# Volcanic Hazards

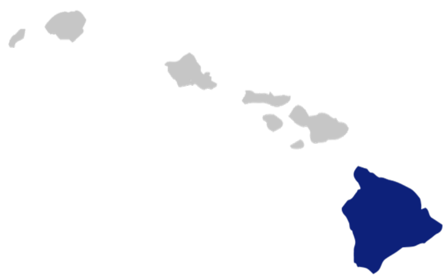
Volcanic eruptions create local and regional hazards. Lava flows can destroy anything in their paths, and the gasses and ash expelled into the atmosphere can endanger plant, animal, and human life as far as the wind carries them. The statistics below represent lava flow hazard areas in Hawai'i and Maui Counties.

## CHANGES SINCE 2018

**+1** Declared Disaster

**+4** Volcanic Events

## COUNTIES MOST VULNERABLE



Kaua'i Honolulu Maui **Hawai'i**

## SOCIALLY VULNERABLE POPULATION

**10%** Of Total Population

**36,475** Persons

## HAZARD RANKING

Low Medium **High**

## COMMUNITY LIFELINES

**239** Total

Food, Water, Shelter — Greatest

## CLIMATE PROJECTIONS

**Projected changes in wind and rainfall frequency and intensity** may alter the dispersion of volcanic gas emissions, adversely impacting human, animal, and plant health

**Carbon Dioxide release** from recent eruptions has *not* been shown to lead to a detectable increase in global warming

**1,115** State Buildings

SQUARE MILES

**1,938** Environmental Resources

**71** Hawaiian Home Lands

**404** Cultural Resources

**241** Miles of State Road

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# SECTION 4. RISK ASSESSMENT

## 4.14 VOLCANIC HAZARDS

### 2023 SHMP Update Changes

- Volcanic hazard events that occurred in the State of Hawaiʻi from January 1, 2018, through December 31, 2022, were researched for this 2023 SHMP Update.
- New and updated figures from federal and state agencies are incorporated.
- This section now includes a discussion of how floods impact socially vulnerable populations and community lifelines.
- Reefs (both artificial and coral) are now separated out for all hazards in the Environmental Resources analysis and listed along with critical habitat, wetlands, and parks and reserves.
- Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) are added to the vulnerability assessment.

### 4.14.1 HAZARD PROFILE

The main Hawaiian Islands are at the tops of giant undersea shield volcanoes, located at the southeastern end of a chain of volcanoes that began to form over 70 million years ago. Each island is made up of one or more volcanoes that first erupted on the ocean floor and emerged above the ocean's surface after countless eruptions over hundreds of thousands of years. All of the volcanic activity in the last 200 years has occurred on the Island of Hawaiʻi. The Island of Hawaiʻi is known for frequent occurrence of lava flow eruptions on Kīlauea near its summit and along its east rift zone and, less frequently, its Southwest Rift Zone. Mauna Loa, the second most active volcano on the Island of Hawaiʻi, averaged one eruption every 5 years before 1950. However, it has erupted only three times since 1975, most recently in November 2022. The 38 years since the previous eruption marked the longest quiet period on record (U.S. Geological Survey 2022).

The likelihood that future lava flows from Kīlauea and Mauna Loa will interfere with human activity and infrastructure increases as communities and other development encroach on these active volcanoes (U.S. Geological Survey n.d.). Hualālai Volcano, although still considered active, has erupted most recently in 1801, whereas Mauna Kea is considered to be dormant, having erupted about 4,000 years ago. Both of these volcanoes are considered to pose comparatively minimal threats of eruptive impact to residents and infrastructure on the island. Haleakalā volcano on Maui last erupted about 500 years ago at its summit and southwest rift zone. It does not currently show signs of unrest and is unlikely to pose a threat in the immediate future.

Kamaʻehuakanaloa (formerly Lōʻihi) is the youngest volcano associated with the Hawaiian chain and is located 15 miles (28 km) southeast of Kīlauea volcano underwater off the southern coast of the Island of Hawaiʻi. There are no estimated potential impacts to residents and infrastructure from Kamaʻehuakanaloa based on its size, location, depth in the ocean, and activity recorded since 1996.

### Volcanic Terms Defined

- **ʻAʻā** – Lava with a rough, rubbly surface composed of broken lava blocks called clinkers
- **Lava** – Molten rock that has reached the surface of the Earth
- **Laze** – Lava haze gas plume created when molten lava flows into the ocean
- **Magma** – Molten rock beneath Earth's surface
- **Pāhoehoe** – Lava with a smooth or ropy surface
- **Vog** – Visible haze of gas, tiny particles, and acidic droplets emitted from a volcano

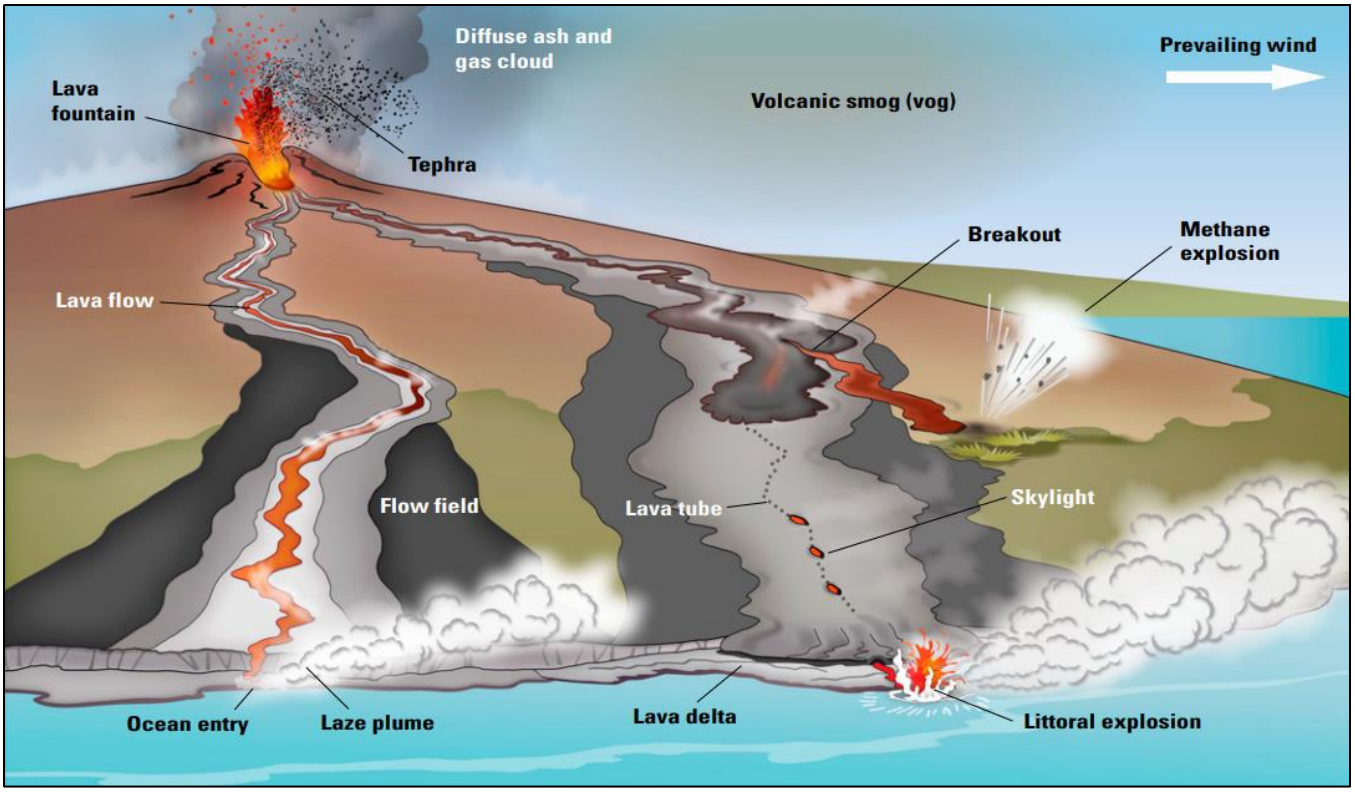
## HAZARD DESCRIPTION

Hawaiian volcanoes are shield volcanoes. Because shield volcanoes dominantly erupt fluid, lava flows form gently sloping, shield-like mountains. Shield volcanoes are the largest volcanoes on Earth. Examples of shield volcanoes (see Figure 4.14-1) are Mauna Loa and Kīlauea, which are located in the County of Hawaiʻi. Volcanic activity in Hawaiʻi is distinct from that occurring at continental margins (e.g., Mt. Shasta, Mt. Saint Helens, etc.) in that the state's volcanoes produce more fluid basalt magmas that are typically less explosive. Hawaiian volcanoes form at the southeast end of the chain and are sequentially transported as they age to the northwest by movement of the Pacific plate. Each volcano develops through a relatively consistent sequence of stages exemplified by Kamaʻehuakanaloa (the youngest), forming an intermittently active submarine volcano on the ocean floor; to Kīlauea, in near constant, vigorous activity producing fluid basalts that are expanding the boundaries of the island to the south and encroaching on the southern flank of its older sister volcano Mauna Loa. Mauna Loa, a less frequently active volcano, continues to discharge fluid basalts at much higher volume rates during its eruptive episodes, whereas Hualālai and Mauna Kea are less active but typically produce more viscous and more explosive lavas.

Mauna Loa last erupted in 2022, and Kīlauea continuously erupted from 1983 to 2018. Kīlauea erupted again from December 2020 to May 2021. A summit eruption occurred from September to early December 2022, and started again in early January 2023.

Lava that flows from shield volcanoes is almost entirely of basalt composition. The fluid, low viscosity of the basalt and the long duration of the flows create the gentle slopes of shield volcanoes. Basalt lava flows are characterized by two morphologies known around the world by their Hawaiian names: ʻaʻā and pāhoehoe. Eruptions from shield volcanoes are not typically explosive unless water has entered the vent (Oregon State University 2022).

*Figure 4.14-1. Shield Volcano and Lava Field Components*




*Source: (U.S. Geological Survey 2019)*

The understanding of the eruptive process is incomplete since subject-matter experts have been able to observe and record only a small fraction of the life cycle of Hawaiian volcanoes; the frequency and intensity of the explosive events is not yet fully understood. Shield volcanoes erupt almost exclusively at their summits or along rift zones. For example, Puʻu ʻŌʻō, the vent associated with the current eruption from 1983 until 2018, is on the east rift zone of Kīlauea Volcano (Patrick, et al. 20220).

Young Hawaiian volcanoes, such as Kīlauea and Mauna Loa, have summit calderas. In Hawaiʻi's shield volcanoes, calderas are depressions several miles in diameter that form as the result of a collapse when magma drains from beneath the summit. Summit eruptions of Kīlauea and Mauna Loa occur within or near their calderas. Flank eruptions usually take place along rift zones, which are highly fractured zones of weakness within the volcano that typically extend from the summit of a volcano toward the coastline and continue under the ocean (University of Hawaiʻi 2023).

## Volcanic Phenomena

Volcanic phenomena appear to be individually isolated and diversified. Some phenomena can pose great risk to people and property near these volcanoes, while others pose no risk to people or property, such as Kamaʻehuakanaloa that produces submarine pillow lavas. Those phenomena that would pose the most risk to people and property include:

- Lava flows at the summits and along the rift zones
- Ground cracking, slumping, or deformation
- Earthquake activity associated with the intrusion of magma
- Possible displacement of volcanic flank (i.e., larger earthquakes) associated with the intrusion of magma into the flanks (e.g., the 2018 M6.9 on Kīlauea's south flank or Mauna Loa's 1868 M7.9 Ka'u event)
- The discharge of volcanic gases (sulfur dioxide and sulfuric acid)
- The potential for explosive eruptions at the summit accompanying drain-out of the summit magma column
- Pit crater formation on the rift zones, possibly accompanied by explosive interaction of groundwater with subsurface magma
- Volcanic weather phenomena such as "fire clouds" or "volcanic tornadoes"
- Bench collapse along newly formed shoreline
- Methane explosions from burning vegetation
- Falling ejecta (ash)
- Tsunamis induced by the earthquakes that trigger or are caused by volcanic activity

Volcanic hazards most prevalent in the State of Hawaiʻi are: lava flow, volcanic gases, bench collapse, and methane explosions. These hazards are further discussed throughout this section.

## Lava Flows

Lava flows typically erupt from a volcano's summit or along rift zones on its flanks. Lava flows present potential threats to homes, infrastructure, natural and historic resources and entire communities. The areas exposed to the highest risk from lava flows are those situated downslope and proximate to the active rift zones of the active Mauna Loa and Kīlauea volcanoes, as was seen with the 2018 eruption of Kīlauea. Lava flows travel downslope toward the ocean, burying everything along the way. Lava entering the ocean may build new land known as lava deltas, which are unstable and prone to sudden collapse. A collapsing lava delta can trigger explosive activity that hurls hot rocks hundreds of yards inland or seaward (U.S. Geological Survey n.d.). Steep slopes may allow lava flows to move quickly from the summit to the ocean in a matter of hours (Pappas 2022).

Explosive volcanic eruptions can produce a variety of pyroclastic material called tephra, including:

- Large fragments (angular blocks and rounded bombs) expelled with great force but deposited near the eruptive vent
- Smaller fragments (lapilli) of ash and thin glass fibers (Pele's hair) carried upward within in a volcanic plume and downwind in a volcanic cloud
- Very fine-grained material volcanic ash carried upward within the plume and blown downwind for very long distances, which can affect communities and farmland across hundreds, or even thousands, of miles.

## Volcanic Gas

Volcanic gas emissions are composed mainly of water vapor ($H_2O$), carbon dioxide ($CO_2$), and sulfur dioxide ($SO_2$), with trace amounts of several other gaseous compounds, including hydrogen sulfide ($H_2S$), hydrogen fluoride (HF), and carbon monoxide (CO). Vog is a hazy mixture of $SO_2$ gas and aerosols, primarily composed of sulfuric acid droplets and other sulfate ($SO_4$) compounds. Aerosols are created when $SO_2$ and other volcanic gases combine in the atmosphere and interact chemically with oxygen, moisture, dust, and sunlight over periods of minutes to days. Vog particles grow by absorbing water vapor and other gases, so they can increase in size in a moist environment such as the nose, mouth, and throat (U.S. Geological Survey n.d.).

When molten lava flows into the ocean, it creates localized air pollution known as laze (combination of the words lava and haze). This is a type of gas plume that results in hazy and noxious conditions downwind of an ocean entry. It forms through a series of chemical reactions as hot lava boils seawater to dryness. The plume is a mixture of hydrochloric acid gas (HCl), steam, and tiny volcanic gas particles. The entry point area and downwind should be avoided by humans, as laze can cause skin and eye irritation and breathing difficulties (U.S. Geological Survey n.d.).

### Bench Collapse

Unstable lava deltas along a newly formed shoreline following volcanic activity can result in what is often referred to as a "bench collapse". The collapses happen because the lava benches build up over unstable, underwater piles of rubble. Shifting or landslides in the rubble below erode the support for the surface outcropping, and finally, the lava deltas collapse. In April 1993, a local native of the Island of Hawaiʻi, a Kona photographer, died at Kīlauea's eruption site when a lava bench which appeared to be solid collapsed. He was attempting to photograph the entry site of lava into the ocean. He and several other onlookers had crossed a rope barrier set up by park rangers. When the bench collapsed, the others were able to scramble to safety, but the photographer was swept into the sea (Sprowl 2014).

### Methane Explosions

Methane gas explosions are caused by lava igniting the pockets of vegetation rotting due to vog. Decomposing vegetation produces methane gas that can travel subsurface beyond the lava front in different directions, accumulating in pockets that can ignite. The methane can seep through cracks several feet away from the lava (see Figure 4.14-2). It can also cause explosions when it is ignited while trapped underground. These blasts can toss blocks several feet away. This methane gas can also be the source of the blue flame that is most recognizable at night during lava flow events.

## Location

This section discusses the best data available to define the locations of the four volcano hazards profiled above for the purpose of assessing the risk from these hazards. To measure risk, assessments need a defined location to measure the vulnerability assets and populations exposed to the hazard. In some cases, for a hazard like vog, may potentially impact the entire planning area. In other cases, such as lava flows, there may be clearly define mapping that allows an assessment to determine exposure and potential impacts from the hazard.

There are six active volcanoes in the State of Hawaiʻi: five located in the County of Hawaiʻi and one located in the County of Maui. Table 4.14-1 summarizes the location of these volcanoes and the associated potential threat/areas at risk.

*Figure 4.14-2. Burning Methane Gas Erupting Through Cracks in a Leilani Estates Street, 2018*


*Source: U.S. Geological Survey/Associated Press*

*Table 4.14-1. Active Volcanoes in the State of Hawaiʻi*

| Name of Volcano | Location of Volcano | Date of Last Eruption | Threat Potential / Areas at Risk |
|---|---|---|---|
| **Haleakalā** | County of Maui | 1600 A.D. | Moderate threat potential; areas at risk include Hana, Keokea, Kula, Pukalani, and Wailea-Makena |
| **Mauna Loa** | County of Hawaiʻi | November-December 2022 and lasted 15 days | Very high threat potential; areas at risk include the districts of South Hilo, Puna, Kaʻu, South Kona, North Kona and South Kohala |
| **Kīlauea** | County of Hawaiʻi | January 2023–ongoing | Very high threat potential; areas at risk include portions of the Puna district; eruptions on the southwest flank of Kīlauea are a threat to land within the Hawaiʻi Volcanoes National Park and the district of Kaʻu |
| **Hualālai** | County of Hawaiʻi | 1801 | High threat potential; areas at risk include the land within the North Kona district |
| **Mauna Kea** | County of Hawaiʻi | Between 6,000 and 4,000 years ago | Moderate threat potential |
| **Kamaʻehuakanaloa (underwater volcano)** | County of Hawaiʻi (located 22 miles southwest) | 1996 | Low to very low threat potential |

*Sources: (U.S. Geological Survey n.d., U.S. Geological Survey 2021)*

## Lava Flows Location

The USGS Hawaiian Volcano Observatory (HVO) monitors six active volcanoes with delineated lava flow hazard areas on the Islands of Hawaiʻi and Maui that may pose a hazard to communities in the state (U.S. Geological Survey n.d.). The lava flow hazard areas are based on past eruption sites, the likely path of lava flows from those sites based on topography and historical flows, and the frequency of lava inundation over the past several thousand years. The lava flow zones are designed to show the relative lava flow hazard across each island and are suitable for general planning purposes. The lower the number zone, the greater severity of the hazard (U.S. Geological Survey n.d.). The lava flow zones in each county are classified differently, meaning Zone 1 in the County of Hawaiʻi is not the equivalent of Zone 1 in the County of Maui. Figure 4.14-3 and Figure 4.14-4 illustrate the lava flow areas in the Counties of Hawaiʻi and Maui, respectively. Descriptions of the lava zones are as follows:

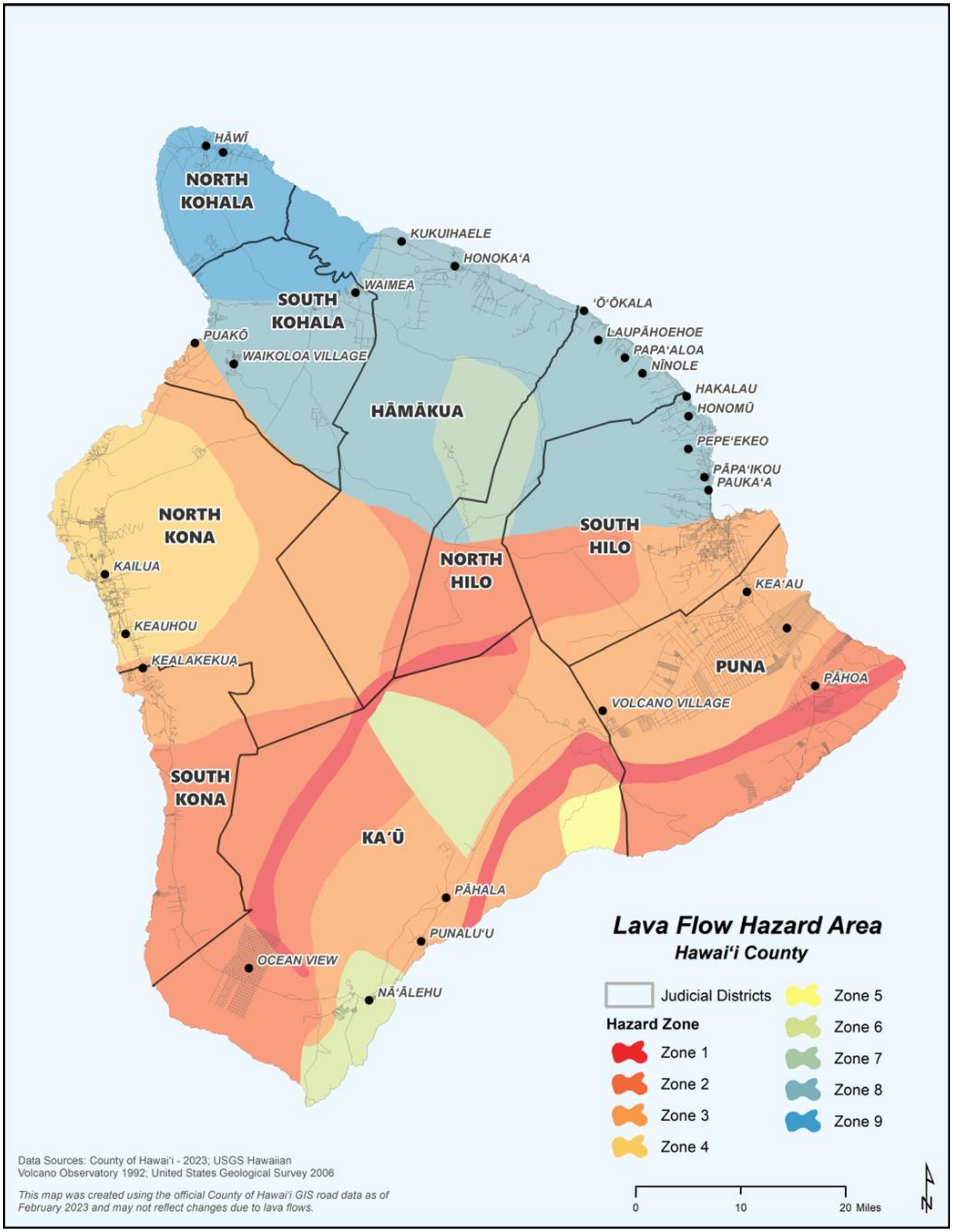
### County of Hawaiʻi

- Zone 1 includes summits and rift zones of Kīlauea and Mauna Loa, where vents have been repeatedly active since written records have been kept (c.a. 1800 CE)
- Zone 2 includes areas adjacent to, and downslope of, Zone 1. Fifteen to 25 percent of Zone 2 has been covered by lava since 1800, and 25 to 75 percent has been covered within the past 750 years. Lava flow hazard within Zone 2 decreases gradually as one moves away from Zone 1.
- Zone 3 includes areas less hazardous than Zone 2 because of greater distance from recently active vents and (or) because of topography. 1 to 5 percent of Zone 3 has been covered since 1800, and 15 to 75 percent has been covered within the past 750 years.
- Zone 4 includes all of Hualālai, where the frequency of eruptions is lower than that for Kīauea or Mauna Loa. Lava coverage is proportionally smaller, about 5 percent since 1800, and less than 15 percent within the past 750 years.
- Zone 5 includes the area on Kīlauea currently protected by topography (the north-facing Koa`e fault system)
- Zone 6 includes two areas on Mauna Loa, both protected by topography
- Zone 7 includes the younger part of much-less-active volcano Mauna Kea; 20% of this area was covered by lava in the past 10,000 years
- Zone 8 is the remaining part of Mauna Kea; only a small percentage of this area has been covered by lava in the past 10,000 years.
- Zone 9 is Kohala Volcano, which last erupted over 60,000 years ago

### County of Maui

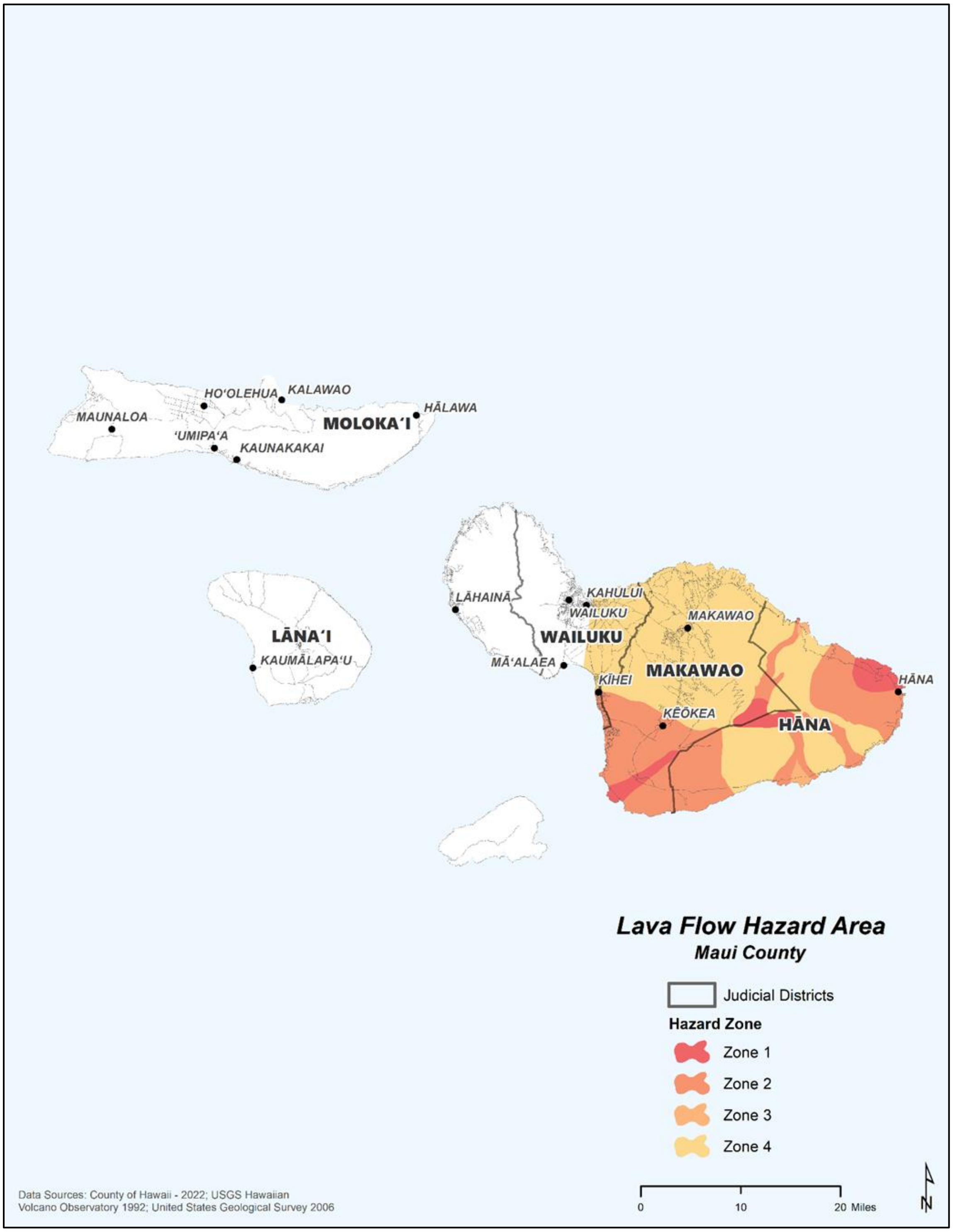
- Zone 1 - Encompasses the lower- and middle-altitude reaches of the southwest and east rift zones, Haleakalā Crater itself, and an area on the northern flank of the east rift zone; all areas where eruptions have occurred frequently in the past 1500 years.
- Zone 2 - Encompasses the volcano's flanks downslope of the southwest and east rift zone axes, chiefly areas where lava has encroached at least once in the past 13,000 years.
- Zone 3 - Demarcates downslope reaches centered low on the Kaʻupo and Koʻolau lava fans. These areas, although within potentially active lava sheds, have become sheltered by buildup of lava upslope during the past 40,000 years that now would deflect new lava toward only the margins of the fans.
- Zone 4 - Encompasses those flanks shielded from lava during the past 100,000 years or for which the sparse eruptive products found are the consequence of off-rift cinder cones from random, infrequent eruptive events. Corresponds to essentially no hazard under most lava inundation conditions.

*Figure 4.14-3. Lava Flow Hazard Areas in the County of Hawai'i*




*Source: USGS HVO 1992*

*Figure 4.14-4. Lava Flow Hazard Areas in the County of Maui*




*Source: USGS 2006*

Table 4.14-2 lists the square miles of these lava flow high risk zones, called the lava flow hazard areas, in each county. These zones were used to assess vulnerability discussed later in this section. The County of Hawaiʻi has the largest percent (65.47%) of the volcano lava flow hazard area (Zones 1 through 4) in the state.

*Table 4.14-2. Lava Flow Hazard Areas in the State of Hawaiʻi*

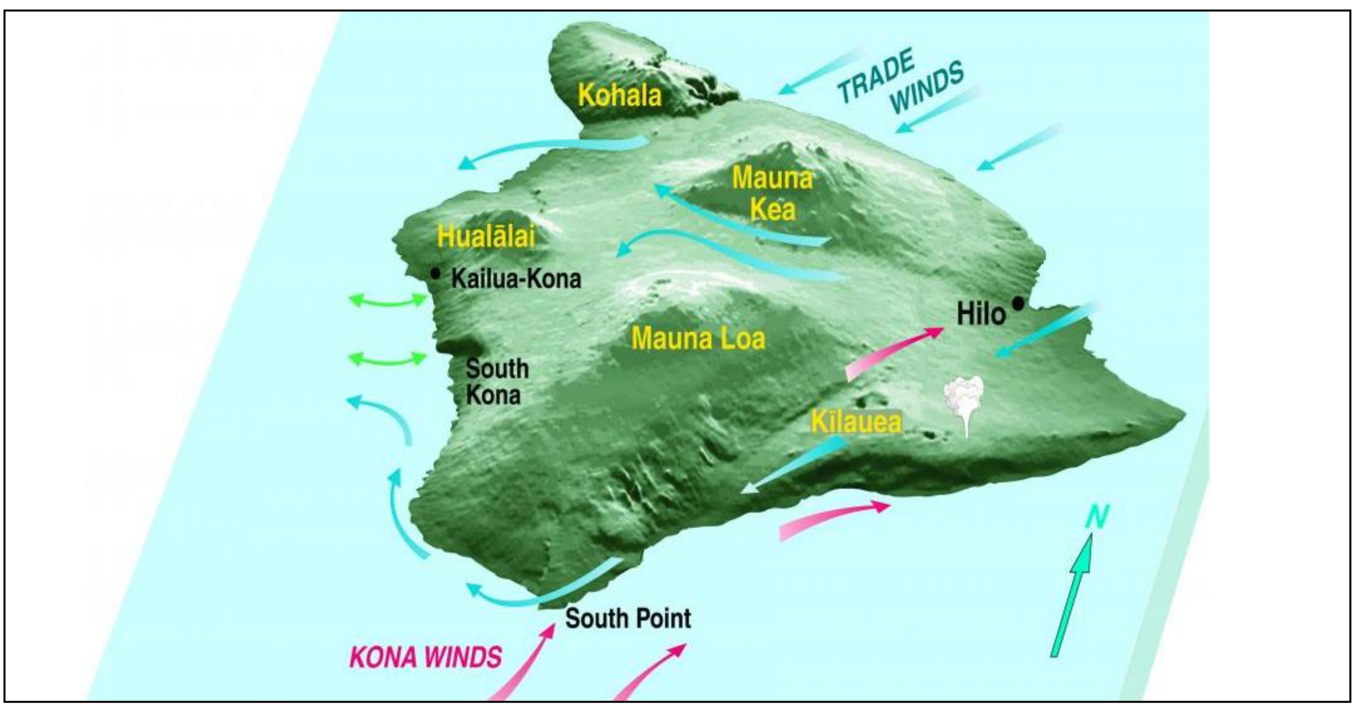
| County | Area (in square miles) | | |
|---|---|---|---|
| | Total Area of the County | Lava Flow Hazard Area | Hazard Area as Percent (%) of Total Area |
| **County of Maui** | 1,176.28 | 216.5 | 18.4% |
| **County of Hawaiʻi** | 4,039.64 | 2,644.80 | 65.47% |
| **Total** | **5,215.92** | **2,857** | **54.77%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; (Kauahikaua and Tilling 2014)*

## Volcanic Gases and Vog

While active volcanoes are only located on the Counties of Hawaiʻi and Maui, the entire state can be impacted by volcanic gases and vog. Vog conditions in the County of Hawaiʻi vary depending on wind direction (northeasterly trade winds, southerly Kona winds) and emission source. Looking at Figure 4.14-5, during prevailing trade winds, the nearly constant stream of vog produced by Kīlauea is blown to the southwest and west, where wind patterns send it up to the Kona coast. Once at the Kona coast, it becomes trapped by daytime and nighttime sea breezes (double-headed arrows on figure). However, when light Kona winds blow (red arrows on figure), much of the vog is concentrated on the eastern side of the island but can reach Honolulu County, which is more than 200 miles to the northwest of the County of Hawaiʻi (U.S. Geological Survey n.d.).

*Figure 4.14-5. Wind Direction and Vog Conditions in the County of Hawaiʻi*




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

Vog risk is considered to be both source (spatially) and time (weather) dependent. The Vog Measurement and Prediction Project (VMAP) provides real-time vog forecasts (may be accessed at http://weather.hawaii.edu/vmap/index.cgi). Vog impacts across the state are not expected to be as severe as those experienced in the County of Hawaiʻi. Though Kīlauea has a more frequent eruption history, Mauna Loa's magmatic gas discharge rate can be ten times that of Kīlauea.

### *Bench Collapse and Methane Gas Explosion*

While no mapping has currently been produced specific to the bench collapse and methane case explosion hazards, their locations can be correlated to where there are likely to be lava flows since both hazards are directly associated with a lava flow. For the purposes of this assessment, the location of the bench collapse and methane gas explosion hazards is associated with the lava flow data, as discussed above.

## EXTENT

The extent (the magnitude or severity) of volcanic hazards in the State of Hawaiʻi vary widely. Eruptions of volcanoes in the state range from almost imperceptible to major events that cover or create hundreds of acres of land, can destroy homes and businesses (see Figure 4.14-6), block or destroy roadways and other infrastructure, and can impact the quality of life, particularly due to vog and other gases. Although explosive eruptions are rare for Hawaiʻi, the magnitude is determined by the degree of interaction between magma and water and ranges from harmless (such as steam blasts of pulverized rock when lava encounters the ocean) to catastrophic (such as those that produce pyroclastic surges that travel from the summit of a volcano several miles outward, killing people and destroying property).

In current times, most eruptions from Hawaiian volcanoes are forecasted due to weeks or months of precursory activity (e.g., seismicity, deformation, methane, littoral explosions, and laze). However, volcanic activity can also occur with little advanced warning. The 2018 eruption on the lower east rift zone was preceded by less than a day of warning. Officials were not seriously anticipating propagation of the 35-year long Puʻu ʻŌʻō rift eruption into lower Puna weeks or months prior to the event. Volcano-alert notifications are produced by volcano observatory scientists and are based on analysis of data from monitoring networks, direct observations, and satellite sensors. They are issued for both increasing and decreasing volcanic activity and include text about the nature of the unrest or eruption and about potential or current hazards and likely outcomes. The USGS employs a nationwide volcano alert-level system for characterizing conditions (Normal, Advisory, Watch, Warning) at U.S. volcanoes. Notifications about the status of activity at U.S. volcanoes are issued through the five regional U.S. volcano observatories. The USGS alert-level system for volcanic activity has two parts:

1. Ranked terms to inform people on the ground about a volcano's status (Table 4.14-3)
2. Ranked colors to inform the aviation sector about airborne ash hazards (Table 4.14-4)

*Figure 4.14-6. Homes and Infrastructure in Hawaiʻi County Inundated by the 2018 Kīlauea Eruption*

*Source: Hawaiʻi Emergency Management Agency*

*Table 4.14-3. USGS Volcano Alert-Level Terms*

| Alert Level | Details |
|---|---|
| **Normal** | Volcano is in typical background, non-eruptive state or, after a change from a higher level, volcanic activity has ceased, and volcano has returned to non-eruptive background state. |
| **Advisory** | Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase. |
| **Watch** | Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, or eruption is underway but poses limited hazards. |
| **Warning** | Hazardous eruption is underway, imminent, or suspected. |

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

### *Table 4.14-4. USGS Volcano Aviation Color Codes*

| Alert Color | Details |
|---|---|
| Green | Volcano is in typical background, non-eruptive state or, after a change from a higher level, volcanic activity has ceased, and volcano has returned to non-eruptive background state. |
| Yellow | Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase. |
| Orange | Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, or eruption is underway with no or minor volcanic ash emissions (ash-plume height specified, if possible). |
| Red | Eruption is ongoing or imminent with significant emission of volcanic ash into the atmosphere likely or eruption is underway or suspected with significant emission of volcanic ash into the atmosphere (ash-plume height specified, if possible). |

*Source:* U.S. Geological Survey n.d.

## *Lava Flows*

The advance of lava flows depends on the type of lava and its viscosity; the terrain of the ground over which it travels; whether the lava flows as a broad sheet, through a confined channel, or down a lava tube; and the rate of lava produced at the vent (U.S. Geological Survey n.d.). Hawaiian lava flows generally advance slowly and can be easily avoided by people. But they can destroy or cover nearly everything in their paths (see Figure 4.14-7). Future lava flows are likely to interfere with human activity and infrastructure as communities and other development encroach on active volcanoes (U.S. Geological Survey n.d.).

*Figure 4.14-7. Lava from the 2018 Kīlauea Eruption Covers a Road in the Puna District*

*Source: Hawaiʻi Emergency Management Agency*

Geologists monitor active vents and lava flows to observe and document newly created volcanic features and to sample lava or tephra for chemical and mineral analyses. This helps in understanding what a volcano is doing and how the activity might impact adjacent communities. Measuring the effusion rate (the volume of lava flow erupted per unit of time) is used to characterize the vigor of an eruption (U.S. Geological Survey n.d.). During ongoing eruptions, lava flows are monitored for changes such as increases in eruption rate and overflows from established channels because these may result in changing hazards downslope.

### Warning Time

The speed of a lava flow is determined not only by the steepness of the terrain but also by the effusion rate and rheology (viscosity, density, etc.) of lava that is erupted, with higher effusion rates producing faster (and usually larger) flows. The leading edge of a basalt lava flow can travel as fast as 6 miles per hour on steep slopes and nearly 20 miles per hour when confined to a channel or lava tube (U.S. Geological Survey n.d.).

During an eruption, advance rates of lava flow fronts are based on any available observations of the flow front and the overall advance rate of similar, earlier lava flows that passed through the same location. However, this method is highly uncertain because factors that control flows are always changing, such as the eruption rate, ground slope, and the complex interaction of ʻaʻā and pāhoehoe flows with the local terrain over which the flow is moving (U.S. Geological Survey n.d.). Figure 4.14-8 illustrates the historical lava flows for eruptions at Mauna Loa (U.S. Geological Survey n.d.).

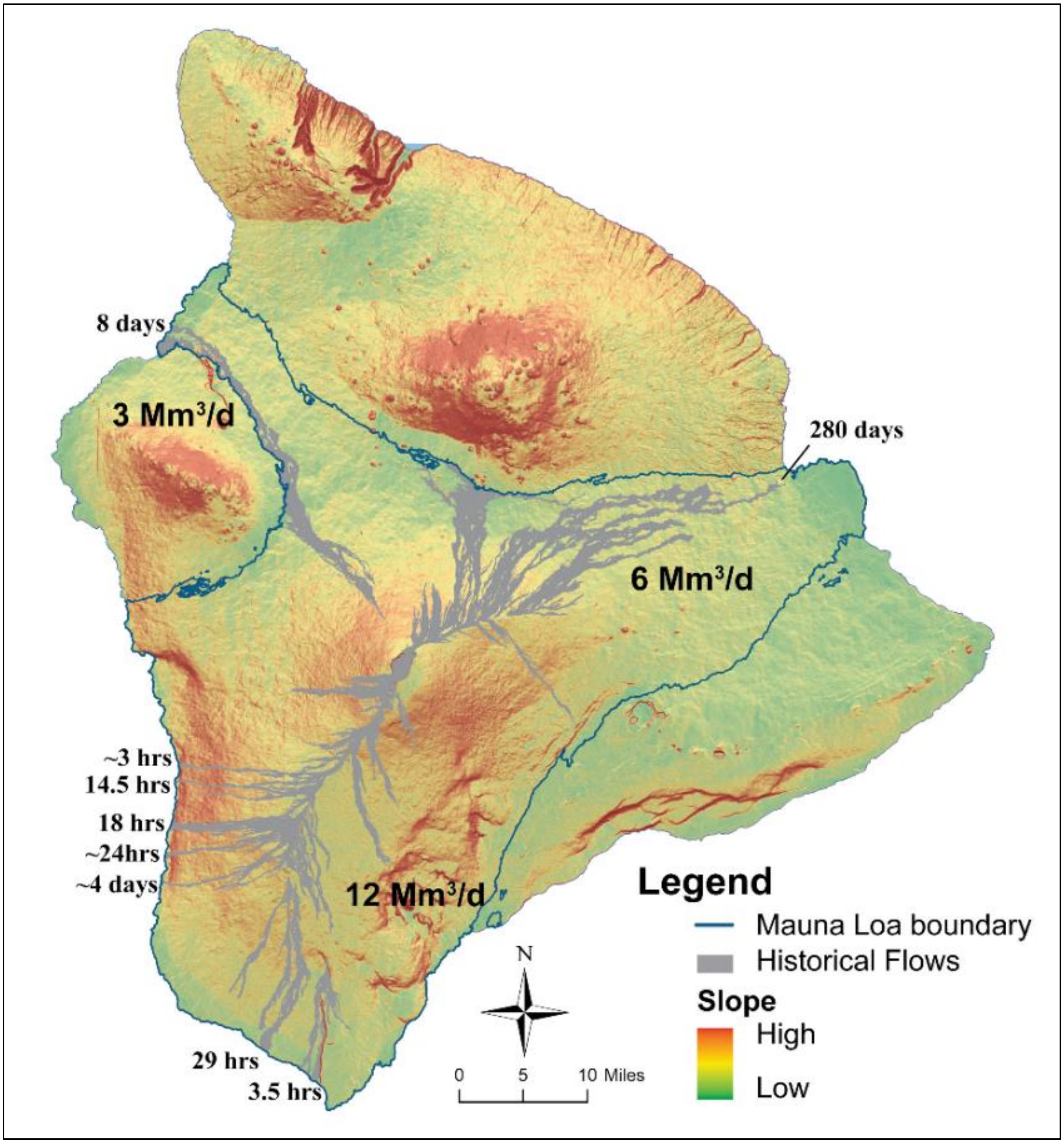
## *Volcanic Gases and Vog*

The extent of the hazard posed by volcanic gases and vog depends on the amount of magma being erupted and the concentration of gas in that magma. The Vog Measurement and Prediction Project (VMAP) provides real-time vog forecasts of vog trajectories and vog concentrations for the state when the emission rate is known. Each day, VMAP provides a summary and forecast for the Island of Hawaiʻi and statewide and is online here: http://weather.hawaii.edu/vmap/. Figure 4.14-9 illustrates an example of the $SO_2$ concentration for the entire state. This particular emission rate is for a period of time when Mauna Loa was below the detection limit and Kīlauea had emissions predicted of 153 tonnes per day.

## *Warning Time*

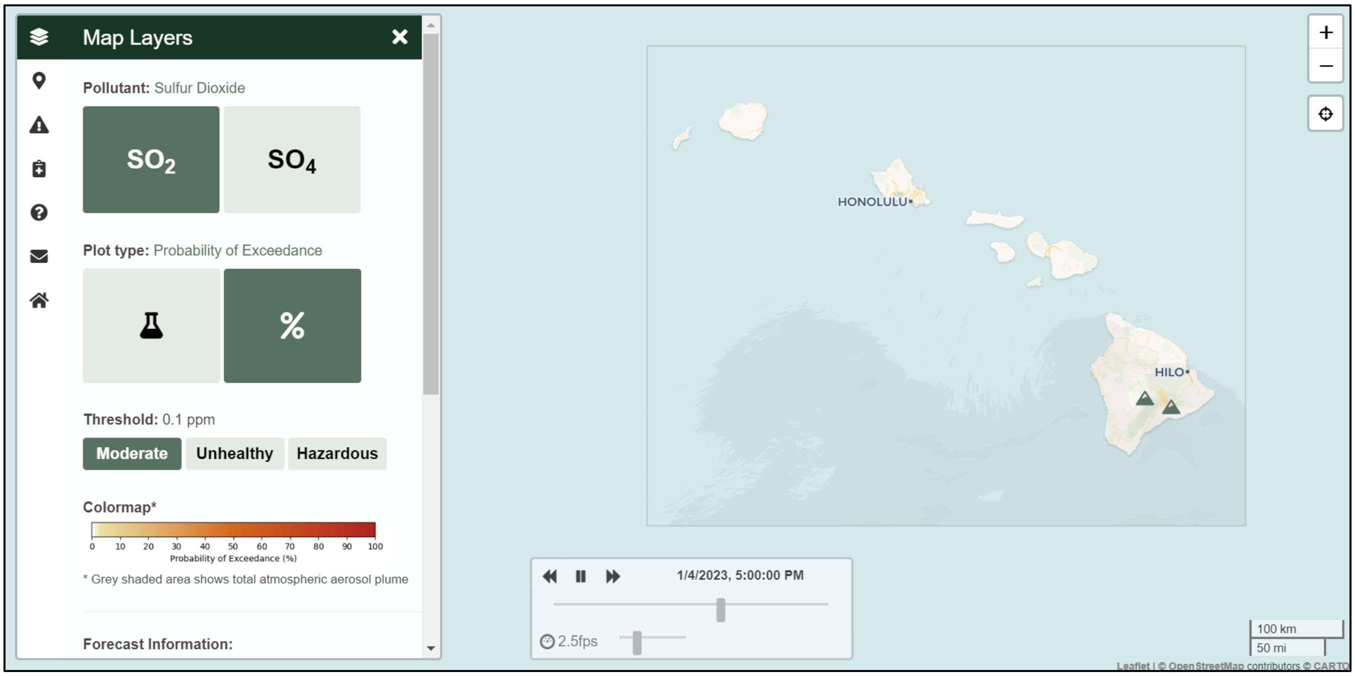
The HVO conducts gas monitoring to determine changes in emission rates of certain gases, chiefly sulfur dioxide ($SO_2$) and carbon dioxide ($CO_2$). Changes are compared with other monitoring information to assess magma supply and eruption rates, issue eruption warnings, improve gas-hazard assessments and vog forecasts, and better understand how Hawaiian volcanoes work. Additionally, the State of Hawaiʻi Department of Health (DOH) monitors the air quality for the state, including vog and its effects on people. Stationary air quality monitors that measure particulate levels are located in Hilo, Keaʻau, Mountain View, Pāhala, Hawaiian Ocean, Kona, and Waikoloa on Hawaiʻi Island, and on Maui, Oʻahu, and Kauaʻi. The State of Hawaiʻi DOH also has air monitoring stations for $SO_2$ on the islands of Hawaiʻi, Oʻahu, and Kauaʻi (U.S. Geological Survey n.d.). The Hawaiʻi Interagency Vog Information Dashboard (HIVID) is an excellent source of background information and up-to-date measurements and observations: https://vog.ivhhn.org/.

*Figure 4.14-8. Lava Flows of Mauna Loa*




*Source: (U.S. Geological Survey n.d.)*
*Note: Mm3/d Million cubic meters per day*

*Figure 4.14-9. $SO_2$ Concentration Map, Statewide*




*Source: School of Ocean and Earth Science and Technology 2023*

## Previous Occurrences and Losses

All eruptions since 1778 have been at Mauna Loa and Kīlauea, except for the 1800–1801 eruption of Hualālai on the west coast of the Island of Hawaiʻi.

Many sources provide information regarding previous occurrences and losses associated with volcanic hazard events throughout the State of Hawaiʻi. The 2018 SHMP discussed specific volcanic events that occurred in Hawaiʻi through June 2018. For this 2023 SHMP Update, volcanic events were summarized between January 1, 2018, and December 31, 2022 (Table 4.14-5). Major events include those that resulted in losses or fatalities, events that resulted in the activation of the State and/or County Emergency Operations Center (EOC), and/or events that led to a FEMA disaster declaration. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement).

*Table 4.14-5. Volcanic Hazard Events in Hawaiʻi, 2018 to 2022*

| Date(s) of Event | Event Type | Counties Affected | Description |
|---|---|---|---|
| **May – September 2018** | Kīlauea Volcanic Eruption and Earthquakes (DR-4366) | Hawaiʻi | ▪ On April 30, the Puʻu ʻŌʻō crater collapsed prompting seismicity in the Lower Puna District.<br>▪ On May 1, the USGS HVO issued a report that a migration of seismicity and deformation downrift (east) of Puʻu ʻŌʻō indicated that a large area along the east rift zone was potentially at risk of new outbreak, possibly in the Lower Puna area.<br>▪ On May 2, the first small ground cracks appeared in the Leilani Estates area.<br>▪ Between May 3 and May 27, 24 fissures opened in the lower east rift zone. |

| Date(s) of Event | Event Type | Counties Affected | Description |
|---|---|---|---|
| | | | ▪ On May 11, FEMA issued a major disaster declaration for the State of Hawaiʻi due to the eruption of Kīlauea. The County of Hawaiʻi was included in this declaration.<br>▪ On May 16, heavy de-gassing was occurring at each vent within the Leilani Estates neighborhood and the lower East Rift. The Hawaiʻi Fire Department reported air quality condition RED (immediate danger to health) in areas around Lanipuna Gardens and surrounding farm lots on Pohoiki Road.<br>▪ On May 17, HVO indicated an explosive eruption at Kīlauea summit occurred at 4:17 a.m. with ash clouds reaching 30,000 feet before drifting downwind.<br>▪ On May 20, white plumes of acid and extremely fine shards of glass billowed over the Island of Hawaiʻi as molten rock from Kīlauea poured into the ocean. The rate of sulfur dioxide gas shooting from the ground fissures tripled, leading County of Hawaiʻi to repeat warnings about air quality. At the volcano's summit, two explosive eruptions unleashed clouds of ash. Winds carried much of it toward the southwest. Since May 3, Kīlauea burned some 40 structures, including two dozen homes, since it began erupting in the Leilani Estates neighborhood. About 2,000 people were evacuated from their homes, including 300 who were staying in shelters.<br>▪ May 31, 2018, Mandatory Evacuation Order in Effect for Leilani Estates. Hawaiian Volcano Observatory reports that vigorous lava eruptions continue from the lower east rift zone fissure system in the area of Leilani Estates and Lanipuna Gardens. Over the following several months, lava continued to erupt, most notably from Fissure 8 (Ahuʻailaʻau) covering 13.7 square miles, more than 600 residences, over 100 other structures, and causing about $800 million in property damage. |
| **December 2020 – March 2021** | Kīlauea Volcanic Eruption | Hawaiʻi | ▪ On December 20, the USGS Hawaiian Volcano Observatory (HVO) detected a glow within Halemaʻumaʻu crater at the summit of Kīlauea volcano. As lava cascaded into Halemaʻumaʻu crater, it instantly vaporized the growing lake of water that had been developing in the crater since 2018.<br>▪ By December 24, the lake of water was replaced by a lava lake more than 500 feet deep.<br>▪ On December 26, the North vent was submerged into the lava lake. The West vent increased its outflow of lava into the lake. The lower inlet of the West vent was eventually submerged, and a dome fountain was created by the upwelling of the outflowing lava.<br>▪ By January 11, 2021, surface activity at the West vent had increased. But the dome fountaining in the lake had ceased. Weeks of lava spatter had formed a large cinder cone, and eruption activity slowed.<br>▪ After 5 months of activity, a decrease in effusion indicated that the eruption in Halemaʻumaʻu at the summit of Kīlauea was going to pause. HVO field crews did not observe any signs of lava lake activity on May 25 and reported no signs of active surface lava. The next day Kīlauea was no longer erupting. The crusted-over lava lake was last measured at 229 m (751 ft) deep and was stagnant across its surface. |
| **September 2021 – January 2023** | Kīlauea Volcanic Eruption | Hawaiʻi | ▪ On September 29, three fissures opened within Halemaʻumaʻu crater. The new fissures generated lava flows on the surface of a previous lava lake surface, creating a new lava lake, eventually growing to nearly 300 acres in size.<br>▪ Lava flooded the floor of the Halemaʻumaʻu crater for the first week of the eruption. The eruption then focused on the West vent in the crater.<br>▪ Over the next 14 months, lava flows continued to fill in the crater, ultimately effusing over 29 billion gallons of lava and raising the crater floor to nearly 500 feet higher than |

| Date(s) of Event | Event Type | Counties Affected | Description |
|---|---|---|---|
| | | | before the eruption. Although the eruption experienced 24 short-term pauses, an active portion of the lava lake was almost always visible, making for ideal viewing from several caldera overlooks for over a year.<br>▪ Lava supply to the crater stopped December 9.<br>▪ The summit eruption resumed January 5, 2023 |
| **November 2022 – December 2022** | Mauna Loa Volcanic Eruption | Hawaiʻi | ▪ On November 27, new fissures opened some distance away from the summit along the Northeast Rift Zone. Soon after, the summit fissures stopped erupting.<br>▪ By Friday, December 2, the eruption was limited to fissure 3 along the Northwest Rift Zone. Fissure 3, the only active fissure, was producing between 50 and 100 cubic yards of lava per second, flowing down slope and out of the park to the north toward Daniel K. Inoye State Highway 200 (Saddle Road).<br>▪ On December 13, 2022, the Hawaiian Volcano Observatory determined that "Mauna Loa is no longer erupting." Adding, "Lava supply to the fissure 3 vent on the Northeast Rift Zone ceased on December 10 and sulfur dioxide emissions have decreased to near pre-eruption background levels." |

*Sources: U.S. Geological Survey 2018; NPS 2022a; NPS 2022b; NPS 2023; Kīlauea Recovery and Resilience Plan 2020*

| | | | |
|---|---|---|---|
| *EOC* | *Emergency Operations Center* | *FEMA* | *Federal Emergency Management Agency* |
| *HVO* | *Hawaiian Volcano Observatory* | *USGS* | *U.S. Geological Survey* |
| *NPS* | *National Park Service* | | |

## *Disaster and Emergency Declarations*

The following disaster declarations and emergency proclamations related to volcanic hazards have been issued for Hawaiʻi:

- **Federal disaster (DR) or emergency (EM) declarations, 1955 – 2022**: 6 events classified as one or a combination of volcano or earthquake with volcanic disturbances
- **Hawaiʻi State Emergency Proclamations, 2018 – 2022**: 2 volcanic events
- **USDA Agricultural Disaster Declarations, 2012 – 2022**: None

One volcanic hazard event that affected the State of Hawaiʻi was declared a FEMA disaster between 2018 and 2022. It is identified in Table 4.14-6. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement). Appendix D (Map Atlas) illustrates the number of FEMA-declared volcanic hazard-related disasters by county.

### *Table 4.14-6. Volcanic Hazard-Related State and Federal Declarations, 2018 to 2022*

| Year | Event Type | Date Declared | Federal Declaration Number | Counties Affected |
|---|---|---|---|---|
| **May 2018** | Hawaiʻi Kīlauea Volcanic Eruption and Earthquakes | May 11, 2018 | DR-4366 | Hawaiʻi |

*Source: FEMA 2023*

## Probability of Future Hazard Events

### Overall Probability

Explosive eruptions of any size take place infrequently in the State of Hawaiʻi. Eruptions are often preceded with some warning. The HVO rates the potential threat, based in part on the probability of future eruptions, from each of the volcanoes it monitors as follows (U.S. Geological Survey n.d.):

- Kīlauea—Very High. This volcano has been erupting continuously since 1983.
- Mauna Loa—Very High. It last erupted in 1984 and is considered certain to erupt again.
- Hualālai—High. It is likely to erupt again.
- Mauna Kea—Moderate.
- Haleakalā—Moderate.

Overall, volcanic hazard events will continue to occur in the State of Hawaiʻi. As noted earlier, there are six active volcanoes in the state, with Kīlauea currently erupting at the time of this plan update. Based on historical record, the state has experienced six FEMA declarations associated with volcanic hazards since 1954. Based on the historic FEMA disaster declaration record, the state may experience a major volcanic event that leads to a FEMA declaration roughly once every 10 years. Looking at volcanic hazard events that occurred in the State of Hawaiʻi since 1823, there have been 92 volcanic eruptions with varying severity and impacts. Based on this data, the State of Hawaiʻi may experience one volcanic eruption every two years. An eruption may last one day, or several decades. Over the last 50 years, about 37 years have included continuous volcanic activity from two eruptions (Maunaulu and Puʻu ʻŌʻō). Based on data from the past five decades, the State of Hawaiʻi has a 72 percent chance of a continuous eruption in any given year.

### Climate Change Impacts

Changing future conditions may impact the dispersion and areas of impact of the volcanic hazard. As discussed in other hazard sections in this plan, projections indicate potential changes in wind and rainfall activity in the state. Any changes in wind and rainfall frequency and intensity may alter the dispersion of volcanic gas emissions, adversely impacting human health. For details regarding climate change as a distinct hazard and its unique impacts to the State of Hawaiʻi, refer to Section 4.2 (Climate Change and Sea Level Rise).

The types of volcanic activity that could impact climate are not those typically associated with Hawaiian volcanoes. The massive outpouring of gases and ash can influence climate patterns for years following a volcanic eruption. The conversion of sulfur dioxide to sulfuric acid is the most significant climate impact from a volcano. The Pinatubo eruption in the Philippines in 1991 was one of the largest volcanic events in the 20th century, injecting 20 million tons of sulfur dioxide into the stratosphere. It ultimately cooled the Earth’s surface by about 1°F for 3 years after its eruption. In contrast, the carbon dioxide released in recent eruptions has not been shown to lead to a detectable increase in global warming (USGS 2005).

## 4.14.2 VULNERABILITY ASSESSMENT

To assess the state's risk from volcanic hazards, the spatially delineated lava flow zones for the Counties of Hawaiʻi (zones 1 through 4) and Maui (zones 1 and 2) were used. The Counties of Kauaʻi and City and County of Honolulu do not have USGS lava maps, Therefore, no results are reported in the tables below.

### Lava Flow Hazard Area Definition

To assess vulnerability to lava flow, the following datasets were used:

- **County of Hawaiʻi** – Lava flow zones 1 through 4 in the spatial layer available on the Hawaiʻi Statewide GIS Programs Geoportal (originally prepared by USGS HVO 1992).
- **County of Maui** – Lava flow zones 1 and 2 in the spatial layer provided by USGS.

HI-EMA selected the following range of zones to define the lava flow hazard areas: Zones 1 through 4 for the County of Hawaiʻi; and Zones 1 and 2 for the County of Maui. Overall, an asset is considered exposed if it is located in a lava flow hazard area. During an active lava flow event, total loss of exposed assets is assumed. A qualitative discussion regarding potential vog impacts is also presented below.

### Assessment of State Vulnerability and Potential Losses

This section discusses the state asset exposure and potential losses due to lava flows. State assets include state buildings, state roads and critical facilities.

#### *State Assets*

The spatial analysis determined that there are 95 state buildings in the County of Maui and 1,020 state buildings in the County of Hawaiʻi located in the lava flow hazard areas (see Table 4.14-7 through Table 4.14-9). Greater than 80% of the state buildings located in the County of Hawaiʻi are located in the lava flow hazard area. The majority of these buildings are occupied by the Department of Education, University of Hawaiʻi, and Hawaiʻi Public Housing Authority. Once the lava flow reaches the buildings, it is assumed the entire structure will be burned, and the land will be buried. Only replacement cost value was available for state buildings; however, a more accurate reflection of loss to the lava flow hazard would be the combined value of the land and structure using tax-assessed data.

*Table 4.14-7. State Buildings Located in the Lava Flow Hazard Area by County*

| County | Total Number of State Buildings | Total Replacement Cost Value | State Buildings in the Lava Flow Hazard Area | | | |
|---|---|---|---|---|---|---|
| | | | Number | Percent (%) of Total | Total Replacement Cost Value | Percent (%) of Total |
| **County of Maui** | 831 | $3,097,491,689 | 95 | 11.43% | $222,068,001 | 7.17% |
| **County of Hawaiʻi** | 1,261 | $4,638,567,141 | 1,020 | 80.89% | $3,061,350,031 | 66.00% |
| **Total** | **2,092** | **$7,736,058,830** | **1,115** | **53%** | **$3,283,418,032** | **42.44%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; State of Hawaiʻi Risk Management Office 2017*

*Table 4.14-8. State Buildings in the County of Hawaiʻi Located in the Lava Flow Hazard Area by Agency*

| Agency | Total Number of State Buildings | Total Replacement Cost Value | Number of State Buildings in Hazard Area | Percent (%) of Total Buildings | Value in the Hazard Area | Percent (%) of Total Value |
|---|---|---|---|---|---|---|
| Dept of Accounting & General Services | 23 | $49,800,037 | 9 | 39.13% | $43,091,860 | 86.53% |
| Dept of Agriculture | 14 | $14,457,181 | 8 | 57.14% | $9,566,284 | 66.17% |
| Dept of Attorney General | 5 | $8,057,004 | 5 | 100.00% | $8,057,004 | 100.00% |
| Dept of Budget & Finance | 4 | $1,102,861 | 4 | 100.00% | $1,102,861 | 100.00% |
| Dept of Business, Economic Development and Tourism | 1 | $21,930,055 | 1 | 100.00% | $21,930,055 | 100.00% |
| Dept of Commerce & Consumer Affairs | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Dept of Defense | 7 | $21,294,676 | 7 | 100.00% | $21,294,676 | 100.00% |
| Dept of Education | 806 | $3,032,014,198 | 621 | 77.05% | $1,558,392,474 | 51.40% |
| Dept of Hawaiian Home Lands | 4 | $4,437,602 | 2 | 50.00% | $2,156,000 | 48.58% |
| Dept of Health | 6 | $16,433,860 | 6 | 100.00% | $16,433,860 | 100.00% |
| Dept of Human Resources Development | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Dept of Human Services | 18 | $26,873,841 | 14 | 77.78% | $19,008,602 | 70.73% |
| Dept of Labor and Industrial Relations | 8 | $14,262,182 | 8 | 100.00% | $14,262,182 | 100.00% |
| Dept of Land and Natural Resources | 2 | $4,309,241 | 2 | 100.00% | $4,309,241 | 100.00% |
| Dept of Public Safety | 52 | $60,003,409 | 52 | 100.00% | $60,003,409 | 100.00% |
| Dept of Taxation | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Dept of Transportation | 7 | $145,908,345 | 5 | 71.43% | $144,544,745 | 99.07% |
| Hawaiʻi State Ethics Commission | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Hawaiʻi Health Systems Corporation | 34 | $268,254,553 | 23 | 67.65% | $241,774,312 | 90.13% |
| Hawaiʻi Housing Finance & Development Corporation | 29 | $86,029,651 | 29 | 100.00% | $86,029,651 | 100.00% |
| Hawaiʻi Public Housing Authority | 63 | $224,042,406 | 55 | 87.30% | $196,187,666 | 87.57% |
| Hawaiʻi State Legislature | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Hawaiʻi State Public Library System | 11 | $42,426,683 | 6 | 54.55% | $19,817,400 | 46.71% |
| Judiciary | 13 | $107,355,122 | 11 | 84.62% | $106,301,953 | 99.02% |
| Legislative Reference Bureau | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of Hawaiian Affairs | 2 | $544,989 | 2 | 100.00% | $544,989 | 100.00% |
| Office of the Auditor | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of the Governor | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of the Lieutenant Governor | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of the Ombudsman | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Research Corporation of the University of Hawaiʻi | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| University of Hawaiʻi | 152 | $489,029,245 | 150 | 98.68% | $486,540,807 | 99.49% |
| **Total** | **1,261** | **$4,638,567,141** | **1,020** | **80.89%** | **$3,061,350,031** | **66.00%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; State of Hawaiʻi Risk Management Office 2017*

*Table 4.14-9. State Buildings in the County of Maui Located in the Lava Flow Hazard Area by Agency*

| Agency | Total Number of State Buildings | Total Replacement Cost Value | Number of State Buildings in Hazard Area | Percent (%) of Total Buildings | Value in the Hazard Area | Percent (%) of Total Value |
|---|---|---|---|---|---|---|
| Dept of Accounting & General Services | 5 | $11,155,000 | 0 | 0.00% | $0 | 0.00% |
| Dept of Agriculture | 6 | $14,837,348 | 0 | 0.00% | $0 | 0.00% |
| Dept of Attorney General | 2 | $4,596,267 | 0 | 0.00% | | 0.00% |
| Dept of Budget & Finance | 3 | $928,470 | 0 | 0.00% | $0 | 0.00% |
| Dept of Business, Economic Development and Tourism | 1 | $9,978,917 | 1 | 100.00% | $9,978,917 | 100.00% |
| Dept of Commerce & Consumer Affairs | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Dept of Defense | 3 | $16,512,909 | 0 | 0.00% | $0 | 0.00% |
| Dept of Education | 563 | $1,643,027,339 | 70 | 12.43% | $128,103,796 | 7.80% |
| Dept of Hawaiian Home Lands | 2 | $689,000 | 0 | 0.00% | $0 | 0.00% |
| Dept of Health | 3 | $4,843,533 | 0 | 0.00% | $0 | 0.00% |
| Dept of Human Resources Development | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Dept of Human Services | 15 | $40,181,697 | 0 | 0.00% | $0 | 0.00% |
| Dept of Labor and Industrial Relations | 6 | $7,933,611 | 0 | 0.00% | $0 | 0.00% |
| Dept of Land and Natural Resources | 15 | $7,364,163 | 1 | 6.67% | $552,425 | 7.50% |
| Dept of Public Safety | 24 | $67,950,438 | 0 | 0.00% | $0 | 0.00% |
| Dept of Taxation | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Dept of Transportation | 28 | $221,677,724 | 1 | 3.57% | $191,500 | 0.09% |
| Hawaiʻi State Ethics Commission | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Hawaiʻi Health Systems Corporation | 36 | $658,673,127 | 21 | 58.33% | $79,315,317 | 12.04% |
| Hawaiʻi Housing Finance & Development Corporation | 28 | $78,210,082 | 0 | 0.00% | $0 | 0.00% |
| Hawaiʻi Public Housing Authority | 4 | $15,058,800 | 0 | 0.00% | $0 | 0.00% |
| Hawaiʻi State Legislature | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Hawaiʻi State Public Library System | 7 | $20,774,018 | 1 | 14.29% | $3,926,046 | 18.90% |
| Judiciary | 9 | $51,294,291 | 0 | 0.00% | $0 | 0.00% |
| Legislative Reference Bureau | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of Hawaiian Affairs | 2 | $331,760 | 0 | 0.00% | $0 | 0.00% |
| Office of the Auditor | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of the Governor | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Office of the Lieutenant Governor | 1 | $2,257,785 | 0 | 0.00% | $0 | 0.00% |
| Office of the Ombudsman | 0 | $0 | 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 | Value in the Hazard Area | Percent (%) of Total Value |
|---|---|---|---|---|---|---|
| **Research Corporation of the University of Hawai'i** | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| **University of Hawai'i** | 68 | $219,215,409 | 0 | 0.00% | $0 | 0.00% |
| **Total** | **831** | **$3,097,491,689** | **95** | **11.43%** | **$222,068,001** | **7.17%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; State of Hawai'i Risk Management Office 2017*

Lava flows can close and ultimately destroy roads. This may result in the isolation of areas and larger regional issues such as loss of commerce and increased traffic on other roadways. Utilities that commonly follow roads, including those underground, will be buried and probably burned or rendered useless by excess heat resulting in disruption of services. Table 4.14-10 shows the length of state roads exposed to lava flow hazard (zones) by county. The County of Hawai'i has the greatest number of miles (218.7 miles) exposed, which makes up 57.67% of all state roads in the county. A complete list of state roads located in the lava flow hazard zones is included in Appendix F (State Profile and Risk Assessment Supplement).

*Table 4.14-10. State Roads Located in the Lava Flow Hazard Area by County*

| County | Length (in miles) | | |
|---|---|---|---|
| | Total Length | Length of State Road in Hazard Area | Percent (%) of Total Length |
| **County of Maui** | 245.9 | 22.1 | 8.99% |
| **County of Hawai'i** | 379.2 | 218.7 | 57.67% |
| **Total** | **625.1** | **240.8** | **38.52%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; State of Hawai'i Department of Transportation 2022*

## Community Lifelines and Critical Facilities

Table 4.14-11 summarizes the total number of community lifelines and critical facilities by category located in the lava flow hazard area in the Counties of Hawai'i and Maui. The County of Hawai'i has 201 community lifelines located in the lava flow hazard area. The County of Maui has 38 community lifelines located in the lava flow hazard area. Table 4.14-12 and Table 4.14-13 summarize the number and percentage of exposed critical facilities by category in the Counties of Hawai'i and Maui, respectively. Hazardous Materials has the largest percentage (100%) of their facilities within the County of Hawai'i lava flow hazard area. Energy has the largest percentage (25%) of their facilities within the County of Maui lava flow hazard area.

Similar to state buildings, only replacement cost value was available for community lifelines and critical facilities; however, a more accurate reflection of loss to the lava flow hazard would be the combined value of the land and structure using tax-assessed data. Additionally, the loss of service provided by each destroyed community lifeline and critical facility would increase the total loss from the hazard.

### *Table 4.14-11. Community Lifelines and Critical Facilities Located in the Lava Flow Hazard Area in Counties of Hawai'i and Maui*

| County | Community Lifeline Categories | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Communications | Energy | Food, Water, Shelter | Hazardous Material | Health & Medial | Safety & Security | Transportation | Total in the Hazard Area | Additional Critical Facilities |
| **County of Maui** | 4 | 1 | 13 | 0 | 6 | 8 | 2 | 34 | 4 |
| **County of Hawai'i** | 24 | 8 | 59 | 4 | 27 | 48 | 15 | 185 | 16 |
| **Total** | **28** | **9** | **72** | **4** | **33** | **56** | **17** | **219** | **20** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020*

### *Table 4.14-12. Community Lifelines and Critical Facilities Located in the Lava Flow Hazard Area in the County of Hawai'i, by Category*

| Category | Total Number of Facilities in the County of Hawai'i | Total Replacement Cost Value | Number of Facilities in Hazard Area | Percent (%) of Total Facilities | RCV in the Hazard Area | Percent (%) of Total RCV |
|---|---|---|---|---|---|---|
| **Communications** | 31 | $93,481,861 | 24 | 77.42% | $73,877,926 | 79.03% |
| **Energy** | 9 | $198,746,450 | 8 | 88.89% | $188,244,650 | 94.72% |
| **Food, Water, Shelter** | 80 | $2,680,336,405 | 59 | 73.75% | $1,938,647,355 | 72.33% |
| **Hazardous Material** | 4 | $145,176,000 | 4 | 100.00% | $145,176,000 | 100.00% |
| **Health and Medical** | 36 | $716,428,294 | 27 | 75.00% | $435,601,169 | 60.80% |
| **Safety and Security** | 65 | $2,231,470,278 | 48 | 73.85% | $1,542,345,673 | 69.12% |
| **Transportation** | 17 | $616,998,000 | 15 | 88.24% | $544,410,000 | 88.24% |
| **Additional Critical Facilities** | 28 | $90,935,100 | 16 | 57.14% | $51,464,800 | 56.60% |
| **Total** | **270** | **$6,773,572,388** | **201** | **74.44%** | **$4,919,767,573** | **72.63%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020*

*Table 4.14-13. Community Lifelines and Critical Facilities Located in the Lava Flow Hazard Area in the County of Maui, by Category*

| Category | Total Number of Facilities in the County of Maui | Total Replacement Cost Value | Number of Facilities in Hazard Area | Percent (%) of Total Facilities | RCV in the Hazard Area | Percent (%) of Total Value |
|---|---|---|---|---|---|---|
| Communications | 22 | $145,876,494 | 4 | 18.18% | $24,153,738 | 16.56% |
| Energy | 4 | $147,298,900 | 1 | 25.00% | $36,294,000 | 24.64% |
| Food, Water, Shelter | 74 | $2,380,051,303 | 13 | 17.57% | $445,330,255 | 18.71% |
| Hazardous Material | 0 | $0 | 0 | 0.00% | $0 | 0.00% |
| Health and Medical | 50 | $784,590,174 | 6 | 12.00% | $147,573,808 | 18.81% |
| Safety and Security | 77 | $23,758,378,102 | 8 | 10.39% | $2,920,913,866 | 12.29% |
| Transportation | 23 | $834,762,000 | 2 | 8.70% | $72,588,000 | 8.70% |
| Additional Critical Facilities | 34 | $193,201,010 | 4 | 11.76% | $16,711,800 | 8.65% |
| **Total** | **284** | **$28,244,157,982** | **38** | **13.38%** | **$3,663,565,466** | **12.97%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; Hawaiʻi Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020*

## Assessment of Local Vulnerability and Potential Losses

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

### *Socially Vulnerable and Total Population*

The communities and populations especially vulnerable to volcanic eruptions include low-income communities, migrant populations, populations whose primarily language is not English, indigenous populations, communities of older adults, and those with respiratory and other health concerns. These populations may be more susceptible to transport and communication challenges. They may also be impacted by the effects of toxic volcanic ash and problems of the respiratory system, eyes, and skin. Psychological effects, injuries, waste disposal and water supply issues, collapse of buildings and power outage are all likely to impact vulnerable populations (Zuskin, et al. 2007).

#### Lava Flows

Lava flows endanger people's property, livelihood, and peace of mind, but less commonly, their lives. The leading edge of Hawaiian lava flows generally move more slowly than the speed at which people walk, although the lava in the channel behind the front may be flowing much faster. On steep slopes, a large flow could travel rapidly enough to endanger persons in its path. During the 1950 eruption of Mauna Loa, the fast-moving lava flows reached the South Kona Coast in about 3 hours, having traveled 11 miles during that timeframe (Hawaiian Volcano Observatory 2016).

For the County of Hawaiʻi, Table 4.14-14 shows that an estimated 80% of the county population is living in the lava flow hazard area. For the County of Maui, Table 4.14-14 shows that an estimated 12% of the county population is living in the lava flow hazard area. This analysis does not include the number of tourists and visitors in the state whose lodgings are located in the lava flow hazard area. Therefore, this estimate may be underestimating exposure and vulnerability.

*Table 4.14-14. 2020 U.S. Census Population Located in the Lava Flow Hazard Area by County*

| County | Population | | | | |
|---|---|---|---|---|---|
| | Total Population | Population in the Hazard Area | Population Exposed as % of Total Population | Socially Vulnerable Population in the Hazard Area | Socially Vulnerable Population Exposed as % of Total Population |
| **County of Maui** | 167,093 | 20,033 | 12% | 0 | 0% |
| **County of Hawaiʻi** | 201,350 | 161,698 | 80% | 36,475 | 18% |
| **Total** | **368,443** | **181,731** | **49%** | **36,475** | **10%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018*

The populations considered most vulnerable to hazards in general include the elderly (persons over the age of 65) and individuals living below the U.S. Census poverty threshold. These socially vulnerable populations are most susceptible based on many factors including their physical and financial ability to react or respond during a hazard. The socially vulnerable population located in the lava flow hazard area makes up approximately 18% of the population in the County of Hawaiʻi and 0% in the County of Maui.

## Volcanic Gases and Vog

The term 'vog' refers to the hazy air pollution caused by the volcanic emissions from Kīlauea volcano, which are primarily water vapor ($H_2O$), carbon dioxide ($CO_2$), and sulfur dioxide ($SO_2$) gas (Interagency Vog Dashboard 2023). Toxic gases emitted from a volcano can travel great distances and cause respiratory distress. Sulfur dioxide ($SO_2$) is irritating to the eyes, nose, throat and respiratory tract. The most vulnerable populations to vog include children and individuals with pre-existing respiratory conditions such as asthma, emphysema, bronchitis, and chronic lung or heart disease. Vulnerable populations may respond to very low levels of sulfur dioxide in the air. Prolonged or repeated exposure to higher levels may increase the danger.

The acute health threats posed by the gas discharges are largely associated with the acid gases, sulfur dioxide being the greatest threat because it is discharged at the highest rates and is also accompanied by sulfuric acid aerosols. The acute threats (to human health) typically fall off rapidly with distance from the vent. Although epidemiological data demonstrating the adverse impacts of gas exposure have been difficult to develop, anecdotal reports of families and individuals moving out of the exposed communities to avoid the effects of the gases are quite common. Future threats from these gases will also be dependent on the location of future eruptions.

As with the acute effects, documentation of the human health impacts of lower-level chronic exposure to the volcanic gases in downwind communities has proven difficult: epidemiological studies have documented only relatively minor impacts from sulfur dioxide exposure, but anecdotal reports of respiratory discomfort and eye irritation are extremely common and extend beyond the County of Hawaiʻi to the City and County of Honolulu during weather conditions conducive to transport of the plume along the island chain.

Of more concern is the presence of fluoride ion in the gas discharges. Because the use of roof-catchment of rainfall for domestic water consumption is a common practice in communities in the County of Hawaiʻi around and downwind of Kīlauea, there is the potential for accumulation of fluoride in these systems. More recent studies by Donald Thomas and Trisha Macomber on public health hazards associated with rainfall catchment systems exposed to vog emitted from Kīlauea's Halemaumau Crater have shown that there is a clear influence on the emissions of vog on rainfall catchment systems located downwind from the source (Thomas and Macomber 2010). Thomas and Macomber's study indicates that an increase in fluoride and sulfate concentrations arise from dry deposition of vog plumes. The study found that levels of these compounds did not exceed the World Health Organization standards for drinking water. However, this finding precludes possible exceedance in the levels of the compounds in the catchment systems due to variations in the levels of the compounds in the plume of vog or exceedance in the levels of the compounds in catchment systems not sampled in the study.

In late 1980s, studies conducted on private rainfall catchment systems in the South Kona area revealed higher than average acidity in several water samples. Drinking the acidic water does not pose a health hazard, but such water can leach lead from the lead roof flashings, lead-headed nails, and solder connections found in many plumbing systems, resulting in unsafe levels of lead in the drinking water. Extensive testing in 1988 determined that many rainfall catchment systems in the County of Hawaiʻi, particularly those in the districts adjacent to or downwind of the active vent, contained elevated levels of lead.

The University of Hawaiʻi's College of Tropical Agriculture and Human Resources notes that acidic rainwater is not normally a problem. The main concern is when heavy metals and other leached materials get into the water and are consumed. A common method for this to occur is when the copper in most water pipes becomes eroded and can be tasted in the drinking water (Hawaiʻi College of Tropical Agriculture and Human Resources n.d.) Hawaiʻi's guidelines on rainfall catchment systems suggests that the key to a good system is to choose building materials that will not leach toxins into the water under normal or acid rain conditions. For example, the most common type of roofing material used for water catchment is galvanized metal that has been painted or enameled with a nontoxic paint. This may be difficult for owners of older homes, which may contain lead-based paint, lead-based solder, or lead-gasketed roofing nails at particularly high risk of lead mobilization into the domestic water supply by the acidic rainwater (Macomber 2020).

## General Building Stock

### Lava Flows

Man-made structures that escape other damage from an eruption can be damaged or destroyed by cracking, tilting, or settling of the ground beneath them. Ground cracks will remain after the eruption is over and can pose a threat to unwary people and animals if the cracks are obscured by heavy vegetation (Aabech n.d.). Similar to the analyses presented earlier, the general building stock data were overlaid with the lava flow hazard area to assess exposure. Table 4.14-15 summarizes the replacement costs and percentages for the Counties of Hawaiʻi and Maui. The County of Hawaiʻi has the greatest estimated potential losses (78.64%) to general building stock. As stated earlier, once lava flow reaches a building, it is assumed that both the structure and land are lost.

*Table 4.14-15. General Building Stock Located in the Lava Flow Hazard Area by County*

| County | Total Replacement Cost Value | Replacement Cost within the Lava Flow Hazard Area | Percent (%) of Total |
|---|---|---|---|
| **County of Maui** | $50,796,693,140 | $8,744,095,957 | 17.21% |
| **County of Hawaiʻi** | $58,395,349,136 | $45,919,253,291 | 78.64% |
| **Total** | **$109,192,042,277** | **$54,663,349,248** | **50.06%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; NIYAM IT 2022; United States Army Corps of Engineers 2022*

A hazard event can have great impacts on the local and statewide economy. In the far downwind community, on the western side of the Island of Hawaiʻi, weather conditions tend to accumulate the vog discharge into a thick haze that results in persistently overcast skies. The economy in the communities on the western side of the island is heavily dependent on tourism; the primary attraction is balmy weather, blue skies, and access to ocean activities. In 2018 during and following the eruption of Kīlauea, discussions on the state's tourism industry expressed concern that the adverse air quality associated with the ongoing eruption is reducing the attractiveness of this area as a vacation spot, resulting in a loss of income to all the businesses that rely on tourism for their success (Hawaiʻi Tourism Authority 2018). During the November 2022–December 2022 eruption of Mauna Loa, the opposite happened; tourism boomed during an otherwise slow tourism season (Selsky, McAvoy and Daley 2022).

The Kīlauea volcanic event placed a damper on the Hawaiian economy. According to interviews conducted by NPR, business owners and their employees indicated the normally busy tourism area felt like a ghost town. Tourism officials stated the booking pace for the summer of 2018 slowed by almost 50%; many local business owners blamed the over-excited news coverage, making possible tourists believe the whole island is erupting and sinking into the sea (NPR 2018). According to the University of Hawaiʻi Economic Research Organization, bookings for travel to the County of Hawaiʻi were down due to the eruption. The 2018 eruption closed Hawaiʻi Volcanoes National Park, the County of Hawaiʻi's biggest tourist attraction (University of Hawaiʻi 2018). Tourists may have been apprehensive to visit, resulting in decreased or canceled bookings that can equate to a direct economic loss potentially in the millions. As discussed later in the Environmental Resources subsection below, agriculture in the state have experienced loss due to the volcanic gases.

### *Land Use Districts*

Table 4.14-16 shows the square miles of the lava flow hazard area in each State Land Use District statewide; refer to Appendix F for results for the County of Hawaiʻi and the County of Maui. More than half of the Conservation District lands statewide are located in lava flow zones. Conservation District lands contain valuable environmental and ecological resources. Additional discussion of exposure and vulnerability of these resource areas can be found in the Environmental Resources and Cultural Assets sections below. Almost a quarter of Urban District lands statewide are located in lava flow zones. Over half (52%) of the Conservation District lands are located in lava flow zones.

*Table 4.14-16. State Land Use Districts Located in the Lava Flow Hazard Area*

| Land Use District | Total (square miles) | Square Miles in Volcano Lava Flow Zones | Percent (%) of Total Area |
|---|---|---|---|
| **Agricultural** | 2,973.6 | 1,122.7 | 37.8% |
| **Conservation** | 3,202.9 | 1,664.0 | 52.0% |
| **Rural** | 16.3 | 3.0 | 18.4% |
| **Urban** | 319.1 | 75.5 | 23.7% |
| **Total** | **6,511.9** | **2,865.2** | **44.0%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; State Land Use Commission, Hawaiʻi Statewide GIS Program 2021; Honolulu County GIS 2022*

## *Environmental Resources*

Besides respiratory tract health effects similar to those in humans, vog can also cause the death of wildlife and livestock because of contaminated food consumption. Wildlife and livestock that graze, for example, can die after ingesting water or grass that has been heavily contaminated by falling ash and other volcanic particles. When vog mixes directly with moisture on the leaves of plants, it can cause severe chemical burns, which can damage or kill the plants. Sulfur dioxide (SO2) gas can also diffuse through leaves and dissolve to form acidic conditions within plant tissue (USGS n.d.).

Also of great concern to wildlife and livestock is the deposition of fluoride salts carried by vog onto forage crops. Scientific literature has documented a number of events where sheep, cattle, and horses have suffered significant losses as a result of acute exposure as well as chronic exposure and accumulation of fluoride salts by grazing animals (Koli, Yadav and Yadav 2017).

In 2010, Donald Thomas from the Center for the Study of Active Volcanoes and Trisha Macomber from the University of Hawaiʻi's College of Tropical Agriculture produced a study on the effects of fluoride and sulfates on forage lands downwind of Kīlauea's Halemaumau Crater (Thomas and Macomber 2010). The study shows that forage samples contained fluoride and sulfate values higher than recommended by the World Health Organization. The study also indicates that although elevated concentrations of fluoride and sulfate do induce adverse health/nutritional effects on grazing animals, the high levels of these compounds do not impact the quality of meat from those animals that would be used for public consumption.

The general effects of sulfur dioxide exposure to plants varies between plant species, age, and the sulfur dioxide dosage; these effects may include:

- reduced seed germination
- enhanced susceptibility to other diseases
- foliar necrosis (spots, blight)
- epicuticular wax erosion
- rupture of epidermis, plasmolysis
- reduced chlorophyll content
- increased membrane permeability of plant leaves
- decreased plant growth (root length, shoot length, leaf numbers)
- plant organ or entire plant death

Downwind of Kīlauea, farmers growing food crops, foliage crops, and cut flowers have all experienced immediate and severe losses due to damage arising from exposure to high concentrations of sulfur dioxide and sulfuric acid aerosols. Although downwind ranches did not experience immediate impacts, over time, they have found that horses, cattle, and goats have developed serious adverse health impairments consistent with chronic fluoride exposure as well as severe mineral deficiencies. At the present time, the mediating factors in these health impacts are not well understood, although excess bone fluoride has been measured and therefore chronic exposure to and intake of fluoride is clearly one aspect of the problem. A secondary economic issue has been greatly accelerated corrosion of fencing, pipelines, and deterioration of ranching equipment. Anecdotal reports of service life losses of 60% to 70% suggest that the economic impacts of these losses could be severe.

The impacts resulting from gas discharge detailed above are based on existing rates of discharge from more or less fixed locations of emissions. In the event of significant increases in the discharge rate from Kīlauea or an eruption by Mauna Loa with 10 or more times the gas production rate of Kīlauea, the impacts from the gas can be expected to increase correspondingly.

Table 4.14-17 summarizes the environmental resources located in lava flow hazard areas. Coastal features, reefs, and other marine habitats, although not located in the lava flow hazard areas, may be impacted once the lava reaches the ocean. In the County of Hawai'i, 74.1% of Parks and Reserves are located in the lava flow hazard area. In the County of Maui, 31.2% of Critical Habitat is located in the lava flow hazard area.

*Table 4.14-17. Environmental Resources Located in the Lava Flow Hazard Area*

| Environmental Asset | Area (in square miles) | | | | | |
|---|---|---|---|---|---|---|
| | County of Hawai'i | | | County of Maui | | |
| | Total Asset Area | Lava Flow Hazard Area | Hazard Area as Percent (%) of Total Area | Total Asset Area | Lava Flow Hazard Area | Hazard Area as Percent (%) of Total Area |
| **Critical Habitat [a]** | 447 | 233 | 52.3% | 293 | 92 | 31.2% |
| **Wetlands** | 1,149 | 4 | 0.3% | 1,382 | 39 | 2.8% |
| **Parks and Reserves** | 2,023 | 1,498 | 74.1% | 409 | 72 | 17.6% |
| **Reefs [b]** | 9 | 0 | 0.3% | 26 | 0 | 0.0% |
| **Total [c]** | **3,627** | **1,736** | **47.9%** | **2,110** | **202** | **9.6%** |

Source: *USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; U.S. Fish and Wildlife Service; Pacific Islands Office 2022l U.S. Fish and Wildlife Service 2021, 2017; Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022; NOAA raster nautical charts 2020; State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021*

Note: *a. Critical habitat 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

Cultural sites are non-renewable resources. Lava flows can cut off or cover cultural sites and native land. A large percentage of the Hawaiian Home Lands are located in lava flow hazard areas; 34.9 square miles in the County of Maui or nearly 34% of the county total; and 35.9 square miles in the County Hawai'i or 18.8% of the county total (see Table 4.14-18). Table 4.14-19 summarizes cultural resources in lava flow hazard areas.

*Table 4.14-18. Hawaiian Home Lands Located in Lava Flow Hazard Area*

| County | Area (in square miles) | | |
|---|---|---|---|
| | Total Area | Lava Flow Hazard Area | Hazard Area as Percent (%) of Total |
| **County of Maui** | 102.6 | 34.9 | 34.0% |
| **County of Hawai'i** | 191.5 | 35.9 | 18.8% |
| **Total** | **294.0** | **70.8** | **24.1%** |

Source: *USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; Hawai'i State Department of Hawaiian Homelands 2021*

### *Table 4.14-19. Cultural Resources Located in Lava Flow Hazard Area*

| Cultural Resource Site Type | Area (in square miles) | | |
|---|---|---|---|
| | Total Square Miles of Asset | Total Square Miles in the Hazard Area | Percent (%) of Total Asset Area |
| **Archaeology** | 90.9 | 19.2 | 21.1% |
| **Burial Sensitivity Area** | 2.1 | 0.5 | 24.5% |
| **Historic Building** | 2.7 | 0.4 | 15.3% |
| **Historic District** | 849.4 | 358.2 | 42.2% |
| **Historic Object** | 9.6 | 9.6 | 99.9% |
| **Historic Structure** | 20.7 | 16.5 | 79.4% |
| **Total** | **975.4** | **404.4** | **41.5%** |

*Source: USGS Hawaiian Volcano Observatory 1992; United States Geological Survey 2006; Department of Land and Natural Resources, Hawaiʻi 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 of Hawaiʻi 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 of Projected Development*

Lava flow hazard areas were overlain on areas that may experience significant changes in development or redevelopment in future years (see Table 4.14-20 below; refer to Section 3 for more information on projected development areas). The results of this assessment indicate that 42.39% of the Maui Development Project areas and roughly 39% of the Enterprise Zones in the County of Maui and the County of Hawaiʻi are located in lava flow hazard areas. County governments may wish to limit the density of development in these areas to prevent increasing exposure of life and property to the lava flow hazard.

### *Projected Changes in Population*

As the age distribution of the population changes resulting in an increase in the number of elderly and young persons in the state, vulnerability to the impacts of volcanic gases and vog may increase as these populations tend to be more susceptible to negative impacts.

### *Table 4.14-20. Maui Development Projects and Enterprise Zones Located in Lava Flow Hazard Areas*

| | Area (in square miles) | | | | | |
|---|---|---|---|---|---|---|
| County | Maui Development Projects (Total Area) | Total Area Exposed to Hazard | Hazard Area as Percent (%) of Total | Enterprise Zones (Total Area) | Total Area Exposed | Hazard Area as Percent (%) of Total |
| **County of Maui** | 27.6 | 11.7 | 42.39% | 1,059.80 | 168.57 | 15.91% |
| **County of Hawai'i** | 0 | 0 | 0 | 1,274.90 | 728.1 | 57.11% |
| **Total** | **27.6** | **11.7** | **42.39%** | **2,334.70** | **896.67** | **38.41%** |

*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.*

## Volcanic Hazard Mitigation Success Story

*Credit: Steven Businger and Nadya Moisseeva 2021*

In 2021, the University of Hawai'i Atmospheric Sciences team was awarded an HMGP grant to install a ceilomoter at Pahala Elementary School in Hawai'i County. This tool has significantly improved the ability to forecast areas of heavy vog and poor air quality from volcanic emissions as part of the Vog Measurement and Prediction Program (VMAP) at UH. Forecasts are used to provide air quality warnings to the community, including the most vulnerable populations.

For more details on the VMAP project, please see Vog Measurement and Prediction (VMAP) | Home (hawaii.edu)