



## SECTION 4. RISK ASSESSMENT

### 4.13 Tsunami

#### 2018 HMP UPDATE CHANGES

- ❖ The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, and probability of future occurrence (including climate change).
- ❖ Tsunami events that occurred in Hawai'i from January 1, 2012, through December 31, 2017, were researched for this 2018 HMP Update.
- ❖ New and updated figures from federal and state agencies are incorporated.
- ❖ The Great Aleutian Tsunami (GAT) inundation area was used to assess exposure and vulnerability.

#### 4.13.1 Hazard Profile

##### HAZARD DESCRIPTION

*Figure 4.13-1. Arrival of Major Wave at Lā'ie Point (Honolulu), March 1957*



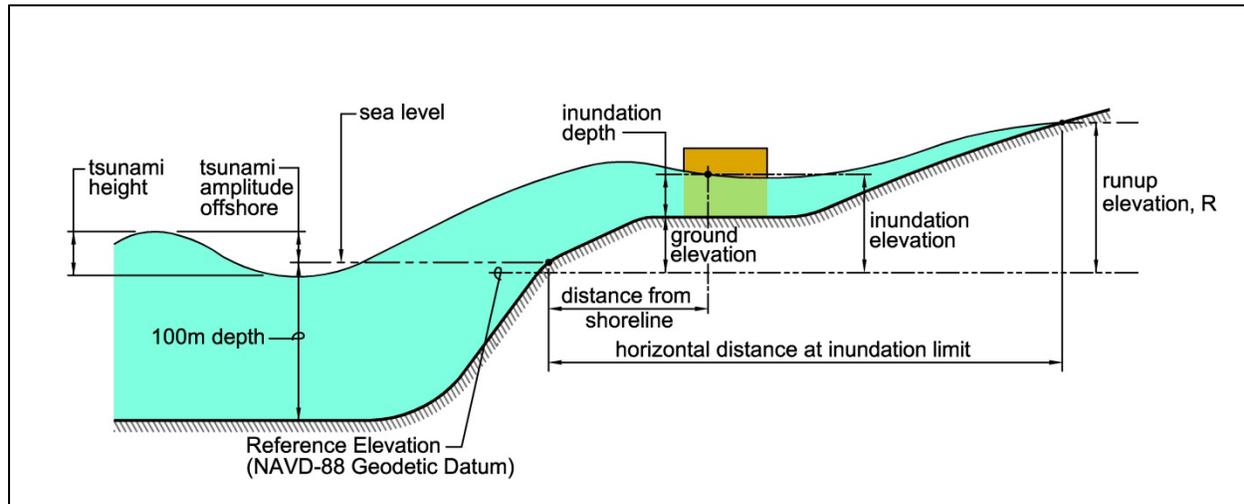
Source: NOAA NGDC 2018

Tsunamis are a series of enormous waves created by an underwater disturbance such as an earthquake, landslide, volcanic eruption, or meteorite. 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 4.13-2 illustrates the makeup of a tsunami and associated terminology.

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 2018). Although landslides and volcanoes cause some local tsunamis, more than 95 percent of tsunamis result from subduction earthquakes (Hawai'i State HMP 2013).



**Figure 4.13-2. Illustration of Tsunami Terminology**



Source: Hawai'i State HMP 2013 (Courtesy of ASCE 7 Tsunami Loads and Effects Subcommittee)

The earthquakes associated with tsunamis are referred to as “tsunamigenic” earthquakes. The association between earthquakes and tsunamis results from the fact that both are generated by the tectonic displacement of the earth’s crust. 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, which acting under the influence of gravity, attempts to regain its equilibrium (Hawai'i State HMP 2013). Refer to Section 4.5 (Earthquakes) for details on the earthquake hazard.

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 (Hawai'i State HMP 2013).

Tsunamis are characterized as shallow-water waves—that is 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 100 to 200 meters (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 100 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.

When a tsunami finally reaches the shore, it may appear as a rapidly rising or falling tide, a series of breaking waves, or even a bore (a step-like wave with a steep breaking front). Although most people imagine a tsunami as a large, steep wave breaking on the shore, 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. Experience has shown that wave heights increase in bays that narrow from the entrance to the



head, but decrease in bays that have narrow entrances. Unlike storm waves, tsunami waves may be very large in embayments, actually experiencing amplification in long funnel-shaped bays. However, shorelines protected by reefs typically do not sustain extensive damage from tsunamis as the reefs disperse the wave energy. Islands in a group may “shadow” one another reducing the tsunami effect. Small islands may experience reduced runup as the tsunami waves may refract around them (USGS 2002; State of Hawai'i 2013).

**LOCATION**

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 Hawai'i. 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 Hawai'i, 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 (Hawai'i State HMP 2013).

The entire state (all islands) may be impacted by a tsunami. 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 Hawai'i. This extreme tsunami was modeled to understand potential impacts on the State and is called the Great Aleutian Tsunami (GAT). Very roughly, the expected recurrence interval for a GAT is 1,000 years (Hawai'i News Now 2014).

The GAT inundation data was provided by the PDC for analysis in the 2018 HMP Update. Table 4.13-1 shows the GAT inundation area in square miles and the percent of the total area by county. In general, the GAT inundation area is larger than the coastal flood inundation area depicted on FEMA FIRMs (discussed in Section 4.6). The City and County of Honolulu has the largest area that may be inundated (61 square miles), followed by the County of Kaua'i.

**Table 4.13-1. GAT Inundation Area by County**

County	Area (in square miles)		
	Total Area	Hazard Area	Hazard Area as Percent (%) of Total Area
County of Kaua'i	620.0	32.8	5.3%
City and County of Honolulu	600.7	61.0	10.2%
County of Maui	1,173.5	28.9	2.5%
County of Hawai'i	4,028.4	20.2	0.5%
<b>Total</b>	<b>6,422.6</b>	<b>143.0</b>	<b>2.2%</b>

Source: PDC 2017

Notes: PDC Pacific Disaster Center



Figure 4.13-3. Great Aleutian Tsunami Inundation Area in the County of Kaua'i

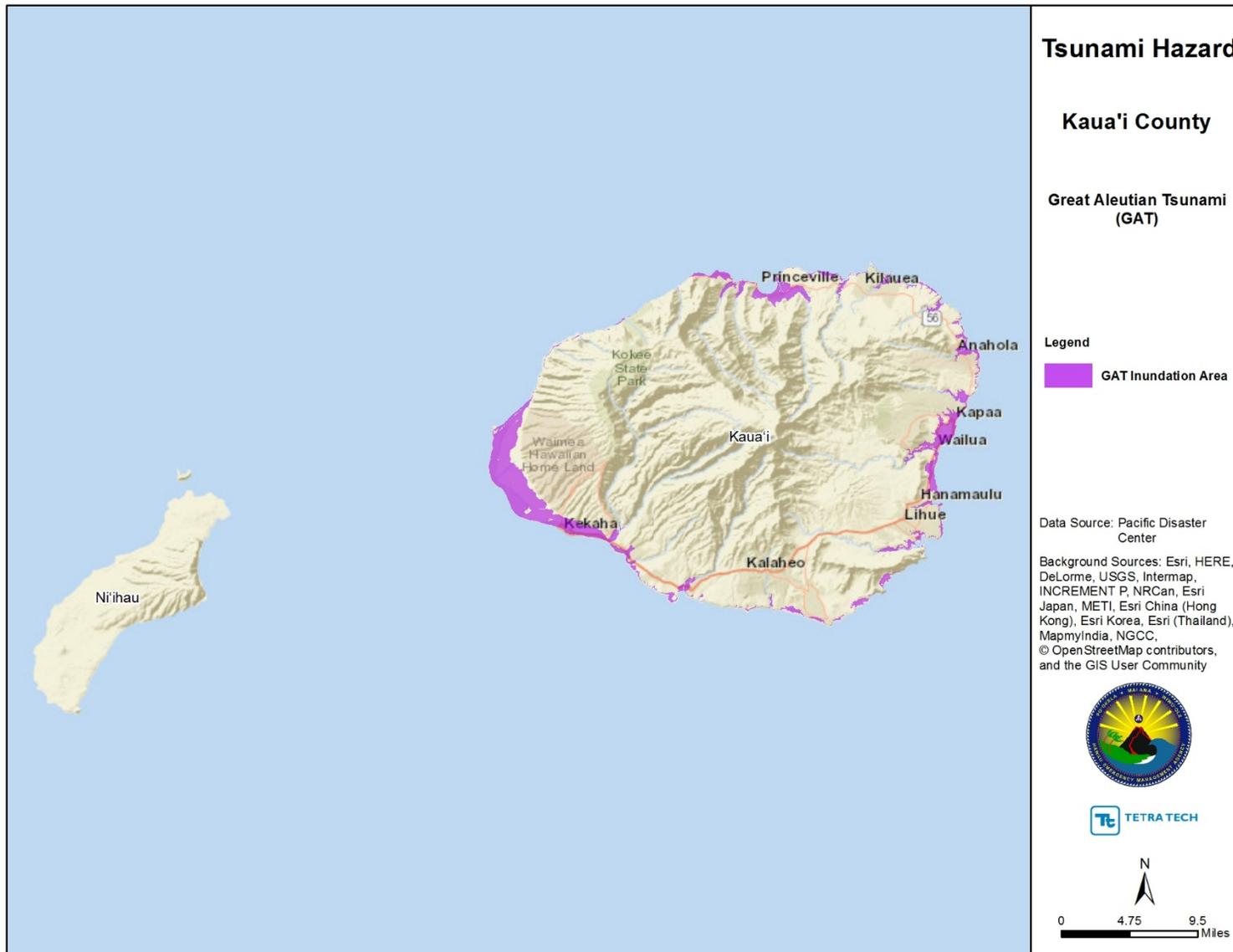




Figure 4.13-4. Great Aleutian Tsunami Inundation Area in the City and County of Honolulu

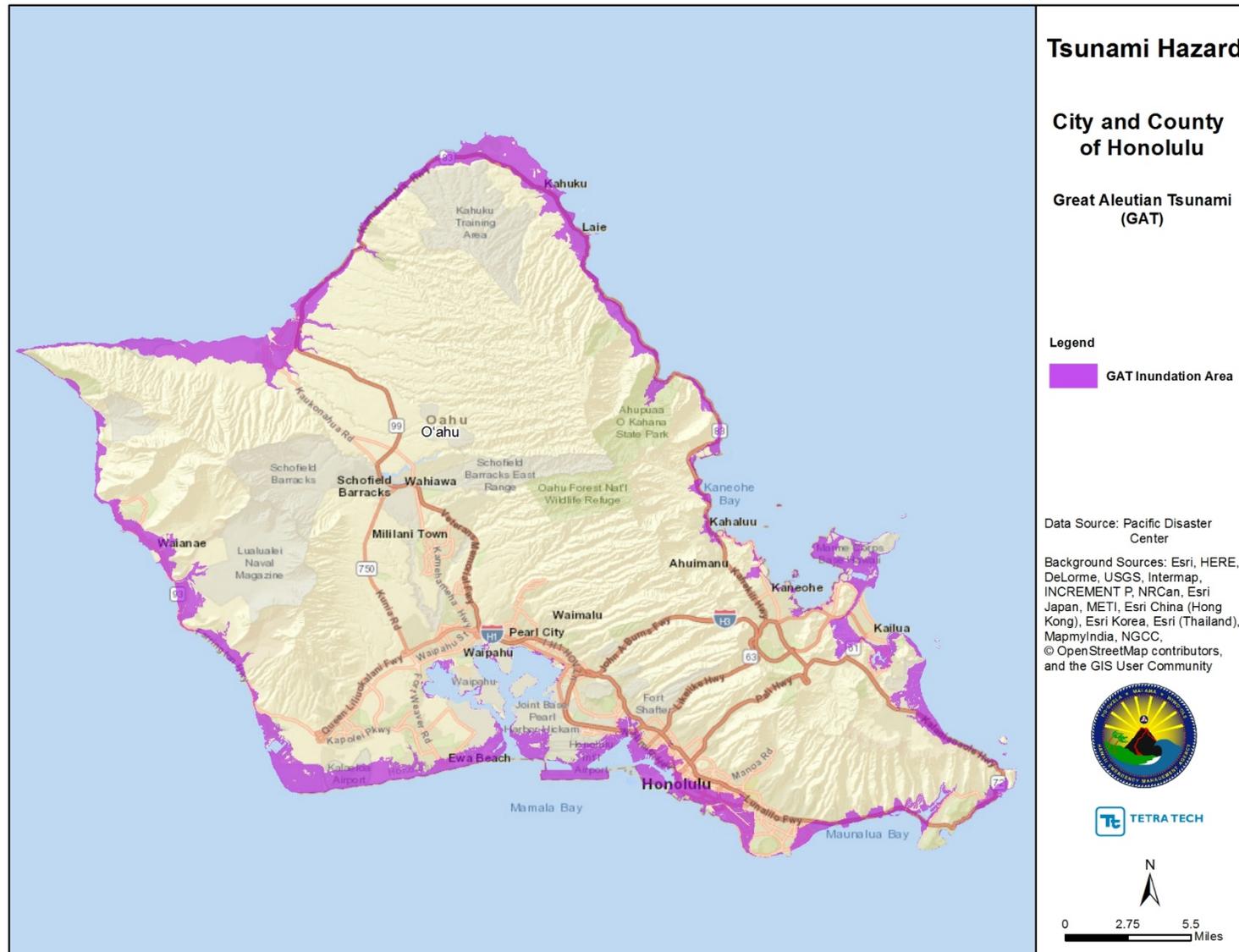


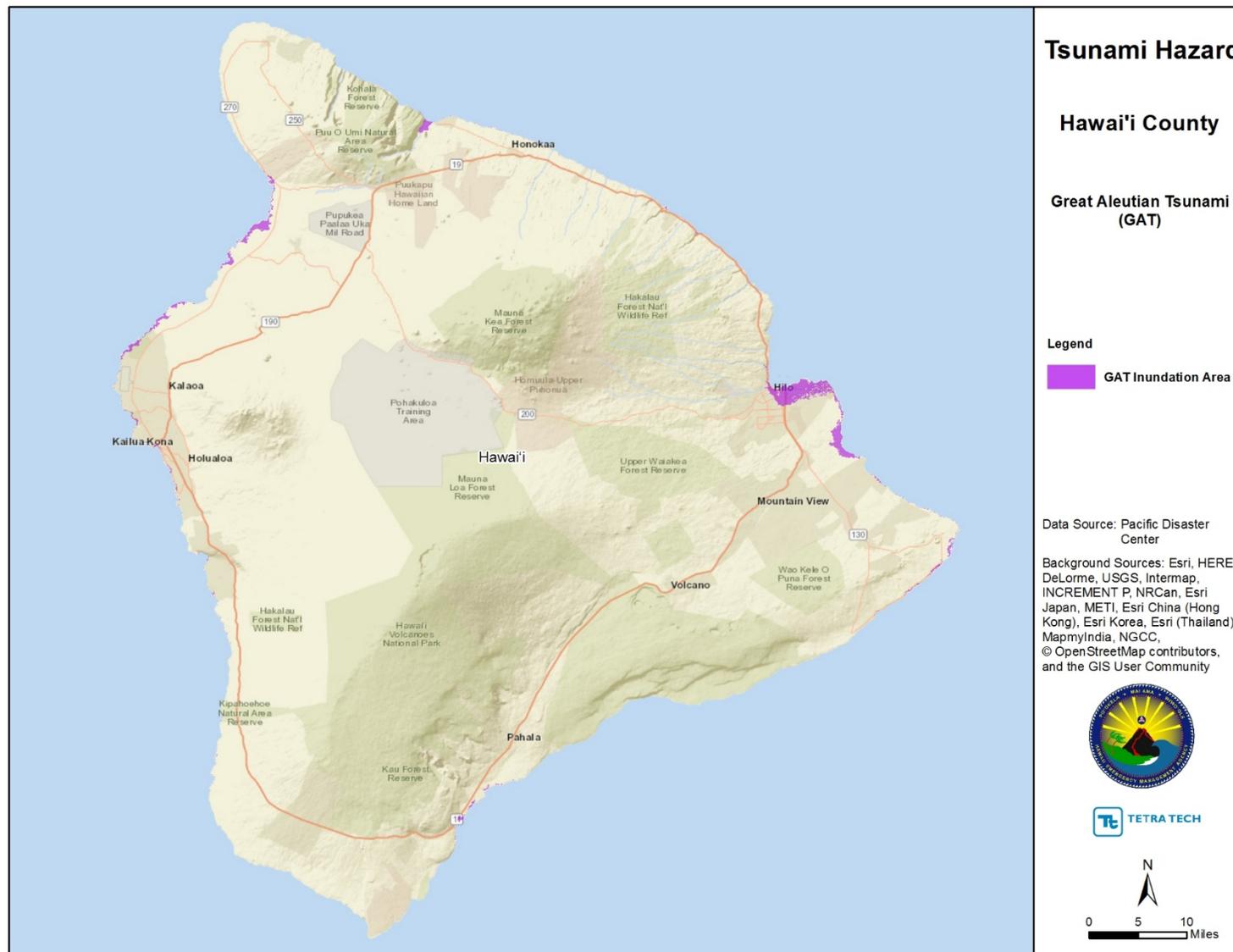


Figure 4.13-5. Great Aleutian Tsunami Inundation Area in the County of Maui





Figure 4.13-6. Great Aleutian Tsunami Inundation Area in the County of Hawai'i



**Tsunami Hazard**

**Hawai'i County**

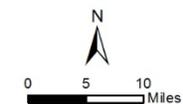
**Great Aleutian Tsunami (GAT)**

**Legend**

GAT Inundation Area

Data Source: Pacific Disaster Center

Background Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community





**EXTENT**

A tsunami's effect at the shoreline is measured in terms of runup (the maximum elevation water reaches onshore, measured from sea level) height and inundation (the limit of flooding, measured horizontally from the shoreline; see Figure 4.12-2). 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 (15 meters) for tsunamis of distant origin, and over 100 feet (30 meters) 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 (State of Hawai'i 2013).

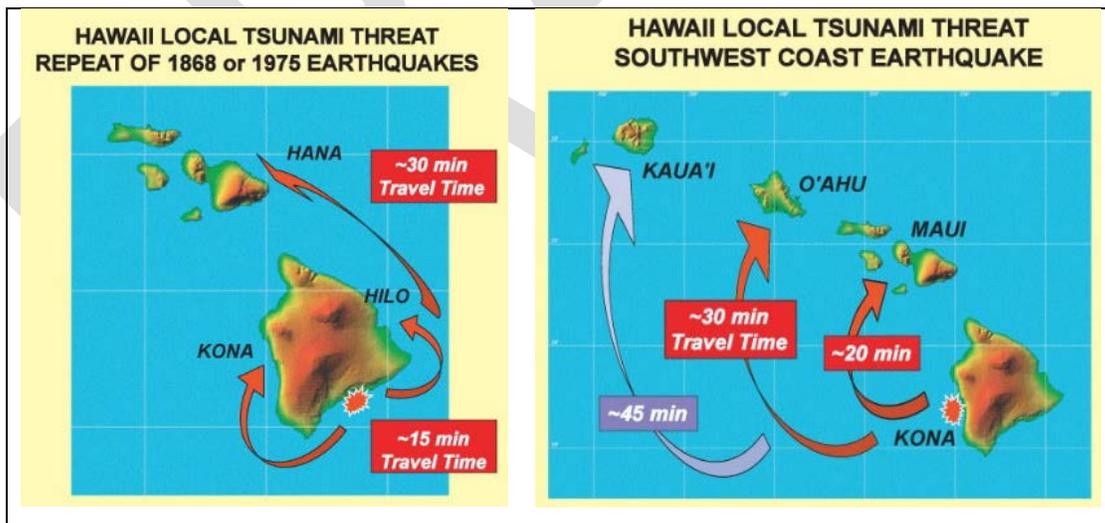
**Warning Time**

Tsunamis affecting the State of Hawai'i may be generated within the state (local-source tsunamis) or may come from across the ocean (distant-source tsunamis). 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 Kilauea. The local tsunami could reach the coastlines of most major Hawaiian Islands in less than one hour (Geist et al 2005). Figure 4.13-7 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 2018

*Distant-Source Events*

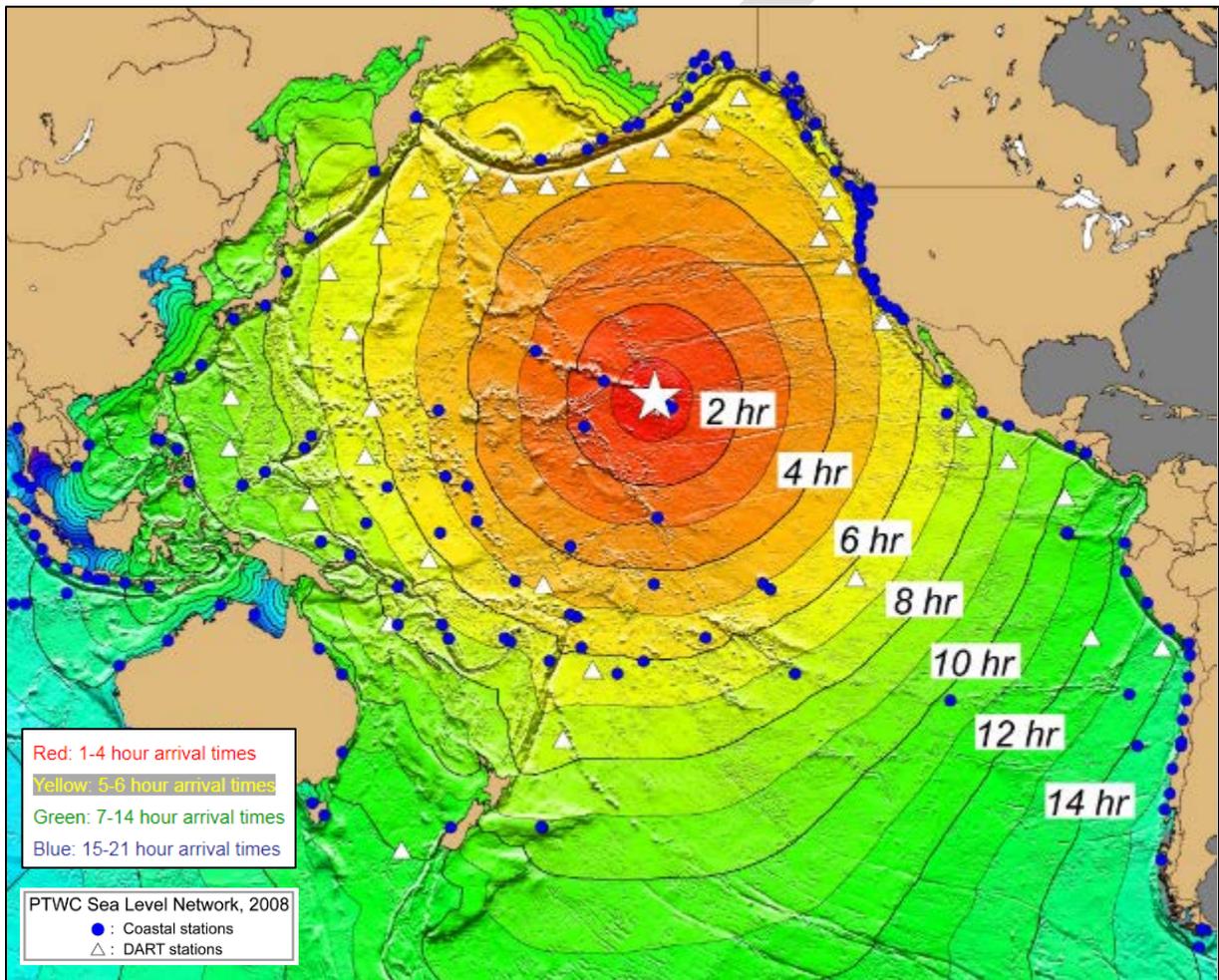
Distant-source tsunamis originate from a faraway source, generally more than 600 miles or more than three hours tsunami travel time from its source. The State of Hawai'i is exposed to these types of tsunamis. In particular, areas with subduction fault lines such as the coasts of the State of Alaska's 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, consequently, 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. Figure 4.13-8 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 2018

**Evacuation Plans and Warning Systems**

An effective early warning system is essential in protecting life and property (Intergovernmental Oceanographic Commission 2014). Tsunamis in the Hawaiian Archipelago have cumulatively killed the largest number of people of all natural hazards affecting the islands. Tsunamis reaching the Hawaiian Islands have exhibited tremendous



variability in terms of their runup heights, inundation distances, and the damage they have inflicted (Hawai'i State HMP 2013).

About half a dozen tsunamis have crossed the Pacific Ocean in the last decade; those which required mandatory shoreline evacuations in Hawai'i occurred in February 2010, March 2011, and October 2012. Because of continually improving techniques and understanding, tsunami hazard, in particular identifying areas most likely to be flooded, is a continuous effort. The previous revision of the tsunami evacuation maps was completed in 2010. The 2011 Japan earthquake and tsunami, however, showed that the hazard had been underestimated. It became apparent that tsunamis could flood significantly farther inland than the limits of the evacuation zones published in the previous year. After a quick modeling study, it was clear that by far the greatest threat facing Hawai'i is a tsunami from the Aleutians. Therefore, a new effort was undertaken from 2012 to 2015 to consider the public safety implications of inundation from a Great Aleutian Tsunami, or as it was termed for the updated Hawai'i Evacuation Plan, an Extreme Tsunami (Chock 2016; Hawai'i State HMP 2013).

The GAT inundation area has been used by the County of Kauai, the City and County of Honolulu, and the County of Maui as the basis for new secondary evacuation zones (also known as Extreme Tsunami Evacuation Zones, or XETZ). The new set of tsunami evacuation zones do not replace the current tsunami evacuation zone; it adds a second zone for a potential extreme tsunami event.

#### *Tsunami Warning Centers*

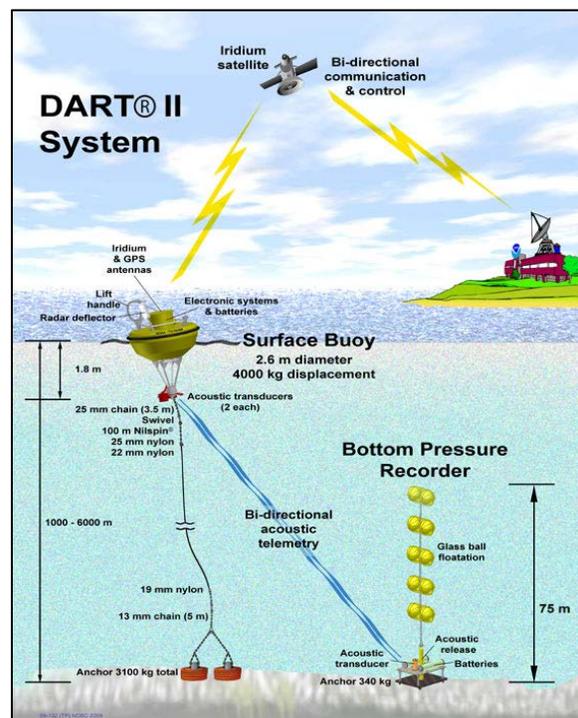
NOAA has two tsunami warning centers (TWC) that are staffed 24 hours a day, 7 days a week. Their mission is to provide early tsunami warnings on potentially destructive tsunamis and help protect life and property from them. The warning centers monitor for tsunamis and the earthquakes that may cause them, forecast tsunami impacts, issues tsunami messages, conduct public outreach, and coordinate with partners to continually improve warning operations (NWS 2018). The Pacific Tsunami Warning Center (PTWC) provides the official tsunami warnings for the State of Hawai'i. PTWC's products include: warnings, watches, advisories, information statements, seismic information statements, and warning cancellations. Operational warning sirens for these warnings exist on the most densely populated coastal areas of all islands (see additional discussion in Tsunami Warning Sirens section below). When the PTWC issues an urgent local tsunami warning (the warning product for a local-source tsunami), or a tsunami warning (the warning product for a distant-source tsunami), a steady three-minute siren tone is the attention alert signal.

- 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 Hawai'i. 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 Cancellation** is the final product indicating the end of the damaging tsunami threat. A cancellation is usually issued after an evaluation of sea level data confirms that a destructive tsunami will not impact the warned area (PTWC 2009). In the event of a damaging tsunami, the cancellation is issued after coastal tide gauges show that waves have fallen below the danger level and no further damaging waves are expected.

Figure 4.13-9. DART II System





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

NOAA, as part of the U.S. National Tsunami Hazard Mitigation Program, implemented the Deep-ocean Assessment and Reporting of Tsunami (DART) project to ensure detection of tsunamis and to acquire data critical to real-time forecasts. For in-depth details on how the DART® system works, refer to: <https://nctr.pmel.noaa.gov/Dart/about-dart.html>. Figure 4.13-9 depicts the operation of the DART system.

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 51 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 Pacific Tsunami Warning Center in Honolulu, Hawai'i. 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 (NOAA 2018).

### *Tsunami Warning Sirens*

Each county in Hawai'i is responsible for tsunami evacuations and issuing the all-clear. For distant-source tsunamis, the State of Hawai'i Emergency Management Agency (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 most densely populated coastal areas of all Hawaiian Islands. They are tested monthly. When the Pacific Tsunami Warning Center (PTWC) issues a warning, a steady three-minute siren tone is the attention alert signal (Hawai'i State HMP 2013). For local-source events, PTWC uses HAWAS to instruct the counties directly to sound the sirens.

### *Runup Detector System*

PTWC measures tsunamis within Hawai'i at nine tide gauges throughout the state as well as at the DART off Kailua-Kona. 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 Hawai'i. 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 Hawai'i 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

**Figure 4.13-10. Tsunami Rushing Up Hakalau Stream, April 1946**



Source: International Tsunami Information Center 2018



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 Hawai'i tsunami was from a 16<sup>th</sup> century Hawaiian chant that described a huge wave that struck the coast of Moloka'i. The earliest confirmed tsunami in the state was on December 21, 1812 when a wave from southern California was observed at Ho'okena on the west coast of the Island of Hawai'i. Since 1812, there have been more than 160 tsunamis (135 confirmed and 26 unconfirmed) in the state, resulting in over 2,000 runup observations. Nine of the confirmed tsunamis caused 294 deaths and damages totaling over \$600 million (International Tsunami Information Center 2018).

From 1812 to December 2017, 27 tsunamis had runup heights greater than one meter have made landfall in the Hawaiian Islands. Seven had significant damaging effects (based on number of deaths, injuries, and damages) (NOAA National Geophysical Data Center/World Data Service [NGDC/WDS] 2018).

Many sources provided tsunami information regarding previous occurrences and losses associated with these events throughout the State of Hawai'i. The 2013 Plan discussed specific tsunami events that impacted Hawai'i through 2012. For this 2018 HMP Update, tsunami events and associated runups were summarized between January 1, 2012, and December 31, 2017. According to the NOAA National Centers for Environmental Information/World Data Service (NCEI/WDS) database, between 2012 and 2017, 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. Table 4.13-2 includes details of tsunami and runup events that occurred in the State between 2012 and 2017. For events prior to 2012, please refer to Appendix X.

### FEMA Disaster Declarations

Between 1954 and 2017, FEMA included the State of Hawai'i in one tsunami-related major disaster (DR) declaration. Generally, these disasters cover a wide region of the State; therefore, they may have impacted many counties. However, not all counties were included in the disaster declarations as determined by FEMA (FEMA 2018).

Based on all sources researched, the State of Hawai'i was not included in any FEMA tsunami-related declarations between 2012 and 2017. For details regarding all declared disasters, refer to Section 4.0 (Risk Assessment Overview).



**Table 4.13-2. Tsunami Events in Hawai'i, 2012 to 2017**

Date(s) of Event	Event Type	Counties Affected	Description
October 28, 2012	Tsunami Runup	Honolulu, Maui, Kaua'i, and Hawai'i	<p>The source of the tsunami was in British Columbia, Canada. The maximum runup of this tsunami near the source was 13 meters. The Pacific Tsunami Warning Center issued a tsunami warning for Hawai'i. There were no reports of damage; however, one person died in a car crash on O'ahu's north shore during the evacuation. From photographs, runup was inferred to have been about one meter at Honouliwai, Moloka'i and at Kapalua, Maui. Runup was measured in all counties:</p> <ul style="list-style-type: none"> <li>• Waianea (Honolulu) had a maximum water height of 0.41 meters (tide-gauge measurement)</li> <li>• Barbers Point (Honolulu) had a maximum water height of 0.09 meters (tide-gauge measurement)</li> <li>• Lahaina (Maui) had a maximum water height of 0.28 meters (tide-gauge measurement)</li> <li>• Kahului (Maui) had a maximum water height of 0.79 meters (tide-gauge measurement)</li> <li>• Hanalei (Kaua'i) had a maximum water height of 0.19 meters (tide-gauge measurement)</li> <li>• Nāwiliwili (Kaua'i) had a maximum water height of 0.03 meters (tide-gauge measurement)</li> <li>• Hale'iwa (Honolulu) had a maximum water height of 0.43 meters (tide-gauge measurement)</li> <li>• Mokuolo'e-Coconut Island (Honolulu) had a maximum water height of 0.09 meters (tide-gauge measurement)</li> <li>• Makapu'u Point (Honolulu) had a maximum water height of 0.27 meters and 0.41 meters (tide-gauge measurement)</li> <li>• Honolulu (Honolulu) had a maximum water height of 0.2 meters (tide-gauge measurement)</li> <li>• Kaunapali (Maui) had a maximum water height of 0.18 meters (tide-gauge measurement)</li> <li>• Kawaihae (Hawai'i) had a maximum water height of 0.56 meters (tide-gauge measurement)</li> <li>• Honokōhau (Hawai'i) had a maximum water height of 0.09 meters (tide-gauge measurement)</li> <li>• Honu'apo (Hawai'i) had a maximum water height of 0.04 meters (tide-gauge measurement)</li> <li>• Kapoho (Hawai'i) had a maximum water height of 0.19 meters (tide-gauge measurement)</li> <li>• Hilo (Hawai'i) had a maximum water height of 0.29 meters (tide-gauge measurement)</li> </ul>
November 7, 2012	Tsunami Runup	Maui and Hawai'i	<p>The source of the tsunami was in Guatemala. The maximum near-source runup of this tsunami was 0.35 meters. Runup was measured in the Counties of Maui and Hawai'i:</p> <ul style="list-style-type: none"> <li>• Kahului (Maui) had a maximum water height of 0.07 meters (tide-gauge measurement)</li> <li>• Hilo (Hawai'i) had a maximum water height of 0.06 meters (tide-gauge measurement)</li> </ul>
February 6, 2013	Tsunami Runup	Honolulu, Maui, Kaua'i and Hawai'i	<p>The source of the tsunami was in the Santa Cruz Islands, where runup reached 11 meters and there were numerous deaths. The tsunami was measured in all counties:</p> <ul style="list-style-type: none"> <li>• Waianea (Honolulu) had a maximum water height of 0.06 meters (tide-gauge measurement)</li> <li>• Barbers Point (Honolulu) had a maximum water height of 0.05 meters (tide-gauge measurement)</li> <li>• Lahaina (Maui) had a maximum water height of 0.12 meters (tide-gauge measurement)</li> </ul>



Date(s) of Event	Event Type	Counties Affected	Description
			<ul style="list-style-type: none"> <li>• Nāwiliwili (Kaua'i) had a maximum water height of 0.01 meters (tide-gauge measurement)</li> <li>• Hale'iwa (Honolulu) had a maximum water height of 0.19 meters (tide-gauge measurement)</li> <li>• Makapu'u Point (Honolulu) had a maximum water height of 0.08 meters (tide-gauge measurement)</li> <li>• Honolulu (Honolulu) had a maximum water height of 0.06 meters (tide-gauge measurement)</li> <li>• Kaunapali (Maui) had a maximum water height of 0.03 meters (tide-gauge measurement)</li> <li>• Kahului (Maui) had a maximum water height of 0.12 meters (tide-gauge measurement)</li> <li>• Kawaihae (Hawai'i) had a maximum water height of 0.09 meters (tide-gauge measurement)</li> <li>• Honokōhau (Hawai'i) had a maximum water height of 0.07 meters (tide-gauge measurement)</li> </ul>
April 1, 2014	Tsunami Runup	Honolulu, Kaua'i, Hawai'i	<p>The source of the tsunami was in Northern Chile, where runup reached 4.4 meters. Runup was measured in the Counties of Honolulu, Kaua'i, and Hawai'i:</p> <ul style="list-style-type: none"> <li>• Waianea (Honolulu) had a maximum water height of 0.09 meters (tide-gauge measurement)</li> <li>• Barbers Point (Honolulu) had a maximum water height of 0.08 meters (tide-gauge measurement)</li> <li>• Nāwiliwili (Kaua'i) had a maximum water height of 0.04 meters (tide-gauge measurement)</li> <li>• Hale'iwa (Honolulu) had a maximum water height of 0.15 meters (tide-gauge measurement)</li> <li>• Makapu'u Point (Honolulu) had a maximum water height of 0.08 meters (tide-gauge measurement)</li> <li>• Waimānalo (Honolulu) had a maximum water height of 0.11 meters (tide-gauge measurement)</li> <li>• Honolulu (Honolulu) had a maximum water height of 0.06 meters (tide-gauge measurement)</li> <li>• Kaunapali (Maui) had a maximum water height of 0.02 meters (tide-gauge measurement)</li> <li>• Kahului (Maui) had a maximum water height of 0.53 meters (tide-gauge measurement)</li> <li>• Kawaihae (Hawai'i) had a maximum water height of 0.22 meters (tide-gauge measurement)</li> <li>• Honokōhau (Hawai'i) had a maximum water height of 0.09 meters (tide-gauge measurement)</li> <li>• Honu'apo (Hawai'i) had a maximum water height of 0.04 meters (tide-gauge measurement)</li> <li>• Kapoho (Hawai'i) had a maximum water height of 0.12 meters (tide-gauge measurement)</li> <li>• Hilo (Hawai'i) had a maximum water height of 0.57 meters (tide-gauge measurement)</li> </ul>
June 23, 2014	Tsunami Runup	Kaua'i, Honolulu, and Maui	<p>The source of the tsunami was in the Aleutian Islands in Alaska. The maximum measured runup in the Aleutians (though some distance from the source) was 0.17 meters. Runup was measured in the Counties of Kaua'i, Honolulu, and Maui:</p> <ul style="list-style-type: none"> <li>• Hanalei (Kaua'i) had a maximum water height of 0.05 meters (tide-gauge measurement)</li> <li>• Hale'iwa (Honolulu) had a maximum water height of 0.04 meters (tide-gauge measurement)</li> <li>• Makapu'u Point (Honolulu) had a maximum water height of 0.03 meters (tide-gauge measurement)</li> <li>• Kahului (Maui) had a maximum water height of 0.1 meters (tide-gauge measurement)</li> </ul>
September 16, 2015	Tsunami Runup	Honolulu, Kaua'i, Hawai'i, and Maui	<p>The source of the tsunami was in Central Chile, where runup reached 13.6 meters. A tsunami watch was issued for the State of Hawai'i, but was cancelled before the tsunami arrived. The tsunami was measured in all counties:</p>



Date(s) of Event	Event Type	Counties Affected	Description
			<ul style="list-style-type: none"> <li>• Waianea (Honolulu) had a maximum water height of 0.23 meters (tide-gauge measurement)</li> <li>• Barbers Point (Honolulu) had a maximum water height of 0.1 meters (tide-gauge measurement)</li> <li>• Nāwiliwili (Kaua'i) had a maximum water height of 0.14 meters (tide-gauge measurement)</li> <li>• Hanalei (Kaua'i) had a maximum water height of 0.03 meters (tide-gauge measurement)</li> <li>• Waimānalo (Hawai'i) had a maximum water height of 0.21 meters (tide-gauge measurement)</li> <li>• Mokuolo'e-Coconut Island (Honolulu) had a maximum water height of 0.04 meters (tide-gauge measurement)</li> <li>• Makapu'u Point (Honolulu) had a maximum water height of 0.01 meters (tide-gauge measurement)</li> <li>• Waimānalo (Honolulu) had a maximum water height of 0.21 meters (tide-gauge measurement)</li> <li>• Honolulu (Honolulu) had a maximum water height of 0.11 meters (tide-gauge measurement)</li> <li>• Kalaupapa (Maui) had a maximum water height of 0.08 meters (tide-gauge measurement)</li> <li>• Kahului (Maui) had a maximum water height of 0.65 meters (tide-gauge measurement)</li> <li>• Kawaihae (Hawai'i) had a maximum water height of 0.27 meters (tide-gauge measurement)</li> <li>• Hilo (Hawai'i) had a maximum water height of 0.91 meters (tide-gauge measurement)</li> </ul>
November 21, 2016	Tsunami Runup	Hawai'i	The source of the tsunami was in Japan off the east coast of Honshu Island. The maximum water height from this tsunami is unknown. A runup from this event was observed at the Midway Islands in Hawai'i, with a maximum water height of 0.09 meters (tide-gauge measurement).
September 8, 2017	Tsunami Runup	Honolulu, Maui, and Hawai'i	<p>The source of the tsunami was in Mexico, where runup reached 2.7 meters. The tsunami was measured in the Counties of Honolulu, Maui, and Hawai'i:</p> <ul style="list-style-type: none"> <li>• Mokuolo'e-Coconut Island(Honolulu) had a maximum water height of 0.03 meters (tide-gauge measurement)</li> <li>• Kahului (Maui) had a maximum water height of 0.18 meters (tide-gauge measurement)</li> <li>• Kawaihae (Hawai'i) had a maximum water height of an unknown height (tide-gauge measurement)</li> <li>• Hilo (Hawai'i) had a maximum water height of 0.17 meters (tide-gauge measurement)</li> </ul>

Source: NCEI Global Historical Tsunami Database 2018

Note: Please note that not all sources may have been identified in order to be researched for this 2018 HMP Update. Additionally, loss and impact information for many events could vary depending on the source. Therefore, Table 4.13-2 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 2018 HMP Update.



## PROBABILITY OF FUTURE HAZARD EVENTS

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, 59 tsunamis have produced a runup of greater than 0.3 meters (the threshold for issuing a tsunami advisory) somewhere in the State of Hawai'i. Of these, 34 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 should expect a potentially damaging tsunami, one requiring coastal evacuation, approximately once every six years. The State of Hawai'i 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 (we have to be careful here, because the historical record for these smaller events is probably incomplete before about 1910). Very roughly, we should expect a tsunami advisory once every three years, or about a 34% chance of one 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 (IPCC) predicts up to 3.2 feet of global sea level rise by 2100; however, recent observations and projections suggest that this magnitude of sea level rise could occur as early as 2060. This projection would have devastating impacts on the State of Hawai'i. Rising sea levels will increase the extent of coastal flooding from tsunamis as they create waves that flood low-lying coastal areas (Hawai'i Climate Change Mitigation and Adaptation Commission 2017). Practically, 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

A statewide tsunami analysis was conducted based on best available data for the State of Hawai'i. The GAT inundation area 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 2018 HMP 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.

#### Tsunami Hazard Area Definition

Great Aleutian Tsunami (GAT) inundation area spatial data, provided by the Pacific Disaster Center, were used to assess exposure and potential loss to the tsunami hazard. The hazard area is called the GAT inundation area.



**State Assets**

The spatial analysis determined there are 1,175 state buildings located in the GAT inundation area. Of these buildings, the greatest number are located in the City and County of Honolulu (760 buildings with a replacement cost value of \$3.102 billion); the majority of these buildings are occupied by the Department of Education and University of Hawai'i. Table 4.13-3 and Table 4.13-4 summarize the state buildings located in the GAT 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	\$957,679,537	130	24.5%	\$239,699,568	25.0%
City and County of Honolulu	3,472	\$16,750,785,426	760	21.9%	\$3,102,858,820	18.5%
County of Maui	831	\$2,862,316,819	153	18.4%	\$559,044,781	19.5%
Count of Hawai'i	1,261	\$4,209,774,236	132	10.5%	\$543,574,970	12.9%
<b>Total</b>	<b>6,095</b>	<b>\$24,780,556,017</b>	<b>1,175</b>	<b>19.3%</b>	<b>\$4,445,178,139</b>	<b>17.9%</b>

Source: Hawai'i State Risk Management Office 2017; PDC 2017

Notes: PDC Pacific Disaster Center

**Table 4.13-4. 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	\$946,504,656	17	25.8%	\$224,412,549	23.7%
Dept of Agriculture	70	\$133,065,375	25	35.7%	\$44,264,540	33.3%
Dept of Attorney General	15	\$95,151,863	6	40.0%	\$30,214,798	31.8%
Dept of Budget & Finance	16	\$26,624,294	6	37.5%	\$20,647,179	77.6%
Dept of Business, Economic Development and Tourism	25	\$612,574,032	6	24.0%	\$529,204,718	86.4%
Dept of Commerce & Consumer Affairs	2	\$35,611,360	1	50.0%	\$31,638,545	88.8%
Dept of Defense	69	\$246,099,477	12	17.4%	\$34,899,610	14.2%
Dept of Education	4,090	\$9,604,111,443	755	18.5%	\$1,511,046,120	15.7%
Dept of Hawaiian Home Lands	12	\$100,471,477	3	25.0%	\$7,158,597	7.1%
Dept of Health	44	\$387,068,440	7	15.9%	\$11,154,835	2.9%
Dept of Human Resources Development	1	\$5,523,320	0	0.0%	\$0	0.0%
Dept of Human Services	130	\$420,004,555	46	35.4%	\$237,628,728	56.6%
Dept of Labor and Industrial Relations	22	\$79,322,626	6	27.3%	\$54,990,991	69.3%
Dept of Land and Natural	90	\$98,666,185	36	40.0%	\$19,584,394	19.8%



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
Resources						
Dept of Public Safety	154	\$427,884,909	23	14.9%	\$53,436,031	12.5%
Dept of Taxation	1	\$6,864,408	1	100.0%	\$6,864,408	100.0%
Dept of Transportation	68	\$2,912,510,888	33	48.5%	\$462,718,699	15.9%
Hawai'i State Ethics Commission	1	\$891,212	1	100.0%	\$891,212	100.0%
Hawai'i Health Systems Corporation	106	\$1,223,962,810	1	0.9%	\$829,553	0.1%
Hawai'i Housing Finance & Development Corporation	86	\$333,526,064	16	18.6%	\$153,919,201	46.1%
Hawai'i Public Housing Authority	273	\$933,255,767	45	16.5%	\$111,586,569	12.0%
Hawai'i State Legislature	2	\$43,024,855	0	0.0%	\$0	0.0%
Hawai'i State Public Library System	53	\$525,584,082	17	32.1%	\$46,999,631	8.9%
Judiciary	41	\$511,093,204	12	29.3%	\$163,124,526	31.9%
Legislative Reference Bureau	1	\$2,686,408	0	0.0%	\$0	0.0%
Office of Hawaiian Affairs	11	\$53,991,251	8	72.7%	\$49,715,963	92.1%
Office of the Auditor	2	\$1,789,788	0	0.0%	\$0	0.0%
Office of the Governor	1	\$2,686,408	0	0.0%	\$0	0.0%
Office of the Lieutenant Governor	2	\$3,977,640	0	0.0%	\$0	0.0%
Office of the Ombudsman	1	\$1,620,944	0	0.0%	\$0	0.0%
Research Corporation of the University of Hawai'i	3	\$3,713,497	0	0.0%	\$0	0.0%
University of Hawai'i	637	\$5,000,692,783	92	14.4%	\$638,246,741	12.8%
<b>Total</b>	<b>6,095</b>	<b>\$24,780,556,017</b>	<b>1,175</b>	<b>19.3%</b>	<b>\$4,445,178,139</b>	<b>17.9%</b>

Source: Hawai'i State Risk Management Office 2017; PDC 2017

Notes: PDC Pacific Disaster Center

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 4.13-5 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 (94.8 miles), followed by the County of Maui (54.2 miles). A complete list of State roads located in the GAT inundation area is included in Appendix X.

**Table 4.13-5. 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	104.0	27.9	26.8%



County	Length (in miles)		
	Total Length	Length of State Road in the GAT Inundation Area	Length as Percent (%) of Total Length
City and County of Honolulu	375.3	94.8	25.3%
County of Maui	238.6	54.2	22.7%
County of Hawai'i	378.7	6.1	1.6%
<b>Total</b>	<b>1,096.5</b>	<b>183.0</b>	<b>16.7%</b>

Source: State of Hawai'i SDOT State Routes GIS layer 2017; PDC 2017

Notes: GIS Geographic Information System  
 PDC Pacific Disaster Center  
 SDOT State Department of Transportation

### Critical Facilities

Table 4.13-6 summarizes the total number of 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 (185) exposed, followed by the County of Maui (102 critical facilities). Table 4.13-7 summarizes the number of facilities and replacement cost exposed by core category. The Energy core category has 51.5% of its facilities located in the tsunami hazard area, followed by Transportation Services (48.2%) and Water, Waste and Wastewater Systems (34.8%).

**Table 4.13-6. Critical Facilities Located in the GAT Inundation Area by County**

County	Core Category of Critical Facilities										Total in the Hazard Area
	Commercial Facilities	Communications	Emergency Services	Energy	Food and Agriculture	Government Facilities	Healthcare and Public Health	Mass Care Support Services	Transportation Services	Water, Waste, and Wastewater Systems	
County of Kaua'i	1	1	6	4	2	2	1	9	2	10	38
City and County of Honolulu	9	20	21	33	1	14	9	26	3	49	185
County of Maui	2	8	9	3	0	7	10	14	14	35	102
County of Hawai'i	3	8	4	6	12	2	4	4	8	12	63
<b>Total</b>	<b>15</b>	<b>37</b>	<b>40</b>	<b>46</b>	<b>15</b>	<b>25</b>	<b>24</b>	<b>53</b>	<b>27</b>	<b>106</b>	<b>388</b>

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2; PDC 2017

Notes: PDC Pacific Disaster Center

**Table 4.13-7. Critical Facilities Located in the GAT Inundation Area by Core Category**

Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Commercial Facilities	60	\$206,894,206	15	25.0%	\$95,637,385	46.2%
Communications	130	\$523,848,060	37	28.5%	\$123,390,205	23.6%
Emergency Services	149	\$1,017,628,710	40	26.8%	\$221,055,140	21.7%
Energy	90	\$2,591,975,628	46	51.1%	\$1,212,476,143	46.8%



Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Food & Agriculture	39	\$829,869,410	15	38.5%	\$276,327,850	33.3%
Government Facilities	100	\$399,781,575	25	25.0%	\$97,717,895	24.4%
Healthcare & Public Health	193	\$3,399,521,375	24	12.4%	\$172,080,183	5.1%
Mass Care Support Services	353	\$11,497,547,155	53	15.0%	\$1,500,066,395	13.0%
Transportation Services	56	\$1,739,256,960	27	48.2%	\$837,469,440	48.2%
Water, Waste, & Wastewater Systems	305	\$9,481,445,760	106	34.8%	\$3,300,771,840	34.8%
<b>Total</b>	<b>1,475</b>	<b>\$31,687,768,838</b>	<b>388</b>	<b>26.3%</b>	<b>\$7,836,992,475</b>	<b>24.7%</b>

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2; PDC 2017

Notes: PDC Pacific Disaster Center

As summarized in Section 4.1 (Climate Change), the primary transportation arteries for the entry of people and goods to the State is the Daniel K. Inouye International Airport and Honolulu Harbor. In addition, each island has critical points of entry for people and goods located along the coast. Because of their geographic location, ports and harbors are especially vulnerable to the tsunami hazard; as well as airports located on the coast. Damages and closures to these critical facilities will likely be long-term have 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 Oahu 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 (SSM International 2011).

### 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.

#### Population

Table 4.13-8 displays the estimated population living in or near the GAT inundation area that could be impacted should a tsunami event occur. For the purposes of the 2018 HMP 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 a number of 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 4.13-8. 2010 U.S. Census Population Located in the GAT Inundation Area by County**

County	Population						
	Total Population	Population in Hazard Area	Population Exposed as % of Total Population	Population Over 65 in Hazard Area	Population Over 65 Exposed as % of Total Population	Income <\$30K/yr in Hazard Area	Income <\$30K/yr Exposed as Percent (%) of Total
County of Kaua'i	67,091	9,961	14.8%	1,502	2.2%	3,519	5.2%
City and County of Honolulu	953,207	185,389	19.4%	25,964	2.7%	55,647	5.8%
County of Maui	154,924	32,595	21.0%	4,116	2.7%	8,598	5.5%
County of Hawai'i	185,079	8,412	4.5%	1,328	0.7%	4,887	2.6%
<b>Total</b>	<b>1,360,301</b>	<b>236,357</b>	<b>17.4%</b>	<b>32,910</b>	<b>2.4%</b>	<b>72,651</b>	<b>5.3%</b>

Source: U.S. Census 2010; PDC 2017

Notes: PDC Pacific Disaster Center

The poverty threshold for the State is \$24,000/year (Federal Register 2017). Utilizing the demographic layer in Hazus, the total households with an income of \$30,000 or less was calculated. Per the U.S. Census Bureau QuickFacts, the average number of persons per household (2012-2016) is 3.03 for the State of Hawai'i. To convert households to residents, three people per household was used.

The analysis indicates that the City and County of Honolulu has the greatest number of people located in the GAT inundation area. 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 inundation area. Therefore, this estimate may be underestimating exposure and vulnerability. It is interesting to note that Hazus estimates a higher day population exposed to the GAT inundation area compared to the night population exposed which is the estimated 2010 U.S. Census population and displayed in Table 4-7. 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), individuals with access and functional needs and visitors. Socially vulnerable populations are most susceptible based on many factors including their physical and financial ability to react or respond during a hazard. The population over 65 makes up about 2.4% of the total population residing in the hazard area. Visitors recreating in or around the inundation areas are vulnerable because they may not be as familiar on 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 4-8 summarizes the estimated casualties (fatalities and injuries) Hazus estimates as a result of the GAT.



**Table 4.13-9. Estimated GAT Fatalities and Injuries by Community Preparedness Level**

County	Community Preparedness Level								
	Good			Fair			Poor		
	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties	Fatalities	Injuries	Total Casualties
County of Kaua'i	0	0	0	2,136	70	2,206	6,618	91	6,710
City and County of Honolulu	0	0	0	45,188	2,959	48,147	143,455	3,473	146,929
County of Maui	0	0	0	8,658	371	9,025	26,273	444	26,717
County of Hawai'i	0	0	0	3,422	131	3,553	10,336	159	10,495
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>59,404</b>	<b>3,531</b>	<b>62,931</b>	<b>186,682</b>	<b>4,167</b>	<b>190,851</b>

Source: PDC 2017

The estimated number of injuries and fatalities is based on the daytime population which is higher than the night population to provide a worse-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. The majority of deaths associated with tsunamis are related to drownings; 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. The impact of the waves and the 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 inundation area. The City and County of Honolulu has the greatest replacement cost value of buildings located in the GAT inundation area. Table 4.13-10 summarizes these values by county.

The PDC calculated estimated potential building damage as a result of the GAT. Total building loss includes structural damage cost, non-structural damage cost and content damage cost. Greater than \$12.8 billion in building damages, or 5.3% of the state's total inventory, is estimated. The City and County of Honolulu is estimated to experience greatest loss (more than \$6 billion in damages to over 17,000 buildings), followed by the County of Maui (more than \$3.5 billion to over 6,000 buildings). The County of Hawai'i is estimated to experience more than \$1.9 billion in building damages to over 2,000 buildings, and the County of Kaua'i is estimated to experience more than \$1.3 billion to nearly 4,000 buildings. According to Hazus, the majority of the building damage in all counties is to residential structures which are damaged beyond repair.



**Table 4.13-10. 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 Building Potential Loss	
				Replacement Cost Value	Percent (%) of Total
County of Kaua'i	\$13,287,882,000	\$2,641,513,000	19.9%	\$1,322,085,389	9.9%
City and County of Honolulu	\$164,787,212,000	\$43,010,342,000	26.1%	\$6,082,130,961	3.7%
County of Maui	\$31,320,693,000	\$9,026,708,000	28.8%	\$3,513,021,920	11.2%
County of Hawai'i	\$33,326,392,000	\$3,595,732,000	10.8%	\$1,951,209,483	5.9%
<b>Total</b>	<b>\$242,722,179,000</b>	<b>\$58,274,295,000</b>	<b>24.0%</b>	<b>\$12,868,447,753</b>	<b>5.3%</b>

Source: State of Hawai'i GIS Program Geospatial Data Portal; Hazus 4.2; PDC 2017

Notes: GIS Geographic Information System  
PDC Pacific Disaster Center

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). Table 4.13-11 summarizes the business interruption losses that the State may incur, in addition to the direct building-related losses summarized in Table 4.13-10 above.

**Table 4.13-11. 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	\$293,086,000	\$106,558,000	\$49,702,000	\$69,439,000	\$67,387,000
City and County of Honolulu	\$1,804,448,000	\$565,135,000	\$322,039,000	\$544,205,000	\$373,069,000
County of Maui	\$1,001,682,000	\$234,788,000	\$241,543,000	\$325,058,000	\$200,293,000
County of Hawai'i	\$601,671,000	\$98,241,000	\$117,593,000	\$322,622,000	\$63,215,000
<b>Total</b>	<b>\$293,086,000</b>	<b>\$106,558,000</b>	<b>\$49,702,000</b>	<b>\$69,439,000</b>	<b>\$ 67,387,000</b>

Source: Hazus 4.2; PDC 2017

Notes: PDC Pacific Disaster Center

### Land Use Districts

Table 4.13-12 shows the square miles of the tsunami hazard area in each State Land Use District statewide; refer to Appendix X for results for each county. More than 20% of Urban District lands statewide are exposed to the tsunami hazard, 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), it is important to note that the inundation area from the GAT event includes more than double the amount of Urban District lands than are located in the SFHA. This means that development in these areas are 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, 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.

**Table 4.13-12. 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	2,942.8	53.7	1.8%
Conservation	3,156.3	22.7	0.7%
Rural	16.1	1.7	10.6%
Urban	319.7	65.2	20.4%
<b>Total</b>	<b>6,434.9</b>	<b>143.3</b>	<b>2.2%</b>

Source: PDC 2017; State Land Use Commission, 2016

Notes: Total area was calculated from the State of Hawai'i State Land Use District GIS layer

Hazard area clipped to coastline were downloaded from State of Hawai'i GIS Program Geospatial Data Portal

Total area may differ slightly between this and other calculations due to slight differences in the shoreline geography.

GIS Geographic Information System

### Environmental Resources

The loss of natural resources across the state is difficult to quantify. Not only do coral reefs benefit the environment, they provide protection from tsunamis. Coasts with offshore reefs receive less wave energy than unprotected coastlines lying in the path of an approaching tsunami. Islands in a group may “shadow” one another reducing the tsunami effect. 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 Hawai'i 2013).

Tsunami impacts range from loss of livelihood for fisherman, 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 Wakīkī 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 (Wakīkī Improvement Association 2008).

As discussed above, there are 53.7 square miles of agricultural land located in the GAT inundation area. 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 Wildlife Federation 2017).

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 inundation area. These results are summarized in Table 4.13-13.

**Table 4.13-14. Environmental Resource Areas Located in the GAT Inundation Area**

Environmental Resource	Statewide		
	Total Square Miles of Resources <sup>b</sup>	Square Miles in the GAT Inundation Area	Percent (%) of Total Resource Area
Critical Habitat <sup>a</sup>	915.2	3.0	0.3%
Wetlands	260.0	25.2	9.7%
Parks and Reserves	2,607.7	18.4	0.7%

Source: State of Hawai'i GIS Program Geospatial Data Portal; HWMO 2013

Notes: GIS Geographic Information System

a. Critical habitat includes the habitats that are known to be essential for an endangered or threatened species. The area mileage includes the combined area of coverage of individual critical habitat areas.

b. Total square miles may be over reported as some environmental asset areas may overlap.

GIS Geographic Information System

HWMO Hawai'i Wildfire Management Organization

### 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 4.13-14). The County of Hawai'i has the greatest number of square miles (2.3 square miles) located in the GAT inundation area; followed by the County of Maui (2.1 square miles).

**Table 4.13-15. 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 Kaua'i	32.0	0.9	2.8%
City and County of Honolulu	10.9	1.4	13.0%
County of Maui	92.6	2.1	2.3%
County of Hawai'i	190.3	2.3	1.2%
<b>Total</b>	<b>325.8</b>	<b>6.7</b>	<b>2.1%</b>

Source: State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Notes: GIS Geographic Information System

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

Table 4.13-15 below; refer to Section 3 for more information on projected development areas). The results of this assessment indicate almost half (48%) of the HCDA Community Development Districts are located in tsunami hazard areas. 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; 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.

**Table 4.13-16. 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	-	-	-	-	-	-	252.3	25.6	10.1%
City and County of Honolulu	-	-	-	-	-	-	288.3	36.4	12.6%
County of Maui	-	-	-	27.6	0.7	2.4%	1,016.7	25.9	2.6%
County of Hawai’i	7.4	3.6	48.4%	-	-	-	1,286.6	15.5	1.2%
<b>Total</b>	<b>7.4</b>	<b>3.6</b>	<b>48.4%</b>	<b>27.6</b>	<b>0.7</b>	<b>2.4%</b>	<b>2,843.9</b>	<b>103.5</b>	<b>3.6%</b>

Source: PDC 2017

Notes: Total area calculated from: (1) HCDA Community Development District GIS layer from Hawai’i Community Development Authority (2) Maui Development Projects GIS layer from Maui County Planning Department (3) Enterprise Zones from Community Economic Development Program, DBEDTS

Hazard area clipped to coastline downloaded from State of Hawai’i GIS Program Geospatial Data Portal

HCDA Hawai’i Community Development Authority



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