	68	$2,935,208,214	25	36.76%	$205,120,358	6.99%
Hawai'i State Ethics Commission	1	$984,533	0	0.00%	$0	0.00%
Hawaiʻi Health Systems Corporation	106	$1,230,852,871	1	0.94%	$936,734	0.08%
Hawaiʻi Housing Finance & Development Corporation	86	$360,851,671	1	1.16%	$222,080	0.06%
Hawaiʻi Public Housing Authority	273	$982,981,701	7	2.56%	$23,967,254	2.44%
Hawaiʻi State Legislature	2	$48,555,381	0	0.00%	$0	0.00%
Hawaiʻi State Public Library System	53	$525,584,082	9	16.98%	$24,625,219	4.69%
Judiciary	41	$534,877,354	5	12.20%	$71,403,089	13.35%
Legislative Reference Bureau	1	$2,996,162	0	0.00%	$0	0.00%
Office of Hawaiian Affairs	11	$54,125,645	6	54.55%	$18,013,415	33.28%
Office of the Auditor	2	$1,921,180	0	0.00%	$0	0.00%
Office of the Governor	1	$2,996,162	0	0.00%	$0	0.00%
Office of the Lieutenant Governor	2	$4,588,849	0	0.00%	$0	0.00%
Office of the Ombudsman	1	$1,818,060	0	0.00%	$0	0.00%
Research Corporation of the University of Hawai'i	3	$4,189,026	0	0.00%	$0	0.00%
University of Hawai'i	637	$5,014,974,503	33	5.18%	$67,420,505	1.34%
Total	**6,095**	**$26,120,855,568**	**420**	**6.89%**	**$1,537,091,275**	**5.88%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Risk Management Office 2017

Table 4.13-8. State Buildings Exposure to the ASCE Inundation Area by State Agency

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Dept of Accounting & General Services	66	$953,963,738	21	31.82%	$343,977,572	36.06%
Dept of Agriculture	70	$147,607,399	26	37.14%	$49,845,241	33.77%
Dept of Attorney General	15	$108,425,480	7	46.67%	$48,759,711	44.97%
Dept of Budget & Finance	16	$28,968,679	6	37.50%	$22,172,194	76.54%
Dept of Business, Economic Development and Tourism	25	$645,480,379	6	24.00%	$560,518,082	86.84%
Dept of Commerce & Consumer Affairs	2	$40,197,360	1	50.00%	$35,605,036	88.58%
Dept of Defense	69	$267,352,836	12	17.39%	$38,237,951	14.30%
Dept of Education	4,090	$10,598,205,739	1004	24.55%	$2,244,599,445	21.18%
Dept of Hawaiian Home Lands	12	$110,427,352	3	25.00%	$7,618,080	6.90%
Dept of Health	44	$387,068,440	8	18.18%	$13,080,541	3.38%
Dept of Human Resources Development	1	$5,973,872	0	0.00%	$0	0.00%
Dept of Human Services	130	$480,212,294	48	36.92%	$274,603,030	57.18%
Dept of Labor and Industrial Relations	22	$90,076,209	4	18.18%	$59,503,487	66.06%
Dept of Land and Natural Resources	90	$101,441,821	42	46.67%	$77,543,352	76.44%
Dept of Public Safety	154	$440,774,415	27	17.53%	$66,868,409	15.17%
Dept of Taxation	1	$7,174,162	1	100.00%	$7,174,162	100.00%
Dept of Transportation	68	$2,935,208,214	36	52.94%	$513,831,729	17.51%
Hawai'i State Ethics Commission	1	$984,533	1	100.00%	$984,533	100.00%
Hawai'i Health Systems Corporation	106	$1,230,852,871	2	1.89%	$2,181,734	0.18%
Hawai'i Housing Finance & Development Corporation	86	$360,851,671	16	18.60%	$156,215,306	43.29%
Hawai'i Public Housing Authority	273	$982,981,701	66	24.18%	$218,620,456	22.24%
Hawai'i State Legislature	2	$48,555,381	0	0.00%	$0	0.00%
Hawai'i State Public Library System	53	$525,584,082	18	33.96%	$370,197,121	70.44%
Judiciary	41	$534,877,354	13	31.71%	$191,779,359	35.85%
Legislative Reference Bureau	1	$2,996,162	0	0.00%	$0	0.00%
Office of Hawaiian Affairs	11	$54,125,645	10	90.91%	$54,019,183	99.80%
Office of the Auditor	2	$1,921,180	2	100.00%	$1,921,180	100.00%
Office of the Governor	1	$2,996,162	0	0.00%	$0	0.00%

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Office of the Lieutenant Governor	2	$4,588,849	0	0.00%	$0	0.00%
Office of the Ombudsman	1	$1,818,060	1	100.00%	$1,818,060	100.00%
Research Corporation of the University of Hawai'i	3	$4,189,026	0	0.00%	$0	0.00%
University of Hawai'i	637	$5,014,974,503	93	14.60%	$649,168,397	12.94%
Total	**6,095**	**$26,120,855,568**	**1,474**	**24.18%**	**$6,010,843,350**	**23.01%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Risk Management Office 2017

State roads are vulnerable to tsunami inundation. Not only will these roads become flooded and may experience extensive damage, but the debris carried by the tsunami may be deposited on the roadway surfaces. Roads may take months to repair and reopen, causing communities to become isolated. Table 4.13-9 shows the length of state roads in the GAT inundation area by county. The City and County of Honolulu has the greatest number of miles exposed (86 miles), followed by the County of Maui (28.5 miles). Table 4.13-10 shows the length of state roads in the SOEST inundation area by county. The City and County of Honolulu has the greatest number of miles exposed (46.2 miles), followed by the County of Maui (20.8 miles). Table 4.13-11 shows the length of state roads in the ASCE inundation area by county. The City and County of Honolulu has the greatest number of miles exposed (103.2 miles), followed by the County of Maui (38.8 miles). A complete list of state roads located in the GAT, SOEST, and ASCE inundation areas is included in Appendix F (State Profile and Risk Assessment Supplement).

Table 4.13-9. State Road Exposure to the GAT Inundation Area by County

County	Length (in miles)		
	Total Length	Length of State Road in the GAT Inundation Area	Length as Percent (%) of Total Length
County of Kaua'i	103.7	25.2	24.30%
City and County of Honolulu	374.9	86.0	22.94%
County of Maui	245.9	28.5	11.59%
County of Hawai'i	379.2	6.0	1.58%
Total	**1,103.70**	**145.7**	**13.20%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Department of Transportation 2022

Table 4.13-10. State Road Exposure to the SOEST Inundation Area by County

County	Length (in miles)		
	Total Length	Length of State Road in the SOEST Inundation Area	Length as Percent (%) of Total Length
County of Kaua'i	103.7	18.4	17.74%
City and County of Honolulu	374.9	46.2	12.32%
County of Maui	245.9	20.8	8.46%
County of Hawai'i	379.2	3.32	0.88%
Total	**1,103.70**	**88.72**	**8.04%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Department of Transportation 2022

Table 4.13-11. State Road Exposure to the ASCE Inundation Area by County

County	Length (in miles)		
	Total Length	Length of State Road in the ASCE Inundation Area	Length as Percent (%) of Total Length
County of Kaua'i	103.7	27.2	26.23%
City and County of Honolulu	374.9	103.2	27.53%
County of Maui	245.9	38.8	15.78%
County of Hawai'i	379.2	8.0	2.11%
Total	**1,103.70**	**177.2**	**16.06%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State of Hawai'i Department of Transportation 2022

Community Lifelines and Critical Facilities

Table 4.13-12 summarizes the number of community lifelines and critical facilities located in the GAT inundation area by county and core category. The City and County of Honolulu has the greatest number of critical facilities (194) exposed, followed by the County of Maui (98 critical facilities). Table 4.13-15 summarizes the number of facilities and replacement cost exposed by core category. The Energy core category has 49.44% of its facilities located in the tsunami hazard area, followed by Transportation (42.86%) and Food, Water, Shelter (35.36%).

Table 4.13-13 summarizes the number of community lifelines and critical facilities located in the SOEST inundation area by county and core category. The County of Maui has the greatest number of critical facilities (71) exposed, followed by the City and County of Honolulu (60 critical facilities). Table 4.13-16 summarizes the number of facilities and replacement cost exposed by core category. The Energy core category has 30.34% of its facilities located in the tsunami hazard area, followed by Transportation (28.57%) and Food, Water, Shelter (21.45%).

Table 4.13-14 summarizes the number of community lifelines and critical facilities located in the ASCE inundation area by county and core category. The City and County of Honolulu has the greatest number of critical facilities (242) exposed, followed by the County of Maui (107 critical facilities). Table 4.13-17 summarizes the number of facilities and replacement cost exposed by core category. The Energy core category has 56.18% of its facilities located in the tsunami hazard area, followed by Transportation (41.07%) and Food, Water, Shelter (38.55%).

As summarized in Section 4.2 (Climate Change and Sea Level Rise), the primary transportation arteries for the entry of people and goods to the state are the Daniel K. Inouye International Airport and Honolulu Harbor. Each island also has critical points of entry along the coast. Because of their geographic location, ports and harbors as well as airports located on the coast are especially vulnerable to the tsunami hazard. Damages and closures to these critical facilities will likely be long-term, causing cascading economic impacts statewide.

The March 2011 tsunami that impacted Japan serves as a point of reference for potential losses to critical assets in the State of Hawai'i. As a result of the tsunami, cargo containers were floating in the flood waters; there is a similar concern that containers may fall into Honolulu Harbor not only losing the cargo itself but blocking ships from accessing the piers and the containers themselves becoming projectiles which can cause more damage. The O'ahu Metropolitan Planning Organization 2011 *Transportation Asset Climate Change Risk Assessment* estimates the Daniel K. Inouye International Airport will experience one-to-three days of downtime for emergency response, and one-to-two weeks of downtime for commercial flights after a tsunami event (SSFM International 2011).

Table 4.13-12. Community Lifelines and Critical Facilities in the GAT Inundation Area, by County

County	Community Lifeline Categories								Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medial	Safety & Security	Transportation	Total in the GAT Hazard Area	
County of Kaua'i	2	3	12	0	1	13	2	33	4
City and County of Honolulu	31	33	52	1	9	56	3	185	9
County of Maui	8	2	36	0	10	19	14	89	9
County of Hawai'i	11	6	22	1	4	4	5	53	4
Total	**52**	**44**	**122**	**2**	**24**	**92**	**24**	**360**	**26**

Source: Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Table 4.13-13. Community Lifelines and Critical Facilities in the SOEST Inundation Area, by County

County	Community Lifeline Categories								Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medial	Safety & Security	Transportation	Total in the SOEST Hazard Area	
County of Kaua'i	1	3	10	0	0	8	2	24	3
City and County of Honolulu	9	17	20	0	1	12	0	59	1
County of Maui	5	2	25	0	9	14	9	64	7
County of Hawai'i	0	5	19	1	0	1	5	31	4
Total	**15**	**27**	**74**	**1**	**10**	**35**	**16**	**178**	**15**

Source: Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Table 4.13-14. Community Lifelines and Critical Facilities in the ASCE Inundation Area, by County

County	Community Lifeline Categories								Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medial	Safety & Security	Transportation	Total in the ASCE Hazard Area	
County of Kaua'i	2	4	9	1	1	10	2	29	4
City and County of Honolulu	42	37	59	2	12	77	3	232	10
County of Maui	9	3	40	0	12	21	12	97	10
County of Hawai'i	11	6	25	1	4	6	6	59	7
Total	**64**	**50**	**133**	**4**	**29**	**114**	**23**	**417**	**31**

Source: Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Table 4.13-15. Community Lifelines and Critical Facilities in the GAT Inundation Area, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Communications	188	$776,797,683	52	27.66%	$185,980,872	23.94%
Energy	89	$3,093,949,530	44	49.44%	$1,453,398,520	46.98%
Food, Water, Shelter	345	$11,847,189,588	122	35.36%	$4,212,175,248	35.55%
Hazardous Material	12	$436,474,800	2	16.67%	$72,588,000	16.63%
Health and Medical	193	$4,606,713,364	24	12.44%	$187,830,564	4.08%
Safety and Security	486	$38,164,188,232	92	18.93%	$9,323,330,742	24.43%
Transportation	56	$2,039,091,600	24	42.86%	$872,949,600	42.81%
Additional Critical Facilities	106	$447,698,794	26	24.53%	$163,837,374	36.60%
Total	**1,475**	**$61,412,103,591**	**386**	**26.17%**	**$16,472,090,919**	**26.82%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020*

Table 4.13-16. Community Lifelines and Critical Facilities in the SOEST Inundation Area, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Communications	188	$776,797,683	15	7.98%	$61,615,375	7.93%
Energy	89	$3,093,949,530	27	30.34%	$852,194,460	27.54%
Food, Water, Shelter	345	$11,847,189,588	74	21.45%	$2,498,503,589	21.09%
Hazardous Material	12	$436,474,800	1	8.33%	$36,294,000	8.32%
Health and Medical	193	$4,606,713,364	10	5.18%	$111,959,314	2.43%
Safety and Security	486	$38,164,188,232	35	7.20%	$5,987,194,407	15.69%
Transportation	56	$2,039,091,600	16	28.57%	$580,704,000	28.48%
Additional Critical Facilities	106	$447,698,794	15	14.15%	$88,799,320	19.83%
Total	**1,475**	**$61,412,103,591**	**193**	**13.08%**	**$10,217,264,464**	**16.64%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020*

Table 4.13-17. Community Lifelines and Critical Facilities in the ASCE Inundation Area, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Communications	188	$776,797,683	64	34.04%	$227,259,427	29.26%
Energy	89	$3,093,949,530	50	56.18%	$1,679,393,240	54.28%
Food, Water, Shelter	345	$11,847,189,588	133	38.55%	$4,625,745,853	39.05%
Hazardous Material	12	$436,474,800	4	33.33%	$145,176,000	33.26%
Health and Medical	193	$4,606,713,364	29	15.03%	$274,599,521	5.96%
Safety and Security	486	$38,164,188,232	114	23.46%	$10,122,891,310	26.52%
Transportation	56	$2,039,091,600	23	41.07%	$836,655,600	41.03%
Additional Critical Facilities	106	$447,698,794	31	29.25%	$178,253,774	39.82%
Total	**1,475**	**$61,412,103,591**	**448**	**30.37%**	**$18,089,974,724**	**29.46%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020*

Assessment of Local Vulnerability and Potential Losses

This section provides a summary of vulnerability and potential losses to population, general building stock, and environmental resources and cultural assets by county.

Socially Vulnerable and Total Population

Table 4.13-18 displays the estimated population living in or near the GAT inundation area that could be impacted should a tsunami event occur (see Table 4.13-19 for the SOEST inundation area and Table 4.13-20 for the ASCE inundation area). For the purposes of the 2023 SHMP Update, the population vulnerable to possible tsunami inundation is considered the same as the exposed population. The degree of vulnerability of the population exposed is based on several factors:

- Is there a warning system?
- What is the lead time of the warning?
- What is the method of warning dissemination?
- Will the people evacuate when warned?

Table 4.13-18. 2020 U.S. Census Population Located in the GAT Inundation Area by County

County	Population				
	Total Population	Population in the GAT Hazard Area	Population Exposed as % of Total Population	Socially Vulnerable Population in the GAT Hazard Area	Socially Vulnerable Population Exposed as % of Total Population
County of Kaua'i	71,949	4,490	6.24%	532	0.74%
City and County of Honolulu	979,682	126,570	12.92%	27,767	2.83%
County of Maui	167,093	21,784	13.04%	4,077	2.44%
County of Hawai'i	201,350	9,098	4.52%	7,325	3.64%
Total	**1,420,074**	**161,942**	**11.40%**	**39,701**	**2.80%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018*

Table 4.13-19. 2020 U.S. Census Population Located in the SOEST Inundation Area by County

County	Population				
	Total Population	Population in the SOEST Hazard Area	Population Exposed as % of Total Population	Socially Vulnerable Population in the SOEST Hazard Area	Socially Vulnerable Population Exposed as % of Total Population
County of Kaua'i	71,949	2,583	3.59%	273	0.38%
City and County of Honolulu	979,682	34,999	3.57%	10,655	1.09%
County of Maui	167,093	14,239	8.52%	1,804	1.08%
County of Hawai'i	201,350	2,607	1.29%	710	0.35%
Total	**1,420,074**	**54,428**	**3.83%**	**13,442**	**0.95%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018*

Table 4.13-20. 2020 U.S. Census Population Located in the ASCE Inundation Area by County

County	Population				
	Total Population	Population in the ASCE Hazard Area	Population Exposed as % of Total Population	Socially Vulnerable Population in the ASCE Hazard Area	Socially Vulnerable Population Exposed as % of Total Population
County of Kauaʻi	71,949	4,861	6.76%	645	0.90%
City and County of Honolulu	979,682	197,348	20.14%	51,346	5.24%
County of Maui	167,093	33,194	19.87%	8,520	5.10%
County of Hawaiʻi	201,350	12,145	6.03%	8,621	4.28%
Total	**1,420,074**	**247,548**	**17.43%**	**69,132**	**4.87%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018

The analysis indicates that the City and County of Honolulu has the greatest number of people (126,570) located in the GAT inundation area; the SOEST and ASCE indicate the same with populations of (34,999) and (197,348), respectively. This analysis does not include the number of tourists and visitors in the state; some may be located on the beach or in other recreational areas or in lodgings that are located in GAT, SOEST, and ASCE inundation areas. Therefore, this estimate may be underestimating exposure and vulnerability. Hazus estimates a higher day population exposed to the GAT, SOEST, and ASCE inundation areas compared to the night population exposed. Therefore, the exposed population depends on the time of day the tsunami occurs.

The populations considered most vulnerable include children, elderly (persons over the age of 65), and individuals with access and functional needs. Socially vulnerable populations are most susceptible based on many factors, including their physical and financial ability to react or respond during a hazard. The cost of interventions to protect properties from tsunami risk may financially stress lower- or middle-income residents. Relocating may be difficult because of the expenses and the availability of accessible housing or the time needed to make housing accessible. The high vulnerability population makes up about 27.92% of the total population residing in the hazard area. Visitors recreating in or around the inundation areas are also vulnerable because they may not be as familiar with appropriate response and the best way to reach higher ground.

Tsunami events can cause injuries and fatalities if timely evacuation does not occur. Further, tsunami waves can carry debris and people out to sea when they retreat. Hazus estimates the number of casualties based on three community tsunami preparedness scenarios ranging from good to poor. “Good” is intended for well-prepared communities such as Tsunami Ready communities. All counties and many communities throughout the state are Tsunami Ready. “Poor” is considered for a community with little to no experience or education programs available. The guidance from Hazus is that areas with large visitor populations, such as the state, may incorporate more than one preparedness level into their planning. Table 4.13-21 summarizes the estimated casualties (fatalities and injuries) Hazus estimates as a result of the GAT (see Table 4.13-22 for SOEST and Table 4.13-23 for ASCE).

Table 4.13-21. Estimated GAT Fatalities and Injuries by Community Preparedness Level

	Community Preparedness Level								
	Good			Fair			Poor		
County	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties
County of Kaua'i	0	0	0	2,260	81	2,341	6,953	102	7,056
City and County of Honolulu	0	0	0	39,802	2,118	41,921	126,964	2,604	129,567
County of Maui	0	0	0	8,225	245	8,471	25,396	325	25,722
County of Hawai'i	0	0	0	4,187	149	4,336	12,862	191	13,052
Total	**0**	**0**	**0**	**54,474**	**2,594**	**57,068**	**172,175**	**3,222**	**175,397**

Source: Tetra Tech Requested Data from Doug Bausch 2022
The estimated number of injuries and fatalities is based on the daytime population which is higher than the night population to provide a worst-case scenario for planning purposes.

Table 4.13-22. Estimated SOEST Fatalities and Injuries by Community Preparedness Level

	Community Preparedness Level								
	Good			Fair			Poor		
County	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties
County of Kaua'i	0	0	0	1,299	33	1,332	4,165	48	4,213
City and County of Honolulu	0	0	0	13,610	68	13,678	44,279	222	44,501
County of Maui	0	0	0	5,630	134	5,764	18,047	200	18,247
County of Hawai'i	0	0	0	1,185	26	1,211	3,843	40	3,883
Total	**0**	**0**	**0**	**21,724**	**261**	**21,986**	**70,334**	**510**	**70,844**

Source: Tetra Tech Requested Data from Doug Bausch 2022
The estimated number of injuries and fatalities is based on the daytime population which is higher than the night population to provide a worst-case scenario for planning purposes.

Table 4.13-23. Estimated ASCE Fatalities and Injuries by Community Preparedness Level

	Community Preparedness Level								
	Good			Fair			Poor		
County	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties
County of Kaua'i	0	0	0	2,035	71	2,106	6,180	93	6,273
City and County of Honolulu	0	0	0	63,351	4,324	67,675	194,226	4,856	199,082
County of Maui	0	0	0	10,757	188	10,945	31,704	285	31,989
County of Hawai'i	0	0	0	5,111	248	5,359	14,987	266	15,253
Total	**0**	**0**	**0**	**81,254**	**4,831**	**86,085**	**247,097**	**5,500**	**252,597**

Source: Tetra Tech Requested Data from Doug Bausch 2022
The estimated number of injuries and fatalities is based on the daytime population which is higher than the night population to provide a worst-case scenario for planning purposes.

According to the Centers for Disease Control and Prevention, the primary health concerns after a tsunami event include clean drinking water, food, shelter and medical care for injuries. Flood waters can pose health risks, such as contaminated water and food supplies. Most deaths from tsunamis are related to drowning; however, traumatic injuries are also a primary concern. Medical care is critical in areas impacted by a tsunami (CDC 2013).

After a tsunami, residents should not return home until after local officials indicate it is safe. It cannot be assumed that after one wave the danger is over; a tsunami is a series of waves that may continue for hours. Debris in the water may be a safety hazard to both people and pets. Residents should not enter their homes or other buildings when they have water in and around the structure; the floors may be cracked, and the walls may collapse.

General Building Stock

All structures along the coast are vulnerable to a tsunami. Waves and scouring associated with debris that may be carried in the water could damage or destroy structures in the tsunami's path. Similar to the analyses presented earlier, the general building stock data was overlaid with the tsunami hazard area to assess exposure; or buildings located in the GAT, SOEST, and ASCE inundation areas. The City and County of Honolulu has the greatest replacement cost value of buildings located in the GAT, SOEST, and ASCE inundation areas. See Table 4.13-24 for the values by county for the GAT inundation area, Table 4.13-25 for the SOEST, and Table 4.13-26 for the ASCE.

The PDC calculated estimated potential building damage as a result of the GAT, SOEST, and ASCE. Total building loss includes structural damage cost, non-structural damage cost and content damage cost. Greater than $47 billion in building damages, or 12.67% of the state's total inventory, is estimated in the GAT inundation area. Greater than $29 billion in building damages, or 8.02% of the state's total inventory, is estimated in the SOEST inundation area. Greater than $73 billion in building damages, or 19.85% of the state's total inventory, is estimated in the ASCE inundation area.

Hazus estimates business interruption losses as a result of a tsunami event. Business interruption losses are the losses associated with the inability to operate a business because of the damage sustained from the tsunami. These losses also include temporary living expenses for those people displaced from their homes (relocation loss). Business interruption losses are in addition to the direct building-related losses listed in the tables above. Table 4.13-27 summarizes the business interruption losses that the state may incur for the GAT inundation area. Table 4.13-28 and Table 4.13-29 summarize the business interruption losses that the state may incur for the SOEST and ASCE inundation area.

Land Use Districts

Table 4.13-30 shows the square miles of the tsunami hazard area in each State Land Use District statewide for the GAT inundation area (see Table 4.13-31 for the SOEST and Table 4.13-32 for the ASCE); refer to Appendix F (State Profile and Risk Assessment Supplement) for results for each county. In the GAT inundation area, more than 16% of Urban District lands statewide are exposed to the tsunami hazard (7.40% in the SOEST and 24.6% in the ASCE), which is concerning due to the concentration of development in these areas. Although tsunami risk is considered to some extent in the delineation of special flood hazard areas (SFHA) in the state (areas where flood resistant construction standards apply), the inundation area from the GAT and ASCE events includes more than double the amount of Urban District lands than are located in the SFHA.

Table 4.13-24. General Building Stock Exposure and Potential Losses to the GAT by County

County	Total Value	Replacement Cost Value in Hazard Area	Replacement Cost Value Exposed as % of Total	Estimated Economic Loss (Losses for Building, Content, Wage, Income, Relocation, and Lost Rent Payments)
County of Kaua'i	$24,246,497,228	$6,043,289,106	24.92%	$5,260,235,045
City and County of Honolulu	$239,152,051,766	$62,462,635,336	26.12%	$20,183,707,566
County of Maui	$50,796,693,140	$17,557,864,308	34.56%	$13,752,319,875
County of Hawai'i	$58,395,349,136	$7,721,540,430	13.22%	$8,029,150,184
Total	**$372,590,591,270**	**$93,785,329,180**	**25.17%**	**$47,225,412,670**

Source: Tetra Tech Requested Data from Doug Bausch 2022; NIYAM IT 2022; United States Army Corps of Engineers 2022

Table 4.13-25. General Building Stock Exposure and Potential Losses to the SOEST by County

County	Total Value	Replacement Cost Value in Hazard Area	Replacement Cost Value Exposed as % of Total	Estimated Economic Loss (Losses for Building, Content, Wage, Income, Relocation, and Lost Rent Payments)
County of Kaua'i	$24,246,497,228	$3,710,486,185	15.30%	$2,972,790,392
City and County of Honolulu	$239,152,051,766	$18,035,989,197	7.54%	$16,352,343,198
County of Maui	$50,796,693,140	$10,881,098,937	21.42%	$7,798,734,287
County of Hawai'i	$58,395,349,136	$2,807,678,584	4.81%	$2,784,799,873
Total	**$372,590,591,270**	**$35,435,252,903**	**9.51%**	**$29,908,667,750**

Source: Tetra Tech Requested Data from Doug Bausch 2022; NIYAM IT 2022; United States Army Corps of Engineers 2022

Table 4.13-26. General Building Stock Exposure and Potential Losses to the ASCE by County

County	Total Value	Replacement Cost Value in Hazard Area	Replacement Cost Value Exposed as % of Total	Estimated Economic Loss (Losses for Building, Content, Wage, Income, Relocation, and Lost Rent Payments)
County of Kaua'i	$24,246,497,228	$6,219,253,544	25.65%	$5,830,032,601
City and County of Honolulu	$239,152,051,766	$77,628,500,586	32.46%	$37,743,118,057
County of Maui	$50,796,693,140	$18,804,707,390	37.02%	$19,583,636,497
County of Hawai'i	$58,395,349,136	$10,192,980,322	17.46%	$10,824,663,660
Total	**$372,590,591,270**	**$112,845,441,842**	**30.29%**	**$73,981,450,814**

Source: Tetra Tech Requested Data from Doug Bausch 2022; NIYAM IT 2022; United States Army Corps of Engineers 2022

Table 4.13-27. Business Interruption Losses as a result of the GAT by County

County	Total Economic Loss	Relocation Loss	Capital-Related Loss	Wages Loss	Rental Income Loss
County of Kaua'i	$1,398,000,000	$181,000,000	$206,000,000	$810,000,000	$201,000,000
City and County of Honolulu	$3,191,000,000	$716,000,000	$725,000,000	$1,244,000,000	$506,000,000
County of Maui	$2,542,000,000	$321,000,000	$613,000,000	$1,122,000,000	$485,000,000
County of Hawai'i	$1,629,000,000	$190,000,000	$360,000,000	$905,000,000	$174,000,000
Total	**$8,760,000,000**	**$1,408,000,000**	**$1,904,000,000**	**$4,081,000,000**	**$1,366,000,000**

Source: Tetra Tech Requested Data from Doug Bausch 2022; Hazus 5.1

Table 4.13-28. Business Interruption Losses as a result of the SOEST by County

County	Total Economic Loss	Relocation Loss	Capital-Related Loss	Wages Loss	Rental Income Loss
County of Kaua'i	$536,000,000	$85,000,000	$102,000,000	$260,000,000	$90,000,000
City and County of Honolulu	$515,000,000	$135,000,000	$106,000,000	$159,000,000	$114,000,000
County of Maui	$1,418,000,000	$196,000,000	$384,000,000	$594,000,000	$243,000,000
County of Hawai'i	$541,000,000	$60,000,000	$132,000,000	$243,000,000	$107,000,000
Total	**$3,010,000,000**	**$476,000,000**	**$724,000,000**	**$1,256,000,000**	**$554,000,000**

Source: Tetra Tech Requested Data from Doug Bausch 2022; Hazus 5.1

Table 4.13-29. Business Interruption Losses as a result of the ASCE by County

County	Total Economic Loss	Relocation Loss	Capital-Related Loss	Wages Loss	Rental Income Loss
County of Kaua'i	$1,103,000,000	$151,000,000	$191,000,000	$574,000,000	$187,000,000
City and County of Honolulu	$4,782,000,000	$1,118,000,000	$1,079,000,000	$1,744,000,000	$840,000,000
County of Maui	$3,355,000,000	$472,000,000	$805,000,000	$1,423,000,000	$655,000,000
County of Hawai'i	$2,398,000,000	$250,000,000	$435,000,000	$1,467,000,000	$247,000,000
Total	**$11,638,000,000**	**$1,991,000,000**	**$2,510,000,000**	**$5,208,000,000**	**$1,929,000,000**

Source: Tetra Tech Requested Data from Doug Bausch 2022; Hazus 5.1

Table 4.13-30. State Land Use Districts Located in the GAT Inundation Area

Land Use District	Total (square miles)	Square Miles in Tsunami Hazard Area	Percent (%) of Total Area
Agricultural	2,973.6	42.2	1.4%
Conservation	3,202.9	18.4	0.6%
Rural	16.3	0.6	3.7%
Urban	319.1	53.7	16.8%
Total	**6,511.9**	**114.9**	**1.8%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State Land Use Commission, Hawai'i Statewide GIS Program 2021; Honolulu County GIS 2022

Table 4.13-31. State Land Use Districts Located in the SOEST Inundation Area

Land Use District	Total (square miles)	Square Miles in Tsunami Hazard Area	Percent (%) of Total Area
Agricultural	2,973.6	19.8	0.67%
Conservation	3,202.9	10.7	0.33%
Rural	16.3	0.4	2.45%
Urban	319.1	23.6	7.40%
Total	**6,511.9**	**54.5**	**0.84%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State Land Use Commission, Hawai'i Statewide GIS Program 2021; Honolulu County GIS 2022

Table 4.13-32. State Land Use Districts Located in the ASCE Inundation Area

Land Use District	Total (square miles)	Square Miles in Tsunami Hazard Area	Percent (%) of Total Area
Agricultural	2,973.6	58.8	2.0%
Conservation	3,202.9	27.3	0.9%
Rural	16.3	0.7	4.3%
Urban	319.1	78.4	24.6%
Total	**6,511.9**	**165.2**	**2.5%**

Source: Tetra Tech Requested Data from Doug Bausch 2022; State Land Use Commission, Hawai'i Statewide GIS Program 2021; Honolulu County GIS 2022

This means that development in these areas is unlikely to have been constructed within any considerations for flood damage reduction and that many of these structures will not be insured against flood losses. Although only less than 1% of the Conservation District lands are exposed to the tsunami hazard for each of the inundation areas, there may be significant ecological consequences in these areas, particularly in the nearshore environment. Conservation District lands contain valuable environmental resources. Additional discussion of exposure and vulnerability of these resource areas can be found in the discussion on environmental resources below.

Environmental Resources

The loss of natural resources across the state is difficult to quantify. Not only do coral reefs benefit the environment, but they also provide protection from tsunamis. Coasts with offshore reefs receive less wave energy than unprotected coastlines lying in the path of an approaching tsunami. Small islands may experience reduced runup as the tsunami waves may refract around them. Fringing and barrier reefs appear to have a mitigating influence on tsunamis by dispersing the wave energy (State of Hawaiʻi 2018).

Tsunami impacts range from loss of livelihood for fishermen to damages to coral reefs, flora and fauna, and beach loss, all of which have cascading economic impacts statewide. An economic impact analysis was conducted for Waikīkī Beach to estimate the potential economic impact if the beach was completely eroded, whether the cause be a tsunami, flood event or climate change. The economic impact on total hotel revenues could be as much as $661.2 million annually, with 6,352 lost jobs in the hotel industry. This is just one example of the potential economic impact to one sector due to the loss of one environmental resource (University of Hawaiʻi 2018).

As discussed above, there are 42.2 square miles of agricultural land located in the GAT inundation area, 19.8 in the SOEST, and 58.8 in the ASCE. As a result of tsunami waves traveling potentially miles inland, salinization of the land may cause soil to be less fertile and increase vulnerability to erosion (World Ecology Foundation 2022).

Septic tanks, cesspools, and other on-site sewage disposal systems are located along the coast. There is a concern that chronic flooding will impact these systems and release wastewater and hazardous materials and waste into nearshore waters and coastal habitats as discussed in the 2017 *Hawai'i Sea Level Rise and Vulnerability Assessment Report*. A tsunami may lead to the failure of these systems diminishing water quality, impacting natural aquatic systems and leading to human health exposure to these hazardous wastes.

Due to its geographic location and isolation, the state faces unique challenges in addressing disaster debris. With limited landfill capacity, advanced planning for large amounts of debris generated by a tsunami is critical. Hazardous materials may be mixed with the debris and need to be considered during staging and disposal.

A spatial analysis was conducted to estimate the square miles of environmental resources, including critical habitat (or habitats that are known to be essential for an endangered or threatened species), wetlands, and parks and reserves located in the GAT, SOEST, and ASCE inundation areas. These results are summarized in Table 4.13-33, Table 4.13-34, and Table 4.13-35, respectively.

Table 4.13-33. Environmental Resource Areas Located in the GAT Inundation Area

Environmental Resource	Statewide		
	Total Square Miles of Resources	Square Miles in the GAT Inundation Area	Percent (%) of Total Resource Area
Critical Habitat [a]	951	2	0.3%
Wetlands	3,637	22	0.6%
Parks and Reserves	2,778	16	0.6%
Reefs [b]	55	1	1.4%
Total [c]	**7,420**	**42**	**0.6%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; U.S. Fish and Wildlife Service, Pacific Islands Office, 2022a, U.S. Fish and Wildlife Service 2021e; 2017b, Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022, NOAA raster nautical charts 2020b, State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021*

Notes: *a. Critical area mileage includes the combined area of coverage of individual critical habitat areas.*

b. Reefs include artificial and coral reefs.

c. Total square miles includes environmental assets within 3 nautical miles of each county and may be over-reported as some environmental asset areas may overlap.

Table 4.13-34. Environmental Resource Areas Located in the SOEST Inundation Area

Environmental Resource	Statewide		
	Total Square Miles of Resources	Square Miles in the SOEST Inundation Area	Percent (%) of Total Resource Area
Critical Habitat [a]	951	1	0.1%
Wetlands	3,637	18	0.5%
Parks and Reserves	2,778	9	0.3%
Reefs [b]	55	1	1.9%
Total [c]	**7,420**	**29**	**0.4%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; U.S. Fish and Wildlife Service, Pacific Islands Office, 2022a, U.S. Fish and Wildlife Service 2021e; 2017b, Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022, NOAA raster nautical charts 2020b, State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021*

Notes: *a. Critical area mileage includes the combined area of coverage of individual critical habitat areas.*

b. Reefs include artificial and coral reefs.

c. Total square miles includes environmental assets within 3 nautical miles of each county and may be over-reported as some environmental asset areas may overlap.

Table 4.13-35. Environmental Resource Areas Located in the ASCE Inundation Area

Environmental Resource	Statewide		
	Total Square Miles of Resources	Square Miles in the ASCE Inundation Area	Percent (%) of Total Resource Area
Critical Habitat [a]	951	3	0.3%
Wetlands	3,637	26	0.7%
Parks and Reserves	2,778	22	0.8%
Reefs [b]	55	1	1.4%
Total [c]	**7,420**	**52**	**0.7%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; U.S. Fish and Wildlife Service, Pacific Islands Office, 2022a, U.S. Fish and Wildlife Service 2021e; 2017b, Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022, NOAA raster nautical charts 2020b, State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021*

Notes: *a. Critical area mileage includes the combined area of coverage of individual critical habitat areas.*

b. Reefs include artificial and coral reefs.

c. Total square miles includes environmental assets within 3 nautical miles of each county and may be over-reported as some environmental asset areas may overlap.

Cultural Assets

Many Native Hawaiian cultural and historical resources are located near the shore and are threatened by a tsunami event, including fishing and cultural practices. The population, built and natural environment, and cultural sites located on Hawaiian Home Lands are vulnerable to the tsunami hazard (see Table 4.13-36 – Table 4.13-38). The County of Hawaiʻi has the greatest number of square miles (2.1 square miles) located in the GAT inundation area; followed by the City and County of Honolulu (1.4 square miles). The County of Hawaiʻi and the County of Kaua'i both have the greatest number of square miles (0.3 square miles) located in the SOEST inundation area, followed by the City and County of Honolulu (0.2 square miles). The County of Hawaiʻi has the greatest number of square miles (3.2 square miles) located in the ASCE inundation area, followed by the City and County of Honolulu (1.6 square miles).

Table 4.13-39, Table 4.13-40, and Table 4.13-41 summarize the cultural resources located in the GAT, SOEST, and ASCE inundation areas, respectively. The cultural resource type with the largest total area and largest area in each of the inundation areas is the Historic District, followed by Archaeological Sites.

Table 4.13-36. Hawaiian Home Lands Located in the GAT Inundation Area

County	Area (in square miles)		
	Total Area	Hawaiian Home Land in the GAT Inundation Area	Percent (%) of Total Area
County of Kauaʻi	32.1	0.8	2.5%
City and County of Honolulu	10.6	1.4	12.9%
County of Maui	102.6	0.1	0.1%
County of Hawaiʻi	191.5	2.1	1.1%
Total	**336.7**	**4.4**	**1.3%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i State Department of Hawaiian Homelands 2021*

Table 4.13-37. Hawaiian Home Lands Located in the SOEST Inundation Area

County	Area (in square miles)		
	Total Area	Hawaiian Home Land in the SOEST Inundation Area	Percent (%) of Total Area
County of Kaua'i	32.1	0.3	0.9%
City and County of Honolulu	10.6	0.2	1.8%
County of Maui	102.6	0.0	0.0%
County of Hawai'i	191.5	0.3	0.2%
Total	**336.7**	**0.8**	**0.3%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i State Department of Hawaiian Homelands 2021*

Table 4.13-38. Hawaiian Home Lands Located in the ASCE Inundation Area

County	Area (in square miles)		
	Total Area	Hawaiian Home Land in the ASCE Inundation Area	Percent (%) of Total Area
County of Kaua'i	32.1	0.8	2.3%
City and County of Honolulu	10.6	1.6	15.2%
County of Maui	102.6	0.5	0.4%
County of Hawai'i	191.5	3.2	1.7%
Total	**336.7**	**6.1**	**1.8%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Hawai'i State Department of Hawaiian Homelands 2021*

Table 4.13-39. Cultural Resources Located in the GAT Inundation Area

Cultural Resource Site Type	Area (in square miles)		
	Total Square Miles of Asset	Total Square Miles in GAT Inundation Area	Percent (%) of Total Asset Area
Archaeology	90.892401	6.314457	6.95%
Burial Sensitivity Area	2.074551	0.88416	42.62%
Historic Building	2.680785	0.469084	17.50%
Historic District	849.360596	12.324423	1.45%
Historic Object	9.6143	0.000252	0.00%
Historic Structure	20.739072	0.532644	2.57%
Total	**975.361705**	**20.52502**	**2.10%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022*

Table 4.13-40. Cultural Resources Located in the SOEST Inundation Area

Cultural Resource Site Type	Area (in square miles)		
	Total Square Miles of Asset	Total Square Miles in SOEST Inundation Area	Percent (%) of Total Asset Area
Archaeology	90.892401	2.633448	2.90%
Burial Sensitivity Area	2.074551	0.605631	29.19%
Historic Building	2.680785	0.313276	11.69%
Historic District	849.360596	6.893097	0.81%
Historic Object	9.6143	0.000122	0.00%
Historic Structure	20.739072	0.373213	1.80%
Total	**975.361705**	**10.818787**	**1.11%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022*

Table 4.13-41. Cultural Resources Located in the ASCE Inundation Area

Cultural Resource Site Type	Area (in square miles)		
	Total Square Miles of Asset	Total Square Miles in ASCE Inundation Area	Percent (%) of Total Asset Area
Archaeology	90.892401	9.997949	11.00%
Burial Sensitivity Area	2.074551	0.888939	42.85%
Historic Building	2.680785	0.621512	23.18%
Historic District	849.360596	21.163075	2.49%
Historic Object	9.6143	0.000484	0.01%
Historic Structure	20.739072	0.803514	3.87%
Total	**975.361705**	**33.475473**	**3.43%**

Source: *Tetra Tech Requested Data from Doug Bausch 2022; Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022*

Future Changes that May Impact State Vulnerability

Understanding future changes that impact vulnerability in the state can assist in planning for future development and ensuring that appropriate mitigation, planning, and preparedness measures are in place. The state considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development
- Projected changes in population
- Other identified conditions as relevant and appropriate, including the impacts of climate change

Potential or Projected Development

The tsunami hazard area was overlain on areas that may experience significant changes in development or redevelopment in future years (see Table 4.13-42, Table 4.13-43, and Table 4.13-44 below and refer to Section 3 [State Profile] for more information on projected development areas). The results of this assessment indicate almost half (48%) of the Hawaiʻi Community Development Authority (HCDA) Community Development Districts are located in tsunami hazard areas in the GAT and ASCE inundation areas.

Table 4.13-42. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones Located in the GAT Inundation Area

County	Area (in square miles)								
	HCDA Community Development Districts (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area	Maui Development Projects (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area	Enterprise Zones (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area
County of Kaua'i	0	0	0	0	0	0	251	21.4	8.53%
City and County of Honolulu	7.4	3.05	41.22%	0	0	0	297.3	29.9	10.06%
County of Maui	0	0	0	27.6	0.5	1.81%	1,059.80	14.4	1.36%
County of Hawai'i	0	0	0.00%	0	0	0	1,274.90	14.1	1.11%
Total	**7.4**	**3.05**	**41.22%**	**27.6**	**0.5**	**1.81%**	**2,883.00**	**79.8**	**2.77%**

Source: Maui County Planning Department 2016; Hawai'i Community Development Authority 2021; Community Economic Development Program, Department of Business, Economic Development & Tourism, County Planning Departments 2021; Tetra Tech Requested Data from Doug Bausch 2022

Table 4.13-43. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones Located in the SOEST Inundation Area

County	Area (in square miles)								
	HCDA Community Development Districts (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area	Maui Development Projects (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area	Enterprise Zones (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area
County of Kaua'i	0	0	0.0%	0	0	0.0%	251	15.4	6.1%
City and County of Honolulu	7.4	0.7	9.5%	0	0	0.0%	297.3	12.2	4.1%
County of Maui	0	0	0.0%	27.6	0.28	1.0%	1,059.80	9.3	0.9%
County of Hawai'i	0	0	0.0%	0	0	0.0%	1,274.90	3.5	0.3%
Total	**7.4**	**0.7**	**9.5%**	**27.6**	**0.28**	**1.0%**	**2,883.00**	**40.4**	**1.4%**

Source: Maui County Planning Department 2016; Hawai'i Community Development Authority 2021; Community Economic Development Program, Department of Business, Economic Development & Tourism, County Planning Departments 2021; Tetra Tech Requested Data from Doug Bausch 2022

Table 4.13-44. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones Located in the ASCE Inundation Area

County	Area (in square miles)								
	HCDA Community Development Districts (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area	Maui Development Projects (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area	Enterprise Zones (Total Area)	Total Area Exposed to Hazard	Hazard Area as Percent (%) of Total Area
County of Kauaʻi	0	0	0.00%	0	0	0.00%	251	23.6	9.40%
City and County of Honolulu	7.4	3.7	50.00%	0	0	0.00%	297.3	38	12.78%
County of Maui	0	0	0.00%	27.6	1.04	3.77%	1,059.80	19.9	1.88%
County of Hawaiʻi	0	0	0.00%	0	0	0.00%	1,274.90	25.2	1.98%
Total	**7.4**	**3.7**	**50.00%**	**27.6**	**1.04**	**3.77%**	**2,883.00**	**106.7**	**3.70%**

Source: *Maui County Planning Department 2016; Hawai'i Community Development Authority 2021; Community Economic Development Program, Department of Business, Economic Development & Tourism, County Planning Departments 2021; Tetra Tech Requested Data from Doug Bausch 2022*

None of these areas are located in the special flood hazard area, so it is unlikely that construction is to standards that would be able to withstand impacts from a tsunami event. Relatively small amounts of the Maui Development Project and Enterprise Zone areas are exposed to the tsunami hazard in the GAT and ASCE inundation areas; however, the exposed area is also greater than the special flood hazard area in these areas.

Projected Changes in Population

As the population in the state ages, more of the state's residents may be unable to quickly evacuate in the event of a local-source tsunami, and additional resources may be needed to support evacuation efforts in the event of a distant-source tsunami.

Other Factors of Change

As sea levels rise, inundation from tsunamis will reach further inland putting more people and property at risk.