County of Hawaiʻi Volcanic Risk Assessment

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Volcanic Risk Assessment

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Prepared for:
County of Hawaiʻi
Department of Research and Development
25 Aupuni Street
Suite 1301
Hilo, HI 96720

Prepared by:
Tetra Tech, Inc.
737 Bishop Street, Suite 2030
Honolulu, Hawaiʻi 96813

TETRA TECH

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The County of Hawaiʻi honors the Hawaiian language and its use of diacritical marks, the glottal stop and the macron (ʻokina and kahakō). The ʻokina and kahakō are only used in this plan when writing the name of the state, islands, island communities and volcanoes; and when utilizing data from a referenced source, without modification.

ACKNOWLEDGEMENTS

The County of Hawaiʻi Department of Research and Development applied for and received a Federal Emergency Management Agency (FEMA) advanced planning and technical assistance grant to conduct a volcanic risk assessment as a means to evaluate the County's current (post-2018 Kīlauea) and future volcanic risk to inform the Kīlauea Recovery and Resilience Plan as well as be incorporated into the County's Multi-Hazard Mitigation Plan Update 2020. The County of Hawaiʻi would like to express their sincere appreciation to the many individuals who developed the County of Hawaiʻi Volcanic Risk Assessment. The County Core Planning Team (CPT), composed of members from various County departments, provided critical support to coordinate the data collection, analysis and stakeholder planning efforts. We especially thank the USGS Hawaiian Volcano Observatory HVO, which advised the CPT throughout the process and provided critical feedback on the assessment.

EXECUTIVE SUMMARY

The unique landscape of the County of Hawaiʻi originates from volcanic activity. The Kīlauea eruption of 2018 provides the most recent evidence of volcanic hazard risk in the County. Impacts to natural and cultural resources, housing, infrastructure, the economy, health and social services, and community planning and capacity building were felt in Puna and island wide. Numerous challenging decisions must be addressed about recovery and rebuilding, including how and where to rebuild or repair damages to reduce risk from future events.

This County of Hawaiʻi Volcanic Risk Assessment describes, and to the extent possible, quantifies risk from volcanic and other natural hazards. The assessment defines High Hazard Areas at greatest risk to future volcanic events and other natural hazards. The assessment was conducted to support recovery and hazard mitigation planning and provide strategic focus for the use of limited recovery and mitigation funds.

Hazards Related to Volcanic Activity

- Lava
- Vog
- Laze
- Explosive Eruption
- Ashfall
- Seismic
- Tsunami
- Ground Failure / Subsidence
- Volcanic Glass
- Acid Rain

The entire County of Hawaiʻi is subject to future volcanic activity. Volcanic activity is comprised of multiple hazards that are not all reflected on the U.S. Geological Survey (USGS) lava-flow hazard zone map. All hazards related to volcanic activity on the island were identified and defined. Best available data at the time of this assessment was then gathered and compiled in a spatial format. The USGS lava-flow hazard zone map, historic lava flow inundation, USGS peak ground acceleration (PGA) mapping, and National Earthquake Hazard Reduction Program (NEHRP) soil classifications were used. A Core Planning Team was formed at the County and, in consultation with USGS Hawaiian Volcano Observatory (HVO), they identified the areas that present the greatest risk to the volcanic hazard from these data sources to delineate a Volcanic High Hazard Area (VHHA) (***Figure ES-0-1***). Additional Natural High Hazard Areas were also delineated as part of the assessment.

The VHHA is the combined areas of lava zones 1 and 2 (with a 1,000-foot buffer), historic lava flow areas dating back to 1790, and NEHRP class soils D and E. Lava zones 1 and 2 were selected because, according to USGS, they are the zones identified with the greatest severity to the lava flow hazard. A 1,000-foot buffer was applied to each lava zone 1 and 2 to account for the uncertainty of the location to these boundaries. Historic lava flow events and associated inundation extent were only available for the last 230 years; however, they were included because lava zones do not have an associated probability and, when considering policy and mitigation, it is important to understand where previous impacts have occurred to avoid future repetitive losses. Further, NEHRP-classified D and E soils, which amplify and magnify ground shaking and increase building damage and losses, were also included in the VHHA.

A spatial analysis was conducted to determine the number of residents, buildings, critical facilities, roads, natural and cultural resources located within each of the USGS lava flow zones, as well as the VHHA; also known as an exposure assessment. In addition, the assets considered most vulnerable to hazard exposure were identified, where possible. A summary of this analysis is provided in ***Figure ES-0-2.***

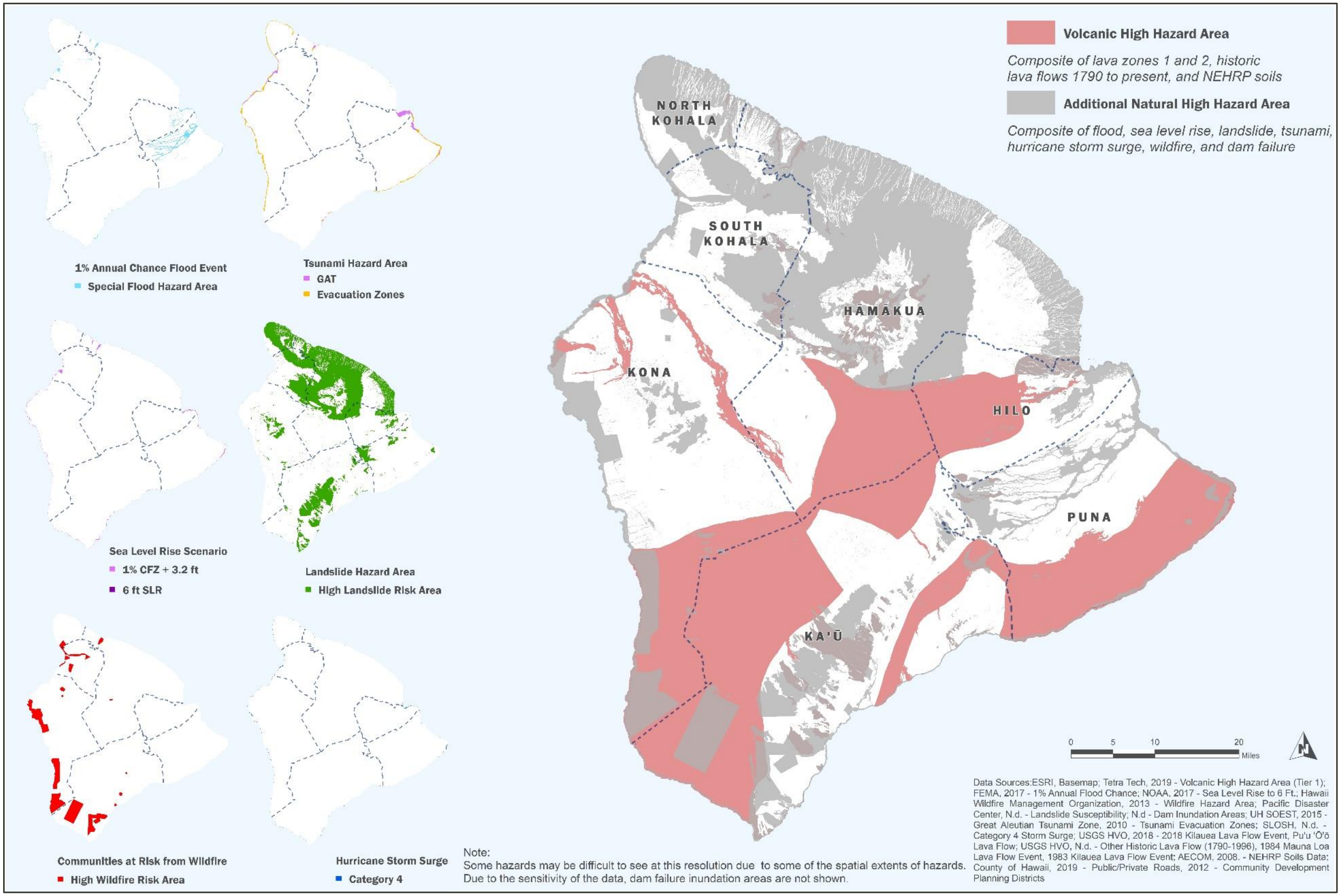

Figure ES-0-1. Volcanic High Hazard and Additional Natural High Hazard Areas Located in the County of Hawaiʻi

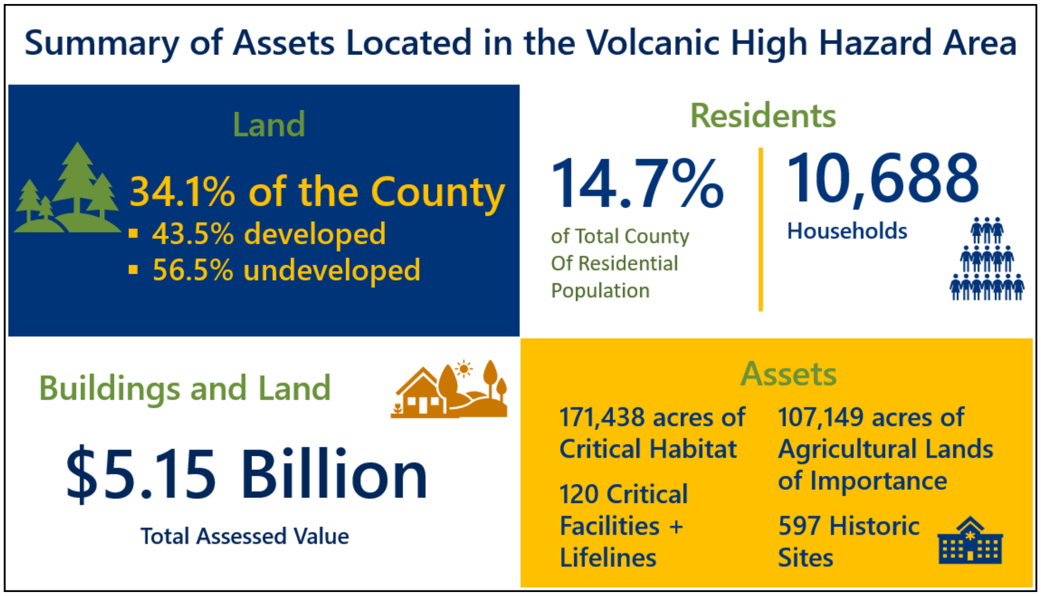

Figure ES-0-2. County Assets Exposed to the Volcanic High Hazard Area (VHHA)

It is also important to understand exposure relative to other natural hazards, when examining exposure to the volcanic hazard, so that the design of recovery and mitigation strategies is robust and resilient to future events. As such, additional Natural High Hazard Areas, including flood, sea level rise, landslide, tsunami, hurricane storm surge, wildfire, and dam failure, were defined and assessed.

The results of the assessment are summarized for the County as a whole and for each Community Development Planning (CDP) area in subsequent individual sections for ease of review and use of this information. It is recognized this risk assessment represents a snapshot in time, based upon currently available data, that will continue to evolve and be updated. However, high-level recommendations are included so this may continue to serve as a foundation to support risk-informed decision making.

Recommendations

1. *Formally recognize the Volcanic High Hazard Area as a hazard overlay to inform future development and land use decisions.*
2. *Incorporate the Volcanic High Hazard Area as a hazard overlay in the General Plan update to reduce future land use development in high hazard areas and develop regulatory tools and incentives to reallocate existing and potential development to less hazardous areas in the County.*
3. *Utilize the Volcanic High Hazard Area hazard overlay to support the land use decisions guiding the 2018 Kīlauea eruption recovery strategies and projects.*
4. *Update the Volcanic High Hazard Area when new and revised volcanic data becomes available.*
5. *Incorporate the Volcanic High Hazard Area and Additional Natural High Hazard Area together as high-risk hazard areas when identifying and designing mitigation projects.*
6. *Integrate the Volcanic High Hazard Area into other planning mechanisms.*
7. *Use a multi-hazard lens when identifying recovery and mitigation projects, regardless of the hazard type of the event, to increase the County's resilience to natural hazards.*

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SECTION 1. INTRODUCTION

The Hawaiian Islands are at the southeast end of a chain of volcanoes that began to form more than 70 million years ago (U.S. Geological Survey [USGS] Hawaiian Volcano Observatory [HVO] 2019). There are five volcanoes located in the County of Hawaiʻi, four of which are considered active: Kīlauea, Mauna Loa, Mauna Kea, and Hualālai. Lōʻihi is an active submarine volcano. It is located 22 miles southeast of the Island of Hawaiʻi.

The volcanic hazard in the County has always been known (***Figure 1-1***). Kīlauea, one of the world's most active volcanoes, is the home of deity Pelehonuamea, who resides in the Halemaʻumaʻu crater. Pele represents magma or lava and is viewed as both a creative and destructive force. Through kānāwai, or natural laws, of Pele, we can see how Native Hawaiians adapted to her presence and this ever-changing environment. In contemporary times, continuous development and population growth have greatly increased the County's volcanic hazard risk profile.

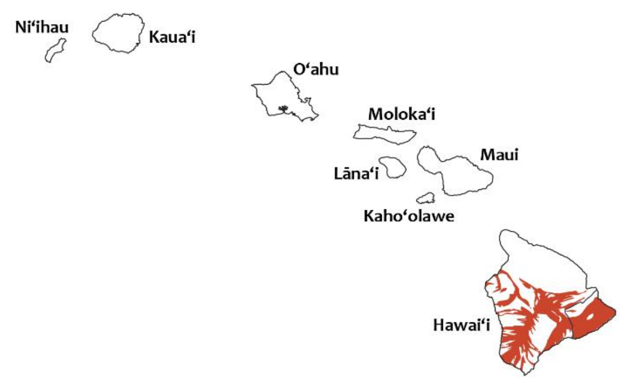


Figure 1-1. Lava flows in the main Hawaiian Islands in the past ~1,000 years

Most recently, Kīlauea erupted with lava flow covering 8,448 acres of land and permanently altered the landscape. Given the volume of lava and associated hazards such as sulfur dioxide, ash, tephra, and laze, County of Hawaiʻi residents were severely impacted, resulting in a federally declared disaster (DR-4366). The complexity and scale of the impacts from this eruption prompted the need for an enhanced understanding of its natural hazard risk county-wide. An updated and detailed volcanic risk analysis is needed to provide the factual basis to support future decisions such as land use, development, and public investments; identify mitigation projects to reduce future impacts to the volcanic hazard; and support the long-term resilience of the County.

The County of Hawaiʻi Department of Research and Development applied for and received a Federal Emergency Management Agency (FEMA) advanced planning and technical assistance grant to conduct a volcanic risk assessment as a means to evaluate the County's current (post-2018 Kīlauea) and future volcanic risk. To support this effort, the County established a Core Planning Team (CPT) composed of members from various County departments to manage and coordinate the multi-faceted and multi-stakeholder planning efforts. The CPT was tasked with evaluating both the 2018 Kīlauea impacts as well as future county-wide volcanic risk to inform the identification and prioritization of volcanic hazard recovery and mitigation strategies (***Figure 1-2)***. The USGS Hawaiian Volcano Observatory HVO advised the CPT to help identify all components of the volcanic hazard (discussed in ***Section 2 - Hazard Profile***) and which best-available spatial volcanic data to use for this assessment.

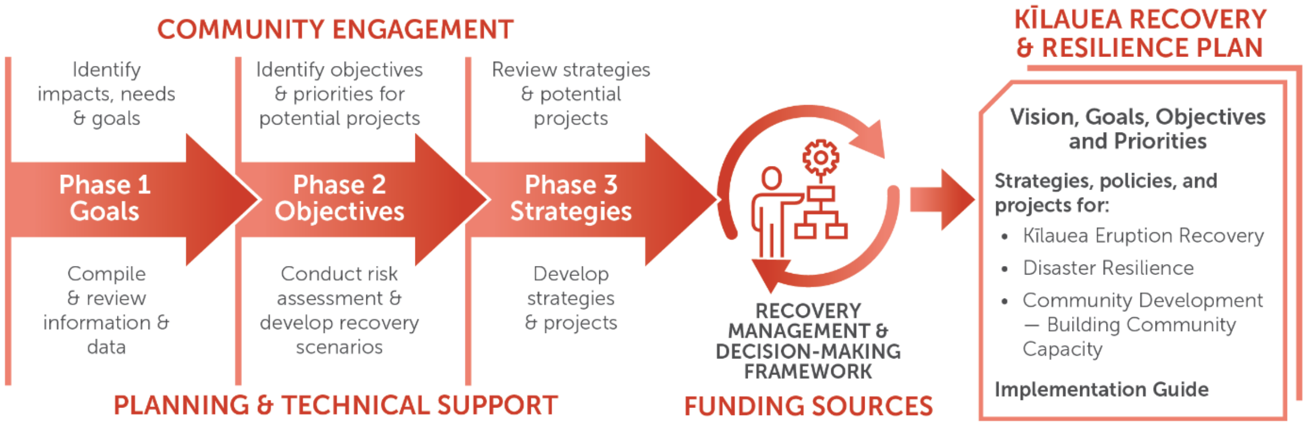


Figure 1-2. Recovery Process (courtesy of the Kīlauea Recovery and Resilience Plan)

The County's exposure to the volcanic hazards was examined post-2018 Kīlauea eruption event to provide an indication of risk to future events, identify vulnerable community assets, and estimate the potential impacts. Results include the amount of land, population, buildings, critical facilities, lifelines, roads, environmental resources and cultural assets that are exposed to volcanic hazards. The built environment was assessed post-2018 Kīlauea to understand current exposure and to inform future recovery and mitigation strategies (discussed in ***Section 3 – Methodology***). The results of the analysis are summarized for the County as a whole and for each Community Development Planning (CDP) area (***Section 4 – Results***) so that the results of this assessment may be integrated into the County General Plan 2040 update (in progress) and future CDP plan updates.

The County is exposed to additional natural hazards. As such, the combined exposure to volcanic hazards and other high-hazard areas (i.e., sea level rise, tsunami, and floods) were incorporated into this assessment. A multi-hazard assessment provides a more holistic evaluation of mitigation needs to support mitigation planning and the achievement of long-term County resilience. The results of the volcanic risk assessment were then utilized to develop recommendations to inform future decision making, whether pre-disaster or in a disaster recovery phase (discussed in ***Section 5 – Recommendations***).

This work is intended to build upon and enhance the existing volcanic risk assessment conducted as a component of the 2015 County of Hawaiʻi Multi-Hazard Mitigation Plan and the Pacific Disaster Center's (PDC) 2019 Kīlauea Eruption Risk Assessment (KERA). As additional hazard and asset data becomes available, this risk assessment will be updated and further refined to continue serving as a technical foundation from which to make risk-informed decisions to ensure the County becomes more resilient to future volcanic and natural hazard events.

SECTION 2. VOLCANIC HAZARD

The Hawaiian Islands are at the southeast end of a chain of volcanoes that began to form more than 70 million years ago (U.S. Geological Survey [USGS] and Hawaiian Volcano Observatory [HVO] 2019). There are five volcanoes located in the County of Hawaiʻi, four of which are considered active (shown in ***Figure 2-1*** and summarized in ***Table 2-1***). Lōʻihi is also an active submarine volcano located 22 miles southeast of the Island of Hawaiʻi.

Figure 2-1. Volcanoes in the County of Hawaiʻi

These volcanoes are called shield volcanoes because they dominantly erupt fluid, lava flows and form gently sloping, shield-like mountains. Shield volcanoes are the largest volcanoes on earth. Hawaii's volcanic activity is distinct from that occurring at continental margins (e.g. Mount Shasta and Mount St. Helens) in that Hawaii's volcanoes produce more fluid basalt magmas that are typically less explosive. The County'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 Lōʻihi (the youngest), forming an intermittently active submarine volcano on the ocean floor. Meanwhile, Kīlauea is 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 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 (Hawaiʻi Emergency Management Agency [HI-EMA] 2018).

Mauna Loa last erupted in 1984. Kīlauea has been continuously erupting since 1983, most recently in 2018 with voluminous lava flows along its Lower East Rift Zone and ash-rich explosions in the summit caldera. 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, ʻaʻā, a lava flow with a rough surface and pāhoehoe, a lava flow with a smooth surface. Eruptions from shield volcanoes are not typically explosive unless water has entered the vent (Oregon State University no date). 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, Puʻu ʻŌʻō, the vent associated with the eruption from 1983 until April 2018, and the 2018 Lower East Rift Zone eruption are from the East Rift Zone of the Kīlauea Volcano (USGS 2018).

Table 2-1. Active Volcanoes in the County of Hawaiʻi*

Name of Volcano	Age of Volcano	Date of Last Eruption	Threat Potential / Areas at Risk
Kīlauea	210,000 to 280,000 years old	April 2018 to September 2018	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 Kaʻū. Summit eruptions are a continued threat for surrounding areas in the Puna district including Volcano Village.
Mauna Loa	0.6 to 1 million years old 300,000 years old (above sea level)	1984 (eruption lasted 22 days)	Very high threat potential along rift zones and summit; areas at risk include the districts of South Hilo, Puna, Kaʻū, South Kona, North Kona and South Kohala. Radial vents located on the southwest, west and north flanks (outside the rift and summit regions) poses serious potential risk to persons and property on the north, west and southwest flanks of Mauna Loa.
Mauna Kea	At least 1 million years old	Between 6,000 and 4,000 years ago	Moderate threat potential
Hualālai	>300,000 years old (above sea level)	1801	High threat potential; areas at risk include the land within the North Kona district
Lōʻihi* (underwater volcano)	<300,000 years old	1996	Low to very low threat potential

** The County of Hawaiʻi includes four active volcanoes. Lōʻihi is approximately 22 miles south of the Island of Hawaiʻi.*

Sources: USGS 2016b; USGS 2017e; USGS 2017g; USGS 2017j; USGS 2018g; USGS HVO 2017a; HIEMA, State of Hawaiʻi HMP 2013

< *Less than*

> *Greater than*

To mitigate future and ongoing hazards produced by volcanic activity in the County, there are notifications, alert systems, and advisories issued to the public. The USGS created a volcano-alert system based on data analyzed from monitoring networks, direct observations, and satellite sensors (USGS 2017p; 2018k). General information about volcanoes are provided to the public as alert notifications accompanied by more specific text. Alert notifications are issued by the USGS for all forms of volcanic activity and are summarized in ***Table 2-2.***

Table 2-2. Volcanic Notification Types Delivered by Volcano Observatory

Notification Types	
Volcano Activity Notice (VAN)	Announces alert-level changes or significant volcanic activity within an alert level; covers all volcanic hazards – lahars (volcanic mudflows), lava flows, ashfall, airborne ash, pyroclastic flows
Daily, Weekly, or Monthly Update	Scheduled update providing steady situational awareness
Status Report	Update about volcanic behavior or monitoring activities during ongoing events of unrest or eruption
Volcano Observatory Notice for Aviation (VONA)	Aviation-sector specific (for pilots, dispatchers, air-traffic managers, meteorologists); focuses on ash emissions
Information Statement	Topical information such as explanation of non-volcanic events at a volcano, changes in monitoring installations, long-term prognoses, etc.

Source: USGS 2018k

Furthermore, signs of volcanic activity or lack thereof are summarized using a two-part system. The USGS alert system issues alerts for persons on the ground (***Table 2-3)*** and for aviators (***Table 2-4***) (USGS 2017i). The aviation alerts use an international color code system to indicate changes in volcanic activity that may affect the aviation sector. Residents can sign up for the USGS alert notifications via email, look up alerts using an interactive map indicating volcano status published on the volcano hazards program website, review the regional volcano observatory websites, or go online and follow social media accounts that are created for all regions of the United States.

Table 2-3. USGS Alert-Level Terms

Alert-Level Terms – a volcano activity notice (VAN) is issued when the volcano alert-level is changed	
Normal	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased and volcano has returned to noneruptive 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 imminent, underway, or suspected

Source: USGS 2017i

Table 2-4. USGS Aviation-Color Codes

Aviation Color Codes – a volcano observatory notification (VONA) is issued when the volcano color code changes	
Green	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased and volcano has returned to noneruptive 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 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 2017i

2.1 Hazard Description

The County collaborated with the USGS HVO to identify all components of the volcanic hazard. A summary for each of these hazards is highlighted in the remaining subsections.

Hazards Related to Volcanic Activity

- Lava
- Vog
- Laze
- Explosive Eruption
- Ashfall
- Seismic
- Tsunami
- Ground Failure / Subsidence
- Volcanic Glass
- Acid Rain

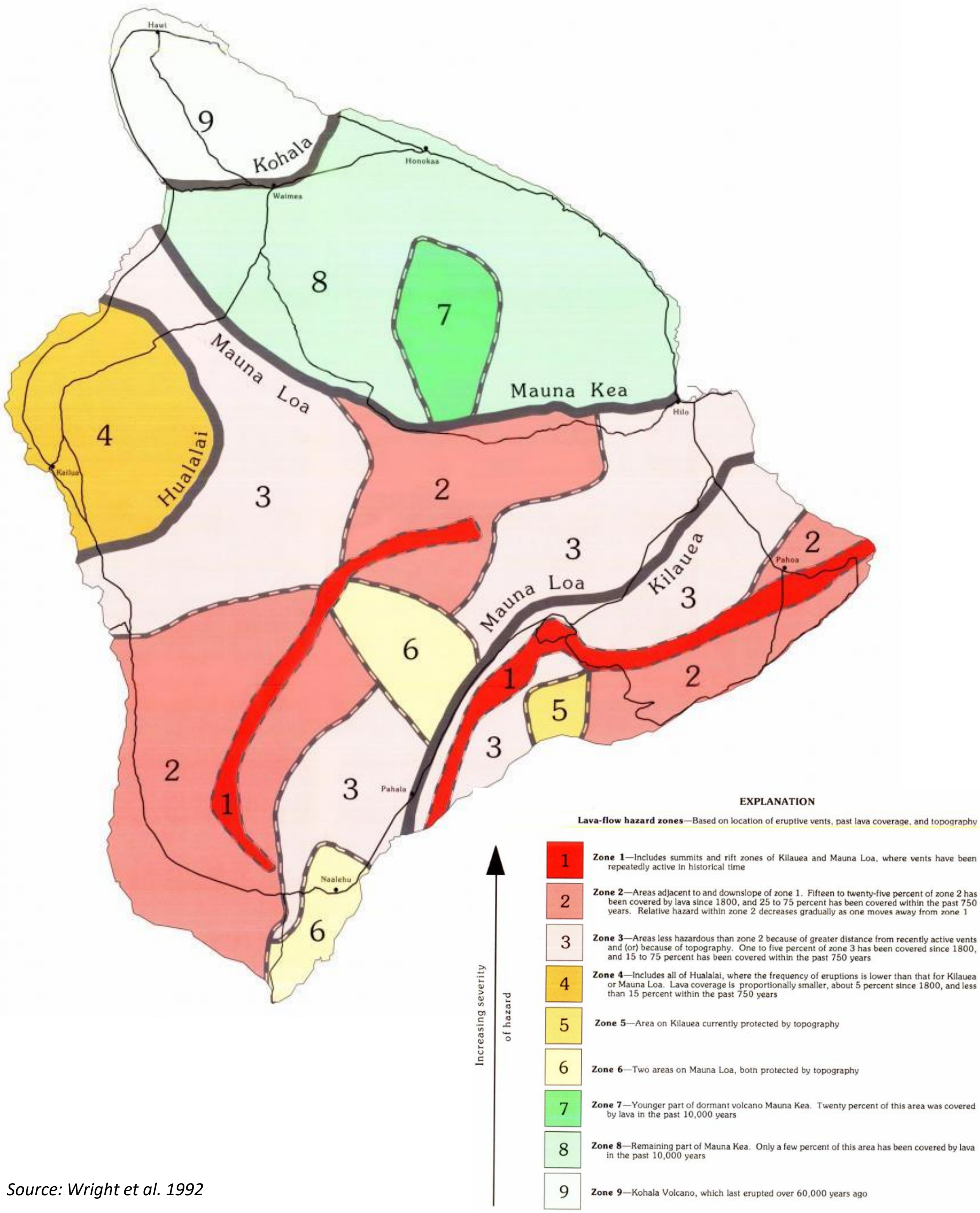
2.1.1 LAVA

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. Lava flows travel downslope toward the ocean, burning and burying everything along the way. Steep slopes may allow lava flows to move quickly from the vent to the ocean in a matter of hours (HIEMA 2013). Lava entering the ocean can build new land, known as lava deltas, which can be unstable and prone to sudden collapse. A collapsing lava delta can trigger local explosive activity that hurls hot rocks hundreds of meters (yards) inland and/or seaward (USGS 2017l). These types of explosions are known as a hydrovolcanic explosions and can be deadly (USGS 2018l). Explosions of this type occurred periodically throughout Kīlauea's East Rift Zone eruption.

Lava Flow After the 2018 Eruption of Kīlauea. Photo Courtesy: USGS, https://volcanoes.usgs.gov/observatories/hvo/multimedia_uploads/multimediaFile-2191.jpg

The first published USGS volcanic hazard zone map of the Island of Hawaiʻi was released in 1974 and revised in 1987 and 1992. Currently, the 1992 map is considered the best available delineating nine lava-flow hazard zones for the five volcanoes (***Figure 2-2***) Lava flows are most likely to occur in lava zone 1 and least likely in lava zone 9.

Hazard zones from lava flows are based chiefly on the location and frequency of both historic and prehistoric eruptions. "Historical eruptions" are defined as those for which there are written records, beginning in the early 1800s and those that are known from the oral traditions of the Hawaiians. Our knowledge of prehistoric eruptions is based on geologic mapping and dating of the old flows of each volcano. The hazard zones also take into account the larger topographic features of the volcanoes that will affect the distribution of lava flows. Any hazard assessment is based on the assumption that future eruptions will be similar to those in the past (USGS 1990). Furthermore, the hazard zones are based on rate of coverage by lava, not probability (Wright et al. 1992). These approximate boundaries can vary in severity within a single hazard zone due to local topography. For example, the hills behind Nīnole that are located above the adjacent slopes of Mauna Loa are at a lower risk of lava flows compared to the surrounding area. It is also important to note that the hazard zones reflect the long-term hazard of lava flows. Therefore, the rate of lava coverage is the basis of these hazard zones, rather than how recent an area was covered in lava. An example of how these rates are applied can be seen between the areas of Kalapana and Leilani Estates. Kalapana is about eight miles downslope of Kīlauea's East Rift Zone. This area did not experience impacts from lava flows until 6 years after the Puʻu ʻŌʻō eruption. The next time this area experienced lava flow inundation was about 20 years later. Even though this area experienced inundation from historical lava flows, this community was placed in lava zone 2 because it is not on the volcano rift zone and has a lower risk than a community on the rift zone. Leilani Estates, on the other hand, is located entirely on the Lower East Rift Zone of Kīlauea. The eruptions in 1955, 1960, and recently in 2018 threatened this community because they took place along the southernmost boundary of the estates or immediately adjacent to the community. The threat of vents surrounding the estates keep this community at risk for each eruption that occurs on Kīlauea's Lower East Rift Zone, which is why this community is placed in lava zone 1.



Source: Wright et al. 1992

Figure 2-2. USGS Lava Flow Hazard Zones

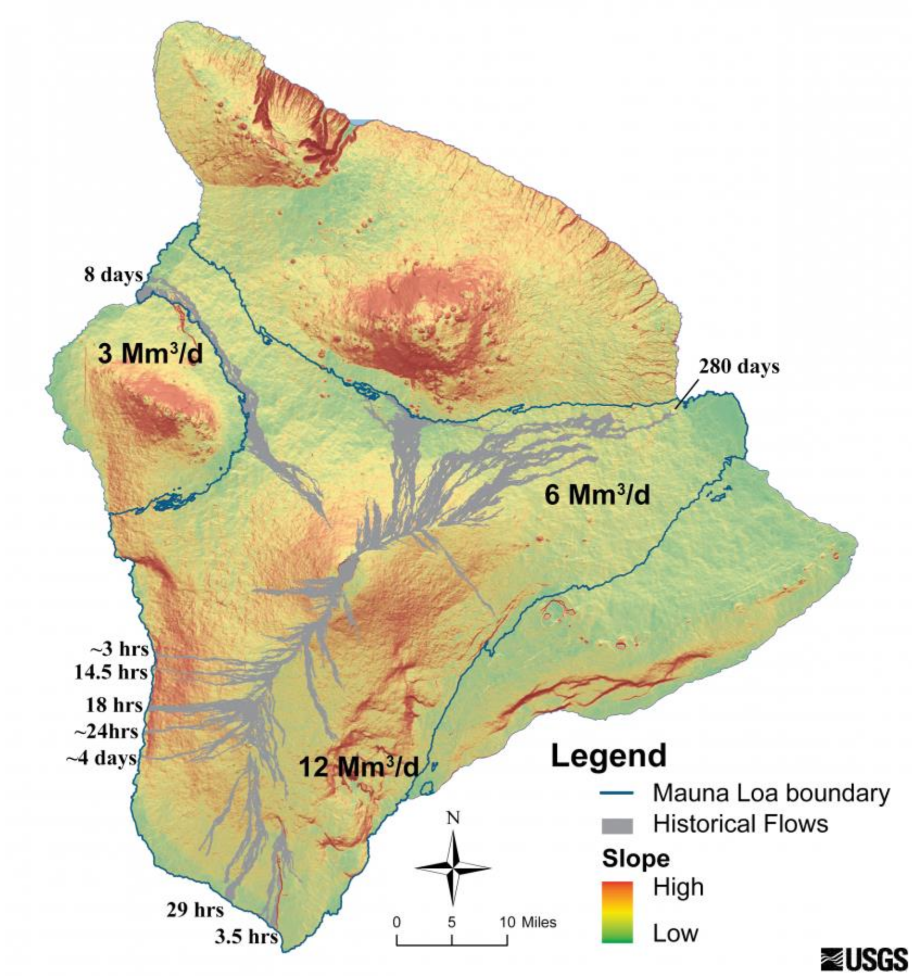
As shown on ***Figure 2-2 ,*** volcano boundaries are depicted as heavy, dark bands, reflecting overlapping of lava flows from adjacent volcanoes along their common boundary. The lava flow hazard zones are drawn as double lines because of the geographic uncertainty of their placement. These boundaries are approximate, gradational, and change in the degree of the hazard that can be found over a distance of a mile or more, meaning these boundaries are not specific enough to determine the absolute degree of danger at any particular site. The lava-flow hazard zones are designed to show the relative hazard across the island and meant to be used for general planning purposes only (USGS HVO 1992).

Lava flow zones 1 through 9 are described below.

- **Zone 1** – Includes summits and rift zones of Kīlauea and Mauna Loa, where vents have been repeatedly active in historic time.
- **Zone 2** – Areas adjacent to and downslope from zone 1. Fifteen to twenty-five percent of zone 2 has been covered by lava since 1800, and 25 to 75 percent has been covered within the last 750 years. The relative hazard within zone 2 decreases gradually as one moves away from zone 1.
- **Zone 3** – 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 Kīlauea 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.
- **Zone 6** – Includes two areas on Mauna Loa, both protected by topography.
- **Zone 7** – Includes the younger part of volcano Mauna Kea; 20 percent of this area was covered by lava in the past 10,000 years.
- **Zone 8** – 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** – The Kohala Volcano, which last erupted over 60,000 years ago (Wright et al. 1992).

Although there is no calculated probability associated with each lava zone, the USGS indicates the probability of future lava flows is not the same for all areas of the County. Moreover, the long-term lava-flow threat is greatest on Kīlauea and Mauna Loa, the two most active volcanoes, followed by Hualālai (USGS 2017i).

Scientists have been forecasting flow paths using paths of steepest descent calculated using geographic information system (GIS) software and digital elevation models of the Island of Hawaiʻi. The steepest descent paths are described as the paths along which fluids (water or lava) would drain the flank of a volcano under the influence of gravity (USGS 2017i). The volume flow-rate of lava along these pathways varies based upon the actual advance rate and dimensions of the current. Volume flow-rates can be affected by eruption rate, ground slope, and the complex behavior of ʻaʻā and pāhoehoe flows, which have a faster flow rate and slower rate, respectively (***Figure 2-3***) (USGS 2017i).



Source: USGS 2017i

Note: Mm^3/d Million cubic meters per day

Figure 2-3. Number of Hours or Days to Reach the Ocean or Most Distant Location post-1823 Mauna Loa Eruption

2.1.2 VOG

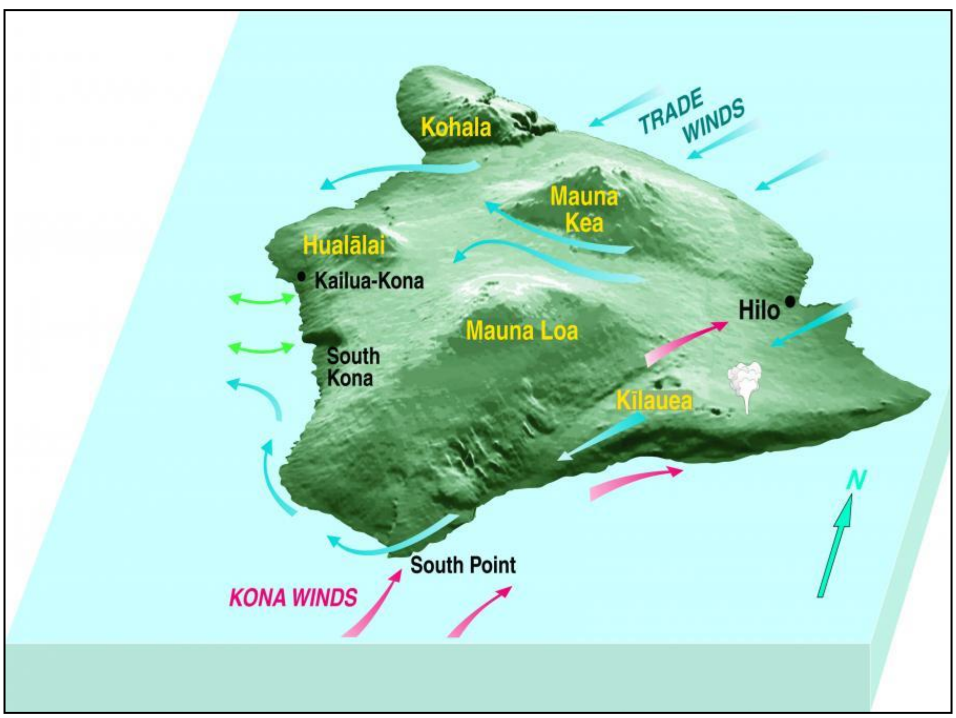
Vog consists of sulfur dioxide (SO_2) gas and aerosols (tiny particles or droplets) which are primarily sulfuric acid and other sulfate (SO_4) compounds. Aerosols are created when SO_2 and other volcanic gases combine in the atmosphere and interact chemically with oxygen, moisture, dust, and sunlight over minutes to days. These airborne hazards are created by volcanic activity, which exacerbates health hazards to residents and visitors of the County with existing respiratory conditions, particularly to people qualified under "sensitive group" categories. Sensitive groups include:

- People with asthma or other respiratory conditions
- People with cardiovascular disease
- Older adults
- Infants and children
- New or expectant mothers

Sulfuric acid droplets in vog have the corrosive properties of diluted battery acid. For example, when vog mixes directly with moisture on the leaves of plants, it can cause chemical burns which can damage or kill the plants. The SO_2 gas can also diffuse through leaves and dissolve to form acidic conditions within plant tissue. SO_2 emissions have been continuously produced from three different vents from 1983 to 2018—Puʻu ʻŌʻō (1983-2018), Halemaʻumaʻu (2008-2018), and the Lower East Rift Zone (LERZ) vents (2018). Farmers in the County, particularly in the Kaʻū District, reported losses of their agricultural crops and flowers as a result of the high SO_2 emissions from the 2018 eruption (USGS 2018).

While volcanic emissions have been a component of all Hawaiian eruptions, they have become a major health hazard due to the increase in population in the last few decades in downwind areas. Starting in May 2018, the LERZ released more than 50,000 tons of SO_2 gas per day, which is more than 50 times the emissions from the top SO_2-producing U.S. power plant. Moving forward, future volcanic events may include emissions concentrations of particulate matter (PM) 2.5 (fine particles that can be inhaled deep into the lung), which reach levels considered "unhealthy" by U.S. regulatory agencies, and regularly reached concentrations designated as "unhealthy for sensitive groups" (U.S. Department of the Interior Strategic Sciences Group 2018).

Vog conditions in the County vary and depend on wind direction (northeasterly trade winds, southerly Kona winds) and emission source. ***Figure 2-4*** shows, during prevailing trade winds, the nearly constant stream of vog produced by Kīlauea is blown to the southwest and west, where wind patterns carry it to the Kona coast. Once wind reaches the Kona coast, the vog 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. Vog can reach the Island of Oʻahu (City and County of Honolulu), which is more than 200 miles northwest of Hawaiʻi Island (USGS 2017d).



Source: USGS 2017o

Figure 2-4. Wind Direction and vog conditions in the County of Hawaiʻi

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). Further, the County and the State of Hawaiʻi Department of Health (DOH) have created a warning system to help the community take protection actions based on the level of SO_2 that has been created as a consequence of vog. The color code is based on a forecast of data and uses volcanic emission levels, weather, wind, and historical data. Although changing conditions make it difficult to predict protective measures, forecasting is intended to provide advanced warning and advice to help in prepare for an emergency (***Table 2-5***).

Table 2-5. Color Code System Used to Identify Risk of Sulfur Dioxide Concentrations in the Community

SULFUR DIOXIDE INFORMATION	
Condition	**Recommended Response**
GREEN (Trace)	**Sensitive Groups**[1]: Highly sensitive individuals may be affected at these levels.
GREEN (Trace)	**Everyone Else**: Potential health effects not expected.
YELLOW	**(Light) Sensitive Groups**[1]: Avoid outdoor activity.
YELLOW	**Everyone Else**: Potential health effects not expected, however actions to reduce exposure to vog may be useful.
ORANGE	**(Moderate) Sensitive Groups**[1]: Avoid outdoor activity and remain indoors.
ORANGE	**Everyone Else**: Potential health effects not expected, however actions to reduce exposure to vog may be useful.
RED	**(High) Sensitive Groups**[1]: Avoid outdoor activity and remain indoors.
RED	**People Experiencing Respiratory-related Health Effects**: Consider leaving the area.
RED	**Everyone Else**: Avoid outdoor activity.
PURPLE	**(Extreme) Sensitive Groups**[1]: Avoid outdoor activity and remain indoors.
PURPLE	**People Experiencing Respiratory-related Health Effects**: Leave the area and seek medical help.
PURPLE	**Everyone Else**: Leave the area if directed by the County of Hawaiʻi Civil Defense.
Note 1: Sensitive Groups are children and individuals with pre-existing respiratory conditions such as asthma, bronchitis, emphysema, lung or heart disease.	

Source: State of Hawaiʻi 2019

Vog data and associated climatology are being collected by the University of Hawaiʻi at Mānoa while the State Department of Health and National Park Service monitor air quality on the island. There are several stations on the Island of Hawaiʻi that collect SO_2 and particulate matter hourly averages corresponding to air quality levels of health concern (Department of Health no date; National Park Service no date). This data was not available for use in this assessment and is discussed qualitatively in Section 4.

2.1.3 LAZE

Laze is formed when molten lava enters the ocean creating a massive cloud of steam that contains other harmful components. The plume is an irritating mixture of hydrochloric acid (HCl) gas, steam, and tiny volcanic glass particles. As a result, this product can travel with the wind and is considered a hazard for persons downwind or along the coasts and inland where winds blow the laze from lava ocean entries (USGS 2019f).

Laze Plume From 2018 Kīlauea Eruption. Photo Courtesy: USGS, https://www.usgs.gov/media/images/k-lauea-volcano-multiple-laze-plumes

A laze plume can be blown in various directions by the wind. Downslope air flow from nighttime through early morning typically blows the laze plume off shore and out to sea. However, between mid-morning and late afternoon, the trade winds can blow the plume along the coast and inland, resulting in poor air quality (USGS 2017o).

The harmful properties of laze can have immediate impacts on persons who have been exposed. These plumes produce acid rain with a pH ranging between 1.5 and 3.5 and have the corrosive properties of dilute battery acid. As a result, the plumes can cause skin irritation, eye irritation, breathing difficulties, and less frequently, death (USGS 2017o).

2.1.4 EXPLOSIVE ERUPTION

Explosive eruptions can occur when the lava column drops below the water table, groundwater interacts with hot rock building steam pressure and resulting in violent steam explosions. Debris and hazardous materials from big explosions can be ejected vertically to an altitude of 35,000 feet reaching the subtropical jet stream. These explosions can also create pyroclastic surges, fast moving clouds of ash, rock and volcanic gas that can travel at hurricane speeds. In 1790, at least 80 people were killed by searing hot gas and ash after Kīlauea erupted (USGS 2019b).

Eruption of Lava that Pulsed up to 50 Meters from Fissure 8 of the Kīlauea Volcano. Photo Courtesy: USGS, https://www.usgs.gov/news/k-lauea-volcano-erupts

Explosive volcanic eruptions can produce a variety of ejecta products, some of which can potentially affect communities and farmland across hundreds, or even thousands of miles. The variety of ejecta products include:

- **Tephra** – fragments of rock that are ejected into the air when a volcano erupts explosively.
- **Large fragments (blocks, bombs) of rock** – tephra larger than 64 millimeters (mm) (2.5 inches [in]) that is usually deposited near the eruptive vent.

- **Smaller fragments (lapilli) of ash** – tephra between 2 and 64 mm (0.08 and 2.5 in) that can be carried upward within in a volcanic plume and downwind in a volcanic cloud.
- **Very fine-grained material volcanic ash** – tephra smaller than 2 mm (0.08 in) that is both easily carried upward within the plume and downwind for very long distances (HIEMA 2018).

At least four debris fans on Mauna Loa, comprised of fragmented rock deposits on top of pāhoehoe lava flows that spread from the summit have been identified. These four sites represent three separate explosive eruptions dating back over 1,000 years (USGS 2020b). For the past 2,500 years, the prevailing style of eruption at Kīlauea was explosive (estimated 60% of the time) (Swanson 2014). While the most recent 2018 Kīlauea eruption did not result in a big explosion, small explosions occurred from the summit of Kīlauea with gas and ashfall transported downwind (USGS 2018m). The magnitude 5.0-earthquake was followed by a collapse in the crater of Puʻu ʻŌʻō creating a reddish-brown ash plume discussed further below (USGS 2018n).

2.1.5 ASHFALL

Volcanic ash is a primary hazard from eruptions that can affect structures, power generation and transmission, water districts, ground and air transportation, agriculture, and human health (USGS 2018i). This hazard is dispersed by wind. Near a vent, ash thickness can be more than 5-10 cm (2-4 in) which can impact person's ability to breath if a well-sealed shelter is not available. Downwind thickness of ash can be in millimeters, or in some areas, in centimeters. This by-product of the eruptions can also fall as a very wet and slick material that covers buildings and infrastructure. Nuisance ash has been a common hazard of volcanic eruptions in the County.

Ashfall from Halemaʻumaʻu Plume that Took Place in 2018. Photo Courtesy: USGS, https://www.usgs.gov/news/k-laueavolcano-erupts

Kīlauea's summit has erupted explosively producing ash deposits for at least the last 30,000 years ago (USGS 2019b). In 1790, at least 80 people were killed by searing hot gas and ash after Kīlauea erupted (USGS 2019b). In 1924, a series of volcanic ash and dust from Kīlauea that traveled at least two miles into the air from steam explosions covered the downwind community of Pāhala, turning "day into night" (USGS 2019b). Muddy ash was also produced in the 1924 Kīlauea eruptions, which covered the railroad tracks in lower Puna disrupting the rail line services (USGS 2019b). Most recently in 2018, the summit of Kīlauea produced a volcanic cloud containing minor amounts of ash that reached as high as 30,000 feet above sea level. To mitigate possible health impacts of the ashfall, the USGS issued a warning to the public to keep track of where ashfall could potentially fall under forecast wind conditions (USGS 2018f).

Health experts advise the public to be aware of ashfall locations to minimize exposure. For fine ash particles, individuals with high exposure can breathe in ash, causing symptoms such as nasal irritation and discharge, throat irritation and sore throat, and airway irritation for those with asthma or bronchitis (International Volcanic Health Hazard Network

[IVHHN] 2019). Coarser ash particles can cause eye irritation and skin irritation (specifically for ash that is acidic). Even persons with high tolerance to ashfall can experience indirect health effects because it creates risks, such as reducing visibility during driving, shutting down critical infrastructural that depend on power supply, contaminating water or damaging water supplies, disabling municipal sanitation systems, and/or collapsing roofs due to its weight.

2.1.6 SEISMIC

The entire County is exposed to the earthquake hazard. In addition to posing a life safety hazard, earthquakes are destructive to the County's infrastructure, including buildings, roads, bridges, and utilities. Strong local earthquakes can trigger coastal subsidence as seen in 1868 and 1975. Damages are intensified in areas of water-saturated soils and on steep slopes and subsequently can lead to landslides due to undermined ground stability.

The earthquake that occurred in 1868 was estimated to have a magnitude of 7.5 to 8.1. Damage occurred across the entire island; however, the devastation was greatest in the Kaʻū district where an earthquake triggered mudflow killed 31 people and coastal subsidence produced a tsunami that destroyed several villages (USGS 1990).

The seismic hazard is often characterized in terms probability of peak ground acceleration (PGA) measured as a percent of Earth's gravitational acceleration (%g) within a fixed time period. The southeast part of the County has the highest expected ground acceleration at a 2% probability of exceeding 100%g over the next 50 years (***Figure 2-5***); high seismic hazard is depicted as warm colors (red to orange) and relatively low hazards depicted with cool colors (green). A PGA of 100%g can cause significant impacts in the County as described in ***Table 2-6*** which describes the potential effects of shaking that correspond to the colors in ***Figure 2-5***. Engineers use this information to develop building codes and design earthquake resistant structures. Non-engineers can use these maps to judge the relative seismic hazard, where high seismic hazards are depicted in warm (red-orange) colors (USGS 2017d).

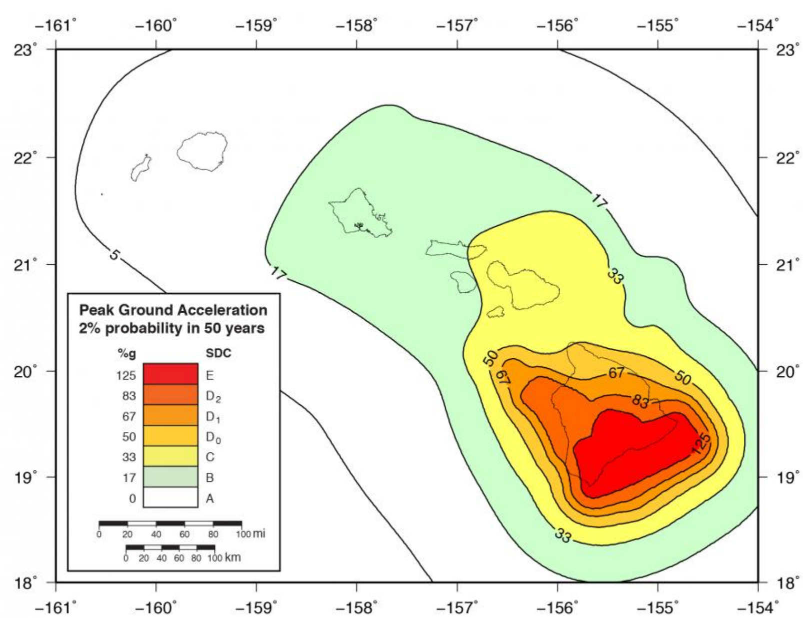


Figure 2-5. Seismic Hazards Across the County
Image courtesy: USGS, https://volcanoes.usgs.gov/observatories/hvo/hazards_earthquakes.html

Table 2-6. Seismic Hazard Zones Reflecting Intensity and Probability of Shaking

SDC	Map Color	Earthquake Hazard	Potential Effects of Shaking*
A	White	Very small probability of experiencing damaging earthquake effects.	
B	Green	Could experience shaking of moderate intensity.	Moderate shaking—Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
C	Yellow	Could experience strong shaking.	Strong shaking—Damage negligible in buildings with good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built structures.
D_0	Dark Yellow	Could experience very strong shaking (the darker the color, the stronger the shaking).	Very strong shaking—Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures.
D_1	Light Orange		
D_2	Orange		
E	Red	Near major active faults capable of producing the most intense shaking.	Strongest shaking—Damage considerable in specially designed structures; frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Shaking intense enough to completely destroy buildings.

*Abbreviated descriptions from the Modified Mercalli Intensity Scale
SDC Seismic design categories

Source: USGS 2017d

The National Earthquake Hazard Reduction Program (NEHRP) states that ground shaking is the primary cause of earthquake damage to buildings and infrastructure (USGS 2017d). The level of potential activity and damages are driven by soil types, such as softer soils which amplify ground shaking. One contributor to shaking amplification is the velocity at which the rock or soils transmits shear waves (S-waves). NEHRP has defined five soil types based on their shear-wave velocity (Vs.) that aid in identifying locations that will be significantly impacted by an earthquake. The NEHRP soil classification system ranges from A to E, where A represents hard rock that reduces ground motions from an earthquake and E represents soft soils that amplify and magnify ground shaking and increase building damage and losses (***Table 2-7***). Therefore, these soil classes inform the seismic design categories (SDC) for the County, which are illustrated in ***Figure 2-6.***

Table 2-7. NEHRP Soil Classifications

Soil Classification	Description
A	Hard Rock
B	Rock
C	Very dense soil and soft rock
D	Stiff soils
E	Soft soils

Source: FEMA 2015

USGS has identified many processes in and around volcanoes that can generate earthquakes (USGS 2016d). Pressurized magma in subsurface reservoirs can create significant stress changes in the crust as magma migrates to the surface. This stressor can create several types of seismic events, such as:

- Volcano-tectonic earthquakes – this process involves the brittle failure of rock that occurs along "tectonic" faults through the movement of magma through pre-existing cracks.

- Long-period or low-frequency earthquakes – this process is caused by cracks created from the movement of magma and gases towards the surface.
- Tremor – this process is caused by the flow of magma through the cracks, which creates continuous seismic events mixed with volcano-tectonic and long-period or low-frequency earthquakes.

These seismic events are typically too small to feel, are generally shallow, and rarely lead to eruptions. However, USGS has observed that most eruptions are preceded by these events.

The 2018 Kīlauea eruption produced unprecedented levels of seismicity in the volcano's instrumental history. On April 30, after Puʻu ʻŌʻō collapsed, earthquakes propagated downrift toward the LERZ. More than 6,000 recorded earthquakes were recorded between May 1 and June 7, ranging in magnitude from 0.5 to 6.9 (HIEMA 2018). The 6.9 earthquake recorded on May 4, 2018 was one of the most significant eruption-related events that took place during the 2018 eruption period. A collapse of Kīlauea's caldera produced the numerous documented earthquake events. The 825 million cubic meter caldera collapse at Kīlauea in 2018 was the largest at the volcano in more than two centuries. The earthquakes that occurred at Kīlauea's summit during the 62 caldera collapse-explosion events resulted in large ground fractures as well as large explosion clouds of rock and debris. Significant damage to infrastructure and structures occurred in the surrounding summit area including Volcano Village resulting from the caldera collapse. Over the course of the eruption and caldera collapse period; over 60,000 earthquake events were recorded. Recent work has clarified the explosive nature of Kīlauea's eruptions. Once thought rare, it is now known that Kīlauea can produce explosive eruptions from its summit caldera region lasting over periods as long as centuries (USGS 2019b).

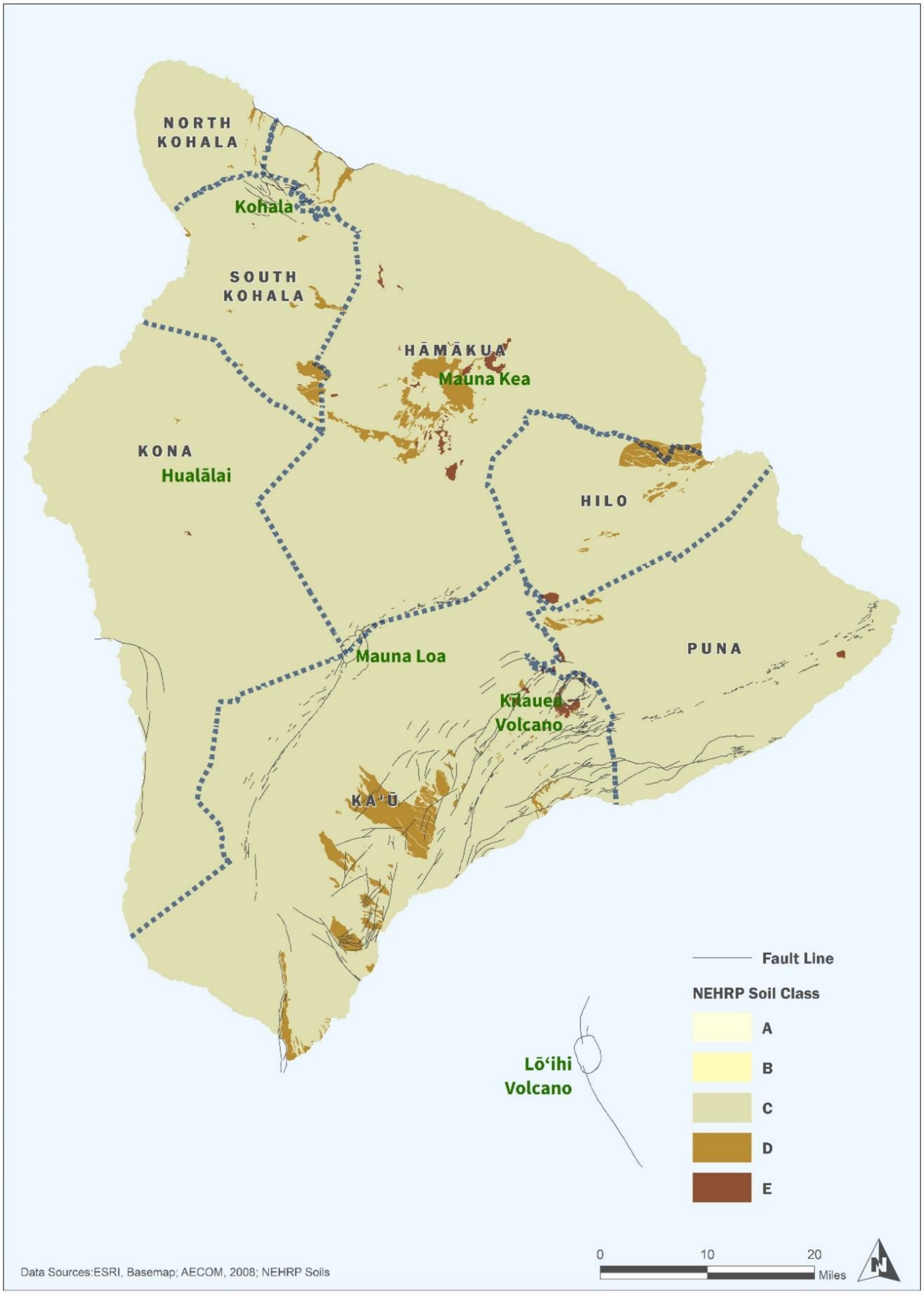


Figure 2-6. National Earthquake Hazard Reduction Program (NEHRP) Soils

2.1.7 TSUNAMI EVENTS TRIGGERED BY EARTHQUAKES

Tsunamis are ocean waves triggered by large earthquakes that occur near or under the ocean, volcanic eruptions, submarine landslides, and by onshore landslides in which large volumes of debris fall into the water (USGS 2019h). These events can last for many hours and range in size. The International Tsunami Information Center (ITIC) has indicated that although infrequent, explosive volcanic eruptions that create a large amount of debris, a volcanic slope failure, or a collapse of the volcanic magmatic chambers can displace a large amount of water and generate tsunami waves in the immediate source area (ITIC 2019). The ITIC has recorded a few instances where a volcanic explosion caused a tsunami, such as the tsunami in 1883 after an explosion and collapse of a volcano in Indonesia. The most notable tsunami recorded by ITIC was in 1980 after the eruption of Mount St. Helens in Washington caused a partial collapse of the volcano's flank creating an avalanche into Spirit Lake, which produced a 780-foot tsunami.

Aftermath of the 1960 Tsunami in Hilo, Hawaiʻi. Photo courtesy: USGS, https://www.usgs.gov/centers/pcmsc/science/could-it-happen-here?qt-science_center_objects=0#qt-science_center_objects

The County has been impacted by tsunamis triggered by both distant as well as local earthquakes. Although a tsunami triggered by an eruption has not been recently witnessed in the County, they can also be triggered by seismic activity and subsidence caused by volcanoes (USGS 2019a). Local-source events are most likely to be generated primarily from earthquakes and large-scale subsidence along the south flank of Kīlauea. Since 1811, the State of Hawaiʻi has seen 32 tsunamis with a runup greater than 1 meter, primarily from earthquakes and large-scale subsidence along the south flank of Kīlauea (USGS 2019a). Tsunamis can cause extensive damage to the coast, so it has been recommended that if you feel an earthquake, immediately go inland to a place at least 30 meters above sea level. This is because tsunamis generated by local earthquakes spread quickly (minutes). Various tsunamis have been documented by USGS, showing that these hazards are dangerous events that can injure people and cause death.

The 1868 earthquake was estimated to have a magnitude of 7.5 to 8.1 causing damage across the entire island. In the Kaʻū district, coastal subsidence produced a tsunami that destroyed several villages and killed 46 people (USGS 1990, USGS 2020c).

In 1975, a 7.7 magnitude earthquake occurred on Kīlauea's south flank. The Kalapana coast subsided as much as 11 feet, generating a huge tsunami that claimed two lives, destroyed houses in Punaluʻu, sank fishing boats in Keauhou Bay, and damaged boats and piers in Hilo (USGS 1990).

The most destructive tsunami event in Hawaiʻi took place in 1946, killing 159 people statewide. Refer to the 2018 State of Hawaiʻi Hazard Mitigation Plan for further details on tsunami events.

2.1.8 GROUND FAILURE/SUBSIDENCE

Underground magma injections and ground shaking from strong earthquakes can produce ground fractures and lead to subsidence, which impacts the environment, human activity, and infrastructure (USGS 2018d). Subsidence most commonly occurs at the summits or rift zones of the active volcanoes during magma intrusions and eruptions. They also occur over broad areas on the flanks of Mauna Loa and Kīlauea during large earthquakes.

Ground Fractures in the Hawai'i Volcanoes National Park During Eruption of Kīlauea in 1969. Photo courtesy: USGS, https://volcanoes.usgs.gov/observatories/hvo/Hawai'i_ground_cracks.html

In 1965, large fractures developed along broad areas in Hawaiʻi Volcanoes National Park as magma rose towards the surface. Common during dike emplacements that lead to eruptions, broad, low areas over the rising magma, known as grabens, can form between parallel fractures (USGS 2018d). Recently, USGS and County-led field teams documented where open cracks and grabens formed in the Leilani Estates area leading up to and during the 2018 Kīlauea eruption (***Figure 2-7***). Gas venting, steaming, heat, can be released from these structures.

Further, ground failure can occur in areas around active vents that have been drained of magma (USGS 2018d). The withdrawal of magma from the summit reservoirs after volcanic activity creates calderas that can span several miles across and hundreds of meters deep. As magma is drained beneath the caldera floor; the caldera collapse will result in multiple hazards. During the 2018 Kīlauea caldera collapse events, tens of thousands of earthquakes occurred at the summit of Kilauea resulting in large ground fractures as well as large explosion clouds of rock and debris. Significant damage to infrastructure and structures occurred in the surrounding summit area including Volcano Village resulting from the caldera collapse.

Landslides or mudflows are also a form of ground failure that can occur due to volcanic activity including:

- Intrusion of magma into a volcano;
- Explosive eruptions;
- Large earthquake directly beneath a volcano or nearby
- Heavy or long-lived rainfall that saturates the ground

As mentioned in section 2.1.6; an earthquake generated mudflow occurred in 1868 and killed 31 persons in the Kaʻū district.

Examples of historical landslides associated with the volcanoes on the Island of Hawaiʻi include Punaluʻu slide, Hilina slump, and South Kona landslide complex.

Ground subsidence is an ongoing process in the Island of Hawaiʻi; as the island is sinking a few millimeters per year. The sinking is caused by the weight of the island pushing down the ocean crust on which the island sits, while some sinking is due to rising sea level. Subsidence in the volcanic rift zones has added more subsidence to coastal areas of the rift zones like Kapoho (Kauahikaua 2019). Previously mentioned in section 2.1.7; the .7.7 magnitude earthquake recorded in 1975 caused the coastline along Kalapa to subside as much as 11 feet, which generated a large tsunami resulting in a loss of 2 lives. Submergence of the island will endanger shoreline infrastructure and development. Low-lying coastal areas will become more vulnerable to damage from storm waves, tsunamis, and inundation.

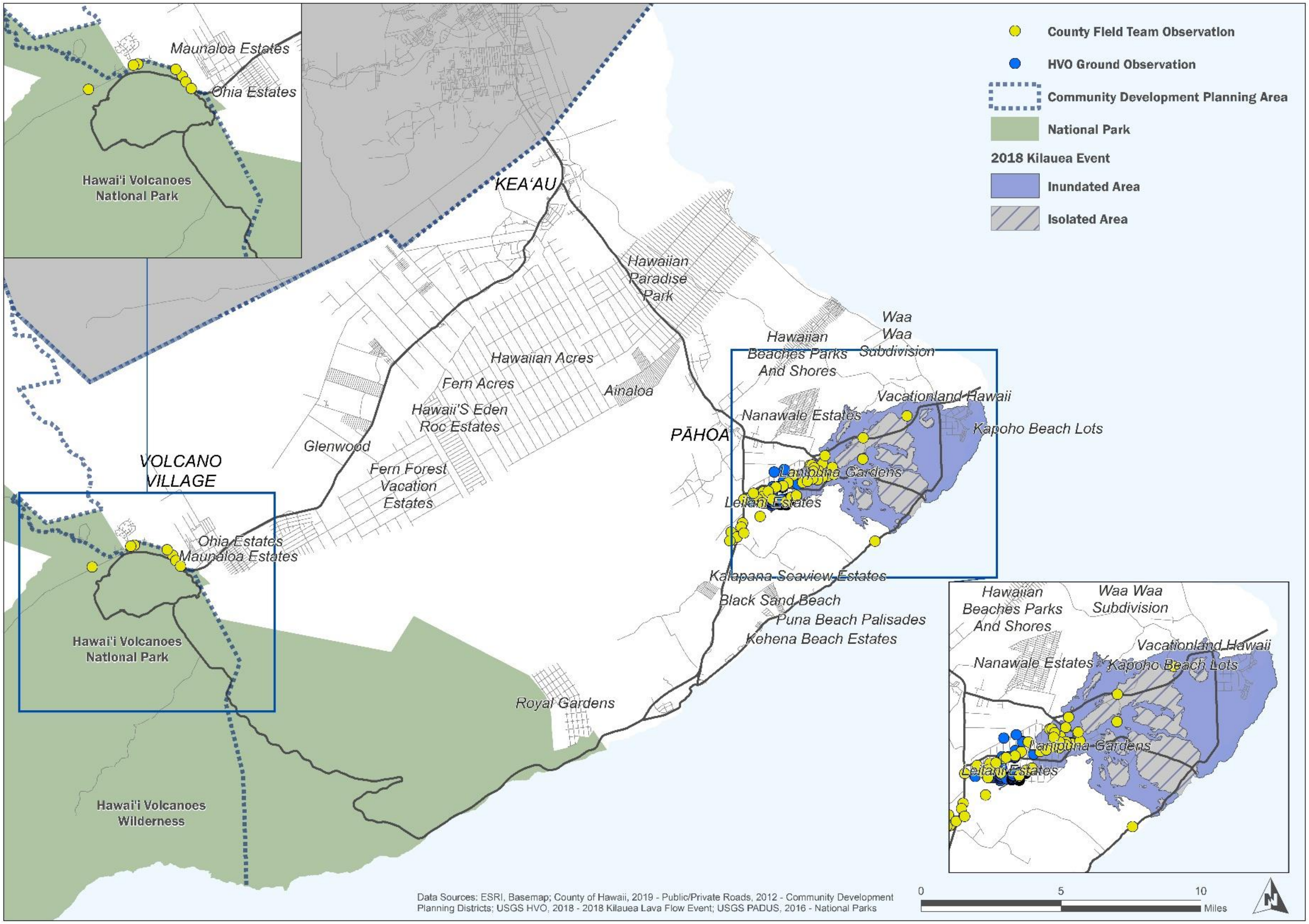


Figure 2-7. Overview of Observed Ground Cracks After the 2018 Kīlauea Eruption

2.1.9 VOLCANIC GLASS

Volcanic glass forms when molten lava cools too quickly for crystals to form. All pāhoehoe flows have a skin of volcanic glass. Molten lava that is ejected into the air forms bits of volcanic glass when cooled. Some of the molten droplets get spun in the air and form basaltic glass fibers called Pele's hair. These are part of laze and are also produced by spattering and/or fountaining lava in vents, as seen with Fissure 8 during the 2018 eruption (Kauahikaua 2019).

Pele's hair was witnessed during and after the Kīlauea eruption in 2018. The glass came from the eruption of Fissure 8. HVO issued a warning to the community to avoid exposure because this type of glass can cause skin and eye irritation similar to volcanic ash (USGS HVO 2018). The community was also warned to avoid walking along glassy lava flow surfaces which were deemed unstable and also cause cuts and abrasions due to the sharp nature of the material.

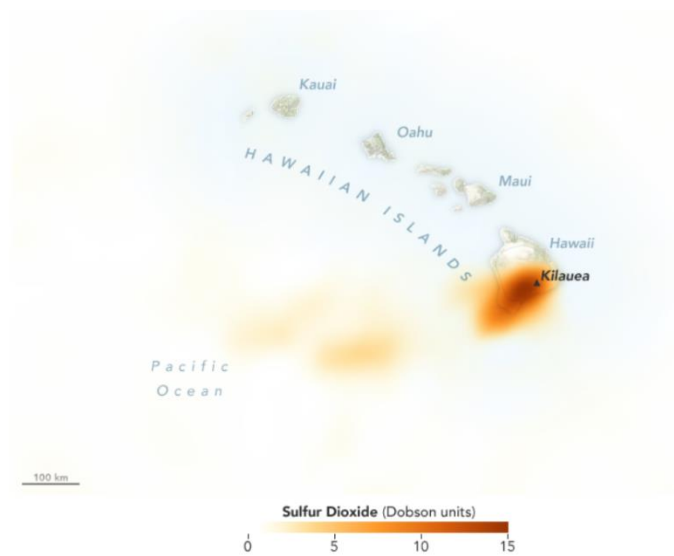
Pele's Hair Formed after a 2017 Kīlauea Explosion. Photo Courtesy: USGS, https://www.usgs.gov/media/images/peles-hair-filaments-volcanic-glass-formed-explosive

2.1.10 ACID RAIN

Volcanic acid rain arises from the plume gasses and sulfur dioxide released from volcanic eruptions (USGS 2018j). Acid rain contains high concentrations of sulfur dioxide in volcanic gas emissions. There was a risk of acid rain after the 2018 eruption of the Kīlauea when National Aeronautics and Space Administration (NASA) observed high concentrations of sulfur dioxide after the eruption.

Therefore, if sulfur dioxide concentrations increase, there is a higher chance that acid rain will take place. Volcanic acid rain can cause a variety of problems for infrastructure and has negative health impacts (USGS 2019i, USGS 1997), such as:

- Corrosion of infrastructure and impacts to drinking water
- Leaching of lead from roofing and plumbing materials, which can contaminate drinking water in rooftop rainwater-catchment systems
- Damage to eyes
- Impacts to the mucous membranes
- Health impacts on the respiratory system



Sulfur Dioxide Concentrations After the 2018 Kīlauea Eruption in Dobson Units. Photo Courtesy: NASA, https://earthobservatory.nasa.gov/images/92107/sulfur-spews-from-Kīlauea

The effects of acid rain can be exacerbated if sulfur dioxide creates sulfate aerosols, which is extremely toxic in high concentrations (USGS 2017n). The actual concentrations in parts per million (ppm) of sulfur dioxide after the 2018 eruption of the Kīlauea are highlighted in ***Figure 2-8***.

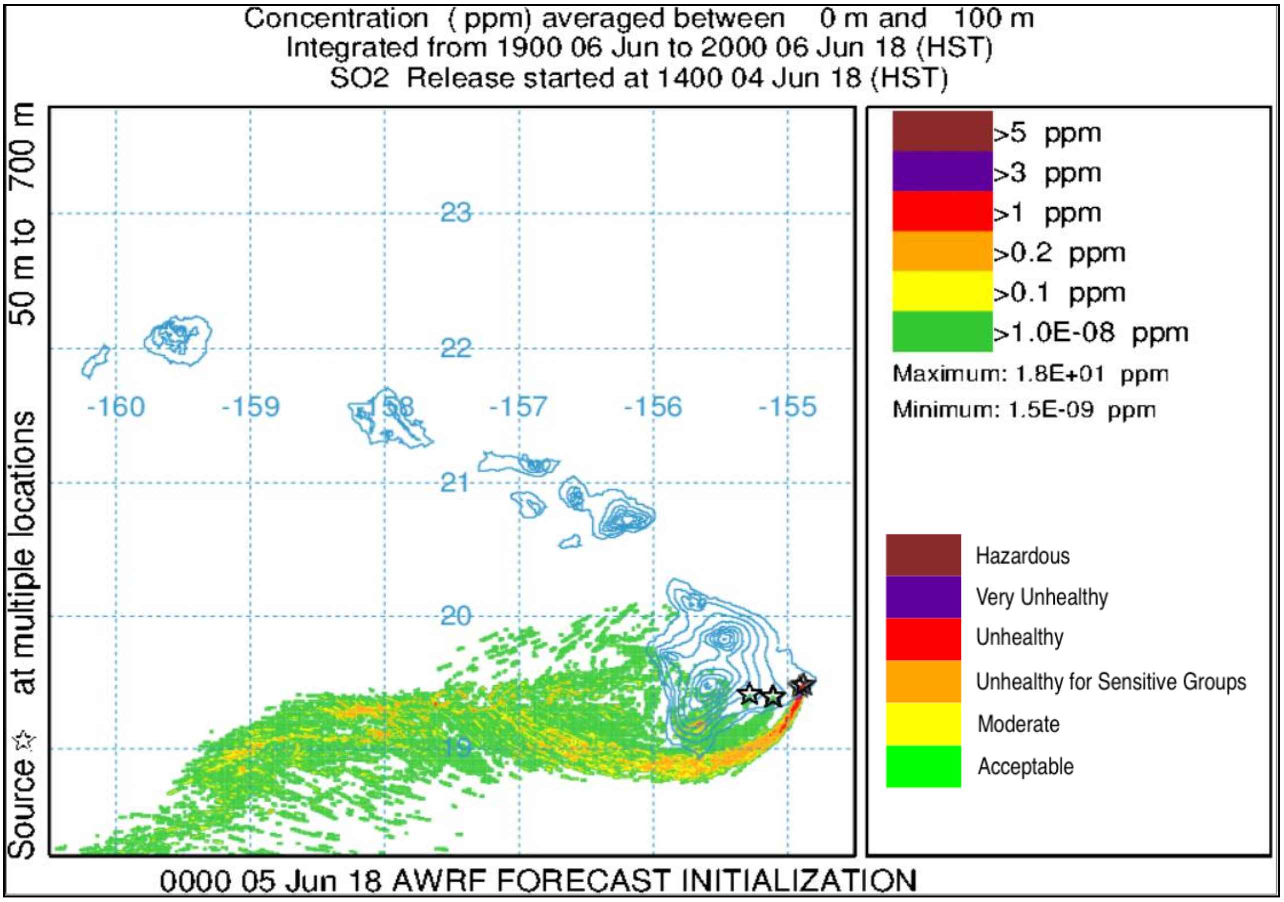
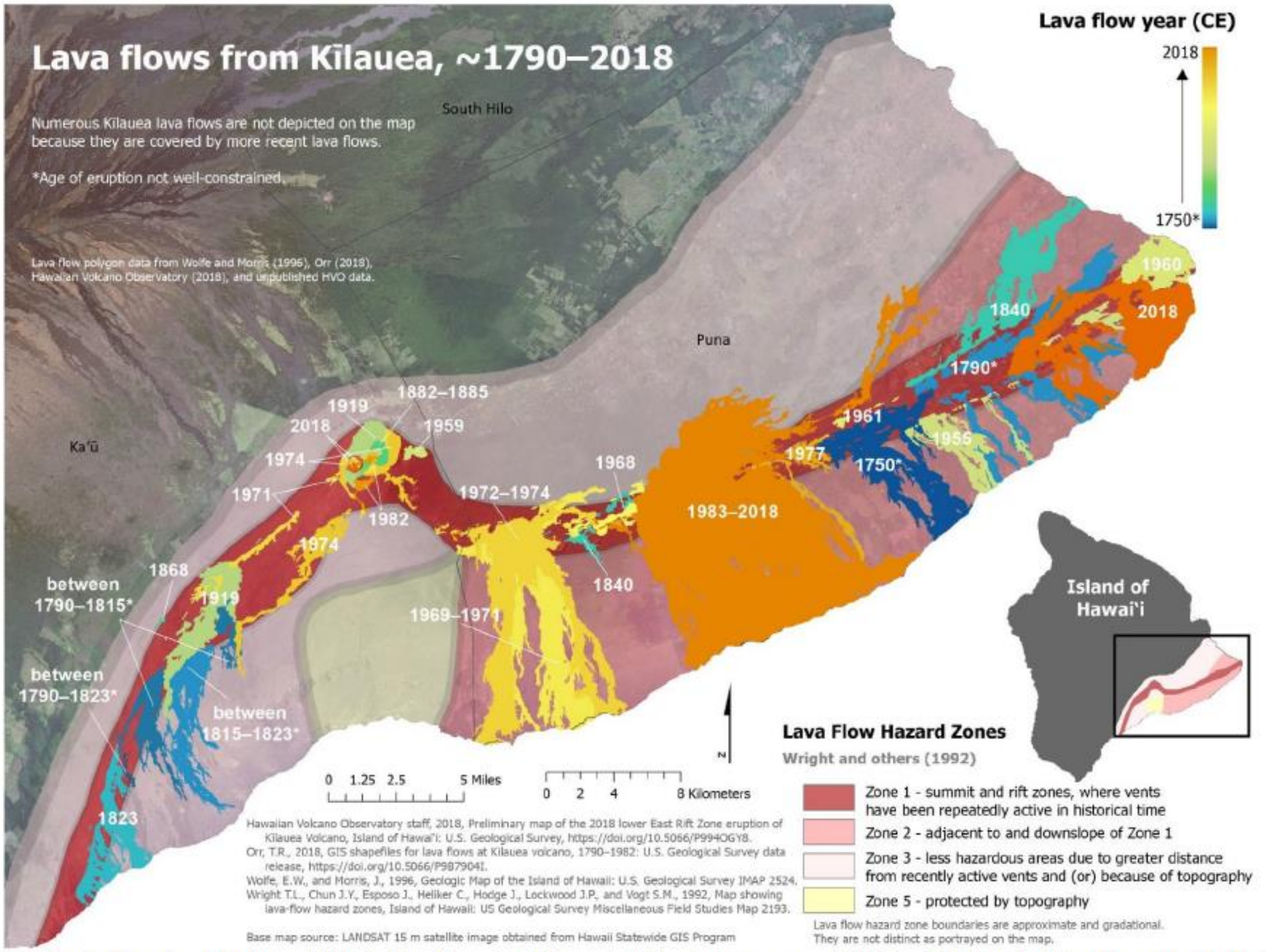


Figure 2-8. Measurements of Sulfur Dioxide post-2018 Kīlauea.
Graphic Courtesy: Vog Measurement and Prediction Project (VMAP), http://weather.hawaii.edu/vmap/index.cgi

2.2 Significant Historic Events and Impacts

This subsection summarizes the geology and historic volcanic events organized by volcano beginning in the 1700s. It is important to note this summary does not reflect the entire historic record of volcanic events that have taken place in the County. ***Figure 2-9a and 9b*** illustrate the geographical extent of historic lava flows (1790 to 2018) relative to the USGS lava-flow hazard zones for Kīlauea and Mauna Loa. These figures are new from USGS (June 2020) and were not available at the time the spatial analysis was conducted for this report. ***Figure 2-11*** summarizes a selection of major volcanic events. For additional information on volcanic events in Hawaiʻi, please refer to the USGS HVO website at: https://volcanoes.usgs.gov/observatories/hvo/hvo_volcanoes.html.



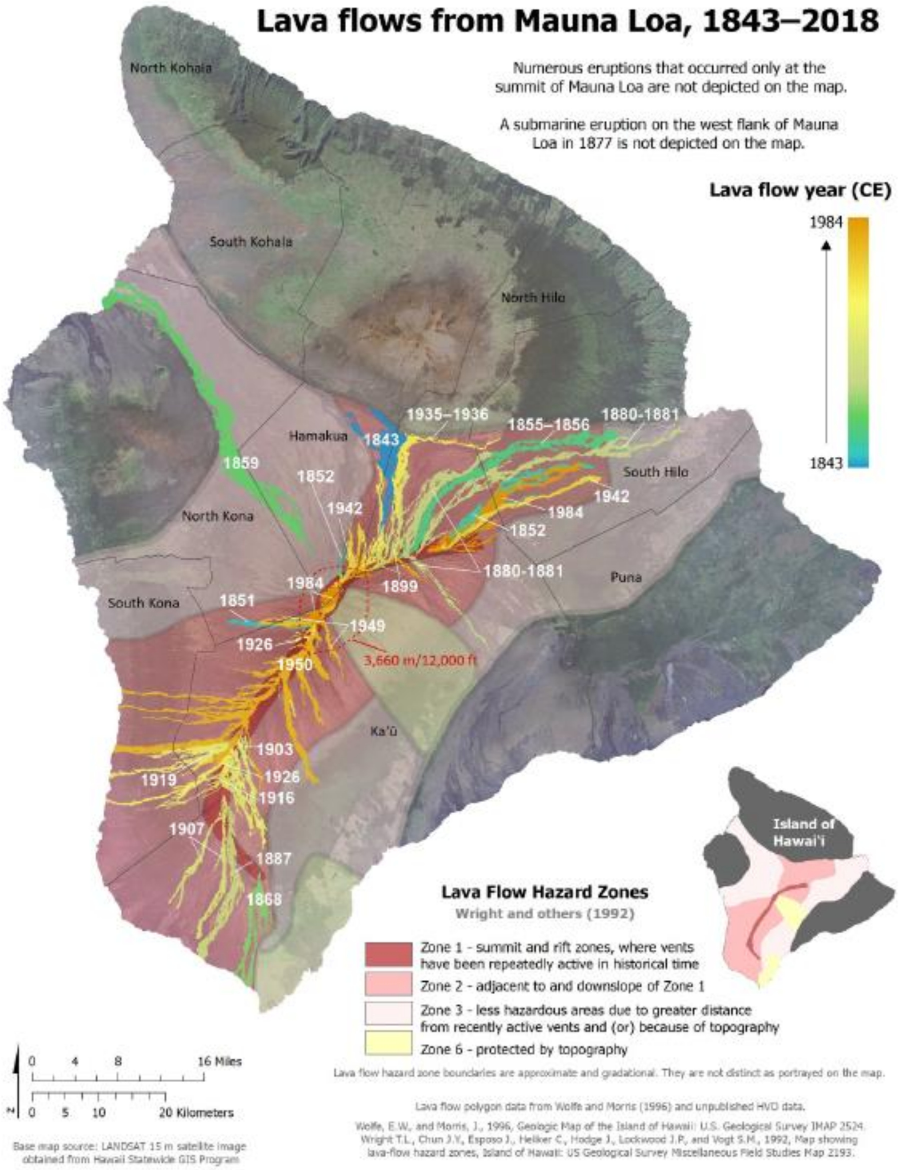
Map showing the subaerial extents of historical lava flows from Kīlauea. Lava flow hazard zones and districts of the County of Hawaiʻi are also depicted.

9

Version 1: June 4, 2020

Figure 2-9a. Historic Lava Flows from Kīlauea (~1790 to 2018)
Graphic Courtesy: USGS 2020

https://volcanoes.usgs.gov/vsc/file_mngr/file-243/HVO_website_Kil_historical_activity_table_20200604.pdf



Map showing the subaerial extents of historical lava flows from Mauna Loa. Lava flow hazard zones and districts of the County of Hawaiʻi are also depicted.

Figure 2-10b. Historic Lava Flows from Mauna Loa (1843 to 2018)
Graphic Courtesy: USGS 2020

https://volcanoes.usgs.gov/vsc/file_mngr/file-241/HVO_website_Mauna_Loa_historical_activity_table_20200604.pdf

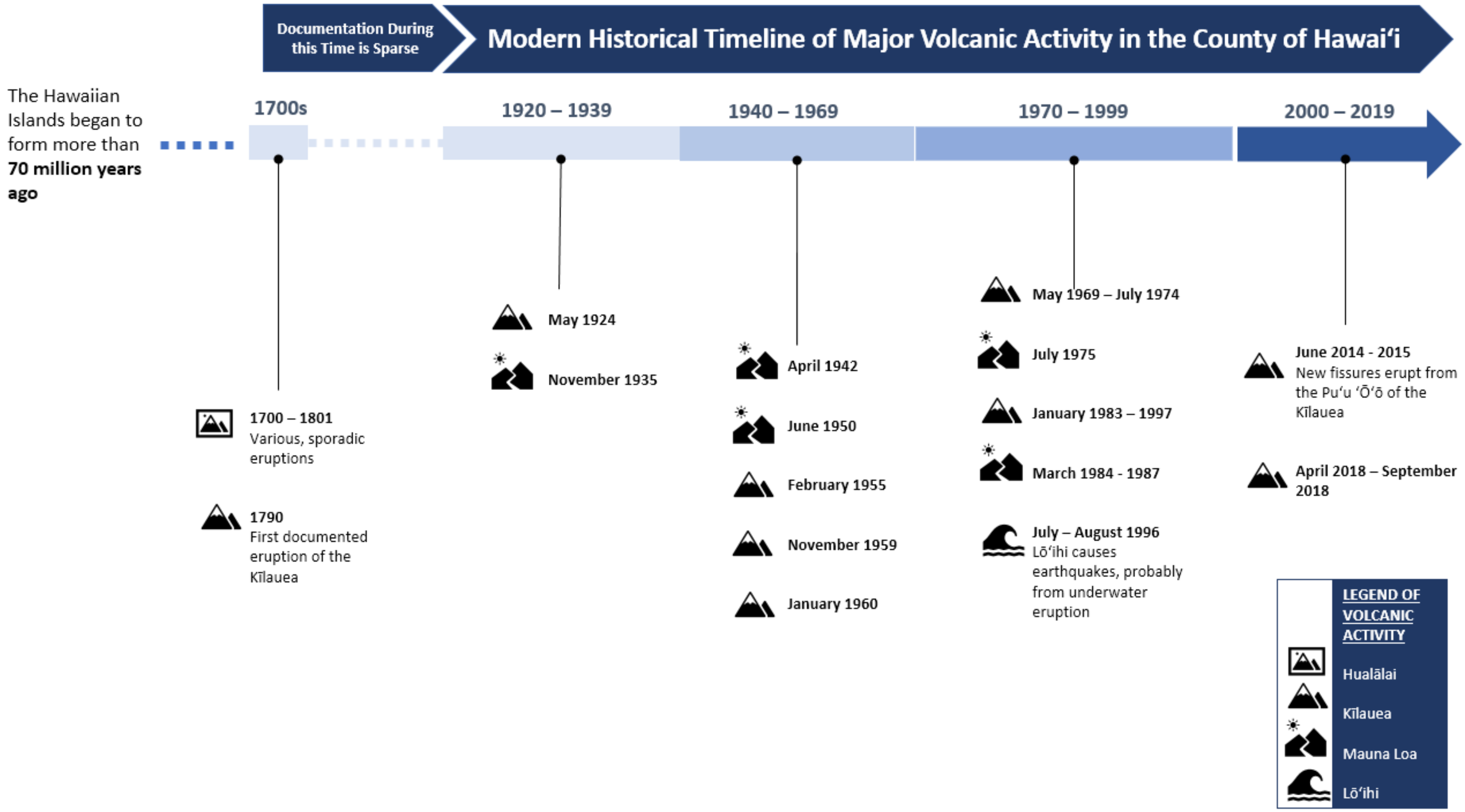


Figure 2-11. Historic Timeline of Volcanic Activity in the County of Hawaiʻi

*Note: This timeline represents a selection of major volcanic events between 1790-2018.

2.2.1 KĪLAUEA

Kīlauea is the youngest volcano on the Island of Hawaiʻi and is located on the southeast portion of the island (USGS 2019e). Present day, the Kīlauea shield volcano is considered the most active volcano in the world, having erupted 34 times since 1952 and almost continuously from 1983 to 2018 within the volcano's East Rift Zone. From 2008 to 2018 the Halemaʻumaʻu Crater, with its active lava pond and prolific gas plume, served as a major tourist attraction. In 2018, the decades-long continuous activity on the middle East Rift Zone subsided, and the summit lava lake drained following an intrusion into Kīlauea's Lower East Rift Zone that resulted in a 4-month eruption. The 2018 eruption represents Kīlauea's largest eruption in approximately 200 years, accompanied by the largest caldera collapse at the summit within the same time period (U.S. Geological Survey [USGS] 2019b).

Although this volcano is not currently erupting according to USGS HVO, monitoring data shows that there are steady rates of seismicity and ground deformation and low rates of sulfur dioxide emissions still ongoing (USGS 2019c). Therefore, hazards still exist on the LERZ eruption area and at the summit, which shows that impacts from eruptions can have a long-lasting impact on the community. A summary of select Kīlauea's historical eruptions is provided below.

PRE-1790

Geologist have determined that there is a lack of old exposed rock at Kīlauea, which makes it difficult to piece together its complete eruption history. Only about 10 percent of Kīlauea's surface consists of rock older than 1,000 years. The other 90 percent of the volcano's surface is covered by lava flows younger than 1,000 years, and about 20 percent of those flows are less than 200 years old (USGS 2019e).

Prior to 1790, research indicates significant explosive eruptions occurred repeatedly during a 300-year period between about 1500 and 1790, and also repeatedly between about 500 and 1000 Common Era. Explosive eruptions of Kīlauea between 1500 and 1790 included the occurrence of at least a dozen fast-moving, ground-hugging clouds of ash, rock, and volcanic gas. Such "pyroclastic surges" are among the most dangerous of all volcanic phenomena—speeding at hurricane velocities and having temperatures of several hundred degrees Celsius. Although explosive eruptions at Kīlauea are infrequent in human terms, they are not rare geologically (USGS 2019e)

1790

Cliff exposure of Explosive Deposits that Erupted Between 1500 and 1800. The 1790 Eruption Deposits are Less than 10 Percent of the Total Thickness from these deposits (top layer).
Photo Courtesy: USGS and Don Swanson.

Before the series of eruptions that happened in the 20th century, Kīlauea's summit collapsed, which formed a deep caldera (Swanson and USGS 2019). As a result, groundwater was able to interact with magma forming explosive, steam-driven eruptions. These eruptions added more than 11 meters of explosive deposits to the rim of the caldera. USGS presumes that at least four of the historical eruptions that dated more than 300 years ago entered the jet stream.

There are historical narratives that describe an eruption that occurred in 1790 that caused several deaths, but the exact number is unknown. To find out more about this event, field research was completed by the USGS and the University of Hawaiʻi at Mānoa to determine the extent of the impacts (Swanson and USGS 2019). The researchers conclude that there was a sequence of explosive deposits from the 1790 event and that there were at least three explosive surges. The researchers have also concluded that if an event occurred today of the same size as the 1790 event, the explosion would affect all of Puna and Kaʻū, and ash plumes could endanger flights to and from Hawaiʻi (Swanson and USGS 2019).

1924 HALEMAʻUMAʻU

In May 1924, Kīlauea's largest crater, Halemaʻumaʻu, was the site of more than 50 explosive events during a 2.5-week period (USGS 2018h). The lava lake within Halemaʻumaʻu drained in February and was followed by earthquake activity, cracking in the ground, faulting, coastal subsidence, and hundreds of felt earthquakes in the Lower East Rift Zone. The explosive events in May created clouds of rock particles, wet ash, and steam and doubled the diameter of the Halemaʻumaʻu. Ash plumes from the larger explosions reached as high as 5.5 miles. Rock fragments as heavy as 400 pounds were ejected from the rim of the crater. Wet ash from these events disrupted the rail line and destroyed rooftops. Large cracks occurred along the coastline and roadways. As a result, there was one fatality and many people evacuated the Puna district because of the destruction created by these volcanic hazards (USGS 2018h).

Explosive Eruption Column from Halema'uma'u Crater in May 1924.
Photo Courtesy: USGS,
https://volcanoes.usgs.gov/volcanoes/Kīlauea/geo_hist_1924_halemaumau.html.

1955 LOWER PUNA

In February 1955, the LERZ along Kīlauea erupted for the first time since 1840 (USGS 2018e). This eruption lasted for 88 days, opening 24 vents that stretched from Kapoho to west of the Pāhoa-Kalapana road (***Figure 2-12***). The lava flows from this event covered more than six miles of public roads. The flows cut off all access to lower Puna and required evacuation of most coastline residents. Several homes and thousands of acres of land were covered by lava (USGS 2018e).

Fountain of Lava Produced by the Iilewa Cone.
Photo Courtesy: USGS,
https://volcanoes.usgs.gov/volcanoes/Kīlauea/geo_hist_1955.html

Volcanic hazards caused by this event included earthquakes, lava flow, subsidence, and ash. At the summit of Kīlauea, earthquakes intensified as the caldera region began to subside, clouds of black ash were released from the explosions and lava continued to flow out of the vents in the LERZ into the surrounding areas. The Hawaiian Volcano Observatory scientists observed that this event had an irregular progression of activity. Typically, flank eruptions retreat up-rift as the magma supply wanes. However, the eruption opened new vents both up-rift and down-rift. Researchers also witnessed unusual magma types.

Characteristics of the lava indicated that the lava was stored near the source vents for a prolonged period of time and it contained more magnesium, suggesting the lava was more primitive (USGS 2018e).

This event marked the first eruption that occurred in any populous area in US territory. The lessons learned from this event led to improved procedures to ensure human safety (USGS 2018e).

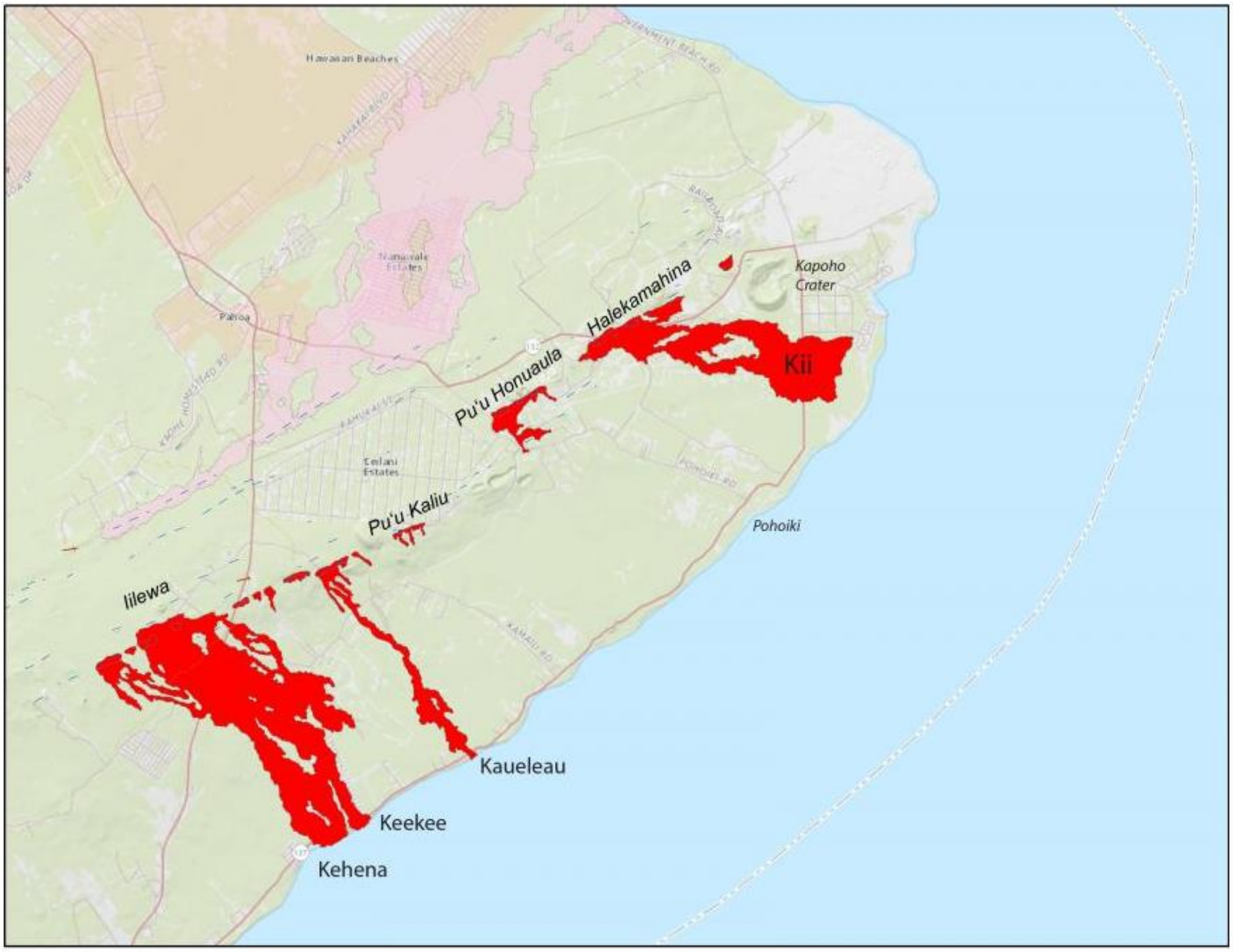


Figure 2-12. Lava Flows from the 1955 Kīlauea Eruption
Map Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/kilauea/geo_hist_1955.html

1959 KĪLAUEA IKI

A few years after the 1955 eruption, another eruption occurred from the Kīlauea Iki Crater in November 1959 (USGS 2018b). This event provided some of the first measurable data about the magma reservoir system at Kīlauea. Three months prior to the eruption, deep earthquakes were recorded about 35 miles below the volcano. As a result, the summit reservoir was beginning to fill with new magma. Several shallow earthquakes followed this fill, which caused magma to move even faster into the summit reservoir. Eventually, a fissure broke through Kīlauea Iki Crater, sending lava to the bottom of the crater where it started to pool forming a lava lake (USGS 2018b).

Lava Fountain Erupting from Iki Crater. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/kilauea/geo_hist_kilauea_iki.html

A single erupting vent contributed to the lava lake and channel, which widened significantly as flow persisted. Black tephra deposits created by Kīlauea Iki Crater built a cone adjacent to the lava fountain, now called Puʻu Puaʻi. During this event, large parts of the Puʻu Puaʻi cone slid into the lava lake, which today are topographic islands above the surface of the area where the lava lake cooled. Lava fountains reached 1,900 feet in height, which is the highest recorded height in the 20th century and damaged roads and guardrails. Variations in wind created a constantly changing pattern of the pumice plumes that were created by the lava fountains. These clouds of glowing lava fragments were typically blown back into the forest before falling to the ground (USGS 2018b).

After 16 episodes of fountaining, the lava lake started to drain back into the open vent. Large sections of the darkened lava lake crust were pulled apart as new lava drained back into the vent. The summit reservoir ultimately gained magma by the end of this event. Researchers found that the summit gained a net of 10 million cubic meters of magma (USGS 2018b).

1960 KAPOHO

Ground Fractures Through Kapoho Village Caused by Magma Moving Underground After the 1960 Eruption. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/Kīlauea/geo_hist_kapoho.html

The resulting gain of magma after the 1959 eruption at the summit was the cause for an eruption in January 1960 in the LERZ near Kapoho (USGS 2018c). The shallow reservoir beneath the summit of the Kīlauea volcano was overfilled with magma, which created more pressure and more earthquakes. More than 1,000 earthquakes were recorded north of Kapoho on January 12, 1960. The following day, the size and frequency of earthquakes increased drastically, severely cracking the ground along the Kapoho fault line through the town. The volcano erupted on January 13, 1960, destroying the villages of Koaʻe and Kapoho. Methane explosions occurred as lava flowed through vegetation. Dark steam clouds carrying high amounts of ash were released as lava interacted with the groundwater. Lava flows traveled 3.2 kilometers (km), reaching the ocean by January 15 and creating new land beyond the old shoreline by 100 meters (USGS 2018c).

After four days of erupting, the summit began to subside as magma left the storage reservoir and flowed down the East Rift Zone to the Kapoho area. The subsidence led to a series of earthquakes and the collapse of the Halemaʻumaʻu Crater. The subsidence also formed cracks in the lava lake cooling shell, which created a pathway for lava to pore into the crater's growing pit. By March, the final collapse of the crater occurred. The total volume of collapse was about 22 million cubic meters (USGS 2018c). ***Figure 2-13*** depicts the fallout deposits of tephra and ash and lava flow from the historical events from 1959 and 1960.

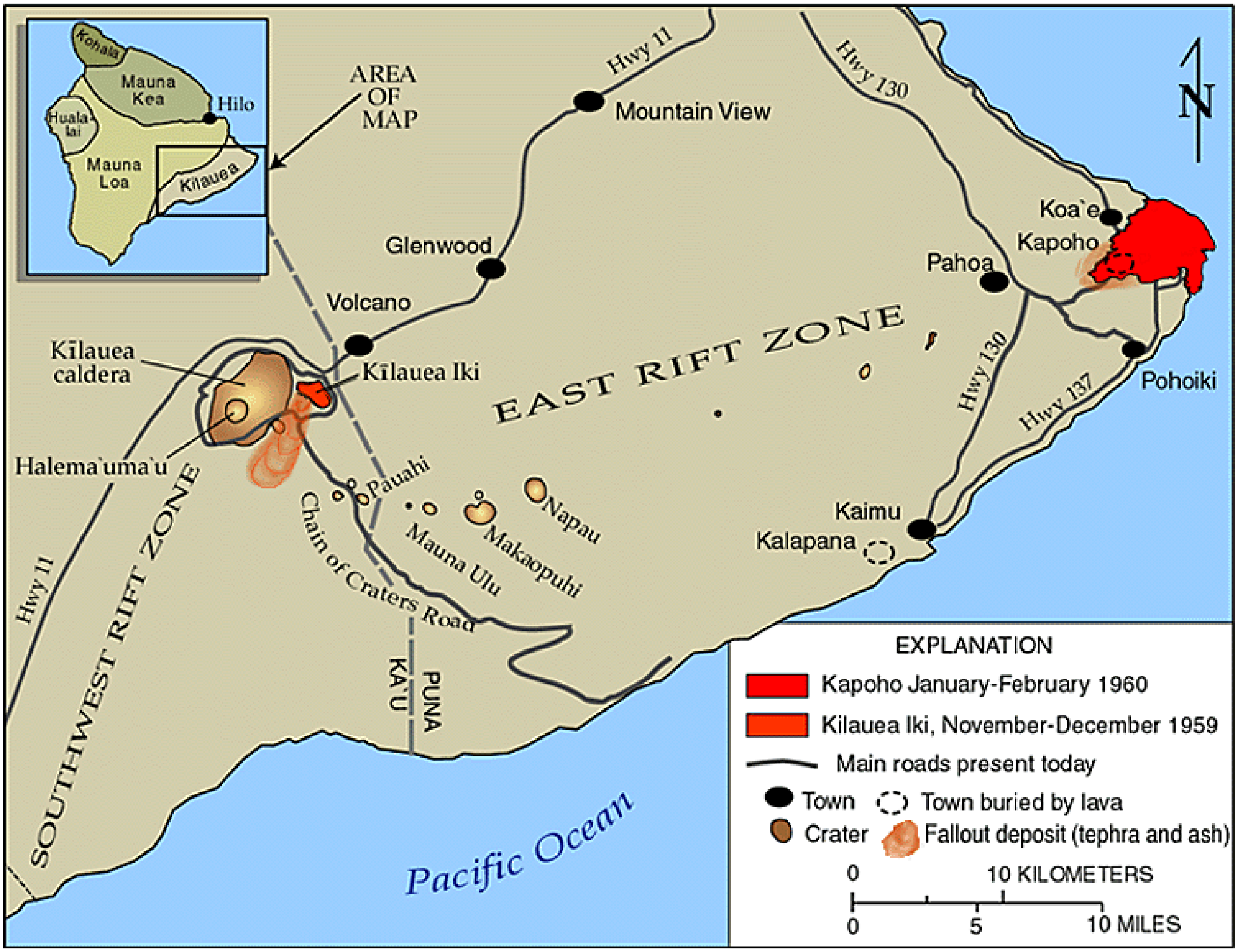


Figure 2-13. Kīlauea and Adjoining Mauna Loa Showing Relation of Kapoho in Lower Puna to the Summit Area where Kīlauea Iki and Halemaʻumaʻu are Located.
Map Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/kilauea/geo_hist_kapoho.html

1969 to 1974 Mauna Ulu

The Mauna Ulu eruption occurred from May 1969 to July 1974 and was labeled at the time as the longest-lasting and most voluminous eruption on Kīlauea's flank in at least 2,200 years (USGS 2017b). The eruption continued over 1,700 days and produced 350 million cubic meters of lava. About nine months prior to the eruption, increased seismic activity and short-lived eruptions broke out along the East Rift Zone of the volcano. The main eruption started along a long fissure system but moved to where the Mauna Ulu was built between two pit craters, ʻĀloʻi Crater and ʻAlae Crater. This area was recently covered by lava flows and vents releasing hot volcanic gas, which created the ideal conditions for lava fountains to occur (USGS 2017b).

Lava Flowing from the Summit Crater of Mauna Ulu Eastward into a Pool at the West End of the Trench in February 1972. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/kilauea/geo_hist_mauna_ulu.html

Eleven fountaining events took place from the site of Mauna Ulu, reaching heights exceeding 1,700 feet (USGS 2017b). The fallout from these fountains formed a tephra mound south of the vent. Lava flows spilled into the ocean and flowed into the ʻAlae Crater, covering fallout deposits from the fountains. By August 1969, the ʻAlae Crater was nearly full, and cracks suddenly opened releasing lava flows far down the rift zone. The Mauna Ulu continued to release lava into the ʻAlae Crater, which created the lava shield that eventually matured into the Mauna Ulu edifice seen today (USGS 2017b).

The edifice continued to grow throughout the years of the eruption. Eventually, the walls of the summit fissure began to collapse, which gradually widened into a crater that contains a lava lake. Lava flows from the lake moved underground and fed a fissure on the east flank of the Mauna Ulu. By June 1971, the activity ended until Kīlauea's summit inflated from pressurization. By February 1972, lava began to enter the summit crater of Mauna Ulu and spilled from the crater into a trench entering a lava tube of the ʻAlae Crater. Lava flows continued to flow along the land and frequently entered the sea (***Figure 2-14***). This lava opened new fissures uprift within the Hiʻiaka and Pauahi Craters (USGS 2017b).

From December 1973 to July 1974, the remaining eruptive activity came from the Mauna Ulu. The shield of the Mauna Ulu continued to grow, and the lava lake became increasingly stagnant, ending the long-running eruption (USGS 2017b).

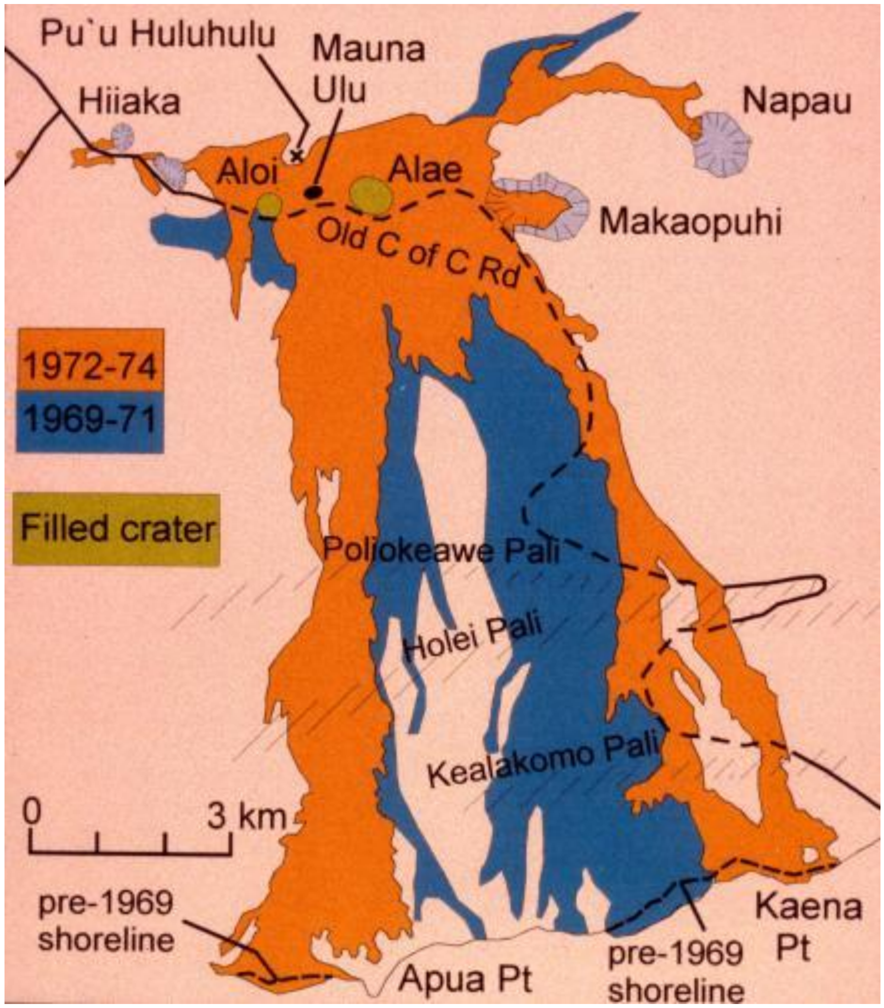
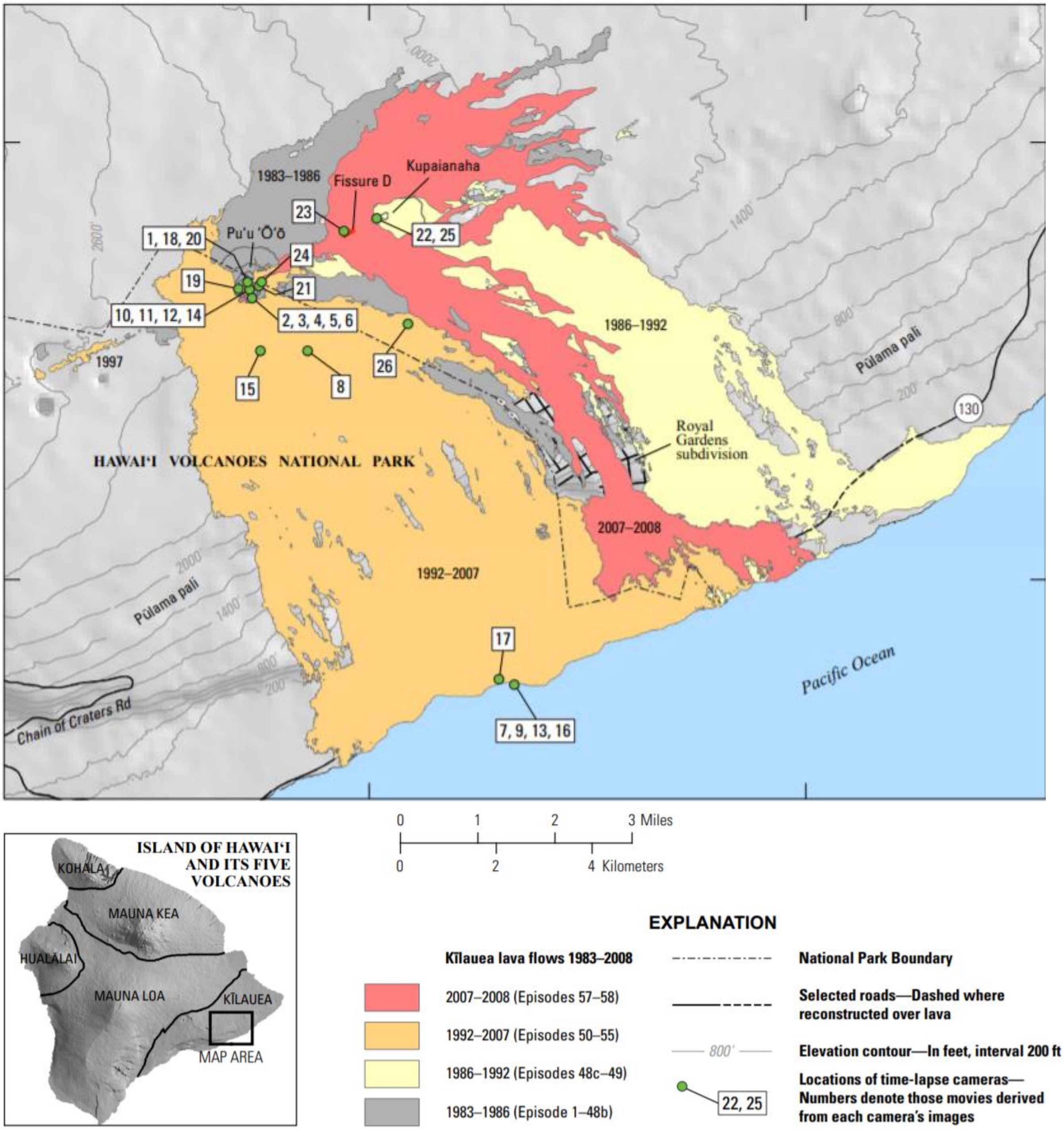


Figure 2-14. Lava Flows of the Mauna Ulu Eruption.
Map Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/kilauea/geo_hist_mauna_ulu.html

1983 TO 2018 PUʻU ʻŌʻŌ

The Puʻu ʻŌʻō eruption began in 1983 and to this day ranks as the longest period of lava flow that came from the Kīlauea's East Rift Zone (35 years) in the last 200 years (USGS 2019g). The lava flows from this eruption have drastically changed the landscape and caused many issues for County residents. This eruption was divided into 61 separate episodes of activity. The first set starts with the eruption that happened in January 1983 as the first set of fissures broke out along the East Rift Zone. By June 1983, the eruption occurred out of one vent. Throughout the next three years, more than 40 separate lava fountaining episodes formed Puʻu ʻŌʻō and some of the surrounding lava flow fields. By the late 80s, activity localized at Kupianaha (USGS 2019g). ***Figure 2-15*** illustrates the extent of lava flow from 1983 to 2008.



Source: Orr 2011.

Figure 2-15. 1983 to 2008 Puʻu ʻŌʻō Lava Inundation Extent

The Puʻu ʻŌʻō is described by USGS to be a cinder-and-spatter cone (USGS 2019g). The lava flows that helped to create this structure impacted the surrounding communities, destroying several homes. As the eruption continued, activity shifted northeast along the Kīlauea's East Rift Zone. The high lava fountains started to wane but led to the start of nearly continuous lava flows from a new vent. As a result, a lava pond started to form over the vent, which built a new shield called the Kupaianaha (USGS 2019g).

View of the Puʻu ʻŌʻō West Flank in 1992 with Shield Growing at Base of the Cone (top photo), and View of the Puʻu ʻŌʻō West Flank in 1997 After Collapse of the Crater (bottom photo). Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/kilauea/geo_hist_1983.html

The eruption took a turn in 1990 when breakouts from a lava tube progressively entered the Kalapana community. This area was completely buried beneath lava by the end of the year. Concurrently, the volume of lava that erupted from Kupaianaha started to decline through 1991 as the Puʻu ʻŌʻō Crater increased (USGS 2019g). Once activity at Kupaianaha stopped, lava started to erupt from fissures in the west flank of Puʻu ʻŌʻō. These flank vents continued to build a broad shield on the southwest side of the cone. Lava flows that were sent to the ocean built a series of lava deltas on Kīlauea's southeast coast, which added about 418 acres of new land to the County (USGS 2019g).

By January 1997, the Puʻu ʻŌʻō cone experienced many collapses, enlarging its crater. The largest collapse occurred when a magma conduit between the summit and Puʻu ʻŌʻō ruptured, cutting off the supply of magma to the eruption (USGS 2019g). As a result, the lava lake in Puʻu ʻŌʻō drained, and the crater floor dropped about 500 feet, creating a large gap on the west side of the cone. Following this gap, new fissures broke open and erupted briefly in and near Nāpau Crater, which lasted over in 24 hours. The next month, the Puʻu ʻŌʻō Crater experienced more lava eruptions from new vents outside its crater on the flanks of its cone. This led to various lava events ranging from several months to several years that occurred from Puʻu ʻŌʻō over the next 10 years (USGS 2019g).

The Puʻu ʻŌʻō continued activity after new fissures erupted on its east flank in June 2014 (USGS 2019g). Those fissures led to the shutdown of the Kahaualeʻa flows and the start of a new lava flow that rapidly advanced to the east. This was spurred by new erupted fissures on the east flank of Puʻu ʻŌʻō. The flow rapidly advanced to the east, toward Pāhoa between July and late October 2014, nearly reaching Highway 130. Highway 130 is the only transit route for nearly 10,000 people who live in the lower Puna District. By mid-December 2014, the flow threatened the Pāhoa

Marketplace but ultimately stagnated. Ultimately, the lava flow halted and cooled just prior to reaching Pāhoa Village Road (USGS 2019g). ***Figure 2-16*** displays the Puʻu ʻŌʻō lava flow from 2014 to 2015.

On May 24, 2016, a new breakout from the east flank of Puʻu ʻŌʻō formed a new flow to the south. The flow reached the base of the Pulama pali by the end of June and entered the sea at Kamokuna on July 26, 2016. On April 30, 2018, the crater floor and lava lake of Puʻu ʻŌʻō catastrophically collapsed, marking the end to the eruption of Puʻu ʻŌʻō.

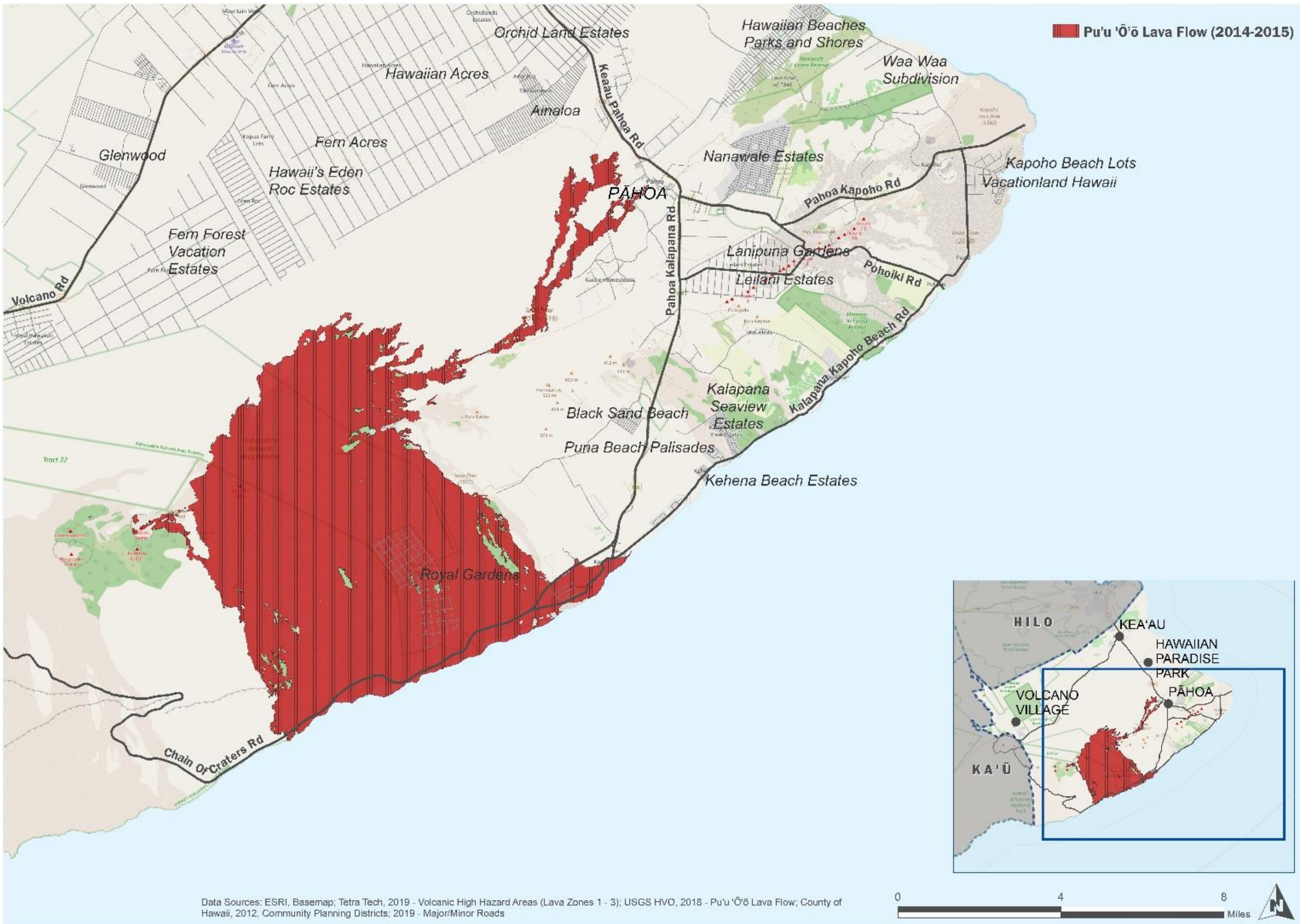


Figure 2-16. Puʻu ʻŌʻō 2014 to 2015 Lava Flow Inundation Extent

2018 Kīlauea – Lower East Rift Zone

On April 30, 2018, a series of earthquakes occurred when the Puʻu ʻŌʻō crater on the east flank of Kīlauea collapsed, and magma moved toward the Lower East Rift Zone. Numerous ground cracks were reported in and around Leilani Estates. On May 3, lava broke through the surface in Leilani Estates, with records indicating a lava fountain spewing from the initial fissure on Mohala Street. As a result, Hawaiʻi County Civil Defense issued evacuation ordersfor the Leilani Estates and Lanipuna Gardens subdivisions. The island experienced its most significant earthquake since 1975 when a 6.9-magnitude earthquake occurred May 4 on Kīlauea's south flank. On May 9, USGS HVO notified the public of potential explosions at the summit of Kīlauea. A Presidential Disaster Declaration (FEMA 4366-DR-HI – Kīlauea Volcanic Eruption and Earthquakes) was issued on May 11.

A Presidential Disaster Declaration (FEMA 4366-DR-HI – Kīlauea Volcanic Eruption and Earthquakes) was issued on May 11, 2018. The lava flow covered 8,448 acres of land and permanently altered the landscape (***Figure 2-17***). The alert level was then reduced from a WARNING to a WATCH on August 17, 2018, allowing officials, residents, and responders to make the transition from response to recovery. There have been no active lava flows since August 2018, though lava was seen in Fissure 8 in Leilani Estates on September 5, 2018. HVO reduced Kīlauea's alert level to ADVISORY on September 5, 2018, after 30 days passed without seeing lava on the surface. The Puna District suffered significant losses especially from lava inundation. Entire neighborhoods, such as Kapoho Vacationland, Kapoho Beach Lots, and Lanipuna Gardens; schools, such as Kua O Ka Lā; and beach parks, such as Ahalanui Warm Ponds; were covered with lava. In addition to lava flows, earthquakes and air pollutants including sulfur dioxide, ash, tephra, and laze, affected not only the residents of Puna but across the island and state.

2018 Kīlauea Impact Facts

- 100+ days of constant eruption and lava flow
- Erupted the equivalent of 8 years of Kīlauea's magma supply in just over 3 months
- Largest summit caldera collapse in 200 years
- Highest SO_2 emission rates ever measured at Kīlauea (>50,000 tons/day)
- 60,000+ earthquakes ranging from 0.5 to 6.9 magnitude
- 13.7 square miles inundated with lava
- 875 acres new land created along shoreline
- 723 structures destroyed, including approximately 293 primary residences
- 3,000 residents displaced
- 116 structures isolated* (prior to road restoration)
- 1,770 parcels impacted

The sheer volume of the magma supply was one of the most significant distinguishing characteristics of the 2018 Kīlauea event (***Figure 2-18***). Simultaneously, Kīlauea's summit experienced its largest collapse in 200 years, with a total of 500 meters (1,640 feet) subsidence and tens of earthquakes each day rattling surrounding communities. Dozens of new fissures opened along a line of craters in the Puna District. Many of these cracks leaked lava into residential areas. Volcanic gases and ash created a cloud of vog that reached the Island of Oʻahu. The simultaneous related events impacted residential, agricultural, business, tourist, cultural, and scientific areas. Hawaiʻi Volcanoes National Park closed, slowing tourism and the local economy. A major power outage of the County's connection to the Hawaiian Electric Light Company (HELCO) occurred, and several roads and critical facilities were inundated or isolated by lava causing multiple road blocks in the County (***Figure 2-19***). The inundation of major roadways was of particular concern because most roads servicing Puna District subdivisions are privately owned and not designed for through traffic. Lava inundated more than 30 miles of roadways in the Puna District.

Infrastructure Impact Facts: 2018 Kīlauea

- 32.3 miles public and private roads inundated
  - 12.44 miles County maintained roads
  - 19.86 miles privately maintained roads
- 14.5 miles waterlines destroyed
- 900 utility poles destroyed
- 2 geothermal wells inundated, 1 isolated
- 1 electrical substation isolated
- 1 water well isolated
- 1 public charter school inundated
- Estimated $236.5 million in damages to roads, waterlines and facilities (e.g. parks)
- Closure of Puna geothermal plant, which supplies 22% of the island's power

The eruption lasted 107 days, one of the longest eruptions in recent history in lower Puna. Within a few months of the start of the 2018 eruption; HVO reported a total of 24 known fissures, 60,000 earthquakes and an eruption equivalent to 8 years of Kīlauea's magma supply. Throughout the eruption, uncertainty regarding the duration of the event, its extent, and total damage remained high. This uncertainty led to social tensions and fatigue across the affected community, responders, and local officials. Although there were no fatalities, the event was quite destructive in terms of displacement of residents, structure destruction, land coverage, and cultural and environmental resources impact.

Natural and Cultural Resources Impact Facts: 2018 Kīlauea

- 500 acres forest reserves inundated
- 17 Exceptional trees inundated
- 80 Anchialine pools inundated
- Pohoiki Boat Ramp isolated
- Pohoiki Bay filled
- Ka Lua Wai a Pele (Green Lake) inundated
- Kapoho Bay inundated
- Waiʻōpae Tidepools Marine Life Conservation District inundated
- Ahalanui Beach Park inundated

The vast majority of destroyed, isolated, or forced vacant homes by mandatory evacuation were owner-occupied homes. It is estimated that there were 800 domesticated animals present in the affected area before the eruption. These animals included dogs and cats, exotic pets, and livestock. Due to lack of sheltering options, animals escaping, and abandonment due to rapid evacuation, many of these animals were not evacuated.

Economic Impact Facts: 2018 Kīlauea

- Small businesses experienced decreased revenues and closures
- Decreased tourism revenue and adjustments to marketing and products
- $296 million reduction in tax rolls (property loss)
- 2,950 jobs lost
- $415 million revenue lost county-wide
- $236 million infrastructure loss
- $296 million home loss
- $99.4 million loss following Hawaiʻi Volcanoes National Park closure
- $27.9 million agriculture loss resulting in decreased agriculture and floriculture production

Puna experienced its most significant earthquake on May 4, 2018, during the recent Kīlauea event, when a temblor measuring 6.9 on the Richter Scale occurred. It was the largest earthquake to impact the County of Hawaiʻi and the Puna District since the 1975 earthquake. The epicenter was located just offshore, nearby the Royal Gardens subdivision. As expected, the shaking was the most severe in the Royal Gardens subdivision area (according to the Modified Mercalli Intensity Scale) with the "moderate-very strong" shaking footprint extending throughout much of Puna's Tier 1 region with the exception of the southeastern tip, containing Kapoho Vacationland and Kapoho Beach Lots. This southeastern tip experienced "light-strong" shaking. The eastern edge, the District's most densely built-up area with the highest concentration of structures built prior to 1985's adoption of the seismic code, experienced moderate levels of shaking intensity ranging from "light-strong" to "very light-moderate" (***Figure 2-20***).

Parcels were inundated and isolated by lava (***Figure 2-21)***.

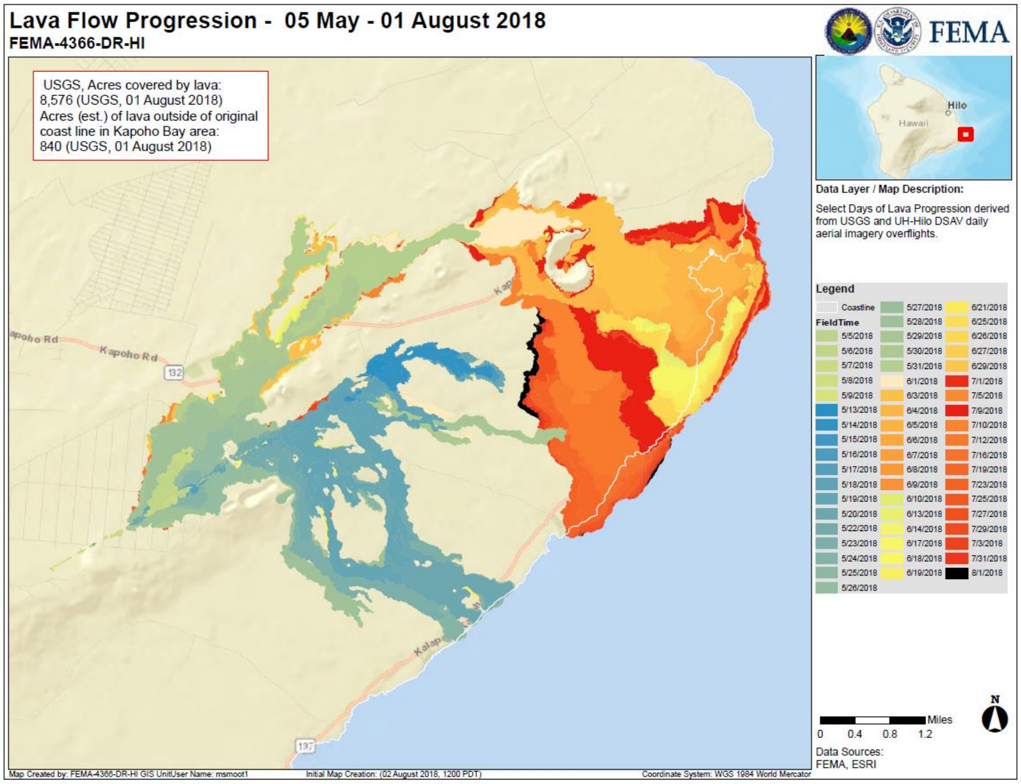


Figure 2-17. Lava Flow Progression from the Kīlauea Eruption from May 5 to August 1, 2018

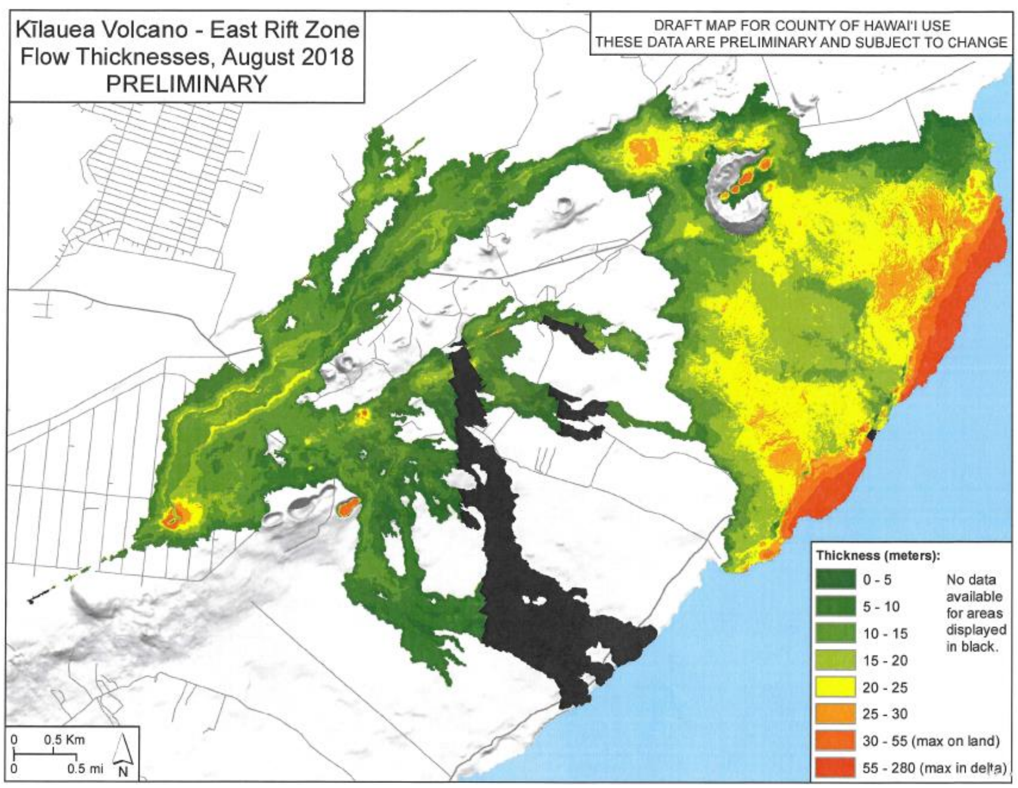


Figure 2-18. East Rift Zone Lava Flow Thickness from the 2018 Kīlauea Eruption

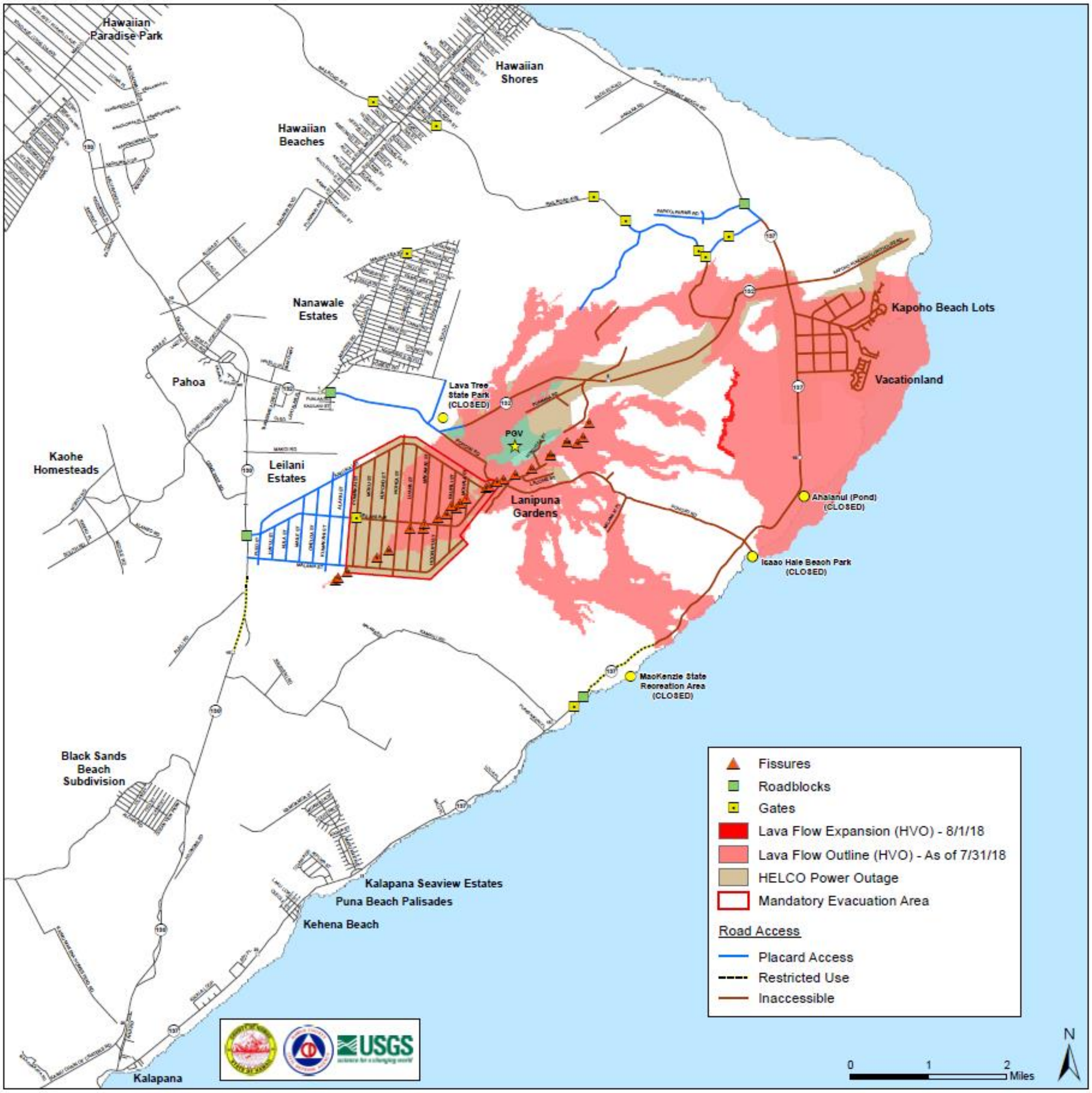


Figure 2-19. Roadblocks and Gates Established for Controlling Road Access During the 2018 Kīlauea Event

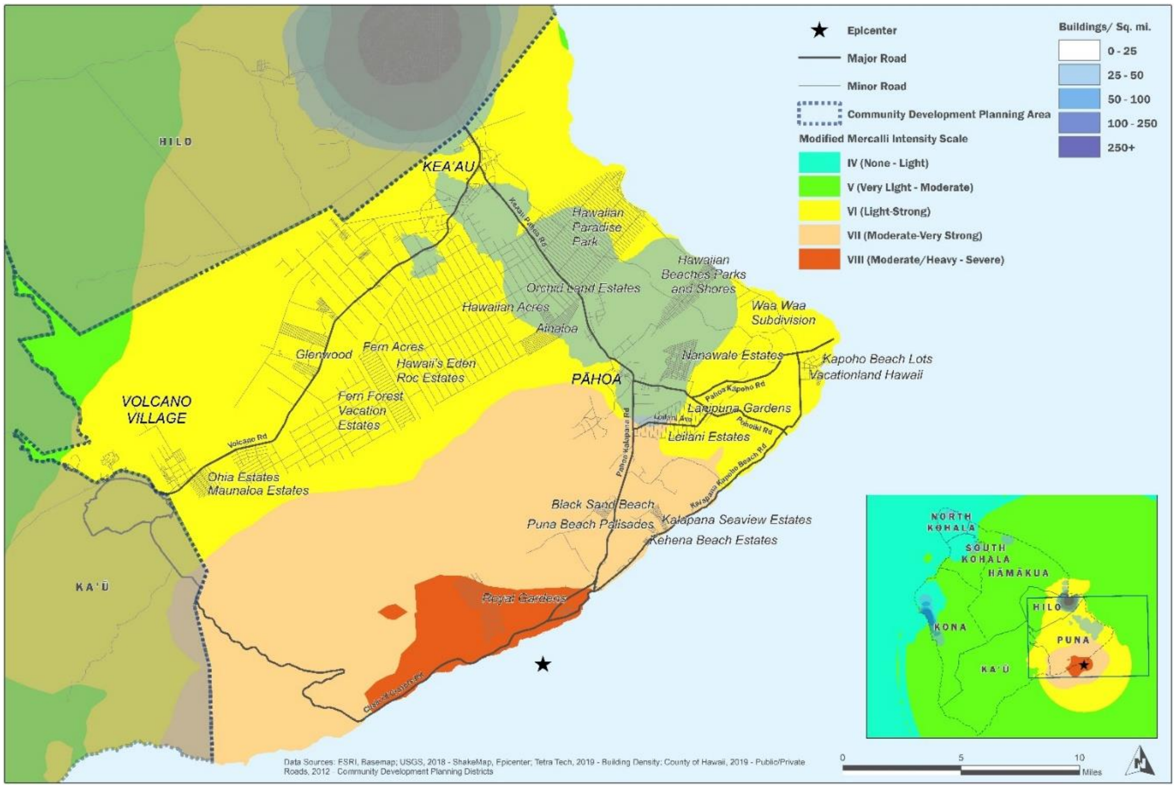


Figure 2-20. Map of May 4, 2018 Earthquake Event and Density of Pre-1985 Structures

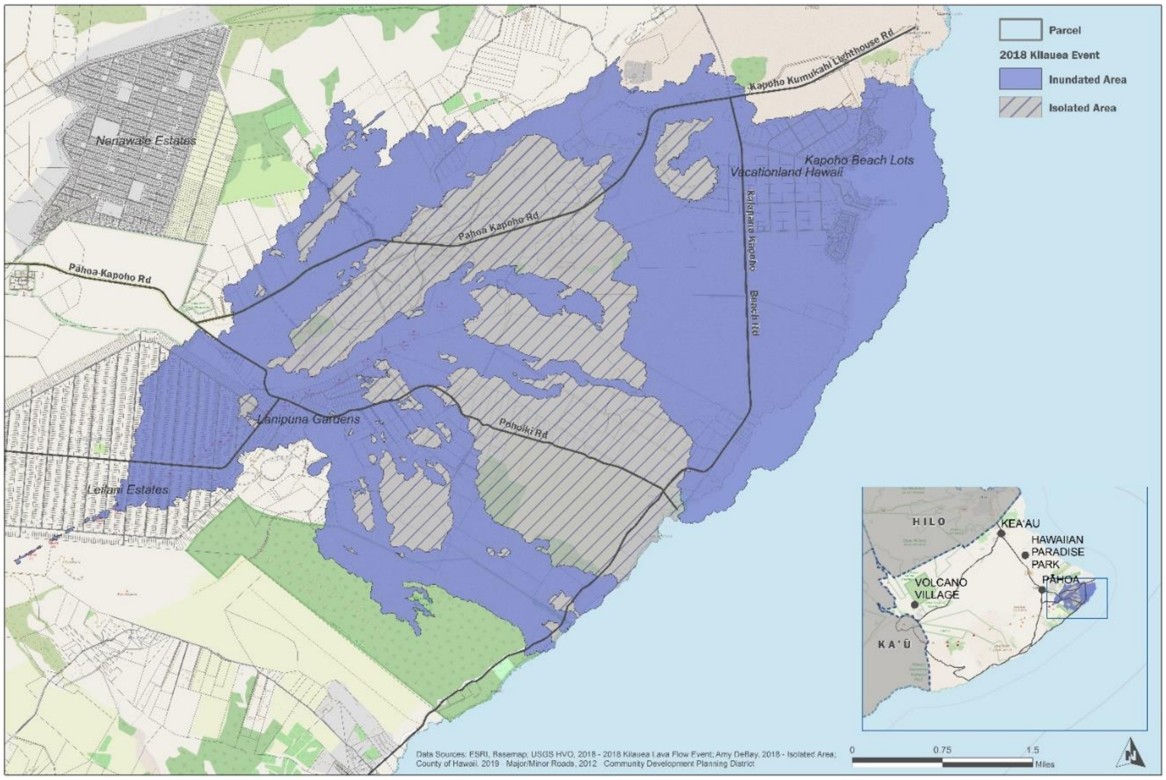
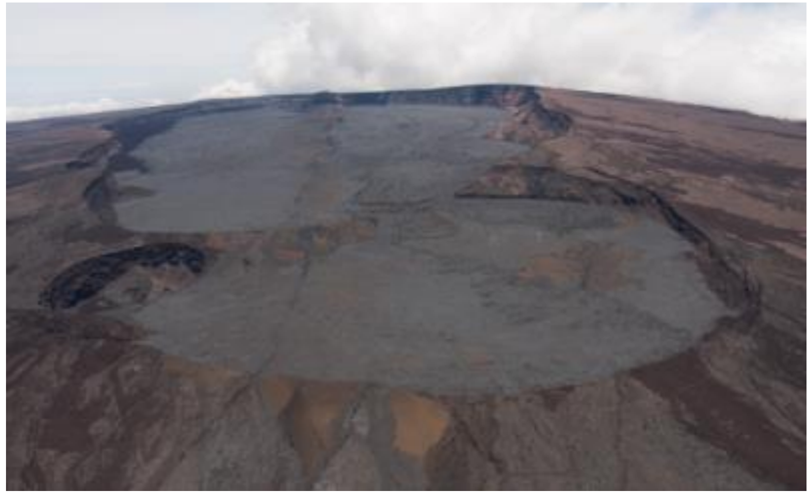


Figure 2-21. Inundated and Isolated Areas from the 2018 Kīlauea Event

2.2.2 MAUNA LOA



Mauna Loa's Summit Contains the Mokuʻāweoweo Caldera Plus Several Pit Craters. This Caldera Formed About 1,000 Years Ago. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_loa/geo_hist_summary.html

Mauna Loa is the largest active volcano on Earth (USGS 2017e); although recently, Pūhāhonu, in the northwest Hawaiian ridge was named the largest volcano using new mapping techniques and calculations (Garcia, Tree, Wessel, & Smith 2020). Mauna Loa's aboveground surface area covers over half the County with a surface area of about 1,900 square miles. This volcano is still in the shield-building stage and is currently in the process of adding as much as 95 percent of its ultimate volume. Scientists have determined that this volcano emerged above sea level about 300,000 years ago and has been growing rapidly upward since then (USGS 2017e).

There are five broad areas on the volcano and across the volcanos surface, 33 radial vents have been observed on the north and west sectors of the volcano (USGS 2017e). This volcano also includes submarine flanks, which have been mantled by landslide deposits. One of these deposits may have produced a giant tsunami about 105,000 years ago. A steep-sided rift zone of the Mauna Loa's southeastern flank, called the Nīnole Hills, has experienced erosion that created deep canyons and valleys where old flows occurred. These hills are an example of how rifts can migrate due to years of erosion and form new features to the volcanic system (USGS 2017e).

Mauna Loa is not known to have produced an explosive eruption since 1843 (USGS 2017e). However, evidence from four debris fans made up of fragmented rock deposits indicate that an explosive eruption is possible. A summary of significant historical eruptions documented by USGS are highlighted in the remaining parts of this section.

1935

Mauna Loa erupted in November 1935. Pāhoehoe lava (smooth, billowy, or ropey) flows traveled one mile east per day toward the residents of Hilo after flowing through the saddle area between Mauna Loa and Mauna Kea (USGS 2016a). The eruptive vent was bombed in December 1935 and flow stopped in early January 1936.

Aerial View by the Naval Air Service of the 1933 Mauna Loa Eruption from a Fissure Across the Rim and Floor of Mokuʻāweoweo Crater at the Volcano's Summit. Photo courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_loa/geo_hist_1935.html.

1942

The April 1942 eruption of Mauna Loa took place while World War II nighttime blackouts were being issued in Hawaiʻi (USGS 2017a). The eruption was kept hidden from the public so that Japanese military would not find out and use the glow of the lava at night to guide warplanes to Hawaiʻi. The eruption began on the western rim of Mauna Loa and migrated down the Northeast Rift Zone. The eruption ended in May and by then had already reached within 7 miles of the upper Waiākea Uka area of Hilo (USGS 2017a).

Aerial Photograph of the 1942 Mauna Loa Lava Flow Spreading Downslope Toward Hilo. Smoke from Burning Trees in Center of Flow and Scattered Cinder Cones at the Summit of Mauna Kea are Visible. Photo courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_loa/geo_hist_1942.html.

1950

Prior to the eruption in 1950, magma pressure in the volcano remained high following an eruption from the summit of Mauna Loa that took place in 1949 (USGS 2018a). Earthquake swarms occurred throughout 1949, and a large 6.4-magnitude earthquake was felt in May 1950. As a result, in June 1950, a fissure erupted on Mauna Loa's Southwest Rift Zone and led to multiple parallel fissures opening along the rift zone (USGS 2018a). Within three hours, the lava flows crossed the main highway on the west coast of the County. Several structures were destroyed and completely inundated by the lava including the structures in the coastal village of Hoʻokena-mauka. The lava flows passed through commercial and residential areas, over highways, through the forests, and continued to flow down into the ocean creating clouds of steam. This eruption lasted for 23 days and erupted 376 million cubic meters of lava. This is equivalent to about 3.5 to 4 years of output from the Puʻu ʻŌʻō eruption of Kīlauea (USGS 2018a).

Kaʻapuna Lava Flows Entering the Ocean during the 1950 Mauna Loa Eruption. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_loa/geo_hist_1950.html

1975

Mauna Loa experienced a short-lived eruption in July 1975 (USGS 2017c). Lava fountains erupted from fissures extending across the length of Mauna Loa's summit caldera, Mokuʻāweoweo, and into the upper ends of the volcano's Northeast and Southwest Rift Zones. Six hours of activity lasted in the caldera. Lava fountaining continued along the Northeast Rift Zone for less than a day before completely ending.

Image from the 1975 Mauna Loa Eruption. Lava Fountains up to 65 Feet High Erupted from Fissures on the North Flank of the Volcano.
Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_loa/geo_hist_1975.html

1984

Mauna Loa erupted in 1984 following a three-year period of increasing earthquake activity beneath the volcano (USGS 2016c). Prior to the eruption, the earthquakes reached a maximum frequency after a 6.6-magnitude earthquake occurred beneath the southeast flank of Mauna Loa. The volcano started to inflate shortly after a brief summit eruption in July 1975. The eruption began in March 1984 after eruptive fissures appeared rapidly down to the southwest rift zone across the southern half of Mokuʻāweoweo. New fissures began to form as magma moved down the Northeast Rift Zone. Eventually, four parallel flows moved down the northeast flank and all eruptive activity became confined to these vents (***Figure 2-22***) (USGS 2016c).

Lava flows started to move from these vents toward the community of Hilo (USGS 2016c). Smoke from burning vegetation, loud explosions from methane gas along the flow front, and levee breaching were a few of the disturbances caused by this eruption. Fortunately, the lava never reached the community. Researchers conclude that this event shows that dense vegetation, gentle slopes, and low temperature of erupted lava can slow down the flow of lava, which is valuable insight to mitigate the risk of future eruptions (USGS 2016c).

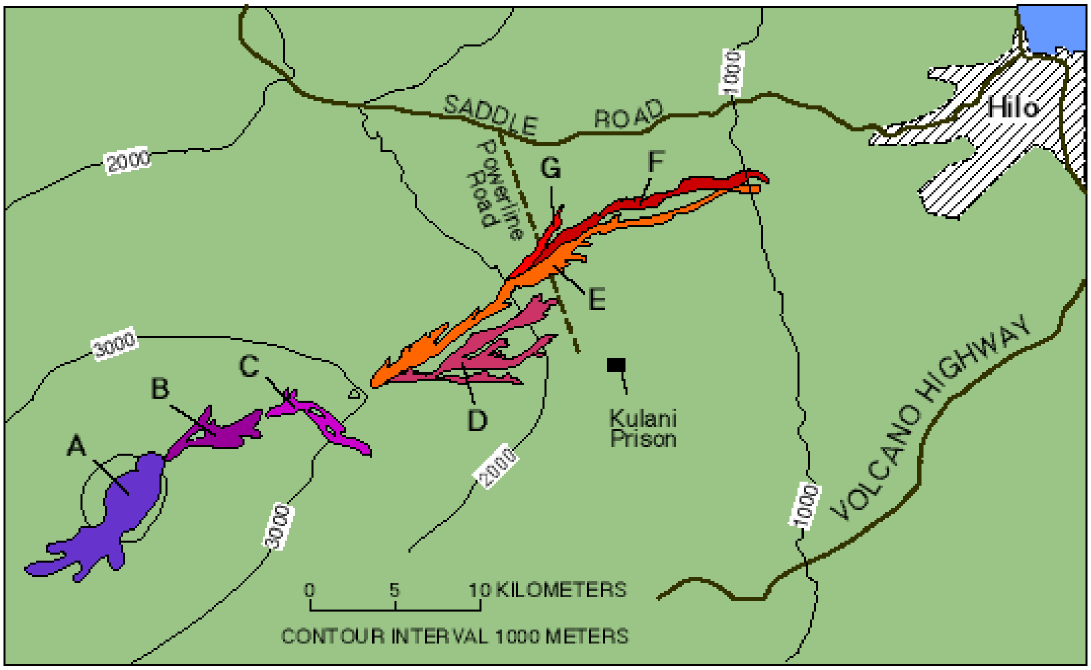
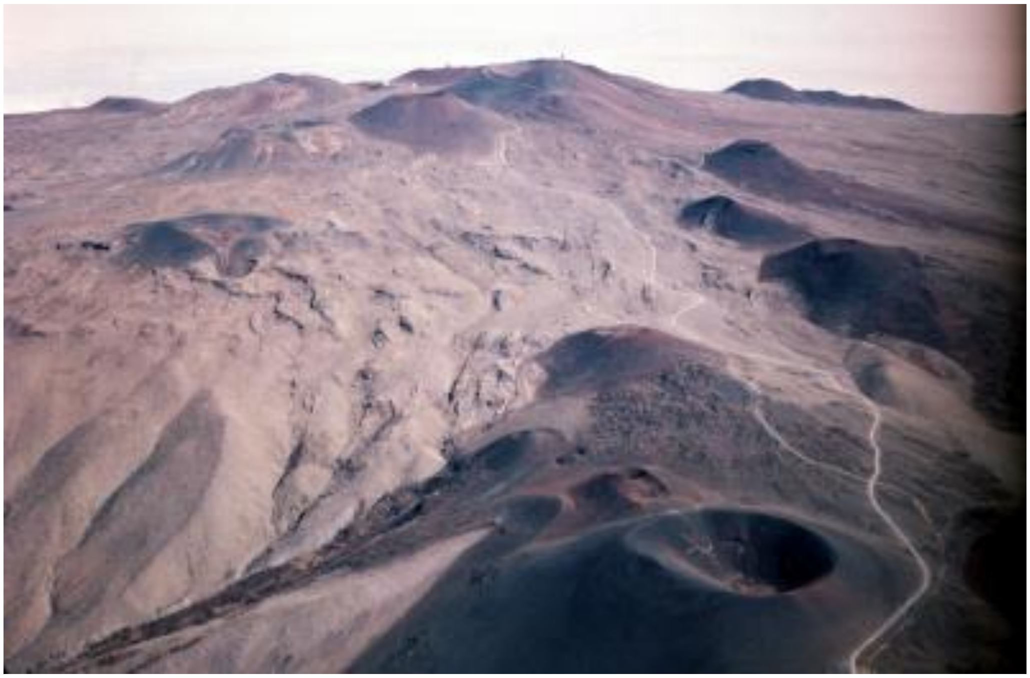


Figure 2-22. Areas Covered by Lava Flows During the 1984 Eruption of the Mauna Loa
Flow A represents eruptive fissures down southwest rift zone across southern half of Moku'āweoweo. Flow B represents lava flows extending across northeast half of Mokuʻāweoweo and into upper reaches of northeast rift zone. Flow C represents new lava fissures in the morning of March 25. Flow D represents four parallel flows moving down northeast flank in the evening of March 25. Flow E represents lava vents moving down Hilo in the morning on March 26. Flow F represents new subparallel flows that formed on March 29. Flow G represents lava flows that broke out on April 5. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_loa/geo_hist_1984.html

2.2.3 MAUNA KEA

Mauna Kea is the highest peak in the County (USGS 2018g). This shield volcano is built upon the southern flank of the Kohala Volcano's Eastern Rift Zone. Mauna Kea erupted most recently between about 6,000 and 4,500 years ago from at least seven separate summit-area vents, producing lava flows and cinder cones. Mauna Kea is in the advanced postshield stage (Hawaii-substage); geologic research has concluded that eruptions from this volcano are less frequent, and the chemistry of the lava has changed moving away from the source of magma generation. The oldest rocks on the surface of this volcano erupted between 200,000 to 250,000 years ago (USGS 2018g). The chemistry of these rocks are typical of a basaltic volcano in the post-shield stage, and this is consistent with Mauna Kea being over one million years old. The steep and more irregular shaped surface of this volcano are evidence that post-shield magma, which has higher viscosity, erupted from the cones of Mauna Kea. This chemistry change in the lava created prominent cinder cones, which are now called the Laupāhoehoe Volcanics. The series of eruptions that formed these structures was likely sporadic clusters of events that produced large volumes of tephra and ashfall. Today, the ash makes up a dominant portion of Mauna Kea's flanks (USGS 2018g). Geologists indicate that Mauna Kea could erupt again after being inactive for 4,000 years; it is a moderate threat volcano in the USGS National Volcano Early Warning System (NVEWS). The Hawaiian Volcano Observatory continues to monitor Mauna Kea for any signs of activity.



Views of the Upper South Flank of Mauna Kea. The Prominent Cinder Cone (lower right) Erupted About 4,000 Years Ago. Most Other Cones are Part of the Laupāhoehoe Volcanics.
Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/mauna_kea/geo_hist_summary.html

2.2.4 HUALĀLAI

Hualālai is the third youngest volcano in the County (USGS 2017h). Currently, it is in the post-shield stage of activity. USGS has documented that six different vents erupted lava between the late 1700s and 1801. Lava flows from two of these events created land on the west coast of the island including the area where the Keāhole Airport is located (USGS 2017i).

Furthermore, 80 percent of Hualālai's surface has been covered by lava flows over the past 5,000 years (USGS 2017h). Over the last few decades, resorts, homes, and commercial buildings have been built on the volcano's flanks. The most recent activity was a series of earthquakes in 1929 that did not result in an eruption. Scientists consider Hualālai a potentially dangerous volcano that is likely to erupt again (USGS 2017h).

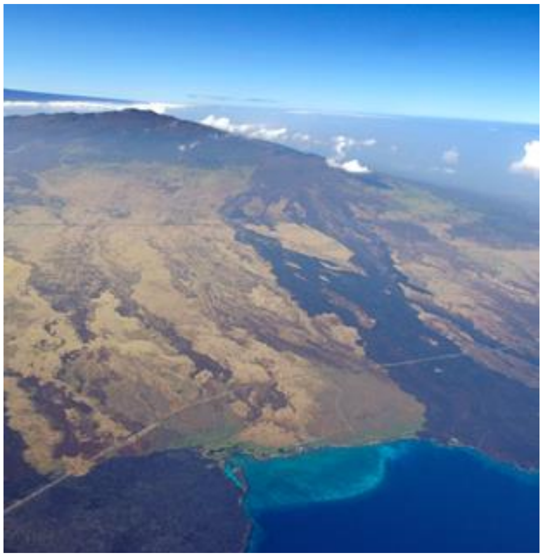
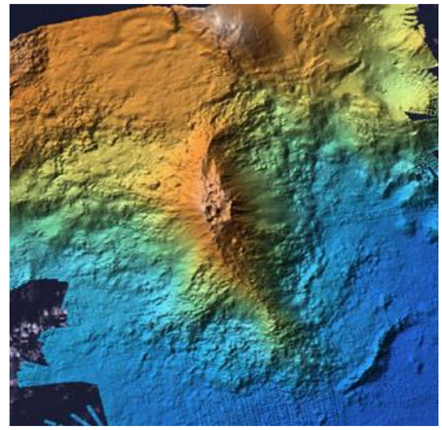


Image of the Hualālai. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/hualalai/

2.2.5 LŌʻIHI

The Lōʻihi volcano is an active volcano on the seafloor south of the Kīlauea. The seamount volcano rises 3,189 feet below sea level and generates frequent earthquake swarms. The summit of this volcano is a caldera-like depression, reaching 1.7 miles wide and 2.3 miles long (USGS 2017k). The most recent confirmed eruption of Lōʻihi occurred in 1996; it was associated with an earthquake swarm that began in July and quickly intensified. Thousands of earthquakes, including over a dozen with magnitudes greater than 4.5, were recorded from beneath the summit and south flank of the volcano between July and September 1996. Scientists observations and mapping of the Lōʻihi summit region showed that a significant portion of it had collapsed. Fresh pillow lavas and glassy fragments collected during submersible dives also confirmed the occurrence of an eruption (USGS 2017q)



Seafloor Map of the Lō'ihi Volcano. Photo Courtesy: USGS, https://volcanoes.usgs.gov/volcanoes/Lōʻihi/

The most recent pit, now called Pele's Pit, was created during the 1996 earthquake. The Lōʻihi volcano has grown from eruptions along its rift zone, but it is not known when it will reach above sea level. However, scientist speculate that with a growth of 16.4 feet per 1,000 years, that it will be as much as 200,000 years before it breaches the ocean surface (USGS 2017k).

Because Lōʻihi is still so deep beneath the ocean's surface, the USGS regards Lōʻihi as a low- to very low-threat volcano. If Lōʻihi were to erupt, it may cause partial draining of its summit magma chamber and summit collapse, as happened in 1996. If an eruption or stronger earthquakes occur, very small tsunami waves may affect southeast shores of the Island of Hawaiʻi (USGS 2020a).

2.2.6 KOHALA

The Kohala volcano is the oldest above-water volcano in the County (Bays and School of Ocean and Earth Science Technology [SOEST] 2015). Scientists indicate that this volcano erupted more than 65,000 years ago. This volcano is an elongated mountain that runs northwest to southeast. It is estimated that nearly 300,000 years ago, a huge avalanche consumed a slice of this volcano's northeast flank, spilling debris more than 80 miles out into the ocean floor (Bays and SOEST 2015).

Kohala Volcano's Northern Flank and Sheer Cliff Walls of the Volcano Today Along the Shoreline.
Photo Courtesy: SOEST, https://www.soest.Hawaii.edu/soestwp/announce/news/a-closer-look-at-kohala-mountain-the-big-islands-oldest-above-water-volcano/

2.3 Probability of Occurrence

Although probabilities of recurrence have not been assigned to lava zones in the County, HVO and USGS have tried to predict future eruptions based on the historical timelines for each volcano. Researchers take note that explosive eruptions of any size take place infrequently in the County. However, additional research has been done to assess the potential risk of Kīlauea's explosive eruptions. Recent work has clarified the explosive nature of Kīlauea eruptions. Once thought rare, it now known that Kīlauea can produce explosive eruptions from its summit caldera region lasting over periods as long as centuries (Fiske et al. 2019). Deposits that were found 9 to 17 km from the proposed vent and spread over 65 square km southeast of the summit from an eruption of the Kīlauea dating back to 900 Common Era suggest that the deposits were dispersed by jet stream winds. According to the researchers, the lithic deposits that were found are too large and too widely distributed across the south flank of Kīlauea to have been dispersed ballistically or by a buoyance eruption column. Therefore, the analysts conclude that the eruption could have only been explosive and that this is evidence that the Kīlauea poses a significant hazard to the surrounding area because of the wide area coverage over which it can spread its deposits.

HVO conducts volcanic monitoring and surveillance which is based on the movement of molten rock or magma and/or volcanic gas beneath a volcano that will precede any large eruption. HVO aims to provide weeks to months of warning guidance of potential eruptions at Mauna Loa and hours to days warning at Kīlauea. The USGS rates the potential threat, based in part on the probability of future eruptions, from each of the volcanoes it monitors as follows (USGS 2005; 2019j):

- Kīlauea—Very High. This volcano last erupted in 2018 and is considered certain to erupt again.
- 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.
- Lōʻihi—High. However, the impacts of the eruptions are underwater.
- Kohala—Low. Volcano is not active.

Overall, volcanic hazard events will continue to occur in the County. To reiterate, the County 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, 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 (HIEMA 2018).

Hualālai and Mauna Kea are both still considered active; Hualālai poses more of a threat than Mauna Kea (Kauahikaua 2019). Hualālai erupted most recently in 1801 whereas Mauna Kea last erupted about 4,500 years ago (USGS 2017g). Another volcano of note is Lōʻihi, which is the youngest volcano associated with the Hawaiian Island chain and is located 15 miles (28 km) southeast of Kīlauea underwater off the southern coast of the County. This volcano's activity has been consistently monitored since 1996 by HVO's on-land seismic network. This growing seamount may eventually break the surface, adding a new island to the Hawaiian Island chain, with an estimate of 200,000 years based on a growth rate of 16.4 feet per 1,000 years. However, there are no estimated potential impacts to residents and infrastructure from Lōʻihi currently (HIEMA 2018).

Based on historical record, the County has experienced six Federal Emergency Management Agency (FEMA) declarations associated with volcanic hazards since 1954 (HIEMA 2018). Further, the historic FEMA disaster declaration record shows that the County may experience a major event that leads to a FEMA declaration roughly once every 10 years. After reviewing the volcanic hazard events that occurred in the County since 1823, there have been nearly 100 volcanic eruptions; with varying severity and impacts (HIEMA 2018).

2.4 Climate Change

Changing future conditions may impact the dispersion and areas of impact of the volcanic hazard. Any changes in wind and rainfall frequency and intensity may alter the dispersion of volcanic gas emissions thus adversely impacting human health. It should be noted that 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. For example, 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 degrees Fahrenheit (°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 HVO 2017c).

Additional hazards produced by volcanic activity could impact the local climate of the County or exacerbate the current environmental effects of climate change, affecting local vegetation and the community. For example, vegetation destroyed by volcanic activity takes time to recover, and the length of recovery is dependent on the amount of rain and changes in the climate that the area is experiencing (Oregon State University no date). The landscape also becomes altered after lava inundation such as changes in infiltration capacity, which influences the type of species that grow after a volcanic event (The National Academics of Sciences, Engineering, and Medicine 2017). In an already dry or water-stressed environment that may be caused by changes in climate or rain frequency, reduced infiltration can cause increased runoff and sediment transport into water supplies and reduce available soil-water content for the growth of vegetation to recover after a volcanic event.

SECTION 3. METHODOLOGY

This county-wide volcanic risk assessment provides the technical data and foundation from which to make risk-informed decisions to ensure the County becomes more resilient to future volcanic hazard events. The following section describes the hazard data collected, community asset inventories compiled, and the methodologies used for the analysis. The risk assessment results are summarized for the County as a whole (***Section 4.1***), and for each Community Development Plan (CDP) District (***Sections 4.2 through 4.8***) so that volcanic risk may be integrated into the upcoming General Plan and CDP District plan updates.

Key Terms

Community Assets: *The land, people, structures, facilities, systems, environment and cultural sites that have value to a community.*

Exposure: *The spatial relationship between the presence of hazards and community assets.*

Probability: *The likelihood of a hazard event occurring in the future.*

Impact: *The consequences or effects of a hazard on a community and its assets.*

Risk *(Probability x Impact): The potential for impacts (i.e. damage or loss) created by the interaction of hazards and their associated probability.*

Vulnerability: *Characteristics of community assets that make them susceptible to impacts from hazard exposure.*

3.1 Volcanic High Hazard Area

Volcanic activity on the island is comprised of multiple hazards that are not all reflected on the U.S. Geological Survey (USGS) lava-flow hazard zone map; refer to ***Section 2 - Hazard Profile*** for detailed descriptions of the volcanic hazards in the County. To focus recovery and mitigation efforts on the areas with greatest volcanic hazard risk, the Core Planning Team (CPT), in consultation with USGS Hawaiian Volcano Observatory (HVO), delineated a Volcanic High Hazard Area based on the best available volcanic hazard spatial data. The Volcanic High Hazard Area is the combined area of lava zones 1 and 2 (with a 1,000-foot buffer), historic lava flow areas dating back to 1790, and National Earthquake Hazard Reduction Program (NEHRP) class soils D and E (***Figure 3-1***).

The following summarizes the best available volcanic hazard spatial data and the reason why individual spatial layers were selected for inclusion in the Volcanic High Hazard Area. If a hazard identified in Section 2 (***Hazard Profile***) is not listed below, there is no geospatial data available to support this evaluation. When additional spatial data becomes available, it is recommended that the Volcanic High Hazard Area as well as the risk assessment be updated accordingly.

Volcanic High Hazard Area: *Area that represents the greatest risk from the volcanic hazard*

- Lava zones 1 and 2
- Historic lava flows (1790-2018)
- NEHRP class D and E soils

3.1.1 LAVA FLOW

As discussed in ***Section 2 - Hazard Profile***, the USGS delineated lava-flow hazard zones 1 through 9 convey the relative volcanic hazard across the island (refer to ***Figure 2-2, in Section 2***). There are no current probability estimates associated with these zones. The map reflects long-term lava-flow hazards based on geologic data. According to USGS

As of November 2019, Kīlauea and Mauna Loa hold a "very high threat potential" (USGS 2019).

HVO, hazard assessments assume that future eruptions will be similar to those in the past. For the past 200 years, eruptions of Kīlauea and Mauna Loa have occurred at their summits and/or along one of their rift zones—and future eruptions on these volcanoes are likely to occur in the same areas. The 1859 eruption of Mauna Loa is an exception; the eruption occurred on the northwest flank of the volcano. Overall, the long-term lava-flow threat is greatest on Kīlauea and Mauna Loa, the two most active volcanoes, followed by Hualālai (USGS 2019).

USGS HVO is clear that the published lava-flow hazard boundaries are approximate and gradational. Meaning "…the boundary between lava-flow hazard zones is not a sharp line that, in one step, you can cross from one zone into the next" (USGS 2019). These boundaries are not specific enough to determine the absolute degree of danger at any particular site. A change in the degree of hazard can be found over one mile or more. The lava-flow hazard zones are designed to show the relative hazard across the island and meant to be used for general planning purposes only (Wright et al. 1992).

The CPT consulted with USGS HVO in July 2019 to determine which lava zones should be included in the County's Volcanic High Hazard Area. It was agreed that lava zones 1 and 2 are the most susceptible to future lava flows. In summary, lava zone 1 includes summits and rift zones of Kīlauea and Mauna Loa, where vents have been repeatedly active in historical time; lava zone 2 includes areas adjacent to and downslope of lava zone 1; with 15 to 25% of lava zone 2 being covered by lava since 1800. As a result, the CPT decided that lava zones 1 and 2 were to be included in the Volcanic High Hazard Area. Utilizing lava zones 1 and 2 for this risk assessment is in alignment with the Pacific Disaster Center's (PDC) 2018 Kīlauea Eruption Risk Assessment (KERA) which assessed exposure to these two lava zones as well.

Lava zones 3 and 4 cover Mauna Loa radial vents and historic lava flows events have crossed into these zones. Although not included in the Volcanic High Hazard Area, USGS indicates lava zones 3 and 4 present moderate risk to potential for future lava flows.

The County added a 1,000-foot buffer to each lava zone 1 and 2 to account for the uncertainty of the location to these boundaries and use in this assessment. Areas in lava zones 2 through 9 that are located within the 1,000-foot buffer of lava zone 1 were recategorized as lava zone 1. Areas in lava zones 3 through 9 that are located within the 1,000-foot buffer of lava zone 2 were recategorized as lava zone 2. All results reported, either when summarizing exposure within the Volcanic High Hazard Area or individual lava zones 1 and 2, include this 1,000-foot buffer.

Although the USGS-delineated lava-flow zones are based on the mapped locations of vents and lava flows, frequencies of past eruptions, and topography, the CPT also included historic lava flow flows in the Volcanic High Hazard Area. The CPT considered these historic lava flow events and associated inundation extent because lava zones do not have an associated probability. However, historic lava flows can establish a pattern of behavior and provide insight into areas that may be impacted by future lava flows. When considering policy and mitigation, it is important to understand where previous impacts have occurred to avoid future repetitive losses.

The historic lava flow spatial data available delineates eruptions dating back to 1790 (***Figure 3-1***). In modern history, 1790 seems like a very long time ago to consider lava flows to inform future decision making. To put things in perspective, the Hawaiian Islands began to form more than 70 million years ago. Mauna Loa likely emerged above sea level about 300,000 years ago, and it has grown rapidly upward since then (USGS 2017a). Mauna Kea, Hualālai, Mauna Loa, and Kīlauea are classified as "active" by HVO because they have erupted within the past 10,000 years and have the potential to erupt again. Kīlauea, the most active volcano on the island, is approximately 90 percent covered with lava flows less than 1,100 years in age. Since 1790, 78.97 square miles (or 50,544.4 acres) of historic lava flows have occurred outside of lava zones 1 and 2; impacting areas in lava zones 3 and 4 (***Figure 3-2***). Therefore, when looking at the entire geologic record of these volcanoes, examining historic events dating back to 1790 is relatively a short period of time. In some cases, the spatial file displaying the historic lava flow extent spans multiple events over decades of time. Therefore, any lava flow repetitive loss analysis in this report presents a minimum count.

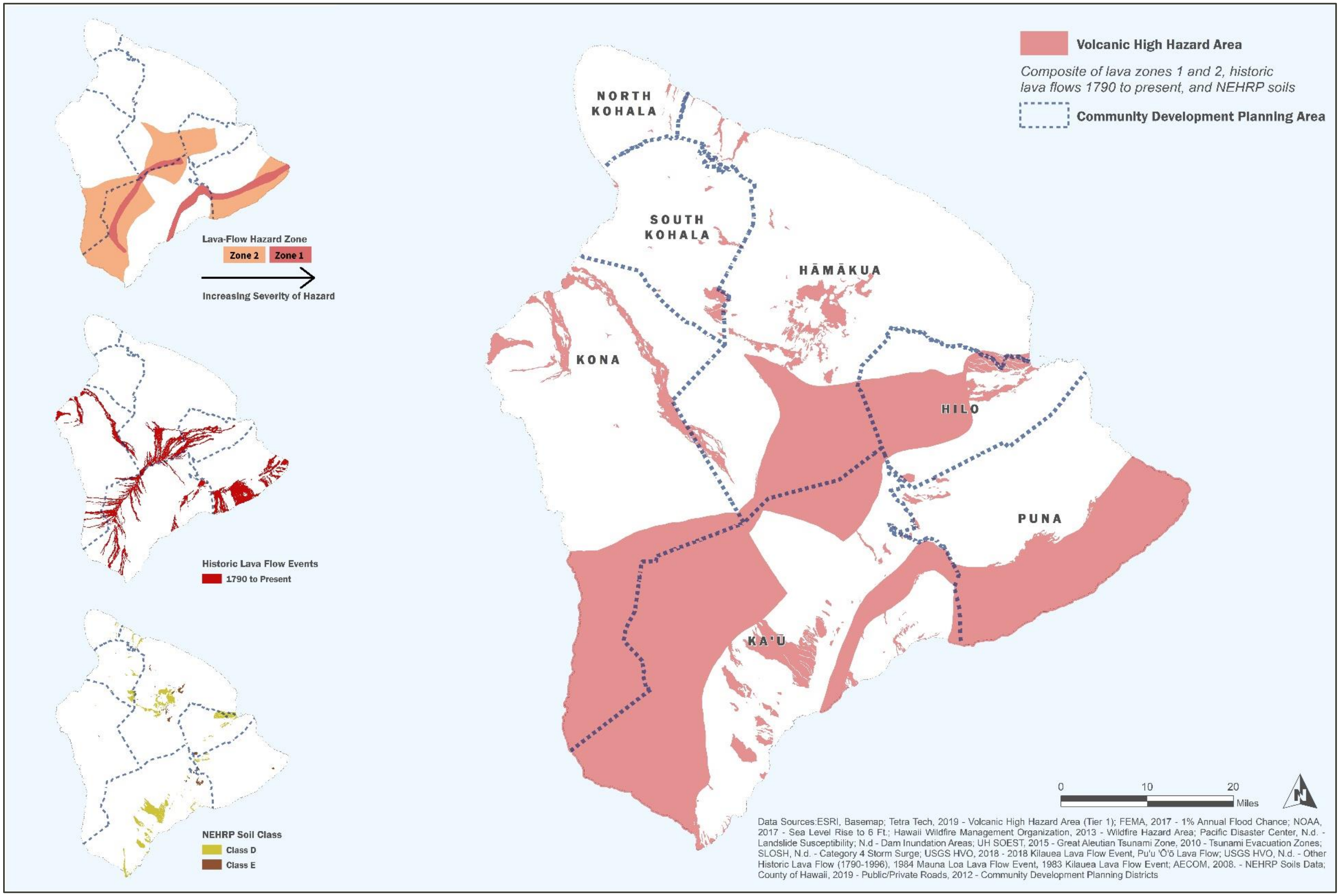


Figure 3-1. Volcanic High Hazard Area

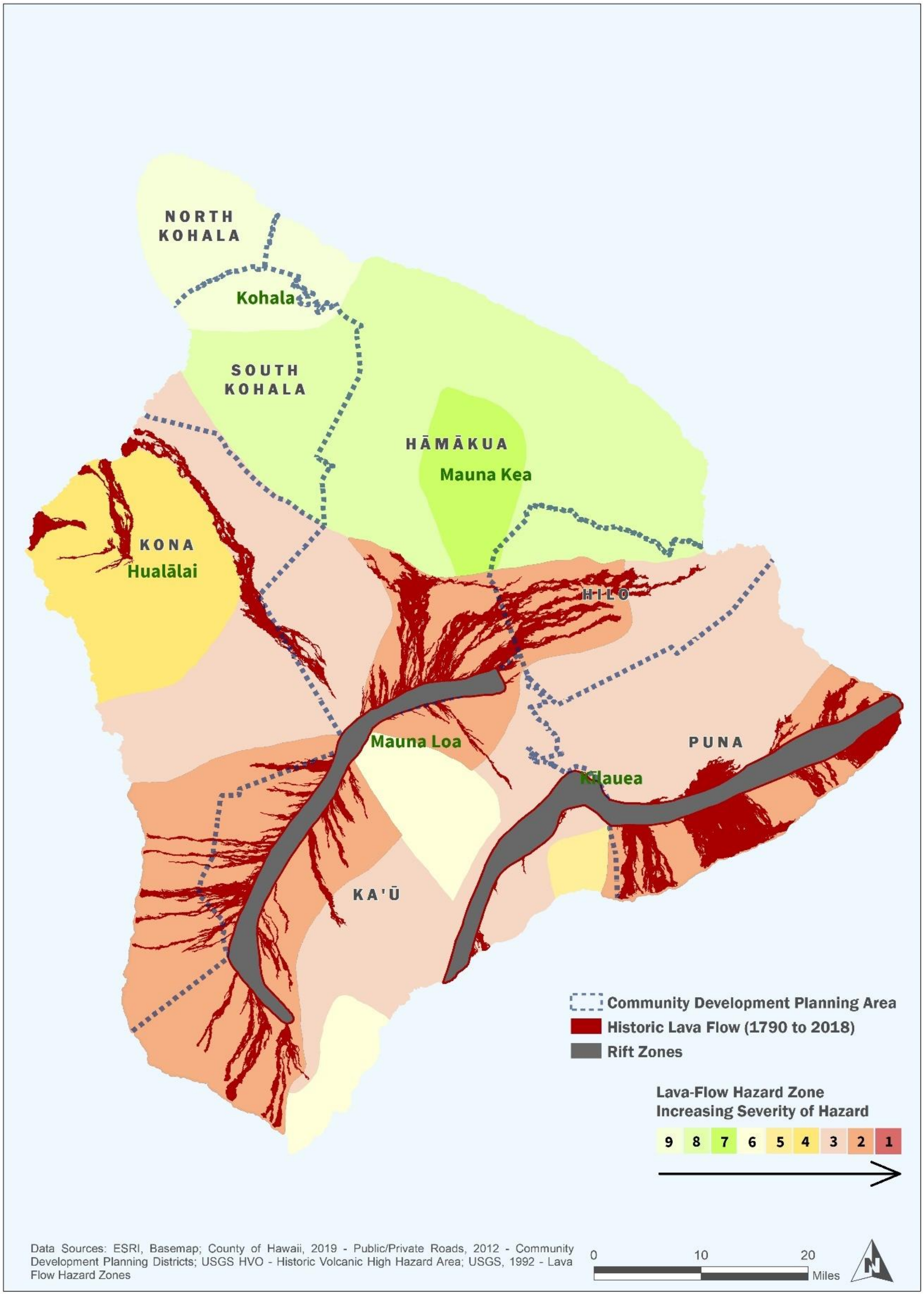


Figure 3-2. USGS Lava Flow Zones and Historic Lava Flow Inundation (1790 to 2018)

3.1.2 EARTHQUAKE

The entire County is exposed to the earthquake hazard; however, the greatest seismic hazard area is in the southern portion of the island as reflected by peak ground acceleration (PGA) greater than or equal to 120%g, which is a measure of ground shaking at a given location. This specific threshold generally corresponds to Seismic Design Code E (~125%g). (see ***Figure 2-5 in Section 2***).

As discussed in ***Section 2 - Hazard Profile***, most of these earthquakes are directly related to magma moving within the volcanoes, accumulating in shallow reservoirs, or erupting at their summits or rift zones. Other earthquakes occur along tectonic faults in the crust and upper mantle (USGS 2017b). Refer to Section 2 (***Hazard Profile***) for additional details that profile the earthquake hazard.

Ground shaking is the primary cause of earthquake damage to buildings and infrastructure. Softer soils amplify ground shaking. One contributor to shaking amplification is the velocity at which the rock or soils transmits shear waves (S-waves). The NEHRP defined five soil types based on their shear-wave velocity (Vs) that aid in identifying locations that will be significantly impacted by an earthquake. The NEHRP soil classification system ranges from A to E. As displayed on ***Figure 2-6*** in ***Section 2***, most of the County is underlain with NEHRP class C soils, with additional areas classified as D and E soils. NEHRP-classified D and E soils amplify and magnify ground shaking and increase building damage and losses (Tetra Tech 2018). Therefore, soil classes D and E were included in the Volcanic High Hazard Area to help identify where buildings and infrastructure may be at greatest risk to earthquake damage. Further, buildings constructed prior to 1985 were built prior to the adoption of the 1982 Uniform Building Code (UBC); therefore, these buildings are also more susceptible to earthquake damage due to the lack of complete load path of connections (Martin and Chock, Inc. 2015).

3.2 Exposure Analysis

Exposure: *The spatial relationship between the presence of hazards and community assets.*

To generate the Volcanic High Hazard Area spatial layer, the individual hazard layers described above were dissolved in ESRI ArcGIS. If any hazard area overlapped other delineated volcanic hazard zones (i.e., lava zones 3 through 9), the volcanic high hazard area designation took precedence.

An exposure analysis was conducted utilizing the Volcanic High Hazard Area, as well as the individual volcanic hazards (i.e., lava zones 1 through 9, historic lava events and NEHRP soils) to determine which community assets are present in these hazard areas. In other words, if you are in the Volcanic High Hazard Area, you are at greatest risk to the volcanic hazard relative to the rest of the County. All community assets were evaluated to determine exposure to each individual natural high hazard area. This report summarizes these results in aggregate; however; the individual results are available to the County to inform future project identification.

The exposure analysis using the Volcanic High Hazard Area layer was conducted independent of the individual volcanic hazard exposure analysis. Therefore, the sum of the individual volcanic hazard exposure results does not equal the total Volcanic High Hazard Area. For example, if a community asset is in located in lava zone 3 but is also located in a historic lava flow area, this asset is identified in the Volcanic High Hazard Area count; and it will also appear when assets are identified as a count for lava zone 3.

3.3 Additional Natural Hazards

The County faces multiple natural hazards and may experience impacts from multiple hazard events at one time. In addition to examining exposure to the volcanic hazard, it is important to understand exposure relative to other natural high hazard zones to identify and design robust and resilient recovery and mitigation strategies. The CPT examined all spatially available natural hazard spatial data sets available in the County to inform the analysis. Then, high hazard zones were selected from within these datasets to develop the Additional Natural High Hazard Areas layer.

Additional Natural High Hazards Evaluated

- Flood
- Sea Level Rise
- Landslide
- Tsunami
- Hurricane Storm Surge
- Wildfire
- Dam Failure

As the County continues on its path to achieving natural disaster resilience, it is critical to consider all natural hazards when identifying mitigation strategies. Integration of the risk and vulnerability data into the General Plan update to guide future land use decisions to minimize or prevent development in high hazard areas will be a significant step towards building a resilient community. In addition, the County has opportunities to utilize the all hazards data to support preparedness and response coordination and identify areas for improved and enhanced capacity to mitigate, prepare and respond to multiple hazard events.

Figure 3-3 illustrates a composite of the additional natural high hazard areas identified for this assessment. All community assets were evaluated to determine exposure to each individual natural high hazard area. This report summarizes these results in aggregate; however, the individual results are available to the County to inform future project identification. The following summarizes the individual natural high hazard zones identified and used to develop the Additional Natural High Hazard Areas layer.

It is important to note that the County is at risk to additional hazards not included in this layer (e.g., chronic coastal flood, drought and high winds) which are being considered and evaluated as part of the County Multi-Hazard Mitigation Plan (MHMP). The 2020 MHMP update to this plan is currently in process. The chronic coastal flood hazard reflects high surf, coastal erosion, passive inundation, high waves and tidal flooding. This hazard area is already included in other layers being utilized and discussed further below (i.e., Federal Emergency Management Agency [FEMA] flood data, sea level rise inundation, and storm surge inundation). Water supply and agricultural drought risk was not available in time to include in the assessment. In terms of the wind hazard, the entire island is exposed to wind events and new development will be built to code which includes standards to withstand high wind events.

For more detailed information about the individual natural hazards, refer to the 2015 County of Hawaiʻi Multi-Hazard Mitigation Plan and the 2018 State of Hawaiʻi Hazard Mitigation Plan.

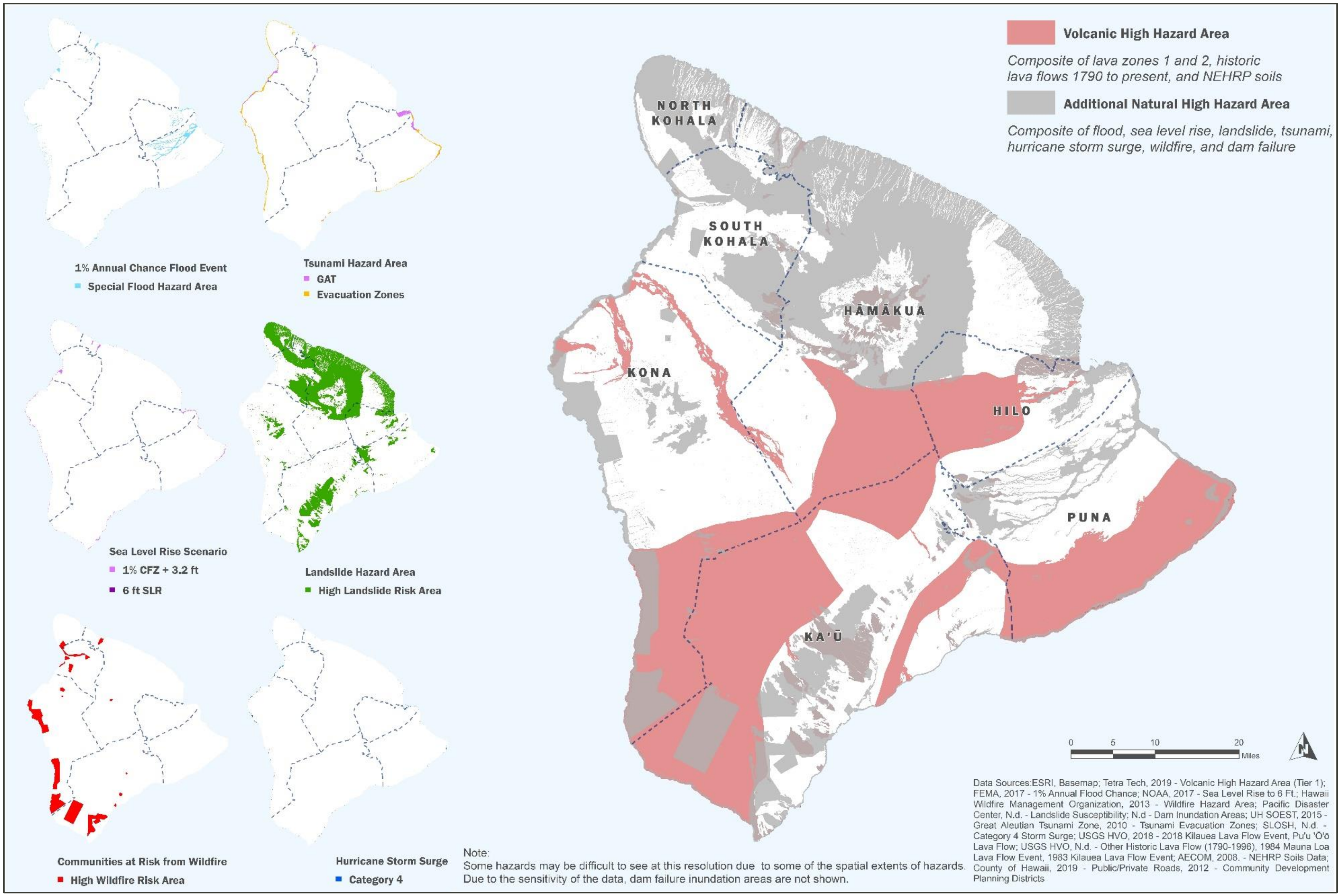


Figure 3-3. Additional Natural High Hazard Areas

3.3.2 EVENT-BASED FLOOD

The County has a Digital Flood Insurance Rate Map (DFIRM), effective September 29, 2017, with the latest Letter of Map Amendment dated October 2, 2017. The DFIRM depicts the FEMA-recognized flood hazard in the County for the purposes of the National Flood Insurance Program. The 1-percent annual chance floodplain boundary depicted on the DFIRM, also known as the Special Flood Hazard Area, is inclusive of both A- and V-zones (riverine and coastal zones, respectively). However, a large portion of the Puna District's flood hazard is not represented on the DFIRM. In 2016, FEMA completed a local flood study in the Puna District which reflects the latest 1-percent annual chance flood boundary in the northern portion of Puna. Together, these two datasets were identified by the CPT as the flood high hazard area in the County (***Figure 3-3***). It is important to note that lava flow events alter the terrain and changes to the flood risk are not known until future studies are conducted.

3.3.3 SEA LEVEL RISE

Projected sea level rise inundation areas are considered a high hazard area by the County because permanent loss of land and community assets will occur as the sea continues to rise. The CPT decided to utilize both the data compiled for the 2017 Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (1-percent coastal flood zone with 3.2 feet of sea level rise [1% CFZ-3.2 ft]) as well as the National Oceanic and Atmospheric Association's sea level rise data (6 feet) to assess exposure (***Figure 3-3***).

3.3.4 LANDSLIDE

The County has several characteristics that make it susceptible to landslides: steep hillsides, heavy rainfall, a warm climate, lush vegetation, and development and other types of construction in upland areas. A landslide susceptibility spatial layer provided by PDC and utilized in the 2018 State of Hawaiʻi Hazard Mitigation Plan was used to inform the exposure assessment. The data are based on topographic slope, geology and soil moisture. The high landslide susceptibility areas were identified as the landslide high hazard areas for this analysis (***Figure 3-3)***.

3.3.5 TSUNAMI

As discussed in Section 2 (***Hazard Profile***) a tsunami may be generated by local and distant sources. Two tsunami spatial layers were available to inform this exposure assessment: County tsunami evacuation zones and the Great Aleutian Tsunami (GAT) inundation area data provided by the PDC and utilized in the 2018 State of Hawaiʻi Hazard Mitigation Plan (***Figure 3-3***). The CPT decided to use a combination of these two layers to ensure the greatest inundation area was evaluated.

3.3.6 HURRICANE STORM SURGE

The County's coastal areas may be impacted by hurricane storm surge. The National Oceanic and Atmospheric Administration (NOAA) generated the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) data which represents the maximum of maximums for each hurricane category 1 through 4; the Maximum of Maximums (MOM) provides a worst-case snapshot for a particular storm category. The FEMA DFIRM V-zones are similar to the SLOSH zones; however, there are locations where category 3 and 4 SLOSH inundation extends beyond the coastal V-zones. Further, the SLOSH and DFIRM data was developed for different purposes. The category 4 SLOSH inundation area was identified as the storm surge high hazard area and included in this analysis (***Figure 3-3***). This aligns with the 2018 State of Hawaiʻi Hazard Mitigation Plan as well as the 2015 Hawaiʻi Catastrophic Hurricane Plan (HIEMA and FEMA 2015).

3.3.7 WILDFIRE

The County of Hawaiʻi is prone to wildfire conditions. On the leeward side, conditions are affected by a greater number of days with dry conditions and expansive grasslands. The windward side of the island has significant grassland cover and, although has less number or dry days, becomes just as vulnerable to wildfire impacts during a drought. In addition, windward areas including Puna and Hawaiʻi Volcanoes National Park, deal with lava-ignited wildfires (Trauernicht 2018).

In 2013, the Hawaiʻi Wildfire Management Organization (HWMO) partnered with the State of Hawaiʻi Department of Land and Natural Resources (DLNR)-Division of Forestry and Wildlife (DOFAW) and the County fire departments across the State of Hawaiʻi to update the Hawaiʻi Community at Risk from Wildfire (CAR) maps. The CAR data were provided by HWMO for use in the 2018 State of Hawaiʻi Hazard Mitigation Plan update. These data are based on the statewide Wildfire Hazard Assessment (WHA) which collected quantitative field data and qualitative firefighting capacity data of 36 hazard characteristics that contribute to wildland fire risk in developed communities. The DOFAW personnel reviewed the WHA and then made adjustments to better reflect consistency across CAR maps, which communicate risk levels based on staff experience. Tetra Tech assigned high, moderate and low fire risk categories to the communities delineated in the CAR data using the "DOFAW 2013: Communities at Risk from Wildfire" map published by HWMO as a reference. The high-risk communities were selected to represent the high wildfire hazard area.

It is important to note that the CAR data focuses on communities, or developed areas. Therefore, the wildfire risk located outside of these communities could not be determined; and it cannot be assumed they are not at risk to wildfire. HWMO provided the following disclaimer with the CAR data:

- *"HWMO will not bear any responsibility for the consequences of using this data set, which are entirely the responsibility of the user. Therefore, the data does not indicate the full range of realistic fire threat, nor does it offer actual quantification of the potential exposure of homes to the ignition, spread, and intensity of wildfires or embers produced by wildfires. Although the data set and subsequent analyses may indicate general wildfire risk for a given area, the actual risk to homes and property can deviate based on the characteristics of the site around an individual home, community, or natural resource area."*

3.3.8 DAM FAILURE

According to DLNR, the County has a total of 10 dams or reservoirs with high or significant classifications. Dams assigned the significant hazard potential classification are those dams where failure or misoperation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in the predominantly rural or agricultural areas but could be in areas with population and significant infrastructure. Dams assigned the high hazard potential are those where failure or misoperation will probably cause loss of human life (Tetra Tech 2018).

A dam failure inundation layer was provided by PDC for use in the 2018 State Hazard Mitigation Plan. The same layer was used in this assessment and delineated dam failure inundation areas for the following, with their classification noted in parentheses are provided below:

- Waikōloa Reservoir No 1 (High Hazard)
- Waikōloa Reservoir No 2 (High Hazard)
- Waikōloa Reservoir No3 (High Hazard)
- Waimea 60 MG Reservoir (High Hazard)
- Puʻukapu Watershed Retarding Dam R-1 (High Hazard)
- Keaīwa Reservoir, Hawaiʻi No 5 Reservoir (High Hazard)
- Puu Pulehu Reservoir (High Hazard)
- Paʻauilo Reservoir (Significant Hazard)

Note, the Punawai Reservoir (High Hazard) spatial layer was provided; however, there were issues associated with the data and it could not be used in the analysis. This data is considered sensitive; therefore, it does not appear as a stand-alone hazard on mapping in this report.

3.4 Community Asset Inventories

It is important to the County to conduct a detailed risk assessment based on best available data. The following text details the data used and methodologies followed to generate the asset inventories used in this assessment.

3.4.1 PARCELS

To assess parcel exposure post-2018 Kīlauea event, the 2019 parcel layer was joined to the June 2019 County of Hawaiʻi Real Property data to generate a countywide parcel spatial layer. All land and building assessed values for parcels that were inundated and isolated by the 2018 Kīlauea event were "zeroed out" by the County and reflected as such in the reported data in this assessment.

In preparation for the County General Plan update, a build-out analysis was conducted to determine residential and non-residential capacity by parcel. These development capacity designations are defined below and their parcel exposure assessed to help inform future land use and policy decisions.

- Greenfield – Parcel with no existing structure that has the potential to be developed and either can or cannot be subdivided
- Redevelopment – Parcel that is already developed with the potential for redevelopment in the future

The parcel data and associated attributes (i.e., occupancy class, assessed value, build-out capacity) were used to estimate the number, area, and assessed value located in each defined hazard area. Parcels that intersected a hazard layer are considered exposed to the hazard. The associated values with the exposed parcel were totaled for each hazard layer. In some cases, a parcel can be located in more than one hazard zone. For example, if a parcel is in more than one lava-flow hazard zone, the parcel was assigned to the zone that has the greater susceptibility according to the USGS map (i.e. if a parcel is located in both lava zones 3 and 4, then lava zone 3 was assigned to the parcel).

The parcel area located in the Volcanic High Hazard Area and Additional Natural High Hazard Area reflects the total hazard area (Volcanic High + Additional Natural High Hazard Areas), even if the parcel extends outside the Volcanic High Hazard Area. In other words, if half of a parcel is in the Volcanic High Hazard Area, but the entire parcel is located in the 1-percent annual chance flood hazard area, then the parcel area in the Volcanic High + Additional High Hazard Area is equal to the entire parcel area.

3.4.2 GENERAL BUILDING STOCK

As noted above, this countywide volcanic risk assessment provides the County the technical data and foundation from which to make risk-informed decisions to ensure the County becomes more resilient to future volcanic hazard events. The evaluation of buildings was conducted using post-2018 eruption data to provide the County an understanding of current risk. This is because the results of this analysis will be used to inform the identification of ***future mitigation and resilience projects.*** Therefore, the June 2019 version of the County of Hawai'i Real Property data was used to generate the general building stock inventory. This enables the County to examine the anticipated exposure and potential loss to the County based on the post-2018 eruption-built environment. Both replacement cost value (RCV) and assessed value were reported for all buildings. These values are used in two different ways and should not be confused with market value as described below.

A replacement cost value was calculated for each building using the Real Property Tax data structural attributes. Replacement cost value is the cost to repair or replace the building with a functionally equivalent building of the same size, based on the current cost of labor and materials. The replacement cost value is most often used by FEMA when calculating estimated potential loss post-event for Public Assistance (PA) (e.g., preliminary damage assessments) and aligns with the State and County Multi-Hazard Mitigation Plans. It is also used in FEMA benefit-cost analyses for certain types of projects. Assessed value was also quantified to provide the County an understanding of the extent to which their tax base is at-risk to the volcanic hazard.

Replacement Cost Value (RCV): *The cost to repair or replace the building with a functionally equivalent building of the same size, based on the current cost of labor and materials.*

Market Value: *The price a willing buyer and a willing seller agree to transact a sale, often determined by an appraiser.*

Assessed Value: *The value assigned to a property to measure applicable taxes.*

Replacement cost value and assessed value should not to be confused with the market value of a building. Market value is the price a willing buyer and willing seller agree to transact at the time of a sale; often determined by an appraiser. For FEMA mitigation buyout programs, the pre- or post-disaster market value is used to calculate the cost to acquire a structure, land or both. The calculation of buyout costs was not the objective of this risk assessment and was therefore not included as a quantified reported value.

The following attributes were obtained from the County of Hawai'i Real Property Tax data: number of stories, construction type (wood, masonry, concrete, steel), square footage, and foundation type (slab, basement, crawl space, pier/pile). RSMeans 2019 valuations were used to estimate the replacement cost value (building and contents value) for each structure; location factors of 1.18 for residential structures and 1.17 for non-residential structures were applied to each structure.

Structures with their centroid located in a hazard area are considered exposed and totaled to estimate the number of buildings and replacement value exposed to each hazard.

3.4.3 POPULATION

Examining resident and household exposure to the volcanic hazard is challenging because parcel-level demographic data is generally not available. Instead, demographic statistics from the 2017 American Community Survey (ACS) were collected for each U.S. census tract within the County. Each tract's 2017 population count and the number of 2019 residential parcels in the tract were used to calculate the average number of persons per household. This data was then used to conduct the population exposure assessment using each parcel's estimated household size. The results of this analysis are limited and should only be used for planning purposes until higher resolution data is available.

Research has shown that some populations, while they may not have more hazard exposure, may experience exacerbated impacts and prolonged recovery if/when impacted. This is due to many factors including their physical and financial ability to react or respond during a hazard. This population is referred to as socially vulnerable to hazard events. At the same time, County of Hawaiʻi residents are unique and, although they are exposed to several natural hazard types and may have experienced historic impacts, this may have increased their overall level of resilience. This is likely due to factors including, but not limited to: institutional knowledge of hazard events, intimate knowledge of the natural elements of the County (particularly for those residents who have lived in the County for an extended period of time), and varying levels of existing self-sufficiency. This will vary from individual to individual and community to community. The relative nature of the County's population's resilience is important to consider when factoring in the strengths of and challenges faced by the County's residents to hazard events While through one lens, vulnerability can be evaluated through typical social vulnerability attributes (i.e. age, income, education level, etc.), another more holistic lens may factor in lived experiences, length of tenure in the community, strength/extent of social network, etc.

In 2019, PDC released the KERA report that identified key social drivers of volcanic hazard vulnerability: (1.) socioeconomic status; (2.) access to information; and (3.) household composition (PDC 2019). To align with the KERA report, the County examined both total population exposure and the exposure of these vulnerable populations to the volcanic hazard. Unfortunately, population data is not available at the individual parcel level. At the time of this risk assessment, the 2017 ACS 5-Year Estimate is considered best available countywide population data. To determine population exposure, the total as well as the following demographic statistics from the 2017 ACS 5-Year Estimate were utilized:

- Household Composition: Population Under 18, Population Over 65, Single-Parent Households, Disabled Population
- *Access to Information: Households without a telephone, households without broadband internet, non-English speaking population
- Socioeconomic Status: Population without a High School Diploma (for populations over 25), unemployment, households receiving federal supplemental nutrition assistance program (SNAP) benefits, population below the poverty line
- Access to Lifelines: Population without health insurance

*This reflects common understandings of potential complications or barriers to information before, during, or post disaster event. However, these barriers may not have the same application in the County as a result of prior or existing work to address diversifying communication channels, language translation, and community hazard education, for example.

These demographic statistics were collected at the census tract level and their individual counts were averaged across all residential parcels located in each census tract. This was performed to use the most up-to-date population statistics and estimate a more precise distribution and density than using the census tract boundaries. For statistics that were available as household counts, the count was multiplied by the average household size for the census tract from the 2017 ACS 5-Year Estimate before averaging the statistic across the residential parcels. The population below the poverty line is available as a percentage of the total population. To estimate the population below the poverty line, the percentage for each tract was multiplied by the total population of the census tract before averaging the statistic among the residential parcels.

Residential parcels with their centroid (otherwise known as "geometric center") located in a hazard area were considered exposed and the average population counts assigned to each were totaled. The number of residential parcels was also totaled for each hazard area. The census tract statistics were applied to this dataset and the averages were calculated per parcel as well. When reporting exposure to the Volcanic High Hazard Area and individual volcanic hazards though, the residential parcels based on 2019 County of Hawaiʻi Real Property data were used. Therefore, these numbers reflect the populations post-2018 Kīlauea event and do not include those that were associated with the parcels prior to the Kīlauea event.

3.4.4 CRITICAL FACILITIES AND LIFELINES

To assess the critical facilities and lifelines exposed to the volcanic hazard, Tetra Tech worked with the County of Hawaiʻi to collect the most up-to-date information to use in the assessment. Six lifeline facility categories were identified to align with the 2015 County of Hawaiʻi Hazard Mitigation Plan as well as FEMA's National Response Framework lifeline categories. The CPT determined that all facilities are both critical and serve as lifelines.

- Safety and Security
- Transportation Lifeline
- Utility Lifeline
- Recovery and Support Facility
- Socially Vulnerable Facility
- Food, Water, Sheltering Lifeline

To assemble the spatial inventory, the best available data was used. The County indicated their preference was to use as many County-sourced spatial datasets as possible, and supplement with spatial data available from the 2018 State of Hawaiʻi Hazard Mitigation Plan as needed. If the County did not have a spatial inventory of a particular facility type, the State data was consulted.

Critical facilities with their centroid located in a hazard area were considered exposed to the hazard. The year built from the 2019 County of Hawaiʻi Real Property Tax data was assigned to critical facilities, where possible. Year built was available for the following critical facility types: Assisted Living, County Government, Department of Public Works (DPW), Emergency Shelter, Financial Institution, Fire Station, Police Station, and Schools. Of the 468 facilities that had easily identifiable year-built data, the exposure to those built before 1985 was conducted to assess additional seismic risk to structures built before the UBC seismic code was adopted (1985).

It is important to note that the number of critical facilities located in a hazard area represents the total facilities associated with that asset category. However, there are facilities that serve multiple purposes. For example, schools were provided as a separate spatial layer and shelters were provided as a separate list. A school can serve as a shelter. To provide the number of schools located in a hazard area this assessment was conducted with the list and layer of schools, independent of the shelters. Similarly, a separate analysis was conducted using the list and layer of shelters. Therefore, a school may be represented twice; once in the count of schools exposed to a hazard (in the Socially Vulnerable facility category), and once in the number of shelters exposed to a hazard (in the Food, Water, Sheltering Lifeline). ***Table 3-1*** lists the critical facility and lifeline types included in the inventory and their data source, organized by six lifeline categories.

Table 3-1. County of Hawaiʻi Critical Facilities and Lifelines Organized by Lifeline Category

Facility Type	Source
Safety and Security	
Civil Defense Emergency Operations Center	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Fire Stations (includes SAR/EMS)	State of Hawaiʻi Office of Planning, 2017
Hospitals/Medical	State of Hawaiʻi Department of Health, 2019
Police Stations	State of Hawaiʻi Office of Planning, 2017
County Government	Google Earth, 2019 (Google maps used to find location of County buildings)
Department of Public Works Base Yards	Google Earth, 2019 (Google maps used to find location of County buildings)
Sirens	County of Hawaiʻi, 2019
Transportation Lifeline	
Harbors	State of Hawaiʻi Department of Transportation Harbors Port Handbook
Airports	State of Hawaiʻi Department of Transportation, 2019
Bridges	State of Hawaiʻi Office of Planning, 2018
Buses	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Utility Lifeline	
Electrical Power	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report; U.S. Environmental Protection Agency, 2013
Puna Geothermal Venture Wells	County of Hawaiʻi, 2019 (Roy Takemoto)
Electric Substations/Transfer Stations	Oak Ridge National Laboratory, 2019
Fuel	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report; Oak Ridge National Laboratory, 2017
Gas	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Wastewater Facilities/Pumps	Hawaiʻi County Department of Environmental Management, 2019 (Waste Water Map)
Communication (wired/cabled)	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Water Wells	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Pump Station – Potable	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Recovery Support Facility	
Debris Clearing and Disposal	Hawaiʻi County Department of Environmental Management - Solid Waste, 2019
Financial Institutions	State of Hawaiʻi Department of Commerce and Consumer Affairs, 2019
Socially Vulnerable Facility	
Schools	State of Hawaiʻi Office of Planning, 2017
Nursing Homes	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Assisted Living Centers	Hawaiʻi County Civil Defense, 2019; Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Residential Care	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report

Facility Type	Source
Extended Care	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Food, Water, Sheltering Lifeline	
Emergency Shelters	Hawaiʻi County Department of Education, 2019; Hawaiʻi County Department of Parks and Recreation, 2019
Ice Distributor (survival supplies)	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Grocery Store Supermarket	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Correctional Facility/Jail/Prison	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Community Center	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report
Gym (potential shelter)	Makani Pahili 2017 Emergency Power Prioritization Workshop Series Final Report

Notes:
EMS Emergency Medical Services
SAR Search and Rescue

The roadway network provides connectivity between communities and resources, as well as emergency access to keep residents safe. It is closely tied to housing providing livable spaces with services needed for communities to thrive. A road layer used, dated May 2019 which included impacted roads from Kīlauea's 2018 eruption (Kalapana-Kapoho Beach Road, Leilani Avenue, Pāhoa-Kapoho Road, Pohoiki Road, etc.) to evaluate the spatial relationship between roads and volcanic hazards. The intersection of the road centerline and the Volcanic High Hazard Area, and lava zones 1 and 2 was determined. Additional analyses can be conducted to evaluate the connectivity of the network to critical assets and lifelines, identify potential roads located outside the high volcanic risk areas that are vulnerable because they may be inaccessible or isolated from a lava-flow event, what routes are at greatest risk that need to remain open because they are the singular access to critical facilities, socially vulnerable populations and essential government services.

3.4.5 ENVIRONMENTAL RESOURCES

In order to assess the impacts to the County's environmental resources, the resource types being used for the 2019 General Plan update were provided to inform this assessment. Tetra Tech worked with the County to determine the best available sources for this information. The inventories were available as two different shapefile types—polygons and points—and had separate exposure methodologies due to their different geometry types.

For polygons, an exposure analysis was conducted to determine the total area of each identified environmental resource located in the hazard areas. The environmental resources were intersected with the hazard areas to determine the total area (acres) and number of resources located in each hazard area. For points, an exposure analysis was conducted to determine the number of each resource type in the hazard areas. Each resource, with its centroid in a hazard area, was considered exposed. Note: if a national park crossed multiple CDP boundaries, it was counted for each CDP it is in (i.e. Hawai'i Volcanoes National Park is in Hāmākua, Kaʻū, Kona, and Puna). Hawaiʻi Volcanoes Wilderness is a subset of Hawaiʻi Volcanoes National Park and is included in the areas and counts as well. Reefs are located offshore and were not able to be assessed like the other environmental resources. For this analysis, reefs that were located within 100-feet offshore and adjacent to a lava zone or hazard area were considered exposed. ***Table 3-2*** lists the environmental resources that were assessed, their shapefile type, and their source.

Table 3-2. County of Hawaiʻi Environmental Resources

Environmental Resources	Shapefile Type	Source
Critical Habitats (endangered and threatened species)	Polygon	USFWS, 2017
Reserves (Federal, Military, State, NGO)	Polygon	Hawaiʻi State DLNR - DOFAW, 2019
State Land Use District - Conservation	Polygon	Hawaiʻi State Land Use Commission, 2016
Open Space		
Protected (government owned)	Polygon	County of Hawaiʻi GP Indicator (Amy DeBay)
General (privately owned)	Polygon	University of Hawaiʻi - Hilo, 2015
Agricultural Land		
Agricultural Land of Importance (State Designation)	Polygon	Hawaiʻi State Department of Agriculture, 2015
Import Agricultural Land (LUPAG)	Polygon	County of Hawaiʻi, 2015
Crops *(Aquaculture, Banana, Coffee, Commercial Forestry, Dairy, Diversified Crop, Flower/Foliage/Landscape, Macadamia Nuts, Taro, Tropical Fruits)*	Polygon	University of Hawaiʻi - Hilo, 2015
Hunting Areas	Polygon	Hawaiʻi State DLNR - DOFAW, 2015
Pasture	Polygon	University of Hawaiʻi - Hilo, 2015
Exceptional Trees	Point	County of Hawaiʻi, 2019 (Roy Takemoto)
Parks		
County	Polygon	County of Hawaiʻi and Placeways, 2016
State	Polygon	USGS PADUS, 2016
National	Polygon	USGS PADUS, 2016
Reservoir	Point	Department of Water Supply, 2019
Anchialine Pools	Point	County of Hawaiʻi, 2016
Wetlands	Point	USFWS, 2017
Reefs (Coral)	Polygon	Division of Aquatic Resources, 2005

Notes:
DLNR Department of Land and Natural Resources
DOFAW Division of Forestry and Wildlife
GP General Plan
LUPAG Land Use Pattern Allocation Guide
NGO Non-governmental Organization
PADUS Protected Areas Database of the United States
USFWS U.S. Fish and Wildlife Service
USGS U.S. Geological Survey

3.4.6 CULTURAL ASSETS

The County is home to many formally designated and recognized cultural assets, historic places and sites that are important for shaping the identity of place and the people. A location-based database of culturally significant sites to Native Hawaiians was not available for use in this risk assessment; disclosure of the location of sacred and otherwise culturally significant sites is prohibited, in some instances, by federal law. In order to assess the impacts to the County's cultural assets, Tetra Tech worked with the County to determine the best available sources for this information and to identify any additional datasets that should be used. To align with the County General Plan update, Hawaiian Homelands, historic sites and trails were used for this analysis. The inventories were available as three different shapefile types—polygons, line, points—and had separate exposure methodologies. ***Table 3-3*** lists the cultural resources that were assessed, their shapefile type, and their source.

Table 3-3. County of Hawaiʻi Cultural Assets

Cultural Assets	Shapefile Type	Source
Hawaiian Homelands	Polygon	State of Hawaiʻi Office of Planning, 2015
Historic Places	Point	DLNR State Historic Preservation Division, 2016
Historic Districts	Polygon	County of Hawaiʻi, 2016
Historic Sites	Point	DLNR State Historic Preservation Division, 2016
Historic Trails	Line	County of Hawaiʻi, 2016

DLNR Department of Land and Natural Resources

For polygons, an exposure analysis was conducted to determine the total area of each identified cultural resource located in the hazard areas. The cultural resources were intersected with the hazard areas to determine the total area (acres) and number of resources located in each hazard area. For points, an exposure analysis was conducted to determine the number of each resource type in the hazard areas. Each resource with its centroid in a hazard area was considered exposed. For lines, an exposure analysis was conducted to determine the length of each resource type in the hazard areas. The resources were intersected with the hazard areas to determine the length exposed to each hazard area in miles.

3.5 Assumptions and Limitations

- There is no countywide population and demographic data at the parcel level.
- The statistics provided in this report are estimates. They were generated using multiple sources and are suitable for planning purposes. For example, population statistics are based on ACS 2017 Census spatial layers and the average statistics in each individual tract. The number of residential households is based on the Real Property attributes and parcel layers provided by the County. These statistic totals in the report are separate, generated using different data sources, and should be interpreted as estimates.
- Existing volcanic hazard data may be updated, and new data generated in the future. The Volcanic High Hazard Area and exposure analysis should be updated to ensure an accurate and current reflection of hazard exposure.
- The University of Hawaiʻi at Mānoa has collected and continues to collect vog data to inform potential public health impacts. This data was requested but not available in a format to use in the analysis at this time.

SECTION 4. RISK ASSESSMENT

4.1 County of Hawaiʻi

4.1.1 OVERVIEW

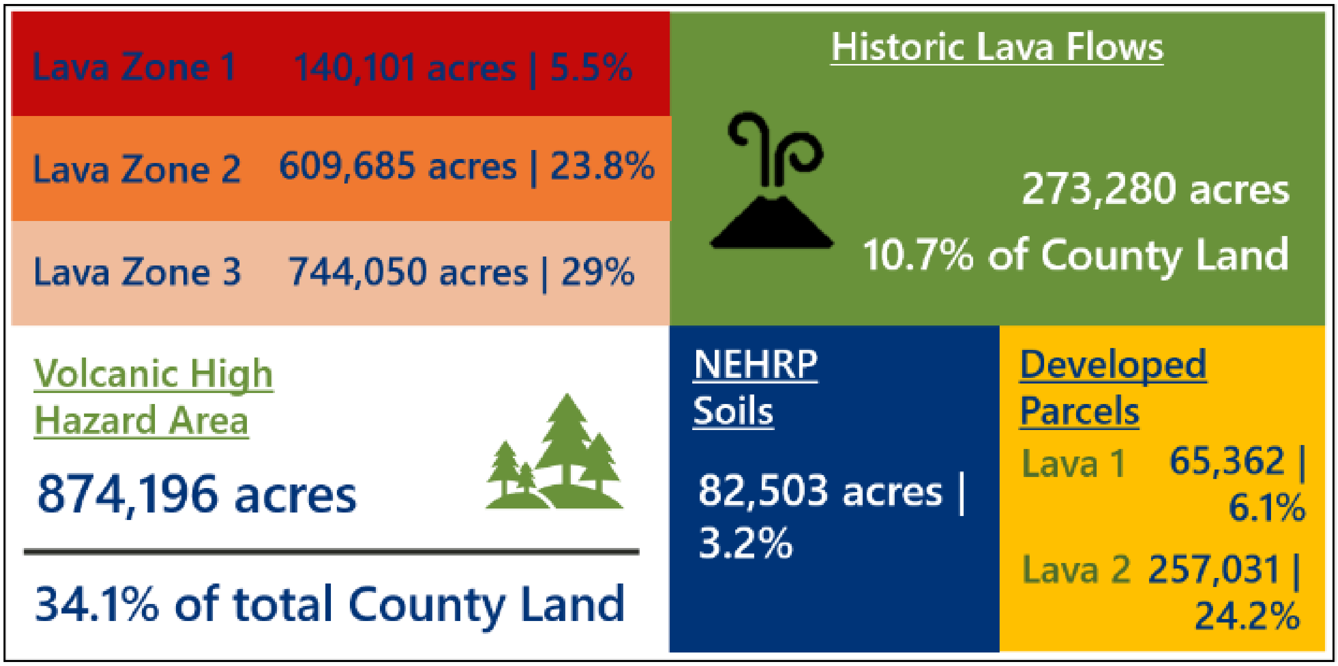
The County of Hawaiʻi, herein referred to as the County, is the State of Hawaiʻi's largest County by land area – just over 5,000 square miles. There are seven Community Development Plan (CDP) Districts in the County, designed to provide a forum for community input into land-use, delivery of government services and any other matters relating to the planning area. Community Development Plans are intended to translate broad General Plan goals, policies, and standards into implementation actions as they apply to specific geographical regions around the Island (CHPD 2019b).

The County is home to five volcanoes, ranging in size, activity, and age. Most recently, it is perhaps most famous 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, is thought to be undergoing a period of dormancy, having erupted only twice during the last 60 years, although its current status is that it's under an advisory. Prior to this most recent era, however, Mauna Loa was much more active, erupting, on average, about every five years.

As volcanoes define the County in-part, it's not a surprise that the island attracts more than 2 million visitors annually to visit the internationally known Hawaiʻi Volcanoes National Park (National Park Service 2017). In 2018, the County experienced the Kīlauea eruption (FEMA DR-4366) located in the Puna Community Development Planning area. The eruption lasted 125 days and is one of the longest consistent lava flow events in the County's recorded history.

The County of Hawaiʻi is rich in natural and cultural beauty and is thus largely rural, compared to other Hawaiian islands. Only 60% of Hawaiʻi County's population lives in one of the eight designated urban areas. Overall, population density is low in both urban and rural parts of the County and can easily be attributed to the relatively large size of the County and the relatively low overall population compared to other Hawaiian Islands. Despite its history of low density and rural landscapes, the County is expected to grow by 50% by the year 2040. At present, visitors make up about 15% of the population. Similarly, 70% of the County's population growth is from immigration, new residents moving into the County, rather than from resident population growth (i.e. in-County births). By the year 2025, a disproportionate number of residents will likely be seniors (65 years and older). Rates of job growth are expected to match population growth, but due to the economy's reliance on lower-paying service sector jobs, median incomes are likely to remain low. At the same time, roughly half the households find housing unaffordable, and many are struggling to make ends meet, often living in overcrowded conditions at the household scale due to general housing unaffordability and housing cost-sharing. The majority of the County's affordable housing is not located in or near job centers, so commutes are cumbersome and even more so for the over 8,000 County residents (4.2% of total population) without access to a vehicle. Visitor units are clustered primarily in West Hawaiʻi, and steady overall growth is expected to continue (CHPD 2019b).

4.1.2 VOLCANIC HAZARDS



Note: All percentages are relative to the County of Hawaiʻi

Figure 4-1. County of Hawaiʻi Volcanic Hazard Exposure Overview

The County of Hawaiʻi was formed by five volcanoes: Hualālai, Kīlauea, Kohala, Mauna Kea, and Mauna Loa. Hualālai is located in the Kona CDP and last erupted in 1801 (USGS 2017g). Despite its relative dormancy over the last 200+ years, Hualālai is still considered active and expected to erupt again at some point in the next 100 years. It is the third most active volcano on the island, behind Kīlauea and Mauna Loa. Kīlauea is the island's most active volcano with its most recent significant eruption in 2018 lasting over 100 days. Its summit is technically located in the Kaʻū CDP but the impacts of the 2018 eruption overwhelmingly impacted the neighboring CDP of Puna, where the Eastern Rift Zone can be found. Kohala is the oldest of all five County volcanoes, formed 700,000 years ago, and has not erupted in over 120,000 years. It is located in the South Kohala CDP and is largely considered inactive, although it does have two active rift zones. Mauna Kea is an active volcano located in the Hāmākua CDP. It is the highest point on the island, rising nearly 14,000 feet above sea level. Measured from its base (which is largely underwater), Mauna Kea would be the tallest mountain in the world. Mauna Loa is an active volcano located in the Kaʻū CDP, last erupting in 1984. It is widely known as the largest volcano on earth. A sixth submarine volcano is located off of the County's southwest shore: Lōʻihi. Lōʻihi is considered active and last erupted in 2007. Although outside County boundaries, it is located closest to the Kaʻū and Puna CDPs.

An overview of the Volcanic High Hazard Area and associated hazards is provided in ***Figure 4-1***. Due to the density of volcanoes in the County nearly every CDP contains some level of volcano risk (***Figure 4-2***), but the land categorized as lava zones 1 to 3 is largely concentrated in the southern portion of the island, closest to the most active volcanoes (Kīlauea and Mauna Loa). Only Puna, Kaʻū, and Hāmākua CDPs contain lava zone 1 land. Lava zones 2 and 3 are found throughout Puna, Kaʻū, Hāmākua, Hilo and Kona CDPs. North Kohala and South Kohala CDPs are currently assumed to have low volcanic risk and with lava zones 8 and 9. For a full description of the County's volcanic hazards, see ***Section 2 - Hazard Profile*** of this report which describes all volcanic hazards island-wide.

A total of 5.5% of land on the island is classified as lava zone 1 (***Figure 4-1***). The Kaʻū CDP has the largest lava zone 1 land area (81,299 acres), followed by the Puna CDP (43,533 acres) (***Table 4-1***). Over 23% of land countywide is classified as lava zone 2 and is most prevalent in Kaʻū CDP (247,214 acres) and Kona CDP (120,984 acres). For comparison, North Kohala and South Kohala have no acres in lava zones 1 or 2.

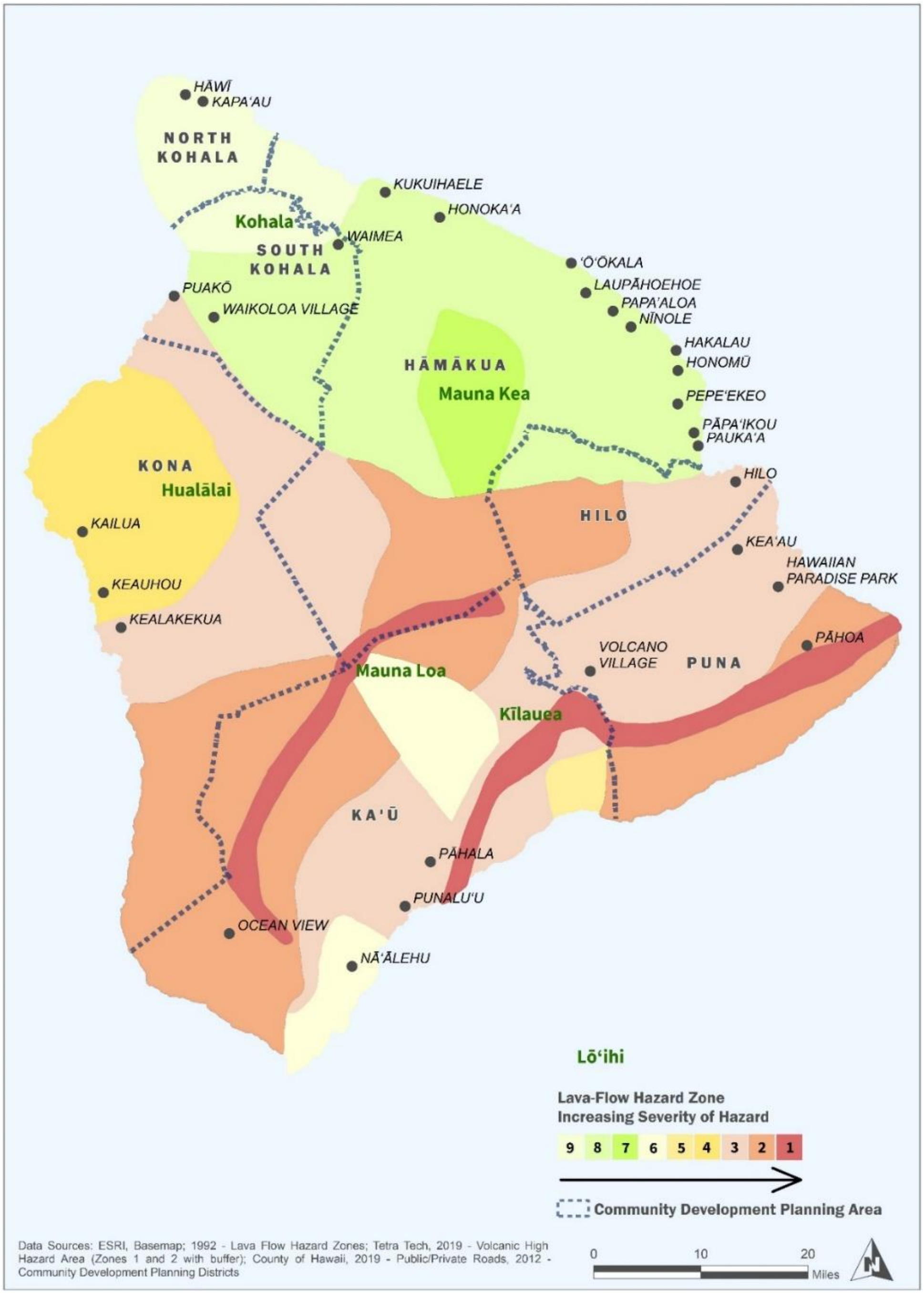


Figure 4-2. Lava Zones in the County of Hawaiʻi

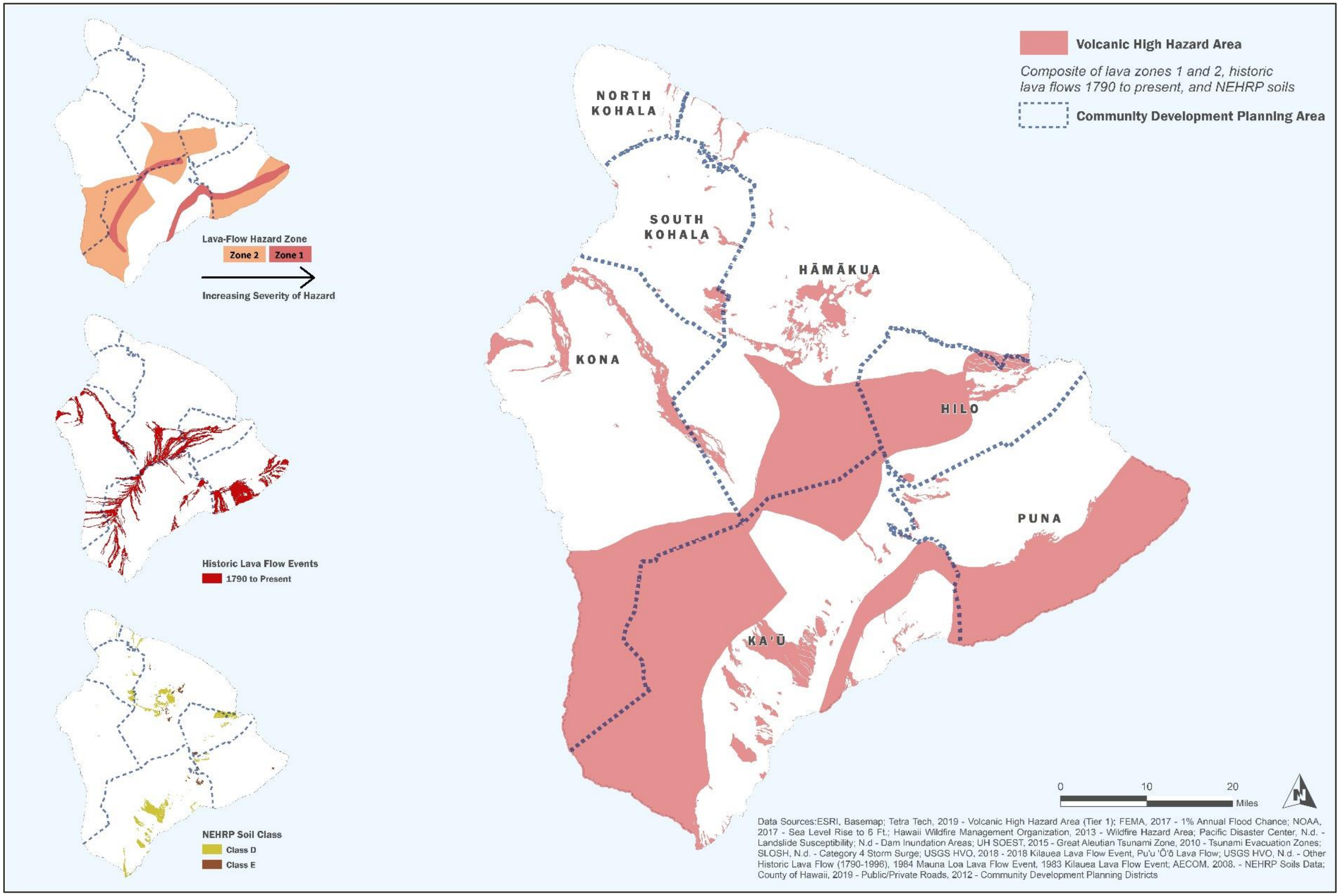


Figure 4-3. Volcanic High Hazard Areas in the County of Hawai‘i

Table 4-1. County of Hawaiʻi Developed vs. Undeveloped Parcel Area by Lava Zone

CDP	Total Area *(acres)*	Lava Zone 1 *(acres)*	Lava Zone 2 *(acres)*	Lava Zone 3 *(acres)*	Lava Zone 4 *(acres)*	Lava Zone 5 *(acres)*	Lava Zone 6 *(acres)*	Lava Zone 7 *(acres)*	Lava Zone 8 *(acres)*	Lava Zone 9 *(acres)*
Hāmākua	**648,934**	**14,556**	**83,124**	**84,757**	**0**	**0**	**0**	**79,650**	**354,768**	**32,019**
Developed	314,670	6,384	50,994	1,406	0	0	0	66,664	185,166	4,040
Undeveloped	334,264	8,172	32,131	83,352	0	0	0	12,986	169,602	27,979
Hilo	**177,757**	**0**	**62,015**	**77,635**	**0**	**0**	**0**	**928**	**37,133**	**0**
Developed	32,476	0	4,659	23,994	0	0	0	211	3,600	0
Undeveloped	145,281	0	57,357	53,641	0	0	0	716	33,533	0
Kaʻū	**653,292**	**81,299**	**247,214**	**192,131**	**0**	**18,308**	**114,292**	**0**	**0**	**0**
Developed	352,175	52,198	164,819	103,672	0	4,640	26,842	0	0	0
Undeveloped	301,117	29,101	82,396	88,459	0	13,669	87,450	0	0	0
Kona	**510,992**	**713**	**120,984**	**191,291**	**197,925**	**0**	**0**	**0**	**51**	**0**
Developed	219,168	0	29,932	90,653	98,567	0	0	0	0	0
Undeveloped	291,824	713	91,052	100,638	99,358	0	0	0	51	0
North Kohala	**79,193**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**79,183**
Developed	24,006	0	0	0	0	0	0	0	0	24,005
Undeveloped	55,187	0	0	0	0	0	0	0	0	55,179
Puna	**324,068**	**43,533**	**96,347**	**184,163**	**0**	**0**	**0**	**0**	**0**	**0**
Developed	50,523	6,780	6,627	37,111	0	0	0	0	0	0
Undeveloped	273,545	36,753	89,720	147,052	0	0	0	0	0	0
South Kohala	**170,056**	**0**	**0**	**14,073**	**0**	**0**	**0**	**0**	**120,058**	**35,863**
Developed	70,997	0	0	5,257	0	0	0	0	45,744	19,986
Undeveloped	99,058	0	0	8,816	0	0	0	0	74,314	15,877

Note: Developed parcels reflect a parcel that contains a building assessment value per the County assessor records.
CDP Community Development Plan

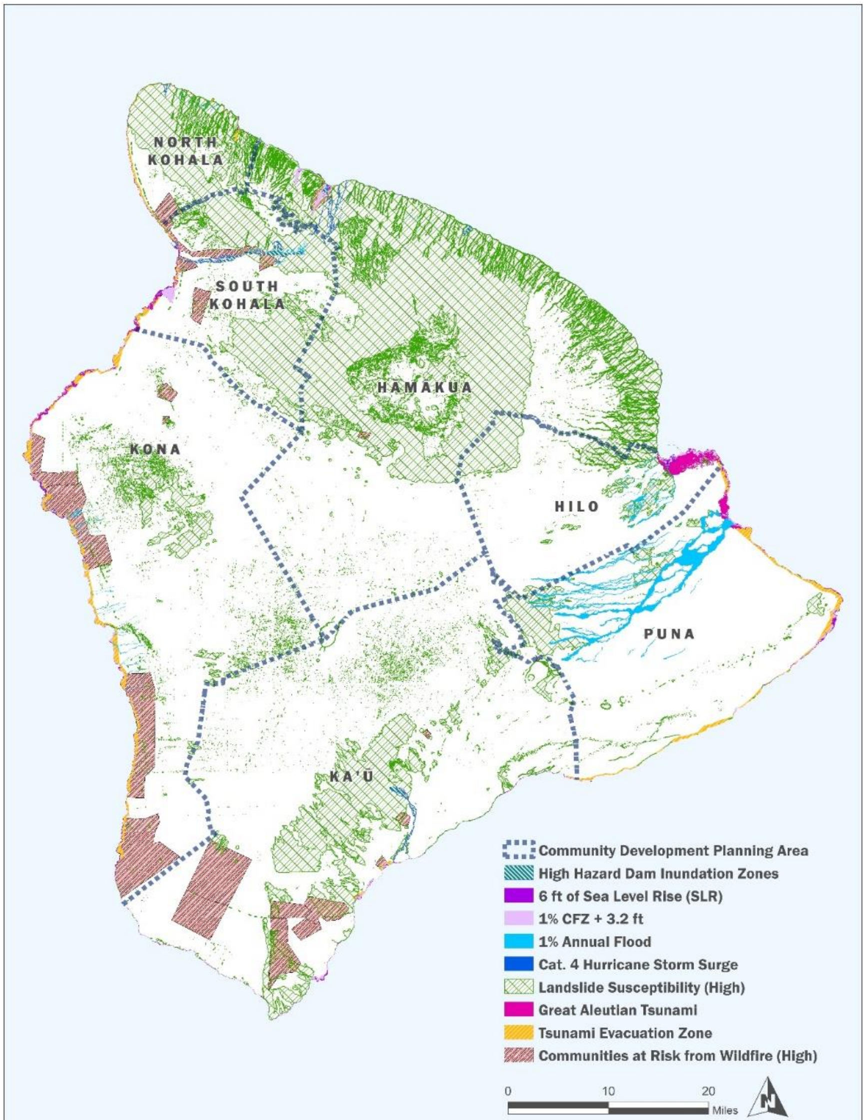
As discussed in ***Section 3*** - ***Methodology***, geographic information system (GIS)-based volcanic hazard areas were aggregated into a single category to identify those areas throughout the County with the greatest volcanic hazard risk: Volcanic High Hazard Area. The Volcanic High Hazard Area includes lava zones 1 and 2, historic lava flow events (1790-2018), and National Earthquake Hazard Reduction Program (NEHRP) D&E soils. Over 30% of the County is located in the Volcanic High Hazard Area (***Table 4-2***). Of that land, more than 40% of parcels contain at least one structure and therefore are considered developed and located in the Volcanic High Hazard Area. The greatest acreage of land is located in lava zone 3, whereas lava zone 5 has the least number of acres (0.71%).

Table 4-2. Volcanic Hazard Areas in the County

Hazard Area	Total Land Area *(acres / %)*	Developed Land *(acres / %)*	Undeveloped Land *(acres / %)*
Volcanic High Hazard Area (VHHA)	874,196 (34.1%)	380,019 (43.5%)	494,177 (56.5%)
Lava Zone 1	140,101 (16%)	65,362 (46.7%)	74,739 (53.3%)
Lava Zone 2	609,685 (23.8%)	257,030 (42.2%)	352,655 (57.8%)
Lava Zone 3	744,050 (29.0%)	262,092 (35.2%)	481,958 (64.8%)
Lava Zone 4	197,925 (7.7%)	98,567 (49.8%)	99,358 (50.2%)
Lava Zone 5	18,309 (0.71%)	4,640 (25.3%)	13,669 (74.7%)
Lava Zone 6	114,292 (4.5%)	26,842 (23.5%)	87,450 (76.5%)
Lava Zone 7	80,578 (3.1%)	66,875 (83%)	13,703 (17%)
Lava Zone 8	512,010 (20.0%)	234,509 (45.8%)	277,500 (54.2%)
Lava Zone 9	147,065 (5.7%)	48,030 (32.7%)	99,035 (67.3%)

Note: Acres in each hazard area was calculated separately as distinct and separate areas; therefore, individual hazard area totals do not equate to the VHHA total.

In addition to volcanic hazards, the County is prone to other natural hazard events. These hazards include tsunamis, earthquakes, flood, tropical cyclones, landslides, subsidence, coastal erosion, sea level rise, high surf, drought and wildfire. There is a significant concentration of landslide risk in the northeast section of the County, centered primarily in Hāmākua and North Kohala. On the drier west coast, there is a concentration of wildfire risk throughout Kaʻū CDP and Kona CDP. Further, as a result of the 2018 Kīlauea event, the lava has developed new terrain and the resulting flood hazard risk in Puna is unknown. In addition to examining the assets exposed to the Volcanic High Hazard Area, it is important to also determine if those assets are located in additional natural high hazard zones to inform the identification of recovery and mitigation strategies. ***Figure 4-4*** illustrates the additional natural high hazard areas located throughout the County of Hawaiʻi. ***Figure 4-5*** shows the combined volcanic high hazard areas and additional natural high hazard areas.



Data Sources: ESRI, Basemap; Tetra Tech, 2019 - Volcanic High Hazard Area (Tier 1); FEMA, 2017 - 1% Annual Flood Chance; NOAA, 2017 - Sea Level Rise to 6 Ft.; Hawaii Wildfire Management Organization, 2013 - Wildfire Hazard Area; Pacific Disaster Center, N.d. - Landslide Susceptibility; N.d - Dam Inundation Areas; UH SOEST, 2015 - Great Aleutian Tsunami Zone, 2010 - Tsunami Evacuation Zones; SLOSH, N.d. - Category 4 Storm Surge; USGS HVO, 2018 - 2018 Kilauea Lava Flow Event, Pu'u 'Ō'ō Lava Flow; USGS HVO, N.d. - Other Historic Lava Flow (1790-1996), 1984 Mauna Loa Lava Flow Event, 1983 Kilauea Lava Flow Event; AECOM, 2008. - NEHRP Soils Data; County of Hawaii, 2019 - Public/Private Roads, 2012 - Community Development Planning Districts

Figure 4-4. Additional High Hazard Areas in the County of Hawaiʻi

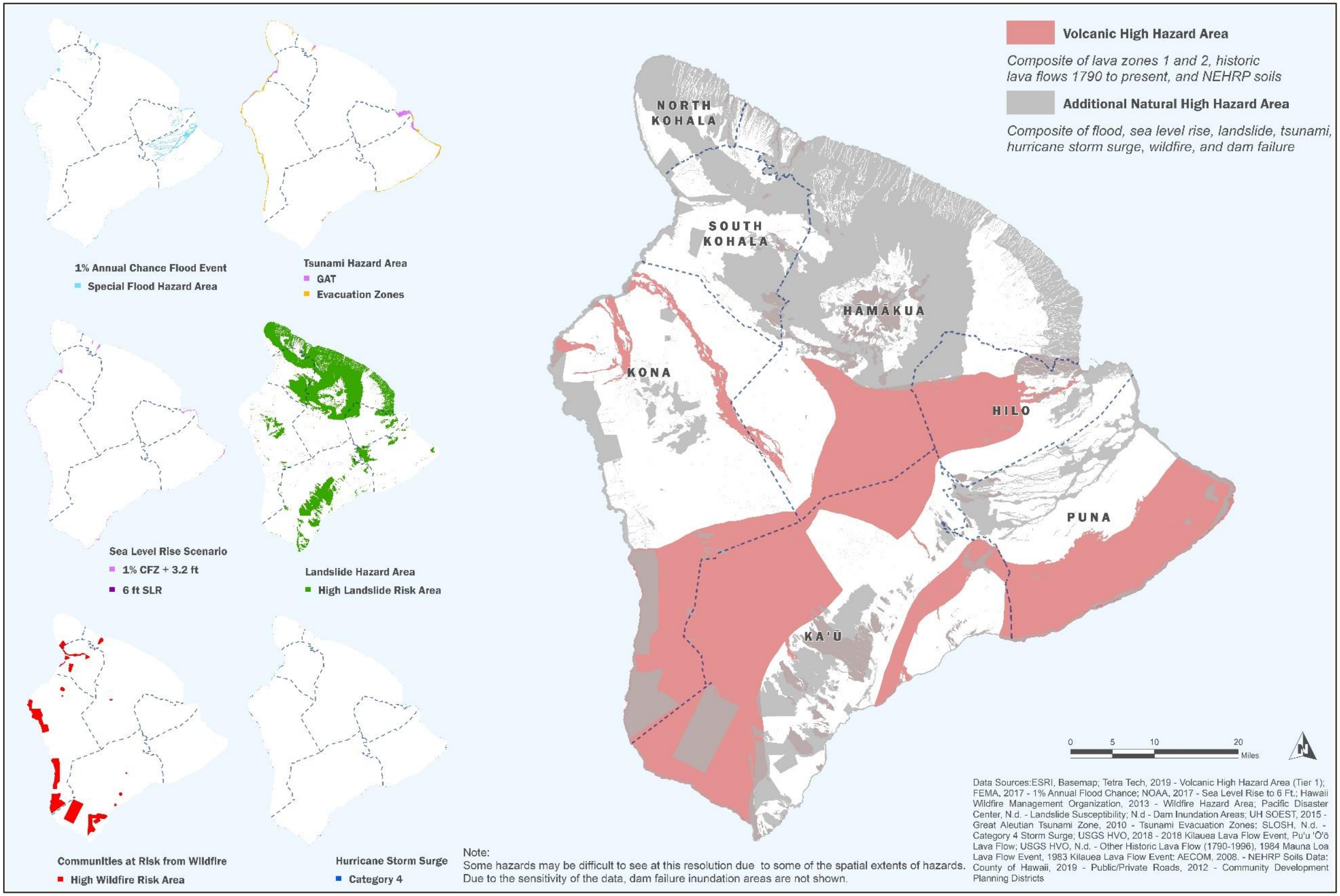
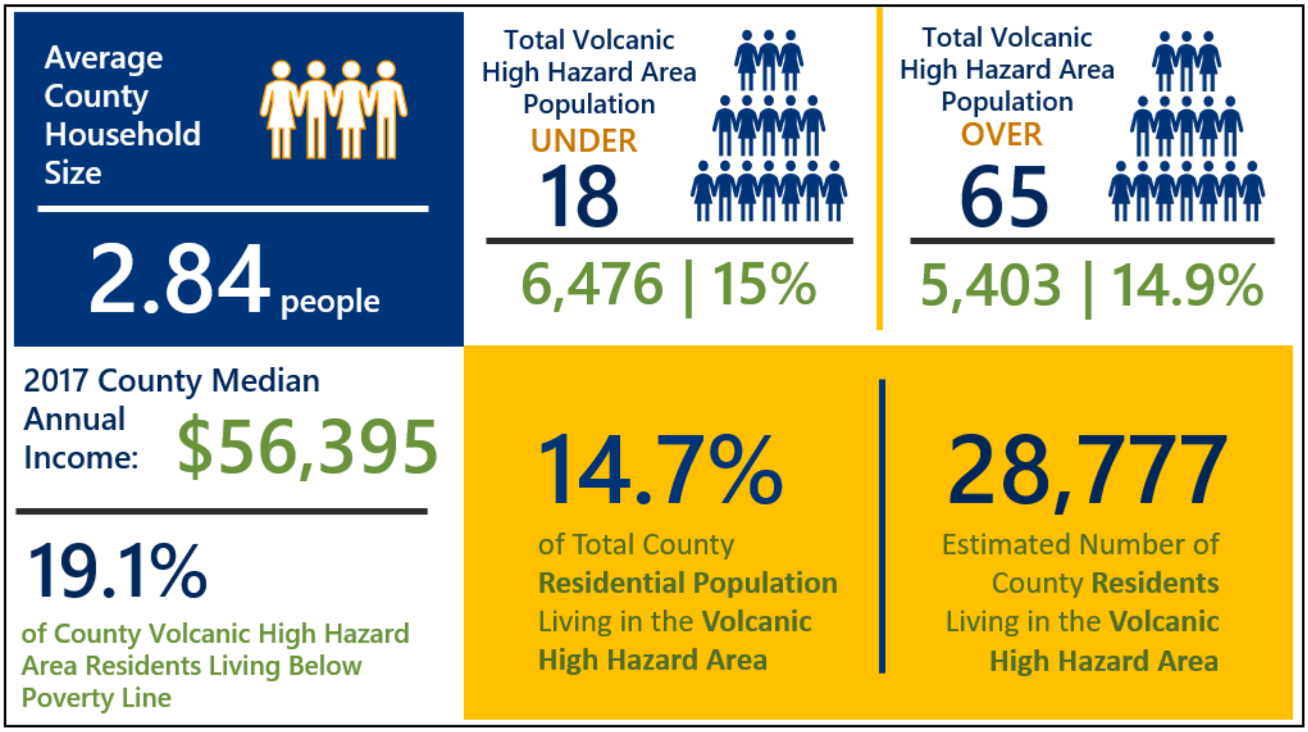


Figure 4-5. Volcanic High Hazard and Additional Natural High Hazard Areas Located in the County of Hawaiʻi

4.1.3 POPULATION



Note: All percentages are relative to the County of Hawaiʻi

Figure 4-6. County of Hawaiʻi Population Exposure to the Volcanic High Hazard Areas

As of 2017, the total population in the County of Hawaiʻi was 200,381 which represents 14.1% of the State's total population (1,424,000) (American Community Survey [ACS] 2017). The 2017 County population reflects an 8.6% population growth since 2010. Since 1983, the population of the County has doubled. According to the 2019 draft County of Hawaiʻi General Plan, the County is expected to grow by 50% by the year 2040. Visitors make up approximately 15% of the population. Similarly, 70% of the growth is from immigration rather than births. A disproportionate percentage of the future population from 2025 and beyond will be seniors, greater than 65 years old (CHPD 2019b). As the County population increases, so too will the numbers of residents at risk to volcanic and other hazards.

As noted in ***Section 3 – Methodology***, examining resident and household exposure to the volcanic hazard is challenging because parcel-level demographic data is generally not available. Instead, demographic statistics from the 2017 ACS were collected for each U.S. Census tract within the County. Each tract's 2017 population count and the number of 2019 residential parcels in the tract were used to calculate the average number of persons per household. This data was then used to conduct the population exposure assessment using each parcel's estimated household size. The results of this analysis are limited based upon the data available and should only be used for planning purposes until higher resolution data is available. An overview of the exposure of the population of to volcanic high hazard areas in provided in ***Figure 4-6***.

The County of Hawaiʻi has 9 distinct lava zones present, ranging from very high risk (1) to low risk (9) (***Figure 4-7)***. As previously noted, there is no current calculated probability associated with each lava-flow hazard zone. The zones,