SECTION 4. RISK ASSESSMENT

4.14 Volcanic Hazards (Lava Flow and Vog)

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 how climate change may alter the dispersion and areas of impact of some of the volcanic hazards, e.g. vog).
- Volcanic hazard events that occurred in the State of Hawai'i from January 1, 2012, through December 31, 2017, were researched for this 2018 HMP Update. Due to the severity of recent events, the May 2018 event is discussed; however, details regarding the full range of impacts are not available at the time of this 2018 HMP Update.
- Maps of volcanoes and associated lava flows have been added.
- The high hazard lava flow zones for Hawai'i (Zones 1 through 4) and Maui (Zones 1 and 2) Counties were used as the hazard areas to assess vulnerability.

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. Most of the volcanic activity in the last 200 years has occurred on the Island of Hawai'i. The Island of Hawai'i 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 Hawai'i, is undergoing a period of eruptive quiescence, having erupted only twice during the last 60 years; prior to this time, Mauna Loa was much more active, erupting, on average, about every five years.

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 [USGS] 2017). Hualalai 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.

Another volcano of note is Loihi, which 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 Hawai'i. This volcano's activity has been consistently monitored since 1996. This emerging seamount may eventually break the surface, adding a new island to the Hawaiian chain, with some estimates ranging from

30,000 to 50,000 years. There are no estimated potential impacts to residents and infrastructure from Loihi at this time.

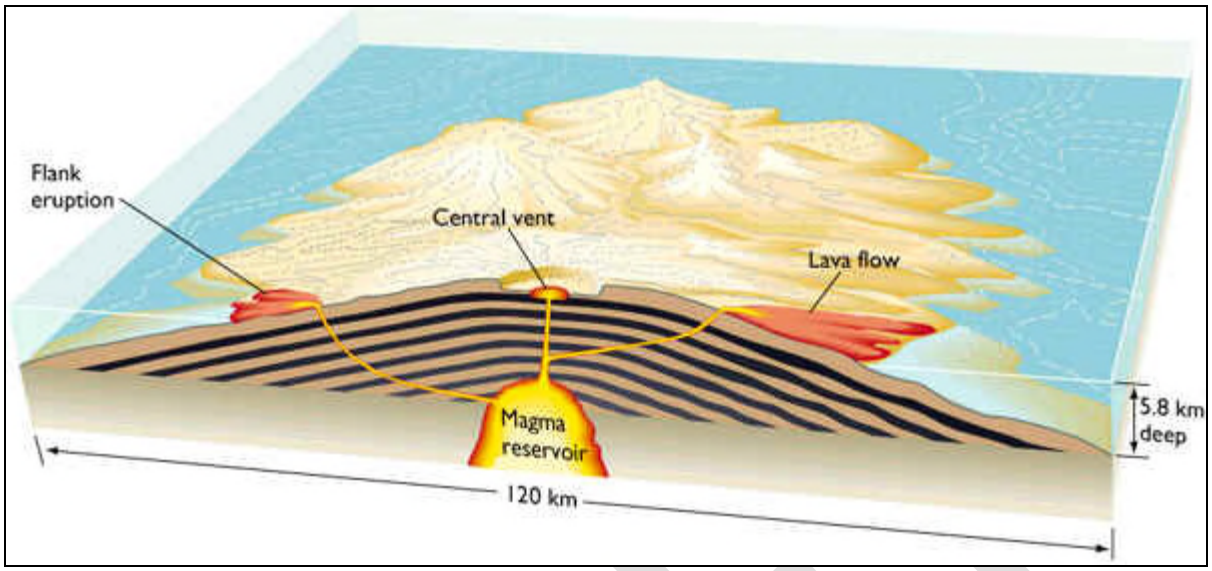
Hazard Description

Hawaiian volcanoes are shield volcanoes, which, because they dominantly erupt fluid, lava flows form gently sloping, shield-like mountains. Shield volcanoes are the largest volcanoes on earth. Examples of shield volcano are Mauna Loa and Kīlauea, which are located in the County of Hawai`i. Hawaii's volcanic activity is distinct from that occurring at continental margins (e.g. Mt. Shasta, Mt. St. Helens, etc.) in that Hawaii's volcanoes produce more fluid basalt magmas that are typically less explosive. Hawaii's volcanoes are formed sequentially with the older volcanoes to the northwest and younger sister volcanoes to the southeast. Each volcano develops through a relatively consistent sequence of stages exemplified by: Loihi (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 Hualalai and Mauna Kea are less active but typically produce more viscous and more explosive lavas.

Mauna Loa last erupted in 1984, and Kīlauea has been continuously erupting since 1983, most recently with voluminous lava flows along its lower east rift zone and ash-rich explosions in the summit caldera. These simultaneous activities started in May of 2018 and have been on-going during the updating of this plan.

Shield volcanoes are gently sloping mountains produced from lava flows (e.g., Hawai‘i Center for Volcanology 2013). Lava that flows from shield volcanoes is almost entirely of basalt composition. The gentle slopes of shield volcanoes are the result of basalt being very fluid (i.e., it has a low viscosity) and of the lava flows being so long. Basalt lava flows are characterized by two morphologies, known around the world by their Hawaiian names, `a`ā and pāhoehoe. Eruptions from shield volcanoes are not typically explosive unless water has entered the vent (Oregon State University 2018). The understanding of the eruptive process – explosive activity included – is incomplete since subject-matter experts have been able to observe and record only a small fraction of the life cycle of Hawaiian volcanoes and, hence, 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, Pu‘u ‘Ō‘ō, the vent associated with the current eruption from 1983 until April 2018, is on the east rift zone of Kīlauea Volcano (Rubin 2016).

Figure 4.14-1. Composition of a Shield Volcano



Source: Nelson 2017

Young Hawaiian volcanoes, such as Kīlauea and Mauna Loa, have summit calderas. In Hawaii'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. (Magma is the term used for molten rock that is still beneath the earth's surface; it is called lava when it reaches the surface). 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 (State of Hawai'i HMP 2013).

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 and/or property (i.e., Loihi produces submarine pillow lavas that pose no measurable risk to residents or infrastructure). Those phenomena that would pose to most risk to people and/or property include:

- Lava flows at the summits and along the rift zones;
- Ground cracking/slumping/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 recent 6.9 on Kīlauea's south flank or Mauna Loa's 1868 7.9 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), and
- Tsunami's induces by the earthquakes that trigger or are caused by volcanic activity

Volcanic hazards most prevalent in the State of Hawai'i 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, the latter as is being 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 meters (yards) inland and/or seaward (USGS 2018). Steep slopes may allow lava flows to move quickly from the summit to the ocean in a matter of hours (State of Hawai'i HMP 2013).

Explosive volcanic eruptions can produce a variety of ejecta products including: tephra, fragments of rock formed when magma or rock is explosively ejected; large fragments (blocks, bombs) of rock from the volcanic conduit can be expelled with great force but are deposited near the eruptive vent; smaller fragments (lapilli) of ash can be carried upward within in a volcanic plume and downwind in a volcanic cloud; and very fine-grained material volcanic ash is both easily convected upward within the plume and carried downwind for very long distances; as it falls out of suspension it can potentially 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), sulfur dioxide (SO_2), and sulfur trioxide (SO_3 – a precursor to sulfuric acid) gases, with trace amounts of several other gaseous compounds, including hydrogen sulfide (H_2S), hydrogen fluoride (HF), and carbon monoxide (CO). Volcanic air pollution (vog) is a hazy mixture of SO_2 gas and aerosols, the latter of which are 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 human upper respiratory tract (nose, mouth, and throat) (USGS 2017).

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 (USGS 2017).

Bench Collapse

Unstable lava deltas along a newly formed shoreline following volcanic activity can result on 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 Hawai‘i, 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. It can also cause explosions when it’s ignited while trapped underground. These blasts can toss blocks several feet away. This methane gas can also be the source on the blue flame that is most recognizable at night during lava flow events.

Blue fire bursting from the ground on May 23 near the Kīlauea volcano in Hawai‘i. AP/USGS

LOCATION

This section discusses the best data available to define the locations of the four volcano hazards profiled above for the purpose 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 and assessment to determine exposure and potential impacts from the hazard.

There are six active volcanoes in the State of Hawai'i – five located in the County of Hawai'i 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.

Table 4.14-1. Active Volcanoes in the State of Hawai'i

Name of Volcano	Location of Volcano	Date of Last Eruption	Threat Potential / Areas at Risk
Haleakalā	County of Maui	Late 1700s	Moderate threat potential; areas at risk include Hana, Keokea, Kula, Pukalani, and Wailea-Makena
Mauna Loa	County of Hawai'i	1984 and lasted 22 days	Very high threat potential; areas at risk include the districts of South Hilo, Puna, Ka'u, South Kona, North Kona and South Kohala
Kīlauea	County of Hawai'i	May 2018 - 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 Hawai'i Volcanoes National Park and the district of Ka'u
Hualālai	County of Hawai'i	1801	High threat potential; areas at risk include the land within the North Kona district
Mauna Kea	County of Hawai'i	between 6,000 and 4,000 years ago	Moderate threat potential
Lō'ihi (underwater volcano)	County of Hawai'i (located 22 miles southwest)	1996	Low to very low threat potential

Sources: USGS 2017; State of Hawai'i HMP 2013

Lava Flows Location

The USGS Hawaiian Volcanic Observatory (HVO) monitors six active volcanoes with delineated lava flow hazard areas on the Islands of Hawai'i and Maui (USGS 2017a) that may pose a hazard to communities in the State. The lava flow hazard areas are based on proximity to rift zones, frequency of lava coverage, and topography [i.e., downslope or not, and distance from rift zones (USGS 1992)]. 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 (USGS 1992). The lava flow zones in each county are classified differently; meaning Zone 1 in the County of Hawai'i is not the equivalent of Zone 1 in the County of Maui. Figure 4.14-2 and Figure 4.14-3 illustrate the lava flow areas in the Counties of Hawai'i and Maui, respectively.

Dr. Donald Thomas, the volcano SME for the 2018 HMP Update, identified Zones 1 through 4 in the County of Hawai'i and Zones 1 and 2 in the County of Maui to assess risk from lava flows based on severity. Table 4.14-2

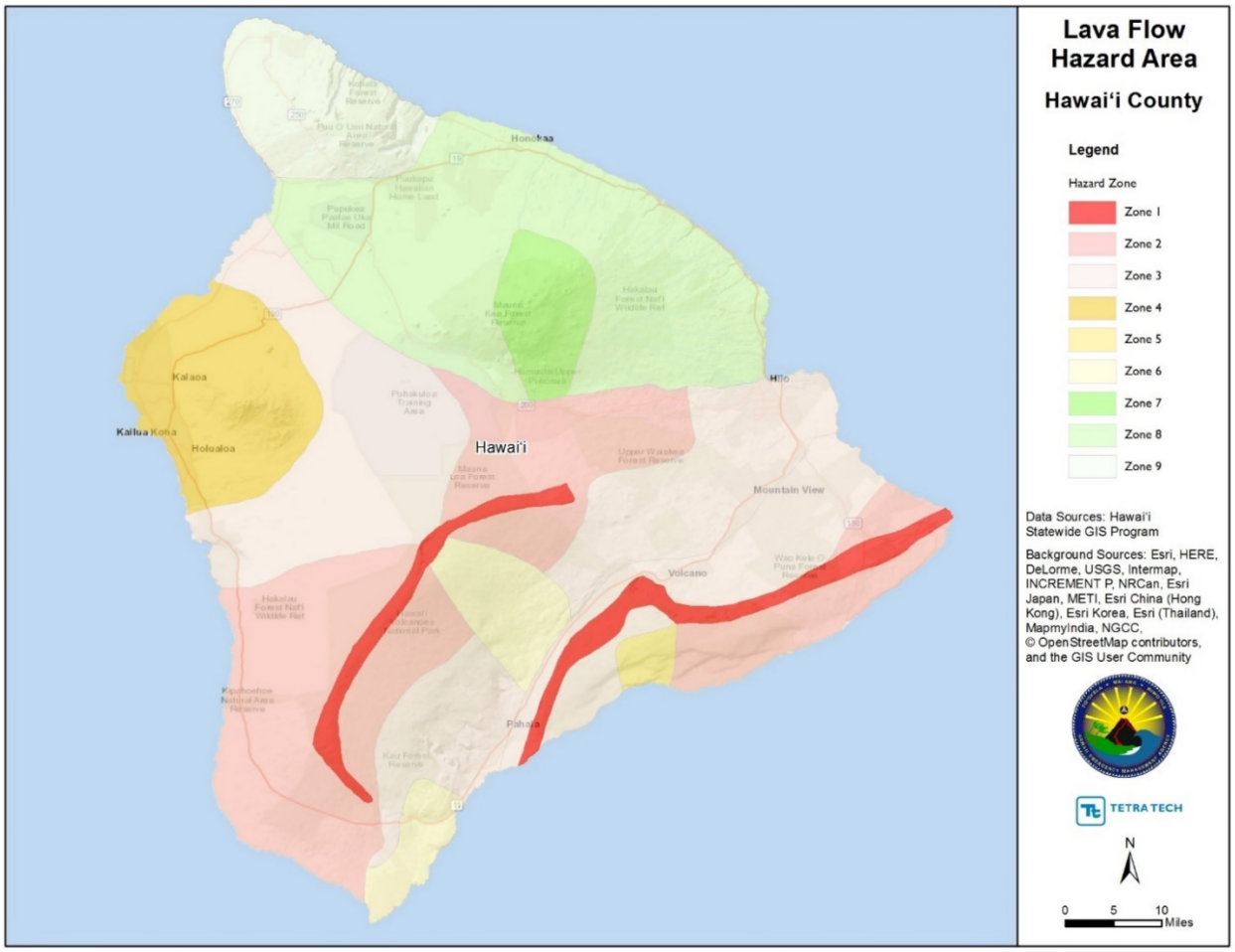
lists the square miles of these lava flow high risk zones, called the lava flow hazard areas, in each county. These zones were used to assess vulnerability discussed later in this section. The County of Hawai‘i has the largest percent (65.7%) of the volcano lava flow hazard area (Zones 1 through 4) in the State. Table 4.14-2 and Figure 4.14-3 illustrate the hazard zone areas for the Counties of Hawai‘i and Maui.

Table 4.14-2. Lava Flow Hazard Areas in the State of Hawai‘i

County	Area (in square miles)		
	Total Area of the County	Lava Flow Hazard Area	Hazard Area as Percent (%) of Total Area
Maui County	1,173.5	212.3	18.1%
Hawai‘i County	4,028.4	2,644.8	65.7%
Total	**5,201.9**	**2,857**	**54.9%**

Source: Hawai‘i Statewide GIS Programs Geoportal 2017; USGS 2006
Notes: County of Kaua‘i and City and County of Honolulu do not have USGS-produced lava flow maps.
The County of Hawai‘i hazard area was calculated using zones 1 through 4. The County of Maui hazard area was calculated using zones 1 and 2.
GIS Geographic Information System
USGS U.S. Geological Survey

Figure 4.14-2. Lava Flow Hazard Areas in the County of Hawai‘i



Source: USGS 1992

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% of Zone 2 has been covered by lava since 1800, and 25 to 75% 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. One to five 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)

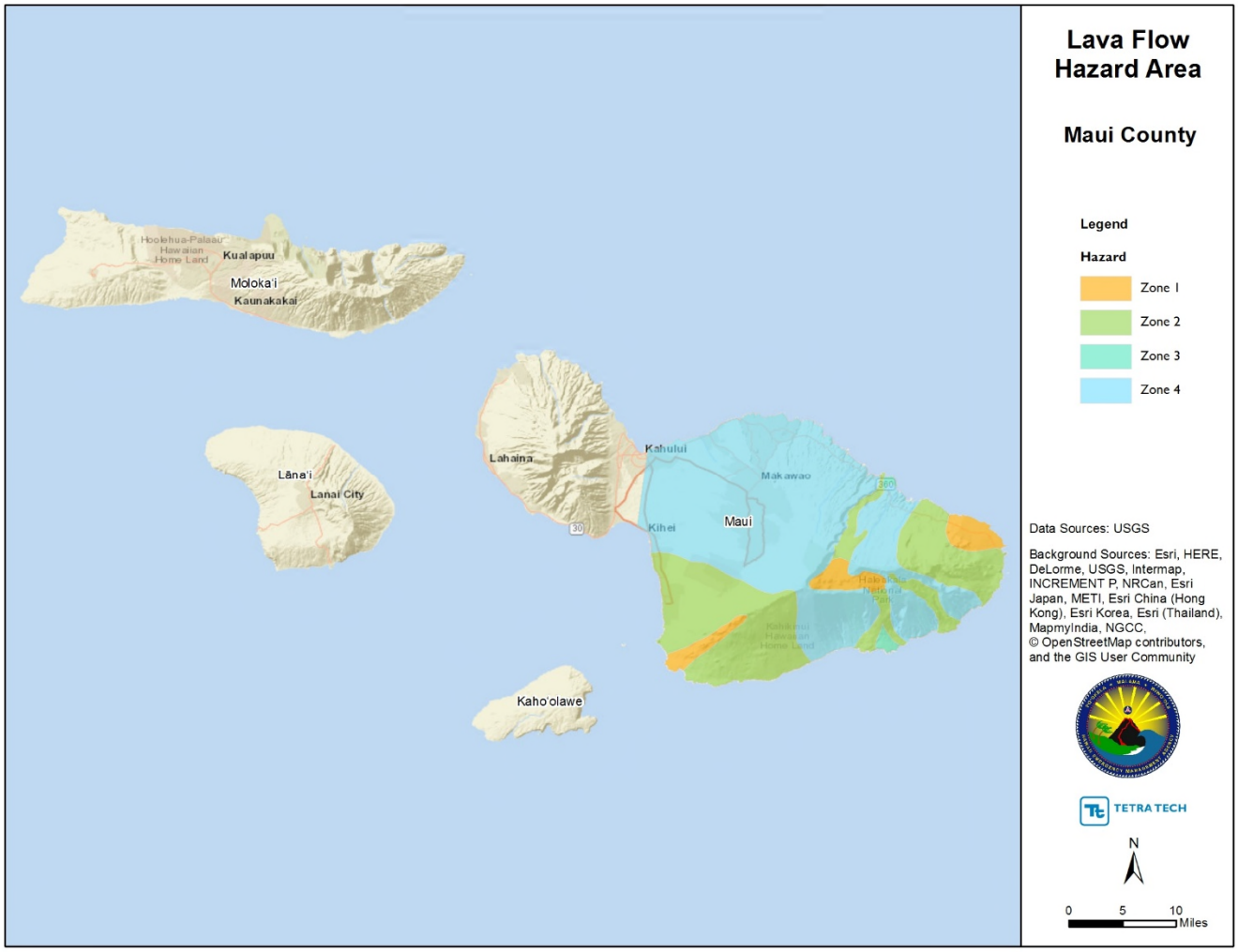
Zone 6 includes two areas on Mauna Loa, both protected by topography

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

Figure 4.14-3. Lava Flow Hazard Areas in the County of Maui



Source: USGS 1992
Zone 1 - Encompasses the lower- and middle-altitude reaches of the southwest and east rift zones, Haleakala 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 Kaupo and Ko'olau 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.

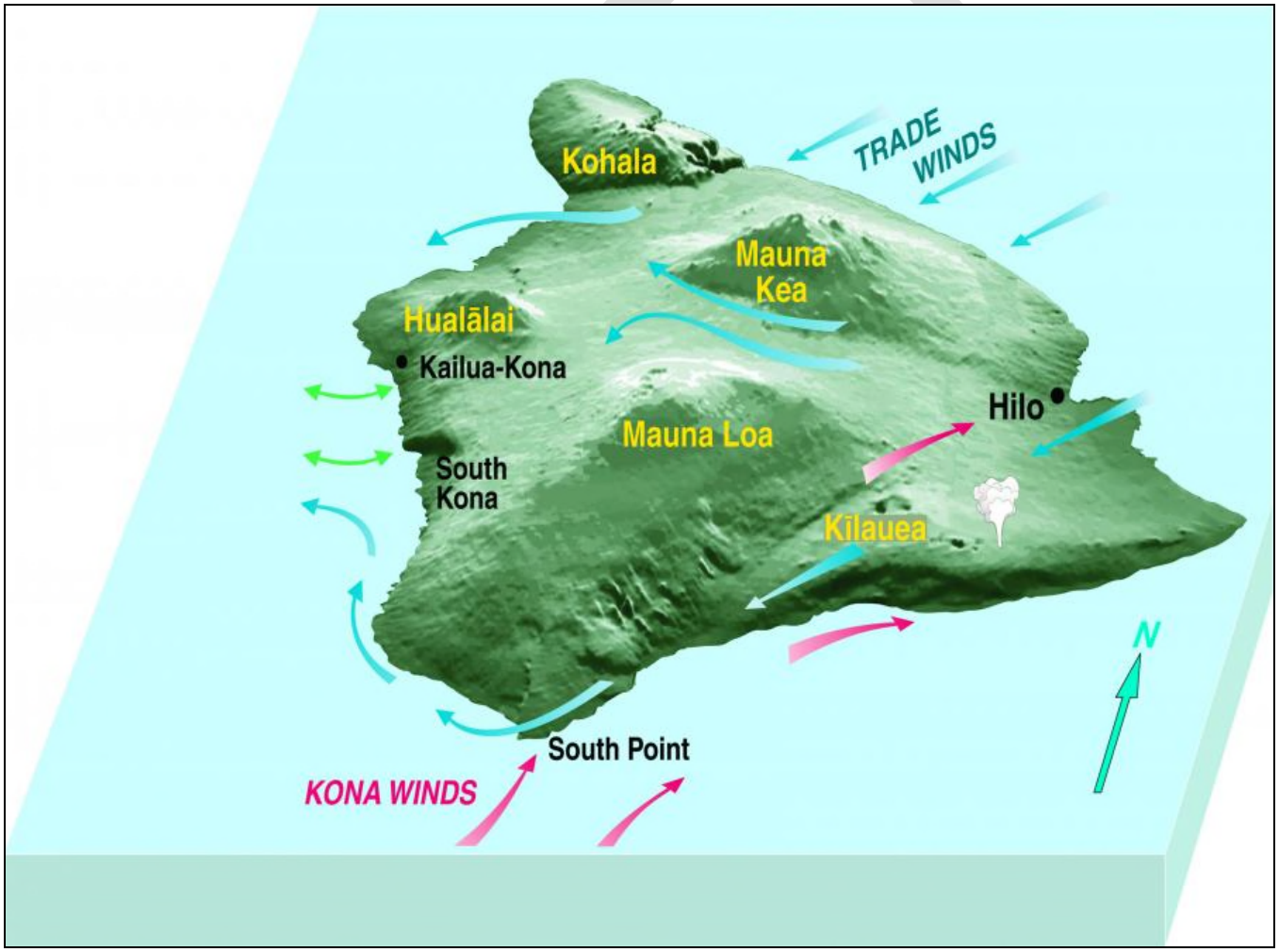
Volcanic Gases and Vog

Whereas active volcanoes are located on the Counties of Hawai‘i and Maui, the entire state can be impacted by volcanic gases and vog. Vog conditions in the County of Hawai‘i vary depending on wind direction (northeasterly trade winds, southerly kona winds) and emission source. Looking at Figure 4.14-4, 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 (red arrows on figure) blow, much of the vog is concentrated on the eastern side of the island but can reach the Island of Oahu (City and County of Honolulu) which is more than 200 miles to the northwest of the County of Hawai'i (USGS 2017).

Vog risk is considered to be both source (spatially) dependent 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 the City and County of Honolulu when southerly Kona winds bring the vog plume to the north from the County of Hawai'i. However, the City and County of Honolulu is not expected to experience the elevated sulfur dioxide levels that may be experienced in the County of Hawai'i. It is important to note that Mauna Loa's magma – and magmatic gas – discharge rate can be ten times that of Kīlauea.

Figure 4.14-4. Wind Direction and Vog Conditions in the County of Hawai'i



Source: USGS 2017

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 Hawai'i vary widely. Eruptions of volcanoes in the State range from almost imperceptible to major events that cover and/or create hundreds of acres of land, can destroy homes and businesses, block or destroy roadways and other infrastructure, and can impact the quality of life (particularly due to vog and other gases). The magnitude of (rare for Hawai`i) explosive eruptions 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) (State of Hawai'i HMP 2013).

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, it is important to note that volcanic activity can also occur with little advanced warning. The 2018 eruption on the lower east rift zone was preceded by only a few hours of warning to at most a day. Officials were not seriously anticipating propagation of the Pu'u O'o rift 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 and 2) ranked colors to inform the aviation sector about airborne ash hazards.

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: USGS 2018
Note: When the volcano alert-level is changed, a Volcano Activity Notice (VAN) is issued
USGS U.S. Geological Survey

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: USGS 2018
Note: When the volcano color code changes, a Volcano Observatory Notification for Aviation (VONA) is issued.
USGS U.S. Geological Survey

Lava Flows

The advance of lava flows is governed by the chemical composition and temperature of the lava, the steepness of the terrain, the volume of lava erupted, the eruption rate, and the duration of the eruption. Hawaiian lava flows generally advance slowly and can be easily avoided by people. But they can destroy or bury pretty much everything in their paths. Future lava flows are likely to interfere with human activity and infrastructure as communities and other development encroach on active volcanoes (USGS 2017).

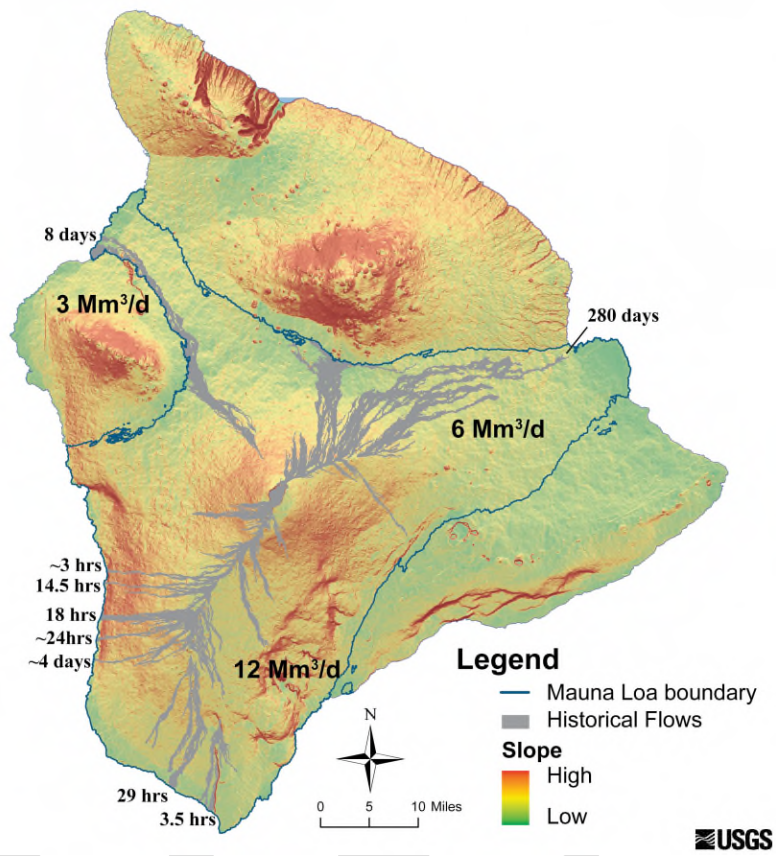
Geologists monitor active vents and lava flows to observe and document newly created volcanic features and to sample lava or tephra for chemical and mineral analyses. This helps in understanding what a volcano is doing and how the activity might impact adjacent communities. Measuring the effusion rate (the volume of lava flow per unit of time) is used to characterize the vigor of an eruption (USGS 2017). 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 of lava that is erupted, with higher effusion rates producing faster (and usually larger) flows. The distance that a flow travels ultimately depends either on the eruption rate (for channel-fed ‘a‘ā flows) and on the duration of the eruption (for tube-fed pāhoehoe flows; State of Hawai‘i HMP 2013).

During an eruption, advance rates of lava flow fronts are based on any available observations of the flow front itself and, if known, 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 [i.e. eruption rate, ground slope the flow is moving over, and the complex interaction of a’a and pahoehoe flows with the local (micro)terrain over which the flow is moving]. ‘A‘ā is a term for lava flows that have a rough rubbly surface composed of broken lava blocks. Pāhoehoe flows consist of lava that has a smooth, hummocky, or ropy surface. This type of flow usually advances as a series of small lobes and toes that continually break out from a cooled crust (USGS 2015). Figure 4.14-5 illustrates the historical lava flows for eruptions at Mauna Loa (USGS 2017).

Figure 4.14-5. Lava Flows of Mauna Loa

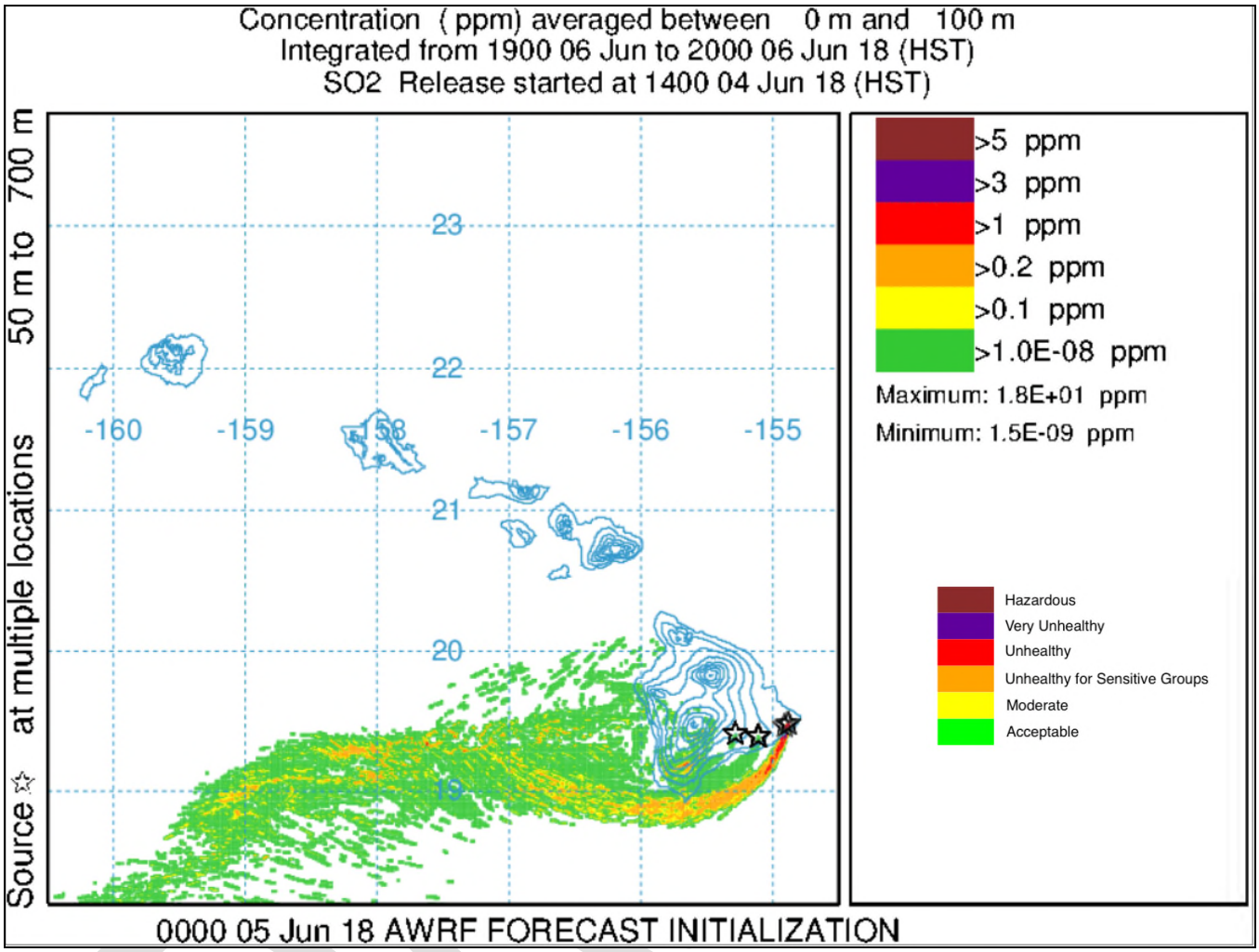


Source: USGS 2017
Notes: Mm3/d Million cubic meters per day
USGS U.S. Geological Survey

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 Hawai‘i and statewide, and is online here: ihttp://weather.Hawai‘i.edu/vmap/fcst/index.cg Figure 4.14-6 illustrates an example of the SO_2 concentration for the entire state. This particular emission rate is for a period of time when multiple vents were discharging sulfur dioxide gas at the summit and the East Rift of Kīlauea.

Figure 4.14-6. SO_2 Concentration Map, Statewide



Source: VMAP 2018

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 Hawai‘i State Department of Health (HDOH) 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, Mountain View, Pāhala, Hawaiian Ocean View Estates, and Kailua on Hawai‘i Island, and on Maui, O`ahu, and Kaua`i. HDOH also has air monitoring stations for SO_2 on the islands of Hawai‘i, O‘ahu, and Kaua‘i (USGS 2017). The Hawai`i Interagency Vog Information Dashboard (HIVID) is an excellent source of background information and up-to-date measurements and observations: https://vog.ivhhn.org/.

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 Hawai‘i. In an exception to the overall northwest-southeast shift of volcanic activity, a series of minor submarine eruptions may have occurred in 1955–56 between the islands of O‘ahu and Kaua‘i and near Necker Island, about 350 miles northwest of Kaua‘i, although there is considerable uncertainty about these (USGS 2010).

Many sources provide information regarding previous occurrences and losses associated with volcanic hazard events throughout the State of Hawai‘i. The 2013 Plan discussed specific volcanic events that occurred in Hawai‘i through 2012. For this 2018 HMP Update, volcanic events were summarized between January 1, 2012, and December 31, 2017 (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. It should be noted that it is recognized that the Kīlauea Volcano entered a new and very damaging phase of its long-running eruption at the end of April of 2018 and this activity continues as this plan is updated. Data regarding those impacts are in the development stage. More complete analysis regarding the eruptions and impacts will be analyzed in the future Hawai‘i County Hazard Mitigation Plan Update as well as the State’s 2023 Update. For events prior to 2012, please refer to Appendix F.

Table 4.14-5. Volcanic Hazard Events in Hawai‘i, 2012 to 2017

Date(s) of Event	Event Type	Counties Affected	Description
September 4, 2014 to June 27, 2015	Pu‘u ‘Ō‘ō Volcanic Eruption and Lava Flow	Hawai‘i	Lava erupted from the northeast flank of Kīlauea’s Pu‘u ‘Ō‘ō cone. Hawai‘i Electric Light Company staff worked to insulate utility poles from encroaching lava flows. Staff were deployed to monitor the lava flow. Crews worked to build new roads around Pahoa in case the lava cut off access to Highway 130. One residence was destroyed and a solid waste transfer station was temporarily out of commission.
June 8, 2017	South Flank Kīlauea Volcanic Eruption and Earthquake	Hawai‘i	A 5.3 magnitude earthquake occurred on the south flank of Kīlauea, due to southward spreading of the volcano. The earthquake was reported felt by about 800 people within an hour. The Hawai‘i County EOC was fully activated.
May – June 2018*	Kīlauea Volcanic Eruption and Earthquakes (DR-4366)	Hawai‘i	▪ On May 1, the USGS HVO issued a report that a migration of seismicity and deformation downrift (east) of Pu‘u ‘Ō‘ō indicated that a large area along the East Rift Zone was potentially at risk of new outbreak, possibly in the Lower Puna area. ▪ On May 11, FEMA issued a major disaster declaration for the State of Hawai‘i due to the eruption of Kīlauea. The County of Hawai‘i was included in this declaration. ▪ On May 16, heavy de-gassing was occurring at each vent within the Leilani Estates neighborhood and the lower East Rift. The Hawai‘i Fire Department reported air quality condition RED (immediate danger to health) in areas around Lanipuna Gardens and surrounding farm lots on Pohoiki Road. ▪ On May 17, HVO indicated an explosive eruption at Kīlauea summit occurred at 4:17am. By the afternoon, HVO reported a new fissure 21 down rift of Makamae Street in Leilani Estates neighborhood. Several fissures reactivated, and flows have been generated. The HVO reported lava was pahoehoe. Residents were issued masks for ash protection and shelters were open for residents. Eruptions continued to occur and fissures reactivated. Lava destroyed homes, led to road closures, caused brush fires, and residents were evacuated. ▪ On May 20, white plumes of acid and extremely fine shards of glass billowed over the Island of Hawai‘i as molten rock from Kīlauea poured into the ocean. The rate of sulfur dioxide gas shooting from the ground fissures tripled, leading Hawai‘i County 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. ▪ 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.

Sources: Cave and Kearns 2014; Taylor 2014; Osher 2017; Thomas 2017

EOC Emergency Operations Center *FEMA Federal Emergency Management Agency*
HVO Hawaiian Volcano Observatory *USGS U.S. Geological Survey*
The Kīlauea Volcanic Eruption is an ongoing event; not all impacts have been captured to date.

FEMA Disaster Declarations

Between 1954 and 2018, FEMA included Hawai'i in six volcanic hazard-related disasters (DR) or emergencies (EM) classified as one or a combination of volcano or earthquake with volcanic disturbances. These disasters have only affected the County of Hawai'i (FEMA 2018).

Based on all sources researched, two known volcanic hazard events that have affected the State of Hawai'i and were declared a FEMA disaster between 2012 and 2018. These are identified in Table 4.14-6. This table provides information on the disaster declarations for volcanic hazard events, including date of event, federal disaster declaration and disaster number, and counties affected. For details regarding all declared disasters, refer to Section 4.0 (Risk Assessment Overview). Appendix E (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, 2012 to 2018*

Year	Event Type	Date Declared	Federal Declaration Number	Counties Affected
September 4, 2014 to March 26, 2015	Pu'u 'Ō'ō Volcanic Eruption and Lava Flow	November 13, 2014	DR-4201	Hawai'i
May 2018	Hawai'i Kīlauea Volcanic Eruption and Earthquakes	May 11, 2018	DR-4366	Hawai'i

Source: FEMA 2018
Notes: DR — Major Disaster Declaration
FEMA — Federal Emergency Management Agency
** — As of June 1, 2018*

Probability of Future Hazard Events

Explosive eruptions of any size take place infrequently in the State of Hawai'i. It should be noted that 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 (USGS 2017a):

- 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 Hawai'i. 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 event that leads to a FEMA declaration roughly once every 10 years. Looking at volcanic hazard events that occurred in the State of Hawai'i since 1823, there have been 92 volcanic eruptions; with varying severity and impacts. Based on this data, the

State of Hawai‘i may experience one volcanic eruption every two years and has a 47% chance of an eruption occurring in any given year.

Potential Impacts of Climate Change on Probability of Future Events

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 thus adversely impacting human health. For details regarding climate change as a distinct hazard and its unique impacts to the State of Hawai‘i, refer to Section 4.1 (Climate Change).

It should be noted that the types of volcanic activity that could impact climate, are not those typically associated with Hawaiian Volcanos. 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 as much as 1.3°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 2017c).

4.14.2 Vulnerability Assessment

To assess the State’s risk from volcanic hazards, the spatially-delineated lava flow zones for the Counties of Hawai‘i and Maui were used. Therefore, the Counties of Kaua‘i and City and County of Honolulu do not appear in the tables below.

In collaboration with the volcanic SME, the following zones were selected to define the lava flow hazard areas: Zones 1 through 4 for the County of Hawai‘i; 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.

Lava Flow Hazard Area Definition

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

- ✓ ***County of Hawai‘i –*** *Lava flow zones 1 through 4 in the spatial layer available on the Hawai‘i Statewide GIS Programs Geoportal (originally prepared by USGS HVO 1991).*
- ✓ ***County of Maui*** *– Lava flow zones 1 and 2 in the spatial layer provided by USGS.*

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 1,021 state buildings in the County of Hawai‘i located in the lava flow hazard areas (see 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 through 4.14-9). Greater than 80% of the state buildings located in the County of Hawai‘i are located in the lava flow hazard area. The majority of these buildings are occupied by the Department of Education, University of Hawai‘i and Hawai‘i Health Systems Corporation. 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	$2,862,316,819	95	11.4%	$210,900,497	7.4%
County of Hawai‘i	1,261	$4,209,774,236	1,021	81.0%%	$2,851,738,537	67.7%
Total	**2,092**	**$7,072,091,055**	**1,116**	**53%**	**$3,062,639,034**	**43.31%**

Source: Hawai‘i State Risk Management Office 2017; Hawai‘i Statewide GIS Programs Geoportal 2017; USGS 2006
Notes: County of Kaua‘i and City and County of Honolulu do not have USGS-produced lava flow maps.
GIS Geographic Information System
USGS U.S. Geological Survey

Table 4.14-8. State Buildings in the County of Hawai‘i 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	$49,197,127	9	39.1%	$42,488,950	86.4%
Dept of Agriculture	14	$12,981,586	8	57.1%	$8,661,919	66.7%
Dept of Attorney General	5	$7,005,694	5	100.0%	$7,005,694	100.0%
Dept of Budget & Finance	4	$963,863	4	100.0%	$963,863	100.0%
Dept of Business, Economic Development and Tourism	1	$21,930,055	1	100.0%	$21,930,055	100.0%
Dept of Commerce & Consumer Affairs	0	$0	0	0.0%	$0	0.0%
Dept of Defense	7	$20,990,069	7	100.0%	$20,990,069	100.0%
Dept of Education	806	$2,640,531,838	621	77.0%	$1,382,525,079	52.4%
Dept of Hawaiian Home Lands	4	$4,426,065	2	50.0%	$2,156,000	48.7%
Dept of Health	6	$16,433,860	6	100.0%	$16,433,860	100.0%
Dept of Human Resources Development	0	$0	0	0.0%	$0	0.0%
Dept of Human Services	18	$23,694,724	15	83.3%	$16,740,733	70.7%
Dept of Labor and Industrial Relations	8	$12,439,257	8	100.0%	$12,439,257	100.0%
Dept of Land and Natural Resources	2	$4,295,538	2	100.0%	$4,295,538	100.0%
Dept of Public Safety	52	$58,352,205	52	100.0%	$58,352,205	100.0%

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 Taxation	0	$0	0	0.0%	$0	0.0%
Dept of Transportation	7	$145,908,345	5	71.4%	$144,544,745	99.1%
Hawai'i State Ethics Commission	0	$0	0	0.0%	$0	0.0%
Hawai‘i Health Systems Corporation	34	$267,489,341	23	67.6%	$241,774,312	90.4%
Hawai‘i Housing Finance & Development Corporation	29	$74,931,443	29	100.0%	$74,931,443	100.0%
Hawai‘i Public Housing Authority	63	$214,946,736	55	87.3%	$188,297,816	87.6%
Hawai‘i State Legislature	0	$0	0	0.0%	$0	0.0%
Hawai‘i State Public Library System	11	$42,426,683	6	54.5%	$19,817,400	46.7%
Judiciary	13	$103,967,864	11	84.6%	$103,016,093	99.1%
Legislative Reference Bureau	0	$0	0	0.0%	$0	0.0%
Office of Hawaiian Affairs	2	$479,656	2	100.0%	$479,656	100.0%
Office of the Auditor	0	$0	0	0.0%	$0	0.0%
Office of the Governor	0	$0	0	0.0%	$0	0.0%
Office of the Lieutenant Governor	0	$0	0	0.0%	$0	0.0%
Office of the Ombudsman	0	$0	0	0.0%	$0	0.0%
Research Corporation of the University of Hawai'i	0	$0	0	0.0%	$0	0.0%
University of Hawai'i	152	$486,382,287	150	98.7%	$483,893,850	99.5%
Total	**1,261**	**$4,209,774,236**	**1,021**	**81.0%**	**$2,851,738,537**	**67.7%**

Source: Hawai‘i State 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	0.0%	$0	0.0%
Dept of Agriculture	6	$13,702,507	0	0.0%	$0	0.0%
Dept of Attorney General	2	$3,993,357	0	0.0%	$0	0.0%
Dept of Budget & Finance	3	$809,916	0	0.0%	$0	0.0%
Dept of Business, Economic Development and Tourism	1	$9,978,917	1	100.0%	$9,978,917	100.0%
Dept of Commerce & Consumer Affairs	0	$0	0	0.0%	$0	0.0%
Dept of Defense	3	$15,307,089	0	0.0%	$0	0.0%
Dept of Education	563	$1,443,495,782	70	12.4%	$116,936,292	8.1%
Dept of Hawaiian Home Lands	2	$689,000	0	0.0%	$0	0.0%
Dept of Health	3	$4,843,533	0	0.0%	$0	0.0%
Dept of Human Resources Development	0	$0	0	0.0%	$0	0.0%
Dept of Human Services	15	$34,878,132	0	0.0%	$0	0.0%
Dept of Labor and Industrial Relations	6	$6,940,947	0	0.0%	$0	0.0%

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 Land and Natural Resources	15	$7,246,459	1	6.7%	$552,425	7.6%
Dept of Public Safety	24	$66,087,940	0	0.0%	$0	0.0%
Dept of Taxation	0	$0	0	0.0%	$0	0.0%
Dept of Transportation	28	$214,582,180	1	3.6%	$191,500	0.1%
Hawai'i State Ethics Commission	0	$0	0	0.0%	$0	0.0%
Hawai‘i Health Systems Corporation	36	$658,565,946	21	58.3%	$79,315,317	12.0%
Hawai‘i Housing Finance & Development Corporation	28	$67,636,635	0	0.0%	$0	0.0%
Hawai‘i Public Housing Authority	4	$15,058,800	0	0.0%	$0	0.0%
Hawai‘i State Legislature	0	$0	0	0.0%	$0	0.0%
Hawai‘i State Public Library System	7	$20,774,018	1	14.3%	$3,926,046	18.9%
Judiciary	9	$45,106,735	0	0.0%	$0	0.0%
Legislative Reference Bureau	0	$0	0	0.0%	$0	0.0%
Office of Hawaiian Affairs	2	$292,187	0	0.0%	$0	0.0%
Office of the Auditor	0	$0	0	0.0%	$0	0.0%
Office of the Governor	0	$0	0	0.0%	$0	0.0%
Office of the Lieutenant Governor	1	$1,956,330	0	0.0%	$0	0.0%
Office of the Ombudsman	0	$0	0	0.0%	$0	0.0%
Research Corporation of the University of Hawai'i	0	$0	0	0.0%	$0	0.0%
University of Hawai'i	68	$219,215,409	0	0.0%	$0	0.0%
Total	**831**	**$2,862,316,819**	**95**	**11.4%**	**$210,900,497**	**7.4%**

Source: Hawai‘i State 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 (218.4 miles) exposed which makes up 57.7% of all state roads in the county. A complete list of state roads located in the lava flow hazard zones is included in Appendix G (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	238.6	22.1	9.3%
County of Hawai‘i	378.7	218.4	57.7%
Total	**617.3**	**240.5**	**38.9%**

Source: State of Hawai‘i SDOT State Routes GIS layer 2017; Hawai‘i Statewide GIS Programs Geoportal 2017; USGS 2006
Notes: County of Kaua‘i and City and County of Honolulu do not have USGS-produced lava flow maps.

GIS Geographic Information System
SDOT State Department of Transportation
USGS U.S. Geological Survey
There are no lava flow zones available in the County of Kaua‘i and City and County of Honolulu; therefore no results are reported.

Critical Facilities

Table 4.14-11 summarizes the total number of critical facilities by core category located in the lava flow hazard area in the Counties of Hawai‘i and Maui. The County of Hawai‘i has 201 critical facilities located in the lava flow hazard area. The County of Maui has 38 critical facilities 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. Food and agriculture have the largest percentage (61.5%) of their facilities within the County of Hawai‘i lava flow hazard area. Transportation Services and Water, Waste, & Wastewater Systems both have the largest percentage (3.6%) of their facilities within the County of Maui lava flow hazard area.

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

Table 4.14-11. Critical Facilities Located in the Lava Flow Hazard Area in Counties of Hawai‘i and Maui

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 Maui	0	4	4	1	1	0	6	9	2	11	38
County of Hawai‘i	9	15	20	8	24	7	27	38	15	38	201
Total	**9**	**19**	**24**	**9**	**25**	**7**	**33**	**47**	**17**	**49**	**239**

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2; Hawai‘i Statewide GIS Programs Geoportal 2017; USGS 2006
Notes: GIS Geographic Information System
USGS U.S. Geological Survey
There are no lava flow zones available in the County of Kaua‘i and City and County of Honolulu; therefore no results are reported.

Table 4.14-12. Critical Facilities by Core Category Located in the Lava Flow Hazard Area in the County of Hawai'i

Core Category	Total Number of Critical Facilities in the County of Hawai'i	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	RCV in the Hazard Area	Percent (%) of Total RCV
Commercial Facilities	11	$26,963,666	9	81.8%	$22,061,182	81.8%
Communications	20	$52,908,180	15	75.0%	$41,177,680	77.8%
Emergency Services	26	$164,280,230	20	76.9%	$132,987,140	81.0%
Energy	9	$170,320,480	8	88.9%	$161,157,640	94.6%
Food & Agriculture	30	$741,388,480	24	80.0%	$574,065,440	77.4%
Government Facilities	8	$31,081,435	7	87.5%	$27,108,620	87.2%
Healthcare & Public Health	36	$338,688,960	27	75.0%	$207,699,670	61.3%
Mass Care Support Services	60	$1,272,598,340	38	63.3%	$1,094,601,660	86.0%
Transportation Services	17	$526,287,360	15	88.2%	$464,371,200	88.2%
Water, Waste, & Wastewater Systems	53	$1,642,379,520	38	71.7%	$1,178,008,320	71.7%
Total	**270**	**$4,966,896,651**	**201**	**74.4%**	**$3,903,238,552**	**78.6%**

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2; Hawai'i Statewide GIS Programs Geoportal 2017; USGS 2006

Notes: GIS Geographic Information System
RCV Replacement cost value
USGS U.S. Geological Survey

Table 4.14-13. Critical Facilities by Core Category Located in the Lava Flow Hazard Area in the County of Maui

Core Category	Total Number of Critical Facilities in the County of Maui	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	RCV in the Hazard Area	Percent (%) of Total Value
Commercial Facilities	2	$63,264,080	0	0.0%	$0	0.0%
Communications	22	$129,434,540	4	18.2%	$21,356,760	16.5%
Emergency Services	24	$299,309,640	4	16.7%	$39,319,560	13.1%
Energy	4	$98,094,820	1	25.0%	$30,958,080	31.6%
Food & Agriculture	4	$72,495,070	1	25.0%	$31,632,040	43.6%
Government Facilities	21	$81,325,860	0	0.0%	$0	0.0%
Healthcare & Public Health	50	$717,287,448	6	12.0%	$236,533,590	33.0%
Mass Care Support Services	75	$1,477,495,075	9	12.0%	$186,730,340	12.6%
Transportation Services	23	$712,035,840	2	8.7%	$61,916,160	8.7%
Water, Waste, & Wastewater Systems	59	$1,826,526,720	11	18.6%	$340,538,880	18.6%
Total	**284**	**$5,477,269,093**	**38**	**13.4%**	**$948,985,410**	**17.3%**

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2; Hawai'i Statewide GIS Programs Geoportal 2017; USGS 2006

Notes: GIS Geographic Information System
RCV Replacement cost value
USGS U.S. Geological Survey

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.

Population

Lava Flows

Lava flows endangers 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, a flow front advanced at an average speed of almost 6 mph for over 2 hours (State of Hawai'i HMP 2013).

The chief threat of lava flows to property owners is that the flows may burn structures and bury land as well as everything in its pathway. There are other effects, however, that may be almost as disruptive. For instance, the residents of the Kalapana community saw their daily commutes increase by nearly 100 miles after lava flows covered almost 2 miles of the coastal highway. Some residents were forced to move. Many others were faced with financial losses as land values dropped and insurance companies refused to issue new homeowners policies (State of Hawai'i HMP 2013).

For the County of Hawai'i, Table 4.14-14 shows that an estimated 77.5% 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 11.4% 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.

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 population over 65 located in the lava flow hazard area makes up approximately 11.1% of the population in the County of Hawai'i and only 1.7% in the County of Maui. The population with less than $30,000 per year annual household income located in the lava flow hazard area makes up about 26.2% of the population in the County of Hawai'i and 2.6% in the County of Maui.

Table 4.14-14. 2010 U.S. Census Population Located in the Lava Flow Hazard Area by County

County	Population

	Total Population	Population in Hazard Area	Population Exposed as Percent (%) of Total	Population Over 65 in Hazard Area	Population Over 65 Exposed as Percent (%) of Total	Income <$30K/yr in Hazard Area	Income <$30K/yr Exposed as Percent (%) of Total
Maui County	154,924	17,654	11.4%	2,617	1.7%	3,975	2.6%
Hawai'i County	185,079	143,370	77.5%	20,620	11.1%	48,408	26.2%
Total	**340,003**	**161,024**	**47.4%**	**23,237**	**6.8%**	**52,383**	**15.4%**

Source: U.S. Census 2010; Hawai'i Statewide GIS Programs Geoportal 2017; USGS 2006
Notes: GIS Geographic Information System
USGS U.S. Geological Survey
$30K $30,000
yr Year
There are no lava flow zones available in the County of Kaua'i and City and County of Honolulu; therefore no results are reported.
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.

Volcanic Gases and Vog

Toxic gasses emitted from a volcano can travel great distances and cause respiratory distress. Sulfur dioxide is irritating to the eyes, nose, throat and respiratory tract. It is important to note that SO_2 is considered to be a volcanic gas, and not a principle component of vog. 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 Hawai'i 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 Hawai'i 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 Halema'uma'u 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 Hawai‘i, particularly those in the districts adjacent to or downwind of the active vent, contained elevated levels of lead.

Other recent studies and tests on rainfall catchment systems suggest that although fluoride levels were not found to be above the EPA Maximum Contaminant Level (MCL) for fluoride, several systems showed levels that were quite near the recommended drinking water limits and suggest that relatively small changes in gas discharge rates, in wind trajectories, or decreases in rainfall rates in the downwind communities could bring about fluoride levels that exceed drinking water standards. It is also noteworthy that the testing showed pH levels as low as 3 were present that could enhance heavy metal leaching from the catchment system and domestic plumbing. Older homes, which may contain lead-based paint, lead-based solder or lead-gasketed roofing nails are at particularly high risk of mobilization of lead into the domestic water supply by the acidic rainwater (State of Hawai‘i HMP 2013).

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 (State of Hawai‘i HMP 2013).

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 Hawai‘i and Maui. The County of Hawai‘i has the greatest estimated potential losses (78.7%) 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	$31,320,693,000	$5,378,580,000	17.2%
County of Hawai‘i	$33,326,392,000	$26,223,254,000	78.7%
Total	**$64,647,085,000**	**$32,601,834,000**	**50.4%**

Source: Hazus v4.2, Hawai‘i Statewide GIS Programs Geoportal 2017; USGS 2006
Notes: GIS Geographic Information System

USGS U.S. Geological Survey
There are no lava flow zones available in the County of Kaua‘i and City and County of Honolulu; therefore no results are reported.

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 Hawai‘i, 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. Current discussion in the State's tourism industry express 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 (2013 State HMP).

It is too soon to estimate economic impacts of the ongoing 2018 Kīlauea volcanic event. According to the University of Hawai‘i Economic Research Organization, bookings for travel to the County of Hawai‘i are down due to the eruption. The current eruption has closed Hawai‘i Volcanoes National Park, the County of Hawaii's biggest tourist attraction (University of Hawai‘i 2018). Tourists may be 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 G for results for the County of Hawai‘i 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

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. Another effect of vog on wildlife that has been noted particularly in the County Hawai‘i is the interruption of pollination by bees during heavy vog concentrations (Big Island Weekly News Update 2009).

Also of great concern to wildlife and livestock is the deposition of fluoride salts carried by vog onto forage crops. The 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 (2013 State HMP).

In 2010, Donald Thomas from the Center for the Study of Active Volcanoes and Trisha Macomber from the University of Hawaii's College of Tropical Agriculture (CTAHR) produce a study on the effects of fluoride and sulfates on forage lands downwind of Kīlauea's Halema‘uma‘u 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 impairment 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.

It should be noted, finally, that 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 ten 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.

Table 4.14-17. Environmental Resources Located the in 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	Total Asset Area	Lava Flow Hazard Area	Hazard Area as Percent (%) of Total Area
Critical Habitat[a]	440.4	227.8	51.7%	263.2	91.4	34.7%
Wetlands	88.2	1.6	1.8%	109.7	38.5	35.1%
Parks and Reserves	1,985.4	1,466.6	73.9%	311.3	0.0	0.0%
Reefs[b]	8.6	0.0	0.0%	25.8	0.0	0.0%
Total[c]	**2,522.6**	**1,696**	**67.2%**	**710.1**	**130**	**18.3%**

Source: State of Hawai'i GIS layers, State of Hawai'i GIS Program Geospatial Data Portal
Notes: GIS Geographic Information System
a. Critical habitat area mileage includes the combined area of coverage of individual critical habitat areas
b. Reefs include artificial and coral reefs. Reefs are offshore and may be impacted once lava reaches the ocean.
c. Total square miles may be over reported as some environmental asset areas may overlap.

Cultural Assets sections below. Almost a quarter of Urban District lands statewide, are located in lava flow zones, including more than 76% of Urban Districts in the County of Hawai'i.

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	2,942.8	1,119.8	38.1%
Conservation	3,156.3	1,659.9	52.6%
Rural	16.1	3.0	18.4%
Urban	319.7	75.5	23.6%
Total	**6,434.9**	**2,858.2**	**44.4%**

Source: USGS 2006; State Land Use Commission, 2016
Notes: Total area was calculated from the State of Hawai'i State Land Use District GIS layer
There are no lava flow zones in the County of Kaua'i or the City and County of Honolulu.
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

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. Another effect of vog on wildlife that has been noted particularly in the County Hawai'i is the interruption of pollination by bees during heavy vog concentrations (Big Island Weekly News Update 2009).

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Reefs[b]	8.6	0.0	0.0%	25.8	0.0	0.0%
Total[c]	**2,522.6**	**1,696**	**67.2%**	**710.1**	**130**	**18.3%**

Source: State of Hawai'i GIS layers, State of Hawai'i GIS Program Geospatial Data Portal
Notes: GIS Geographic Information System
a. Critical habitat area mileage includes the combined area of coverage of individual critical habitat areas
b. Reefs include artificial and coral reefs. Reefs are offshore and may be impacted once lava reaches the ocean.
c. Total square miles 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 38% of the county total; and 35.3 square miles in the County Hawai'i or 18.5% of the county total (see Table 4.14-18.).

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	92.6	34.9	37.7%
County of Hawai'i	190.3	35.3	18.5%
Total	**282.9**	**70.2**	**25.8%**

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 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 4.14-19 below; refer to Section 3 for more information on projected development areas). The results of this assessment indicate that 42% of the Maui Development Project areas and 39% of the Enterprise Zones in the County of Maui and the County of Hawai'i 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 4.14-19. Maui Development Projects and Enterprise Zones Located in Lava Flow Hazard Areas

County	Area (in square miles)					
	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	42.2%	1,016.70	176.7	17.4%
County of Hawai'i	-	-	-	1,286.60	726.1	56.4%
Total	**27.6**	**11.7**	**42.2%**	**2,303.4**	**902.8**	**39.2%**

Note: There are no lava flow zones in the County of Kaua'i or in the City and County of Honolulu
Total area calculated from: (1) Maui Development Projects GIS layer from Maui County Planning Department (2) Enterprise Zones from Community Economic Development Program, DBEDT
Hazard area clipped to coastline downloaded from State of Hawai'i GIS Program Geospatial Data Portal