Cooperator Report to the Federal Emergency Management Agency, Hawai'i County, Hawai'i State Department of Health, and Hawai'i Emergency Management Agency:

Results from the Department of the Interior Strategic Sciences Group Technical Support for the 2018 Kīlauea Eruption

U.S. Department of the Interior Strategic Sciences Group

Lava pours from the ~47m tall cone at Fissure 8 forming a well-established lava flow that extends to the sea. For scale, the white rooftops of spared houses can be seen in the upper left of the photo. Fissure 8 opened on May 5, 2018 in the Leilani Estates Subdivision in Hawai'i. Photo credit: USGS, photo taken June 24, 2018.

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Executive Summary

On May 3, 2018 Hawai'i's Kīlauea volcano erupted, ultimately covering 35 square kilometers (13.5 square miles) of land in lava, destroying over 700 homes in multiple subdivisions, and displacing over 2500 residents in the Puna District on the southeast flank of the volcano. 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. These simultaneous events impacted residential, agricultural, business, tourist, and scientific areas. Hawai'i Volcanoes National Park closed, slowing tourism and the local economy. The building housing the United States Geological Survey (USGS) Hawai'ian Volcano Observatory also closed, displacing scientists responsible for monitoring the erupting volcano. The eruption lasted 107 days, one of the longest eruptions in recent history in lower Puna. 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.

At the direction of the USGS Director, serving as the Science Advisor to the Secretary of the of the Interior, the Department of the Interior (DOI, hereafter also referred to as "the Department") Strategic Sciences Group (SSG) convened a multidisciplinary group of 13 experts in Hilo, Hawai'i, on July 17-19, 2018. The SSG was charged with considering the cascading short- and long-term social, economic, and environmental consequences of the 2018 Kīlauea eruption to DOI resources, employees, and facilities as well as to the surrounding communities. Established in 2012, the SSG is designed to complement ongoing response efforts by providing strategic science to identify potential social, environmental, and economic consequences and potential interventions during a crisis event affecting Departmental resources. This activation of the SSG was funded by the USGS. It was the first official activation of the SSG since it supported Hurricane Sandy recovery in 2013 and provided the unique opportunity to test new methods, including bolstering the social science expertise on the team and interacting directly with stakeholders before, during, and after deployment.

The SSG Kīlauea Team developed three scenarios focused on 1) the impacts of continued seismicity and deformation at the summit; 2) vog (volcanic smog); and 3) the eruption in the lower East Rift Zone. Across all scenarios, areas of concern included human health (physical and mental); biosecurity (for example, protecting threatened and endangered species); infrastructure (impacts caused by seismic activity, vog, and lava); communications (internal and public-facing); long-term planning (related to tourism, access, housing); and ongoing needs for community engagement and empowerment. The SSG Kīlauea Team identified 59 potential actions for mitigation. Highlights of these actions were delivered to stakeholders during briefings in August and September 2018. Examples of potential actions included:

- Seize opportunities to develop new partnerships within and outside of DOI to address facilities issues caused by seismic damage and park closure.
- Educate community members and new workers to increase early detection of invasive species and establish new wash stations to address biosecurity threats to the park posed by more frequent commuting from new temporary Hilo locations.
- Create a "vog officer" position to ensure coordination and consistency in communication about vog hazards across federal, state, and county agencies.

It is important to note that the potential actions are *suggestions* and are not intended to be prescriptive. The SSG uses "blue sky thinking" when developing these potential actions to encourage creative approaches to problem solving. In some cases, some of the suggested potential actions derived by the SSG are actions that were already underway, or already under consideration and helped to affirm activities by different stakeholders. In other cases, the actions may be new ideas. Some were applicable to immediate response, while others are more relevant to long-term recovery.

This report details the results from the July 2018 activation of the SSG. It includes background on Kīlauea and the 2018 eruption, an overview of SSG methodology, and a complete list of the potential actions to mitigate cascading consequences identified by the SSG. Importantly, Appendix 4 includes several rapidly assembled “issue papers” on a variety of topics for consideration for recovery and future preparedness and response activities. This report is designed to be used by both the Department and more broadly by partners, including the Federal Emergency Management Agency, Hawai'i County, Hawai'i Department of Health, and the Hawai'i Emergency Management Agency.

Introduction

The 2018 eruption of Hawai'i’s Kīlauea volcano began on May 3, 2018 and declined rapidly on August 4, 2018. The volcanic alert level was lowered from Warning to Watch on August 17, 2018. The eruption was characterized by two simultaneous hazard events: prolonged seismic activity and collapse at the summit of the volcano and fountaining and the eruption of lava in Kīlauea’s lower East Rift Zone (LERZ) (Neal and others, 2018). Frequent, small earthquakes rattled the summit and surrounding communities, while larger collapse events released the energy equivalent of a magnitude 5.2+/- earthquake every ~8-64 hours with an average of every 28 hours. Occasional weak ash plumes extended up to 10 kilometers (km) (over 6 miles) above sea level and there was potential for abrupt hazardous explosive activity (USGS, 2018a). In the lower East Rift Zone (LERZ), lava erupted at rates over 100 cubic meters per second (over 3,500 cubic feet) (Neal and others, 2018) and ultimately covered 35km^2(13.5 square miles (sq mi) of land. Lava flows extended to the ocean in several locations, creating a new lava delta of approximately 875 acres (nearly 1.4 square miles) (Neal and others, 2018).

The eruption devastated surrounding communities, destroying over 700 houses (Burnett, 2018a). Approximately 2,500 people were evacuated from their homes, sometimes with very little notice. Ultimately, lava covered 58 miles of road, destroyed 900 utility poles, and shuttered the Puna Geothermal Venture energy plant, which had previously supplied 22% of the island’s power (Okinaka, 2018; Perez, 2018). In addition to activity at the summit and LERZ, air quality was compromised by the release of record amounts of sulfur dioxide (SO_2) gas, averaging 15-20 kilotons of SO_2 gas per day (Neal and others, 2018). Volcanic smog, or “vog,” posed respiratory challenges for residents and responders in the affected area and Kona and was detected as far away as Guam.

Most of Hawai'i Volcanoes National Park (HAVO) closed on May 11, 2018, contributing to a significant drop in tourism (for example, Schaefers, 2018; Xinhua, 2018). The USGS Hawai'ian Volcanoes Observatory (HVO) and Pacific Island Ecosystems Research Center (PIERC) also closed, displacing scientists engaged in the response.

To support the Department of the Interior (DOI) and its partners in the response to this event, the USGS activated the DOI Strategic Sciences Group (SSG). The SSG is designed to provide the Department with the capacity to rapidly assemble teams of experts to develop science-based interdisciplinary scenarios of environmental crises affecting DOI resources (Appendix 1). When deployed, the SSG quickly convenes a multidisciplinary team of experts to assess the short- and long-term environmental, social, and economic consequences of the crisis and identify actionable interventions. SSG deployments result in several deliverables: scenarios of cascading consequences, a list of potential actions to mitigate negative cascading consequences, briefings of initial results, and a final report.

On July 17-19, 2018, the SSG convened a multidisciplinary group of experts in Hilo, Hawai'i, to consider the cascading consequences of the 2018 Kīlauea eruption to DOI resources, employees, and facilities as well as to the surrounding communities. The team developed three scenarios to identify potential actions and known knowledge gaps for mitigating the negative effects of the eruption specific to seismic activity and deformation at the summit, vog, and lava in the LERZ. This activation of the SSG was funded by the USGS and was the first time the SSG has been used in an official capacity since it supported recovery from Hurricane Sandy in 2013 (U.S. Department of the Interior Strategic Sciences Group, 2013).

This report details the results from the July 2018 deployment of the SSG. It includes background on Kīlauea and the 2018 eruption, an overview of SSG methodology, and a complete list of the potential actions to mitigate cascading consequences identified by the SSG. Importantly, Appendix 4 includes several rapidly assembled “issue papers” on a variety of topics for consideration for recovery and future preparedness and response activities. This report is designed to be used by both the Department and more broadly by local partners, including Hawai'i County, the Federal Emergency Management Agency (FEMA), Hawai'i Department of Health, and the Hawai'i Emergency Management Agency.

The 2018 Kīlauea Eruption

Kīlauea Geology

Kīlauea is the most active volcano in the world in the 21st century and is one of three active volcanoes on the Big Island of Hawai'i. Located on the southeast side of the island, Kīlauea has a series of embedded craters at its summit (‘the caldera’) and two lines of vents (the ‘rift zones’) that stretch to the east/northeast and southwest of the caldera. Molten rock (magma) is thought to be stored in two vertically stacked regions beneath the summit (H and SC in Figure 1). Eruptions take place when magma and volcanic gases leave the summit storage regions and move towards the surface and/or the rift zones.

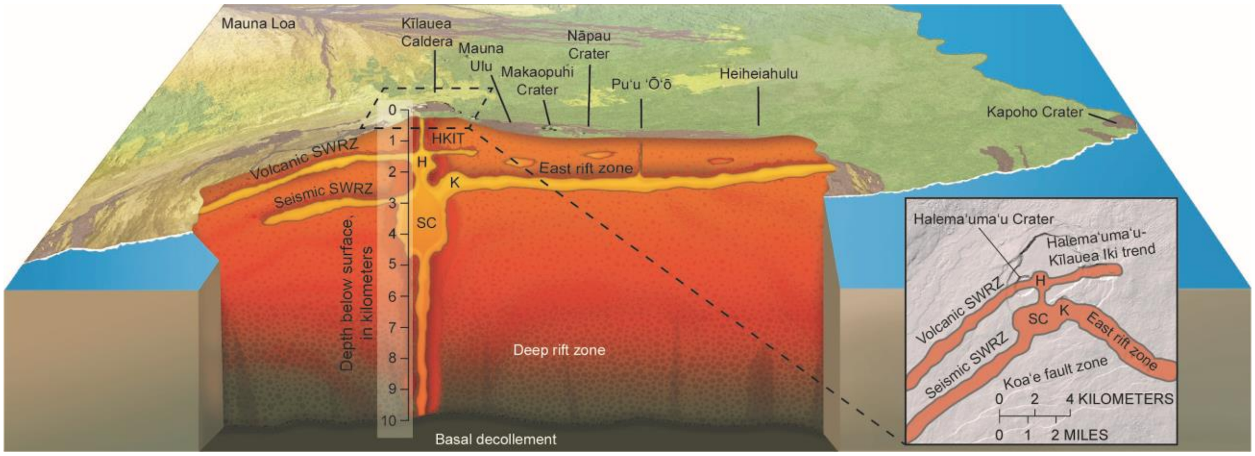

Figure 1: *Illustration of proposed structure of Kīlauea’s subsurface magma plumbing system. Schematic cut-away shows a cross section through Kīlauea’s summit and rift zones. Magma pathways and storage areas are exaggerated in size for clarity. H, Halemaʻumaʻu reservoir; K, Keanakākoʻi reservoir; SC, south caldera reservoir; SWRZ, Southwest Rift Zone. The plan view in the lower right shows the relations of magma pathways to surface features and topography in the vicinity of Kīlauea Caldera, including the East Rift Zone (from Poland and others, 2014).*

The history of Kīlauea's eruptions is well-documented in other publications (for example, Tilling and others, 2010; Poland and others, 2016). Since 1983, eruptive activity has been focused at and near the Pu'u 'Ō'ō cone, 20 km (over 12 miles) down-rift from the summit on the middle part of the East Rift Zone (Orr and others, 2013). In March 2008, a small crater and lava lake formed and began erupting within Halemaʻumaʻu Crater in the summit caldera. This eruption led to increased levels of SO_2 and other gases on Hawai'i and beyond. Prior to 2018, the most recent hazardous eruption in the East Rift Zone was in 2014-2015, which threatened the town of Pahoa in the Puna District, stopping just short of consuming the town (Poland and others, 2016).

Hawai'i is divided into nine lava flow hazard zones used for planning (Figure 2 inset). The southeast flank of Kīlauea is in the Puna District of Hawai'i (Figure 2). Most of Puna is in hazard zones 1 or 2, which include flows that surround the vents, which have a history of frequent lava flows (zone 1) or are adjacent to or downslope from zone 1 areas (zone 2) (Wright and others, 1992).

It is important to note the Puna District is prone to other hazards in addition to lava, vog, and tephra fall. Additional threats include tsunamis, earthquakes, floods, tropical cyclones, landslides and rockfalls, subsidence, coastal erosion, high surf, drought, and wildfire.

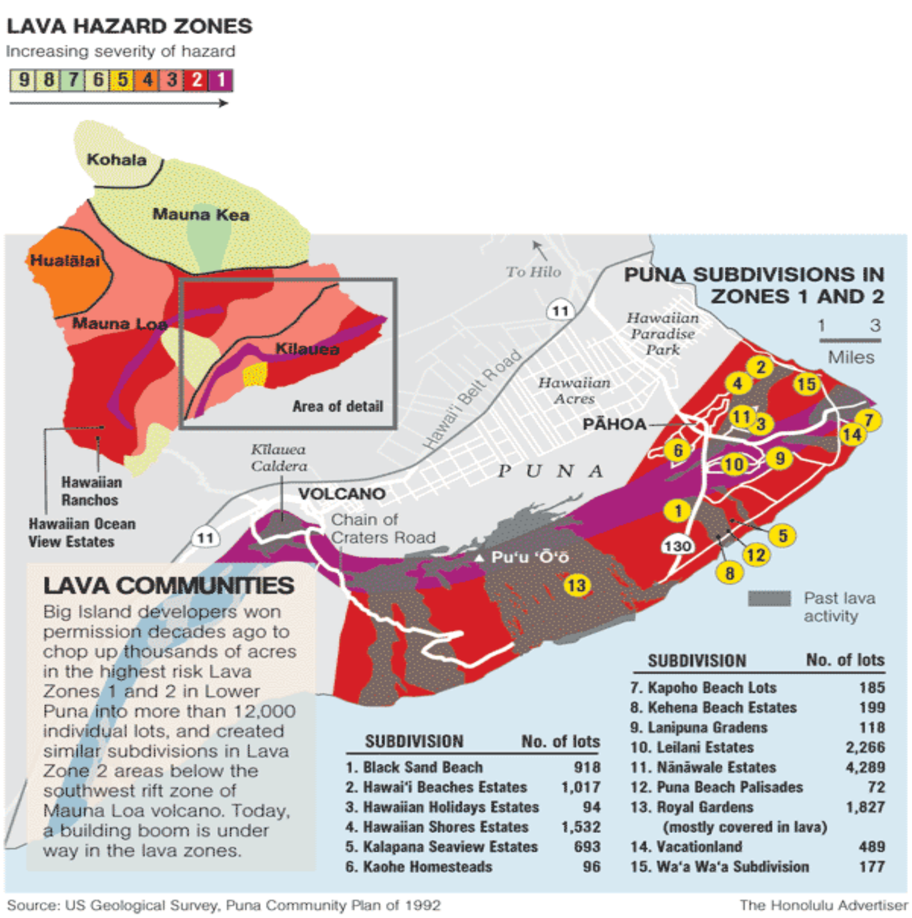

Figure 2: *Hazard zones and subdivisions in the Puna district of Hawai'i. This map shows how Leilani Estates, the epicenter of the 2018 eruption, is located in hazard zone 1. Reprinted with permission, courtesy of the Honolulu Star-Advertiser.*

The 2018 Kīlauea eruption is described by Neal and others (2018), which includes a detailed timeline of the eruption. The LERZ eruption began on May 3, 2018, in the Leilani Estates subdivision. Signs of activity began on April 30, 2018, when the Pu'u ʻŌʻō cone collapsed and magma began to migrate eastward, down rift towards Puna. The lava lake level at the summit began to drop on May 1, 2018, as magma drained. This caused the floor of the main caldera to gradually subside and blocks from the rim and walls of Halemaʻumaʻu Crater to fail more catastrophically. Ultimately, these events enlarged Halemaʻumaʻu Crater to an area of 1 km^2 (0.3 sq mi) and a depth of 500 m (over 1600 feet), the largest collapse volume in 200 years (Neal and others, 2018). In May, small explosive eruptions ejecting ash and blocks of rock accompanied the larger collapses and created dilute ash plumes rising up to 10 km in height. On May 4, 2018, a M6.9 earthquake occurred, 19 km (over 11 mi) south-southwest of Leilani Estates. This was the largest earthquake on the island in 43 years (Neal and others, 2018). As the eruption progressed, a total of 24 fissures opened along the LERZ and lava covered 35.5 km^2 (over 13 sq mi) of land (Neal and others, 2018) (Figure 3). Prior to pausing on August 4, 2018, the 2018 eruption was the longest and largest recent eruption in lower Puna with the second highest eruption rate in Kīlauea's recorded history. This deviation from previous trends introduced significant uncertainty about the duration of the event throughout the eruption (USGS, 2018b).

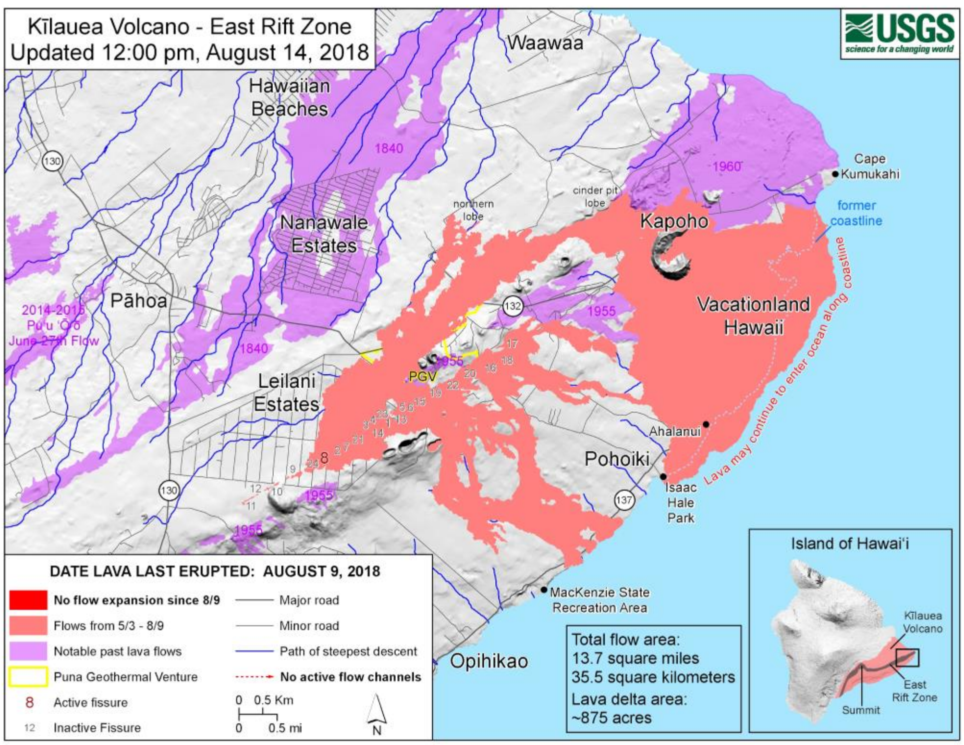

Figure 3: *Map of lava flow coverage as of August 14, 2018. Red areas indicate May 3 - August 14, 2018 activity. Purple denotes lava flows from eruptions between 1840-1960. Credit: USGS.*

Eruption Impacts

Summit Area and DOI Assets

Much of Kīlauea is undeveloped land protected by the Hawai'i Volcanoes National Park (HAVO) (Figure 4), which was founded on August 1, 1916, predating both the establishment of the National Park Service (August 25, 1916) and Hawai'ian statehood (August 21, 1959) (National Park Service, 2018a). The Park has over 2 million visitors each year who spend around $166 million in communities near the park (Cullinae Thomas and others, 2018). This spending supports over 2,000 local jobs (Cullinae Thomas and others, 2018Cullinae Thomas and others, 2018). While geologic sites are the primary feature of HAVO, the Park has made painstaking efforts to preserve, protect, and restore the unique native flora and fauna present on the island from the impacts of invasive plants, animals, and insects that have decimated much of the habitat outside of Park boundaries. Fences, repeated surveillance, and education campaigns are all part of these efforts. The park also protects a range of prehistoric Native Hawaiian and Euro/American historic sites and is a site of spiritual significance for Native Hawaiian communities today.

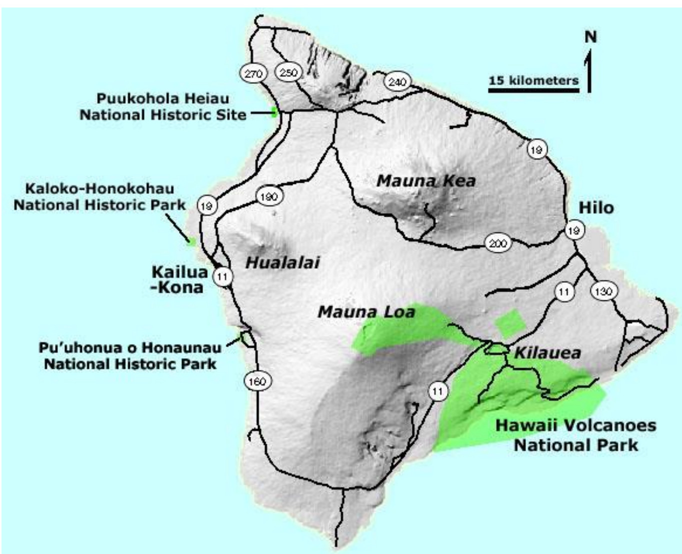

Figure 4: *Much of Kīlauea volcano is undeveloped land protected as Hawai'i Volcanoes National Park. Credit: USGS.*

For USGS, HAVO has been home to the HVO, which is perched on the northwest rim of the summit caldera near the Park's Jaggar Museum. The observatory was established in 1912 and hosted an average of 25 scientists as well as a variety of critical geophysical instruments, laboratories, and radio systems critical to monitoring the volcano. Hundreds of volunteers have helped HVO's scientific mission. HAVO is also home to the USGS Pacific Island Ecosystems Research Center (PIERC), which was established in 1994 to serve the needs of resource managers to tackle current and emerging critical conservation issues (USGS Pacific Island Ecosystems Research Center, 2014). PIERC hosts a staff of approximately 20-25 scientists and an average of six volunteers.

At the summit, frequent earthquakes and collapse events led to significant damage to infrastructure and roads in HAVO. Most of the Park closed on May 11, 2018, due to increased volcanic and seismic activity of Kīlauea volcano. The events caused unprecedented damage to park infrastructure, including building damage, rock falls, deep cracks in roads and trails, and numerous breaks to water and sewer lines

(National Park Service, 2018b). The seismic activity at the summit forced the closure of HVO and PIERC (Figure 5a). Staff were moved to interim facilities in Hilo or asked to telework (Figure 5b). Along with these closures, some instruments placed within the caldera to monitor volcanic activity were either destroyed or lost connection with HVO systems due to the rapid subsidence in the crater. In addition to damage in the Park, surrounding gateway communities including Volcano suffered minor structural damage to homes and businesses due to frequent ground shaking and residents experienced emotional hardship due to the uncertainty of the duration of the eruption. Hotels, shops, and service-providers lost business and in some cases were shuttered due to the closure of the Park and tourists' concern about personal safety (for example, Brestovansky, 2018).

Lower East Rift Zone

There are many communities and subdivisions in the Puna District including Leilani Estates, Lanipuna Gardens, Nanawale Estates, Vacationland, and Kapoho Beach (Figure 2). Most residents in these areas rely on catchment systems for water supply and many residents live "off-the-grid" and are not connected to central power. According to the 2012 Puna Community Development Plan, "Puna is experiencing the fastest rate of growth of all the districts in the County of Hawaiʻi. The Census population count in 2000 for Puna was 31,335. In March 2007 the estimated population was 43,071, an increase of over 37% in less than 7 years. By 2030, the population is projected to grow to approximately 75,000" (Hawai'i County Planning Department, 2012). The 2012 report goes on to note, "an increasing number of people and property improvements are being put at risk due to natural hazard." Complicating the increasing population in the area, the Puna District has a high percentage of low income residents (for example, the 2017 median annual income of residents in Pahoa was $31,176 -- one of the lowest incomes on the island) (U.S. Census Bureau, 2013-2017 American Community Survey 5-Year Estimates) and there are "many residents without adequate housing" (Puna Community Development Plan, 2012, p. 3-11). Beyond the residential areas, the Puna District includes agricultural, commercial, and protected areas. Agriculture in the region includes papaya, marijuana, and orchid farming. The area's tide pools, surfing spots, and Lava Tree State Park attracts locals and tourists alike.

As a whole, tourism is the single largest contributor to Hawai'i's gross domestic product. With tourists spending more than $15 billion annually statewide, tourism makes up more than 24% of the state's economy (Hawaiʻi Tourism Authority, 2016). Hawai'i Island accounts for 14% of the state's total tourism (Hawai'i Guide, 2018).

Because Kīlauea has been active for so long, there is a certain cultural acceptance of many of the hazards in the area (for example, Romero, 2018). Some residents whose homes were destroyed in previous lava flows have rebuilt on top of the lava. Others who lost their homes in the 2018 eruption were resigned to Madame Pele "cleaning house" and left offerings to the goddess of fire as lava encroached on their communities. However, this was not a universally shared sentiment, especially among newcomers to the area. Due to the sustained high levels of uncertainty about the duration and extent of the 2018 eruption, tensions were high among residents and responders.

Large lava flows covered land southeast of HAVO (Figure 5c) and had devastating effects on residential communities (Figure 5d). The majority of homes that were destroyed, isolated, or forced to be vacated by mandatory evacuation were owner-occupied. It is estimated that there were 800 domesticated animals present in the affected area before the eruption (Kimura, pers. comm., 2018 and June 27th [2014] Lava Flow Community Needs Survey website, 2018). 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. During the eruption, Puna community members established the Pu'uhonua o Puna Information and Supply Hub (“the Hub”) to help displaced residents find supplies and information resources.

Although the eruption stimulated parts of the local tourism economy (for example, lava tours by helicopter and boat), tourism dropped by an estimated 5% between May and June on Hawai'i Island, losing an estimated 38 thousand visitors and $50 million for the months of May and June alone (Schaefers, 2018). In addition, on July 16, 2018, 23 tourists on a tour boat were severely injured by an ocean entry explosion, underscoring the challenges of safeguarding residents and tourists alike during this event (Burnett, 2018b; Associated Press, 2019).

Vog

Vog, or volcanic fog, is a visible haze composed of water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), and particulate matter (PM) including acid droplets and is present on Hawai'i at elevated levels during eruptions (Elias and Sutton, 2017; Hawai'i Interagency Vog Information Dashboard, 2018). While volcanic emissions have been a component of all Hawaiian eruptions, they have only become a major nuisance because of the increase in population in the last few decades in downwind areas. Starting in May 2018, the LERZ was releasing between 15 and 20 kilotons of SO_2 gas per day or about 50x the emissions from the top SO_2-producing U.S. power plant (Elias, pers. comm., 2018). As SO_2 was released from Kīlauea’s eruptive vents, it converted to fine particles in the atmosphere, and was blown by prevailing trade winds to the communities to the southwest. Regular ash emissions from the summit of Kīlauea, and an acidic ocean entry plume generated as lava flows into the sea, known as ‘laze’ (Figure 5e), also contributed to poor air quality in downwind locations. Populations in the downwind areas were chronically exposed to elevated levels of SO_2 gas and acidic sulfate aerosol, with unquantified concentrations of other pollutants which could include hydrochloric acid (HCl), hydrofluoric acid (HF), volcanic glass, and a variety of metals. Downwind populations were understandably concerned about the effects of this volcanic pollution on their families and communities. At times during the eruption, concentrations of $PM_{2.5}$ (fine particles that can be inhaled deep into the lung) reached levels considered ‘unhealthy’ by U.S. regulatory agencies, and regularly reached concentrations designated as ‘unhealthy for sensitive groups.’ During some wind conditions, the entire island and state are affected by the volcanic pollution from Kīlauea. Particulates related to Kīlauea even were found as far away as Guam, over 6,000km (3,500 miles) away.

Figure 5: a) *Aerial photo of Halemaʻumaʻu and part of the Kīlauea caldera floor during a helicopter overflight of Kīlauea's summit on July 13, 2018. In the lower third of the image, you can see the buildings that housed the USGS Hawai'ian Volcano Observatory and Hawaiʻi Volcanoes National Park's Jaggar Museum, the museum parking area, and a section of the Park's Crater Rim Drive. The drab gray landscape is a result of multiple thin layers of ash that have blanketed the summit area during the ongoing explosions. Photo credit: USGS, Photo Taken July 13, 2018.* ***b)*** *Due to the potential dangers from eruptive events at the summit during the eruption, HVO employees were relocated to a temporary location in Hilo or asked to telework. Photo credit: S. Brantley, USGS. Photo taken July 2018.* ***c)*** *Fountains from Fissure 20 in Kīlauea Volcano's lower East Rift Zone. Photo credit: USGS. Photo taken May 19, 2018.* ***d)*** *The remains of a destroyed home in the Leilani Estates Subdivision. Photo credit: Anna Stull, USGS. Photo Taken July 18, 2018. e) Laze plumes near the ocean entry of lava from the 2018 Kīlauea eruption. Photo credit: Anna Stull, USGS. Photo Taken July 12, 2018.*

SSG Kīlauea Activation

Charge

On July 3, 2018, the SSG received direction from the Director of the USGS, serving as Science Advisor to the Secretary of the DOI, to stand up a technical support team to assist DOI in its ongoing role in the Kīlauea eruption. The SSG was directed to examine the short- and long-term social, economic, and environmental cascading consequences of the 2018 Kīlauea eruption to support the DOI and as appropriate, the needs of local stakeholders including the Hawai'i Emergency Management Agency, Hawai'i Civil Defense, the Federal Emergency Management Agency, and others. The full description of the charge is in Appendix 2.

Methods

Reconnaissance Trip

At the direction of the SSG Co-Leader, the SSG Staff Scientist conducted a June 11-15, 2018 reconnaissance trip to meet with stakeholders to determine issues of concern and applicability of SSG methods. This was the first time the SSG has conducted such a trip. Support provided by the DOI Senior Interagency Liaison Cadre (SILC) Liaisons in Hilo and the HVO Scientist in Charge proved critical for making on-the-ground connections with a variety of stakeholders. Major issues of interest included: social and economic impacts, health outcomes, evacuation and relocation of affected populations, and new or cascading events (for example, a major summit eruption or hurricane). Stakeholders were interested in these issues over both the short- and long-term. The trip proved to be a valuable tool for information gathering and making contacts, and findings shaped the scope of the SSG scenarios once the SSG was activated.

SSG Kīlauea Team Formation

Between July 3 and July 13, 2018, the SSG established a team of 13 experts tailored to the 2018 Kīlauea eruption. SSG staff first identified the types of expertise needed, including experts in native Hawai'ian culture; natural resources; economics; geography; public health; risk communication; social/behavioral science; structural engineering; materials science; urban planning; vog geochemistry; and volcanology. SSG staff then used the SSG's network of professional society partners and professional contacts to identify and invite experts to fill the roster for the SSG Kīlauea Team. All areas of expertise were filled other than a specialist in materials science, who could not arrange travel in time to attend the meeting. The SSG Kīlauea Team included two NPS employees, three USGS employees, and one displaced resident who had lost her home to the eruption in Leilani Estates. Two thirds of the team members were Hawai'i residents. Participants are listed in Appendix 3.

Scenario Building

The following methods were developed by the DOI Strategic Sciences Working Group in 2010 (U.S. Department of the Interior, 2010 and 2012) and refined by the SSG in 2013 (U.S. Department of the Interior Strategic Sciences Group, 2013). The SSG staff defined the timing and geographic scope of the scenarios based on information from the reconnaissance trip. The scenarios focused on the short- and long-term (next 10 years) impacts of 1) continued seismicity and deformation at the summit; 2) vog); and

3) the eruption in the LERZ. Next, the SSG developed scenarios using facilitated discussion among the SSG Kīlauea Team members during the July 17-19, 2018 meeting to identify the cascading consequences for each scenario. SmartDraw™ software was used to illustrate the scenarios (see example in Figure 6) in real time during group discussions. The group used the scenario discussions to develop potential actions that could be taken by a decision maker to mitigate negative cascading consequences.

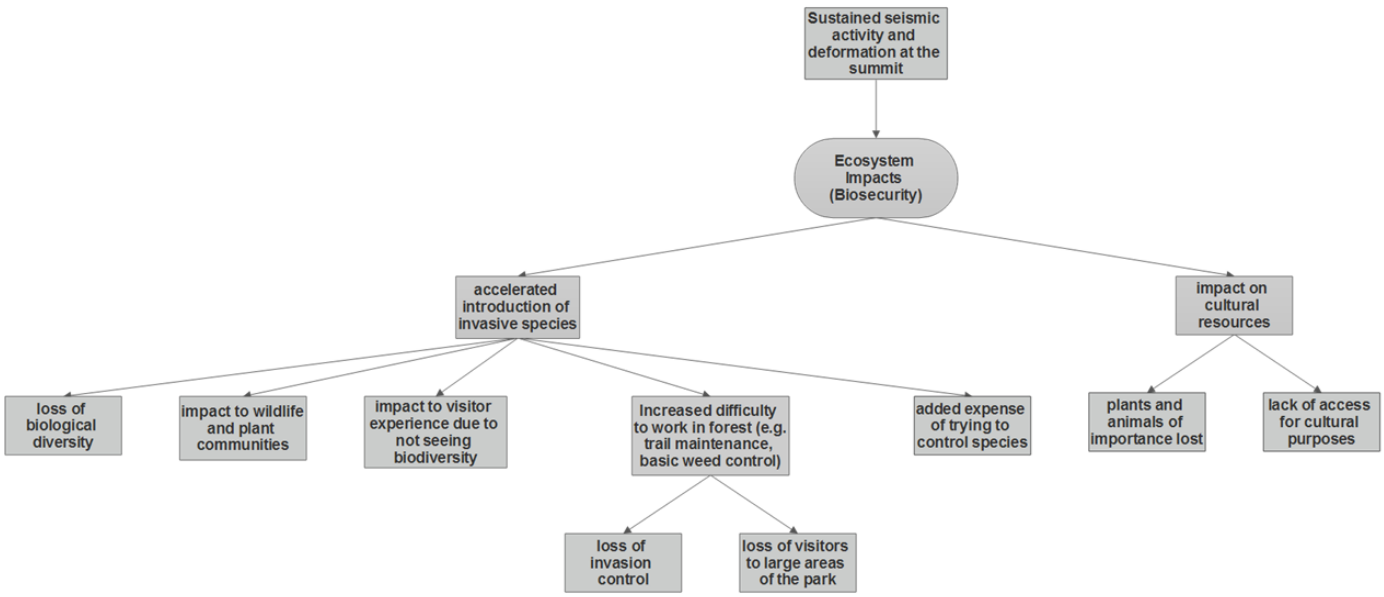

Figure 6: *Example of an SSG scenario created using SmartDraw™ software. This example shows a small segment of the chain of consequences stemming from sustained seismic activity and deformation at the summit.*

It is important to note that the potential actions are *suggestions*, generated quickly (three days) by a group of experts. These actions are not intended to be prescriptive. In some cases, suggested potential actions derived by the SSG are already underway, or are already under consideration. In such cases, the SSG can help to affirm activities by different stakeholders. In other cases, the actions may be new ideas. The SSG uses “blue sky thinking” when developing these potential actions to encourage creative approaches to problem solving.

Across all scenarios, areas of concern included human health (physical and mental); biosecurity (for example, protecting threatened and endangered species); infrastructure (impacts caused by seismic activity, vog, and lava); communications (internal and public-facing); long-term planning (tourism, access, housing); and ongoing needs for community engagement and empowerment. Following discussion with stakeholders and reviewing findings during the workshop, workshop participants identified subject areas that required further research on their part. Participants with relevant expertise provided brief concept papers on these topics in the two weeks following the workshop and these are included in Appendix 4.

Briefings

SSG staff presented key potential actions to stakeholders during a series of briefings in July-September 2018. The potential actions developed during the July 17-19, 2018 discussions were clarified and elaborated on by SSG staff and are included in the Results section of this report. It is important to note some of these were applicable to immediate response, while other actions are more relevant to long-term recovery and economic diversification. While some of these actions may no longer be applicable to the current situation in Hawai'i, they may be useful to consider should a similar event occur again in the future.

Results: Potential Actions and Future Considerations

Scenario 1: Seismic and Collapse Activity at the Summit

Scenario 1 assessed the short- and long- term cascading consequences of continued collapse of the Halema'uma'u Crater and associated deformation and ongoing seismicity at the summit of Kīlauea. Discussion topics included health (both mental and physical), facilities (with a special focus on DOI facilities); tourism and economics of the region; biosecurity; community engagement; and cultural practices. As a result, the team identified 25 potential actions that could be taken to mitigate potential future negative cascading consequences.

These actions are listed below and have been organized into categories by the SSG staff. They are not ranked. Some are relevant to short-term response, others are more relevant to long-term recovery.

Table 1: *Potential Actions to Mitigate Consequences of Seismic Activity at Kīlauea Summit*

Category	Potential Action
	Addressing Economic Losses Due to Park Closure
Tourism/Economics	**Promote alternative tourism options to Hawai'i Volcanoes National Park:** Examples include: agricultural tourism, promotion of local art communities, and local cultural events (for example, festivals). Additional options include promoting tourism sites outside the core of the Park, such as rainforest ecotourism, hiking, and camping near Mauna Loa and/or Kamehameha Schools/Bishop Estates Lands and other state area trails. Creating bike trails in the Volcano area may support bike tourism. Holding a "meet a ranger day" in Volcano/other locations is another potential option to safely share information about ongoing volcanic activity. *During eruptions when the Park is closed, the region would benefit from the promotion of alternative activities to continue to draw tourists to the Volcano area and surrounding gateway communities. The region offers many potential options for ecotourism, agricultural tourism, and outdoor activities where some would need additional infrastructure (for example, bike lanes) and others already exist and would benefit from additional public promotion.*

Tourism/Economics	**Continue geologic tourism to Hawai'i Volcanoes National Park during the eruption:** Create controlled, safe access to the Park wherein visitors are able to experience the activity with registered guides and/or commercial operators. *Similar to viewing the semi-regular eruptions of Old Faithful geyser in Yellowstone National Park, some tourists may be able to "schedule" an experience of ground motion near the summit during a collapse event. Alternatively, devise a way to establish an earthquake simulator in the area as a safe option for tourists to experience seismic activity. This could be advertised as a unique opportunity to "experience an earthquake" and draw tourists to the Volcano area.*
Tourism/Economics	**Expand focus of Park tourism:** Expand focus of park tourism from the summit area to tropical rainforest biodiversity, cultural history, and Hawai'ian traditions. Focus on Kahuku and Ola'a Tracts. *While most of Hawai'i Volcanoes National Park was closed starting May 11, 2018, the Kahuku and Ola'a areas remained open to visitors, representing an important area for additional tourism. Starting August 15, 2018, the Park extended hours for tourists visiting the Kahuku Unit (*National Park Service, 2018c*)*
Economics	**Create fertile ground for a diversified economy:** Subsidize non-tourism-based companies (for example tech companies) to come to Hawai'i. Create economic opportunity zones or consider not charging taxes for a certain number of years to stimulate new businesses in the county. *Developing lucrative alternatives to the tourism industry would create an economic safety net for the island's economy if a similar event occurred in the future. Currently 17% of the island's workforce is employed in the tourism industry (Hawai'i Island Chamber of Commerce, 2018).*
City and Regional Planning	**Move Park visitor center to Volcano:** Create a state-of-the-art visitor center annex in Volcano that uses drone footage and collapse simulations to interpret recent activity at the summit. Use existing planning documents to guide this process (for example the General Park Management Plan, which "presents strategies for the protection, preservation, and management of shared values at Hawai'i Volcanoes National Park" (National Park Service, 2016). *Should a similar event happen in the future and given the 2018 eruption damage to Park infrastructure, it may be worth considering creating a new visitor center in Volcano where visitors could safely learn about the Park. Images, data, and video footage from the 2018 eruption could be highlighted in new exhibits.*
City and Regional Planning	**Increase access to the Volcano area to stimulate tourism:** Increase public transit routes to Volcano from Hilo or other populated areas. *Private tour operators bring visitors from Hilo to Volcano, but the Volcano area may benefit from public transit options for tourists to access Volcano from Hilo.*

	Address concerns of summit access for cultural practitioners
Culture	**Ensure cultural practitioners have access to the caldera area to prevent loss of recorded oral history:** Create process to facilitate access for cultural practitioners to access the summit area to write chants documenting the collapse of the summit. *Traditionally, Hawai'i residents and cultural practitioners have recorded geologic history though chants and stories. At the time of the SSG meeting, there were concerns that cultural practitioners may have encountered challenges in accessing the caldera. Enabling cultural practitioners to access the summit is critical to preserving and encouraging the tradition of recording oral history.*
	Addressing Potential Seismic Damage to Structures and Infrastructure
Facilities	**Support building retrofits:** Create a program to allow public institutions and homeowners to retrofit structures and homes to prepare for earthquakes. Prioritize schools, hospitals, and other critical services. *Although none of the seismic events occurring near and around the summit were enough to destroy a structure, the constant shaking from multiple earthquakes per day could cause cumulative damage over time. Looking forward, retrofits may ensure the seismic safety of buildings and homes.*
Facilities	**Enforce existing building codes:** Conduct regular inspections of critical services buildings as well as private dwellings to ensure seismic (and general structural) safety. *Ensuring that buildings are kept up to code will ensure their safety in the face of ongoing seismic events. Enforcing building codes would ensure that dangerous shortcuts were not taken and that structures have a minimal level of security.*
Facilities	**Launch seismic safety education plan**: Create curriculum materials for teachers to educate students on seismic safety and potential seismic impacts to structures. *Educating school children is one method of educating a community. There may be potential for collaboration between USGS, NPS, and local schools in this endeavor.*
City and Regional Planning	**Consider encouraging managed retreat:** For areas like the Golf Course Community that were potentially losing access due to seismic activity and sinkholes, encourage communities to take up residence elsewhere in the case of future, similar events. *Although managed retreat is often a very unpopular proposition, it can effectively remove residents from hazardous areas. It would be important to take a multi-hazard approach in relocating these residents, however, to ensure that residents moved to areas that were hazard-free. Should a summit collapse event like 2018 happen again, fewer residents in harm's way would prevent losses and conserve response resources.*

Emergency Management/City and Regional Planning	**Plan for evacuation:** In the event of more catastrophic eruptions in the future, community members should be encouraged to create personal evacuation and meet-up plans. *Thinking through personal evacuation and meet-up plans is a practice that can be useful in the event of multiple hazards, not just eruptions. Materials available at ready.gov are available to help with this type of planning.*
Health	**Address health care access issues:** Address limited access to health care caused by road closures or fear of seismicity using telemedicine. Recruit doctors and nurses from off-island to mitigate increased stress to on-island health care providers. Introduce or expand access to telemedicine. *Telemedicine is a good option to alleviate stress associated with access to healthcare. It may also expand the number of people who have access to healthcare in rural or remote communities. Using off-island support will alleviate stress on an already heavily used system.*
	Addressing Potential Mental Health Issues Caused by Stress of Ongoing Seismicity
Health	**Initiate mental health related public service campaigns:** Create campaigns on billboards, radio, or other media outlets to encourage reflection and conversation about the eruption experience and potential mental health issues. Encourage caregivers and teachers to seek out mental health services to moderate post-traumatic stress disorder. *Normalizing mental health concerns and creating a supportive community to help address them is one way to reduce stigmatization of mental health disorders as well as long-term mental health problems in communities affected by disasters. New Zealand's "All Right" campaign, launched in 2013 following the Christchurch earthquake, encourages community members to reach out to each other and talk about how they are feeling, consider how to feel better, and to encourage each other to get help, if needed (All Right campaign website, 2018).*
	Addressing DOI Facilities Issues Caused by Summit Collapse and Park Closure
Facilities	**Support redundancy and relocation efforts:** Support ongoing efforts to create redundancy for HVO instrumentation through alternate instrumentation or siting. *HVO is a critical resource for data collection and dissemination. Given its location in an area prone to explosive eruptive events, it is important to find ways to create redundancy for its operations to allow for seamless data collection.*
Facilities	**Establish regular building integrity check-ups:** Identify minor cracking or damage to DOI structures in order to prevent weather damage. Conduct regular maintenance of damage incurred to stop larger issues. Engage licensed structural engineers in this process. *The sustained magma withdrawal and collapses at the summit caused damage to HVO, the Jaggar Museum, and other Park structures, however most were not professionally inspected during the eruption. With ongoing seismic activity, small*

	cracks or fissures can lead to weather-related water leaks which can create much more harm to building interiors through mold, rot, or damage to furniture, carpeting, or drywall. Identifying and repairing minor damage through regular maintenance and assessment can ensure that these secondary issues do not occur. Using licensed professionals will ensure that this process is undertaken correctly and in keeping with existing building codes and specifications.
Facilities	**Seize opportunity to develop collaborative spaces and new partnerships:** Develop a collaborative space that can accommodate HVO, PIERC, and the NPS in one building to foster collaboration. Potential co-location options include University of Hawai'i (UH) Hilo and Kamehameha Schools. *When deliberating new locations and/or facilities for DOI employees, consider that co-locating DOI employees and/or academic and traditional scientists (i.e., cultural practitioners) may result in beneficial new partnerships and research agendas. Collaborative space can also act as a means of drawing in new and different types of expertise and may offer new opportunities for outreach in local schools and communities.*
Facilities	**Develop a new field station in Hawai'i Volcanoes National Park:** If the current HVO facility is determined to be unusable, USGS and NPS staff could use this loss as an opportunity to create a new, joint field station within the park. *HVO was originally located at the rim of the Kīlauea caldera because the potential impact of future summit collapses and explosive eruptions were under-estimated. Scientists are constantly out in the field conducting experiments on the landscape. If HVO is lost, it is important to create a new facility within the Park in order to make it possible for scientists to easily continue their research, as well as to minimize commuting time, and maintain the exchange between HVO and National Park visitors and staff.*
Health	**Establish enhanced wellness programs for employees:** Capitalize on the disruption of employees moving into new facilities (temporary or permanent) to ensure a healthy workplace. Promote exercise programs and wellness activities. Examine work shift limits for future eruptions. *A shift in physical location may allow for employees and supervisors to establish new habits and activities to promote workplace health. These activities may also serve to relieve stress, build community, and improve productivity in the wake of the disaster.*
	Address Limited Communication and Uncertainty Amongst and Within Affected DOI Entities
Employees and Communication	**Establish consistent communication/collaboration amongst DOI Groups and partners:** Find a way for DOI Groups (for example, NPS, HVO, and PIERC staff) and partners (for example, UH Hilo, local cultural practitioners) to meet on a semi-regular basis to discuss biosecurity, facilities, and other issues. *Although NPS and USGS employees in Hawai'i are all under the same DOI umbrella, there are limited opportunities for formal discussion about shared interests, issues, and facilities. Opportunities for ensuring consistent communication across DOI*

	bureaus may include DOI Town Hall meetings and creating a formalized research agenda across PIERC, HVO, HAVO, UH Hilo, and cultural practitioners. Coordination is critical to reducing duplication of efforts, and to leveraging existing resources appropriately, and to enhancing partnerships. Semi-regular meetings during non-response times may improve collaboration across bureaus and ultimately improve response to future hazard events.
Employees and Communication	**Address uncertainty amongst DOI Staff:** Develop trigger points or thresholds of decision-making as to when the "temporary" situation will become permanent. Clearly communicate these trigger points and involve DOI staff in the decision-making process as much as possible. *At the time of the SSG meeting, there was uncertainty as to the future of USGS and NPS facilities, as well as to how decisions were being made at higher levels. Developing and communicating decision points would improve understanding about the decision-making process.*
	Address Biosecurity Threats to the Park Posed by More Frequent Commuting from Hilo, New Groups Using the Park, and Loss of Surveillance and Mitigation Capacity
Natural Resources	**Establish new vehicle wash stations:** Establish new vehicle wash stations at the entrance of HAVO and within the Volcano community. Creating a business tax-credit to start a car wash facility in the community may help spur development of these wash stations. *Because Hawai'i Volcanoes National Park (HAVO) has worked hard to exclude and eradicate invasive species from its lands, it is critical to maintain these efforts even as the park is closed. One of the concerns during the eruption was the potential increase of vehicle traffic between Hilo and HAVO due to road closures and displaced workforces, introducing potential new biosecurity threats. Wash stations are one way to ensure that invasive species accidentally transported from the Hilo area where many more exotic plants and animals are present are eradicated before entering the park.*
Natural Resources	**Educate new workers and community members to increase early detection:** Create an education campaign for new workers and/or responders (for example UAV crews) and community members on the identification of invasive species and how to prevent their spread (for example distribute ID cards in vehicles). Encourage the use of citizen science to help identify areas of invasion quickly. *When dealing with invasive species, early detection is critical to stopping their spread. Educating newcomers, as well as community members as to what invasive species look like, and what to do if they are found is critical to preventing their spread into HAVO. Using citizen science apps like iNaturalist is another way to encourage early detection amongst workers and community members. With this platform species can often be identified by experts in minutes or hours, and entries are geo-located, allowing them to be re-located by eradication crews, if necessary.*

Scenario 2: Vog

Scenario 2 assessed the short- and long- term cascading consequences of vog across the island. The decision to dedicate a separate scenario discussion to vog was made on-site, due to the unique, broad geographic impacts of vog, which affected not only communities in lower Puna, but also along the Kona coast and elsewhere in the state. Concerns over vog exposure also seemed to be a point of serious concern for those responding to the incident, local residents, and displaced populations. Discussion topics included: public health (both mental and physical); communications; natural resources; facilities; water quality; and agricultural impacts. Due to limited time, the team was unable to delve deeply into issues surrounding water quality and agricultural impacts even though these were recognized as cascading consequences.

The team identified 18 potential actions that could be taken to mitigate potential future negative cascading consequences. These actions are listed below and have been organized into categories by the SSG staff. They are not ranked.

Table 2: *Potential Actions to Mitigate Consequences of Vog*

Category	Potential Action
	Address Inconsistent or Confusing Communication About Vog Hazard and Risk
Health	**Develop regional vog push notifications:** Use existing technologies to disseminate spatially specific vog notifications across Hawai'i County and beyond. Potentially add the capacity for users to upload observations or pictures. Host a hackathon to facilitate further app development. *Currently, air quality alerts are geographically generalized--sometimes delivered at the zip-code scale, which often cover broad areas. Most, if not all, of these notifications are only available for those seeking them out and are not "pushed" to phones as tornado warnings are in the Midwest of the U.S. mainland. Thus, many people miss information, or receive information that is not specific enough to act on. Creating a method for push-notifications, and for users to verify reported data, enables local communities to take specific actions and be included in the monitoring process.*
Health	**Develop consistent messaging:** Develop a comprehensive strategy to represent and consistently communicate findings of air quality monitoring (for example color coding, time averaging, sensitivity of instruments). *Currently, there are numerous groups and systems in place for monitoring air quality in Hawai'i. Often these groups and systems use different means of communicating their data, are measuring different things at different intervals, and with varying levels of sensitivity. Thus, it is difficult for a layperson to easily understand the data presented and take action. Ensuring that reporting is cohesive and standardized will better empower users to make decisions based on this information.*

Health	**Improve risk communication and education about health impacts of vog:** Engage community-based organizations, health-care workers, and educators (i.e. trusted information brokers) in understanding and communicating vog risks and what interventions can be taken to mitigate these risks. Empower communities to understand the condition of their current residence and workplace. Investigate local communities' perspectives on vog and incorporate this into education campaigns. Ensure that authoritative, regionally-specific (for example, Puna vs. Kona), and evidence-based information is used. Use social-marketing techniques. *Vog is known to exacerbate existing health issues like asthma. The effects of long-term exposure to vog are less studied but may lead to chronic cardio-respiratory, cerebrovascular, and endocrine diseases. Ensuring that communities have site-specific and culturally-tailored information on vog will help them take concrete actions that may protect their health.*
Health	**Use non-digital communication for warnings:** To the extent possible given changes in weather, use signs or flags to warn of poor air quality to ensure awareness amongst all affected communities. *Elderly, poor, or rural communities may not have access to digital forms of communication. Using simple technologies such as flags or signs to warn of poor air quality ensures that all communities are informed and able to take precautions.*
	Address Ongoing or Potential Vog-Related Health Risks
Health	**Increase health-care capacity:** Increase public-health nursing services in affected areas using door-to-door services. Ensure that the affected population is met on their level and in their homes rather than placing travel and scheduling requirements on them. *Because the affected area is one of the poorest on Hawai'i Island, some residents may lack the ability to travel to health-care providers regularly. The same may be true of elderly residents. Providing door-to-door public-health nursing services can serve to identify and address health issues before they become serious.*
Health	**Identify and promote the best products to mitigate vog health effects:** Formalize accurate information on room air-cleaners, dehumidifiers, and air conditioners and disseminate information on the best models. Promote air conditioner use in affected areas. Prioritize and underwrite the costs of installation and continued use of these products in schools and health-care facilities. *Many products exist that purport to mitigate the indoor air-quality impacts of vog. Providing accurate information on the efficacy of these products will allow community members in affected areas to take well-informed protective actions. Underwriting the costs of installation and continued use of these options would ensure broad integration of these mitigation efforts.*

Health	**Enhance baseline health of the population:** Continue and promote anti-smoking and cardiovascular health campaigns that will keep the general population healthier and better able to deal with the negative health impacts of vog. *Vog is known to exacerbate existing health conditions. By promoting baseline wellness in the community, it is possible to also mitigate the impacts of vog exposure.*
Health	**Develop Standardized Metrics:** Develop standardized metrics of the impacts of vog on human health. *For example, it would be advantageous to have metrics on how cardiovascular, cerebrovascular, endocrine, and mental health varies depending on duration and concentration of exposure.*
Health	**Create a "Vog Officer" position**: Create a vog officer for Hawai'i Island. This person would collaborate with Federal, State, and County officials to ensure coordination across groups and consistency in communication. *Vog is a hazard that falls between administrative jurisdictions. The Environmental Protection Agency (EPA), USGS, Hawai'i Department of Health, and others are involved in its monitoring, as well as in communication, public outreach, and education on this topic. Having a single coordinating officer would ensure that standard messages are shared with the public, and that there is not redundancy in monitoring or education efforts in the state. Coordination may also help agencies leverage their resources by collaborating with others on shared projects and initiatives.*
Health	**Include vog considerations in the State Asthma Plan:** Revise the State of Hawai'i Department of Health Asthma Plan to include the current state of knowledge regarding the impacts of vog on those with asthma and other respiratory conditions. *Currently, Hawai'i County has the highest percent (13.8%) of children with asthma of any county in Hawai'i, as well as the highest percent of adults with asthma in the state (Hawai'i State Department of Health, 2016). Even though vog is known to exacerbate asthma symptoms, sulfur dioxide and particulate matter is only mentioned once in the State Asthma Plan, wherein a stated goal is to “reduce exposure to small particulate matter (less than 2.5 micrometers), sulfur dioxide and other air pollutants” (Hawai'i State Department of Health, 2016). Prioritizing vog in the next version of this Plan may help decrease geographic asthma disparities, improve disease management, and lead to the development of better mitigation opportunities in the future.*
	Address Known Gaps in Knowledge About Vog
Facilities	**Identify vog-resistant construction materials:** Develop studies that identify the best materials to use in residential and commercial contexts in vog-affected areas. Communicate these findings to the public.

	Certain building materials such as metal nails, roofs, or fences can be corroded quickly due to exposure to vog. Identifying and communicating which building materials are most resistant can limit long-term costs and damage.
Natural Resources/ Economics	**Identify long-term impacts to agriculture:** Develop long term studies on the impacts of vog on agriculture (livestock and crops). Include SO_2, aerosols, and acid rain impacts in these studies. *There is incomplete evidence as to the long-term impacts of vog on agriculture. Short term impacts on livestock may include eye infections, as well as gastrointestinal and respiratory problems (State of Hawai'i website, 2018). Impacts on diverse crops are not as well identified. A better understanding of these impacts may allow for effective mitigation strategies to limit future losses.*
City and Regional Planning	**Identify vog hotspots to inform planning:** Use modelling to develop a better understanding of long-term hot-spots of vog across the island for use in the public health, city planning, and ecological arenas. Site development outside of vog zones to prevent or decrease future vog-related health problems. *Using long-term modelling, it may be possible to identify hotspots where vog will be at the highest levels during different wind conditions. Using this information, city planners can discourage further or new development in areas that are or may be heavily impacted by vog and/or implement exposure mitigation interventions in existing facilities.*
Natural Resources and Health	**Develop a vog forecast model:** Support advances in research and development of the Vog Measurement and Prediction project (VMAP) vog forecast model. *VMAP provides real-time vog forecasts. Providing accurate vog forecasting allows for timely alert notifications to be shared with affected communities, enabling them to take precautionary actions in advance of elevated vog levels in their areas.*
	Address Known Gaps in Monitoring and Surveillance
Health/Natural Resources	**Monitor metal deposition:** Monitor vog metal deposition in water, soils, plant tissue, animal tissue, and air over the long-term. *It is known that heavy metals are present in lower levels of vog. Thus, with higher levels of vog there is a concern that these heavy metals may be deposited in water, soils, and agricultural areas leading to bioaccumulation in livestock, and impacting human health through contact with the environment.*
Health	**Monitor health impacts:** Monitor vog-related health impacts over time. *Currently, little is known about the potential for vog to cause chronic disease. More research is needed to better understand this issue, as well as the efficacy of preventative measures.*
Health	**Monitor water catchments:** Develop testing protocols for water catchments (pH, heavy metals, etc.). Identify best tests and monitoring systems available, create tax-credits for residents who install monitoring systems. Communicate this

	information with homeowners. *Many homes in Hawai'i use water catchment systems, rather than utilities, to provide water for drinking, bathing, cleaning, and gardening. With high levels of vog there is concern that the water in these catchments is being contaminated with heavy metals, and/or chemicals that can cause harm to human health. Developing best-practices for monitoring these systems will both alleviate stress on homeowners and ensure that water quality is of an acceptable standard. Technological solutions, such as systems that disconnect gutters from the catchment in case of high vog and acid rain or first-flush systems may also be advantageous.*
	Address Ecological Impacts of Vog
Natural Resources	**Improve and encourage ecological resilience:** Cache seeds, preserve genetics of very rare species, establish migration corridors to allow adaptation to bad air quality. Develop plans to manage and monitor endangered species (for example endangered crow). *Although the plants and animals on Hawai'i island have adapted with volcanic eruptions, pressures placed upon them by invasive plant species and land development have made them less resilient to damage from high-heat and vog. To ensure the survival of extremely rare and endemic species, it is important to preserve their genetics and create a means for them to move across the landscape to safer areas.*

Scenario 3: Fissure eruptions in the lower East Rift Zone (LERZ)

Scenario 3 examined the short- and long-term cascading consequences of lava production in the LERZ. Discussion topics included facilities; city/regional planning; emergency management; community resilience; and communications. Particular areas of focus included exploring options for rebuilding the communities in lower Puna, addressing concerns for pet owners, and determining options if the Pohoiki Boat Ramp were to close (ultimately spared from the lava, the ramp was under imminent threat at the time of the SSG meeting. It has since been closed due to an extensive sand bar that developed across the front of the ramp as a result of the eruption). In total, the team identified 19 potential actions that could be taken to mitigate potential future negative cascading consequences. These actions are listed below and have been organized into categories by the SSG staff. They are not ranked.

Table 3: *Potential actions to address impacts of lava in the Lower East Rift Zone*

Category	**Potential Action**
	Address Need for Resilient and Aware Communities in Lava Zones
Facilities	**Enforce existing code:** Ensure that existing limits on subdivisions are enforced, especially in high risk areas. Enforce regulations on short-term rentals. *Enforcing existing building regulations may mitigate losses in future events.*

City and Regional Planning	**Propose a competition for land use and multi-hazard risk planning:** Propose a competition to identify innovative solutions for land use and multi-hazard risk planning. Require partnering with the affected community. Integrate traditional/adaptive building into designs and identify opportunities for STEM education projects. *It was recognized that it is important to take a long-term and whole-community approach to rebuilding and recovering from the destruction of homes and community assets in the LERZ, and that multiple areas of expertise are necessary to inform the recovery process. One model of long-term recovery planning is the "Rebuild by Design" competition that was launched in New York following Superstorm Sandy. This approach considers multi-hazard risk planning to ensure that displaced populations are not resettled in existing or other high-risk hazard zones and requires engagement with the affected community to ensure that solutions are tailored to the impacted group.*
City and Regional Planning	**Consider land swaps:** Consider land-swaps–moving communities out of high-risk areas to areas of lower risk. If people are resettled elsewhere, ensure that they are resettling to areas that are Lava Zone 3 and above. In so doing, learn from past mistakes and try to make the process faster and nimbler. *Land swaps have occurred on the Island of Hawai'i before, including following the 1960 tsunami that devastated Hilo and following the 1980s eruption that destroyed homes in Kalapana. According to those with experience with the process, these land swaps took an extremely long time and were difficult for displaced residents to navigate due to high levels of bureaucracy and a lack of transparency. Evaluating previous land swaps and improving on these issues might entice people to move out of hazardous zones to safer areas.*
City and Regional Planning	**Create public safety fee requirements:** If members of the community wish to build or rebuild in areas of known high risk, require them to pay a "public safety fee or assessment." This would be similar to fees paid by community members in high fire-risk zones in California. *It is recognized that people will always want to reside in hazardous areas. These areas often have stunning views and locations and/or may have deep cultural or family significance. In places like California where people continue to build in fire-prone areas, residents are charged a "fire prevention fee" to offset future expenditures by the state when disaster strikes. These fees may also deter people from living in high-hazard zones. It is critical, however, to consider how to maintain social equity and to avoid exacerbating existing inequalities with these fees.*
City and Regional Planning	**Strengthen and enforce agricultural land rules:** Ban subdivision of agricultural land in high-risk lava zones to minimize the number of residents in these areas if an eruption occurs.

	Limiting residential development of agricultural land in high-hazard zones would help limit economic losses in the event of disaster.
City and Regional Planning	**Encourage strict covenants, conditions, and restrictions (CCRs) in Homeowner Associations (HOAs):** Encourage HOAs to limit building in lava zones and to limit subdivision of properties already in lava zones. If possible, set minimum standards for CCRs. *Often HOAs are able to enact their own rules and regulations far more easily than states or counties, making them more nimble entities to shift development in lava prone areas.*
Cultural Resources	**Support ethnographic studies and art programs:** Capture stories of the eruption to share with current residents and future generation to inform mental health wellness during recovery and inform future public and private planning activities. *Similar to the 2014 Puna Disaster Resiliency Study, ethnographic studies with affected communities can be useful for understanding how individuals, families, and business owners cope with disasters. Capturing stories of the experience of the 2018 Kīlauea eruption is also useful for sharing with visitors and future generations. Another model to follow is “Quake Stories,” developed by the New Zealand Ministry for Culture and Tourism for Kiwis to share stories of how earthquakes affect their lives.*
Cultural Resources/Health	**Empower communities to retain and share knowledge of past disasters:** Work with arts communities to create memorials and means of communicating the impact of past disasters. Consider creating orientations for newcomers that incorporate local knowledge. Encourage and empower community record-keeping practices (for example, dance [hula], chants, oral history, etc.). Leverage existing institutions (for example, "The Hub", local schools) to support existing communities of practice to promote this work. Increase awareness of practical Hawai'ian place-name meanings for newcomers. *This type of work may be empowering for local communities who were displaced due to the eruption and may create opportunities for collective healing and grieving, and preservation of memory well after the initial event.*
Policy	**Redistribute risk:** Develop new economic risk models (insurance, reinsurance, etc.) that redistribute risk. *It is important to ensure that new deterrents to living in lava zones, as well as economic incentives for moving out of such zones do not reinforce economic and physical inequities that are currently present in the Lower Puna area. The recovery process may be a means of achieving more social and economic equity in the community.*

Policy	**Adapt bureaucracy:** Use town halls, surveys, and other instruments to determine community needs and visions for the future (for example, land swaps). Adapt bureaucratic processes to meet these needs in a timely and nimble fashion. *Previous land swaps and other land deals involving displaced people have been noted to be too slow to keep pace with the real needs of citizens. Finding ways to adapt the process to be nimbler and more responsive to individual and community needs could resolve these issues.*
	Address Pet-Related Needs
Communication/Emergency Management	**Develop animal evacuation education programs:** Communities should be given access to information and programs that make pet evacuation possible in the event of a disaster. Include pet-related information in alerting and warning systems (for example confine your pets, stage kennels, etc.) so that community members are prepared to evacuate efficiently. *Many people lost or were separated from their pets as they had to evacuate quickly and were unable to re-enter their homes. Helping people put plans in place is critical to a smooth evacuation process, and one that accounts for animals so that they are not released into the wild, causing potentially significant ecological harm.*
Emergency Management	**Deliver pet kennels and create pet-friendly transitional housing:** Deliver pet kennels and find transitional housing for people who have pets, especially those with a large number of pets (for example pig-hunting dogs). *Concerns over the ability to take pets to shelters is a known reason for why people do not evacuate when asked to do so. In Lower Puna, displaced people faced similar issues; unable or unwilling to stay in shelters because of their pets, pointing to the need for pet-friendly transitional housing.*
Emergency Management	**Pre-identify homeowners willing to shelter pets:** Pre-identify homeowners who may not be willing to shelter families, but who may be willing to shelter pets in the event of a disaster. Existing apps like "Rover" may be useful to facilitate this planning. *Concerns over the ability to take pets to shelters is a known reason for why people do not evacuate when asked to do so. Some displaced residents had large packs of hunting dogs that were not easily housed in kennels. Finding willing caretakers of these animals would relieve anxiety on the part of displaced people and enable them to stay safely in shelters. Further, finding good temporary homes for these animals could prevent the release of exotic animals into the wild–an activity that can have serious ecological consequences for local ecosystems. Though it is too late for this action to help resolve outcomes of the 2018 eruption, it is*

	important to put plans in place for future events.
	Address Known Gaps in Knowledge
Emergency Management/City and Regional Planning	**Investigate demographic changes:** Identify the people who have left the area or the island due to the lava flow and where they went. Work to understand these subsets of communities and their backgrounds. *This information may help with future forecasting, crisis management, and recovery.*
Cultural Resources	**Understand and protect information on lost or endangered cultural resources:** Use LiDAR in heavily forested areas to help identify cultural and or archeological sites in high-risk areas, or in areas in the path of approaching lava. Access to these data should be heavily restricted. *This sensitive work would require collaboration with cultural practitioners. It would be important for prioritizing the documentation of these sites and efforts to save artifacts or sites before they are destroyed by future disasters.*
	Address Lost Community and Public Resources
City and Regional Planning	**Create new boat launch:** Revamp the old sugar cane pier in Whittington State Park to be used as a boat launch facility. Other potential areas for a boat ramp might be Shipman LLC Area, and King's Landing. *The Pohoiki Boat ramp, to which access was ultimately blocked by sand and other debris due to the eruption, was a critical ocean entry point for local fishermen and recreationalists. The loss of this boat ramp may mean much longer commutes and potential conflicts over natural resources in other areas. Finding a nearby alternative would help alleviate these issues.*
Communication	**Develop youth enrichment opportunities:** Create community programs where kids who have been displaced or are affected by the eruption can be interns, research assistants, or participate in summer programs with the National Park Service, USGS, the UH-Hilo Center for the Study of Active Volcanoes (CSAV) or other institutions during the summer months. *Not only would this exchange work enrich both students and sponsoring agencies, but it may act as an effective communication conduit to affected communities about the hazards on the island and how to avoid them.*
Tourism/City and Regional Planning	**Make plans to rapidly create a supervised public viewing area for future eruptions:** Consider creating lease agreements between the National Park Service and affected landowners to create a public lava viewing area for future eruptions. *During the eruption, tourists and residents wanted to see the lava, and at times were disregarding roadblocks and other security measures to enter the closed subdivisions. This posed challenges for ensuring the security of*

	houses and the safety of the trespassers. A public viewing area may have alleviated some of these challenges and should be considered for future eruptions. Such a viewing area could also be used to focus and control tourism on the margins of the affected area.

Future Considerations

Several cross-cutting themes emerged from all of the scenarios. These included issues of infrastructure, economic impacts, human health, ecosystem health, communications, long term planning, and community engagement and empowerment. These themes are important to consider for recovery from the 2018 Kīlauea eruption and for mitigation planning for future eruptions and other hazards. Additional insights and details on many of these issues are included in the “Issue Papers” in Appendix 4.

Infrastructure

Seismicity, lava flows, and vog have all had major impacts on infrastructure on the island of Hawai'i. While lava often completely inundated homes or isolated them, the numerous seismic events resulting from the eruption may have caused serious, yet less obvious damage. While typically a 0.2 or 1.0M earthquake would have little to no impact on a structure, 60,000 ground accelerations may have had cumulative effects. These earthquakes may have caused building connections to loosen, resulting in buildings becoming more flexible and prone to “knock-on” damage (for example, cracking of drywall, doorways deforming and jamming, windows jamming or cracking). Housing using the post and pile type of construction where the ground floor is elevated from grade (for example, with crawl spaces) can be more vulnerable to this type of damage. High concentrations of vog may have also played a role in compromising structures on the island and resulting acid rain can cause intense corrosion of metals such as those found in nails, roofs, and fencing. Understanding the full extent of impacts to structures due to seismicity and vog is critical in assessing and rehabilitating the housing and commercial stock in affected communities. Further, understanding the extent of damage to underground utilities may speed recovery and subvert future failures in the short term. This knowledge may also inform housing codes and architectural designs that may allow structures to better withstand similar events in the future.

Economic Impacts

In the short term, park closures, concerns over vog, and property damage and destruction due to summit collapse and lava flows have had significant socio-economic impacts on communities in lower Puna, Hilo, and towns near Kīlauea’s summit. Funding long-term emergency response to these hazards will likely have significant financial consequences for federal, state, and local governments. Estimated direct financial losses have already reached several hundreds of millions of dollars, but this does not include indirect impacts on businesses, or direct and indirect socioeconomic and health impacts for years to come. Families of low socioeconomic conditions are disproportionately affected. The long-term financial, social and health effects of this eruption are not yet known. Collecting localized (as opposed to state or county-wide) information on these impacts over time may help evaluate mitigation plans and guide future response efforts.

Human Health: Physical

Physical health impacts are critical to consider when evaluating the Kīlauea eruption. Although serious physical injury from lava was largely avoided through timely warnings, vog remains to be a serious consideration for human health. It is known that vog can exacerbate existing health conditions such as asthma and cardiovascular disorders which are already prevalent on the island of Hawai'i. Though little research has been done in this area, there is biological plausibility for development of chronic disease from vog. Probable chronic diseases include: (1) adult-onset cardiorespiratory, cerebrovascular and endocrine diseases (for example, chronic obstructive pulmonary disease, reactive airway dysfunction syndrome, diabetes, and various cardiovascular diseases), and (2) pediatric airway, allergic, and cardiovascular diseases. Chronic disease can result in adverse outcomes for the economic status, social structure and psychological health of the people affected. Using research and monitoring to better understand exposure and long-term health outcomes can help improve the overall health status of the island's population. Determining what types and lengths of exposure can lead to chronic disease, what treatments are most effective, and best existing interventions and mitigations can inform future responses and education campaigns and potentially address socio-economic, ethnic, age, and gender disparities in health outcomes.

Human Health: Mental

Mental health is also a serious concern in any disaster. Acute collective stressors, such as natural disasters and terrorism events have been associated with short- and long-term mental health effects among adults and children. The primary psychological and behavioral impacts associated with these acute catastrophic events include post-traumatic stress disorder (PTSD), major depressive disorders (MDD), generalized anxiety disorders, mental health distress, and substance use disorders. On average, 17.4% of disaster-exposed populations experience mental health effects (Rubonis and Bickman, 1991). Stress is the mechanism through which a disaster produces mental distress. Certainty or control over one's future and one's environment can play an important part in increasing or decreasing an individual's stress. These stresses may lead to substance use disorders, or chronic mental health disorders, particularly if there are limited therapeutic services available to intervene. Better understanding potential stressors can inform programmatic and policy efforts. Addressing these stressors may not require simply deploying teams of mental health professionals to engage in therapeutic activities, but rather interventions such as transitional housing, disaster case management, continuity of educational, social, and cultural services, and financial counseling and planning, all of which may be better positioned to help alleviate concerns associated with loss of control about one's future and environment.

An additional tool for supporting mental health wellness during recovery is the arts, including music and dance, which play a particularly important role in Hawai'ian culture (Appendix 4). In general, the arts are a critical but frequently overlooked part of disaster response, recovery, and adaptation. In disasters, often arts can suffer because artists loose artistic spaces (studios, theatres, venues) to perform or engage in the creative process. These losses rarely get financial support because they are perceived as "secondary" needs. Housing, building, and infrastructure rebuilds receive more focus, funding, and attention because of the immediacy of these needs. However, recovery of the arts community is critical because these communities assist in building social capital, which may have been compromised due to evacuations (which can scatter communities and strain social connections). Expressive arts can help create social cohesion through creating a sense of place, self, heritage, and honoring cultural identities, which is also a critical component of resilience. These aspects of identity and sense of place are critical to recovery; if a community is involved in its own recovery, its members are more likely to recover faster than if they feel excluded from the process.

Ecosystem Health

Ecosystem health was a serious topic of concern during the Kīlauea crisis. Hawai'ian ecosystems are characterized by a high number of endemic and rare species whose habitats have already been compromised by invasive species and development on the island. This eruption posed a new threat as it further destroyed available habitat. Marine and forest protected areas like Waiopae Tidepools Marine Life Conservation District at Kapoho Bay were destroyed by lava flows. Vog and high heat emitted from lava flows also heavily impacted native ecosystems. As HAVO, HVO, and PIERC operations moved to coastal areas, and response teams moved between Puna and HAVO, there were major concerns over the transport of invasive species found in coastal areas into areas where they had been excluded or eradicated by the park. It is important to conduct new surveys of native ecosystems and rare species in eruption impacted areas to provide a current assessment of the status of these resources for management and planning purposes. It is also important to understand how native plants and animals are able to recover from exposure to vog and other eruption stressors for future management efforts. Finally, intensive and continuing invasive species campaigns are important for limiting the spread of these dangerous organisms to intact ecosystems on the island.

Communication during Response and Recovery

For each of the topics mentioned above, it is critical to ensure good communication both within response and scientific organizations, as well as with people impacted by the eruption or interested in the event. A challenge is to extend this into the long recovery process. Encouraging awareness of the potential ongoing mental, physical, ecological, and infrastructural hazards of a disaster, and how to best address those hazards, empowers individuals and communities alike to make informed decisions. In order to ensure two-way communication, community members affected by the eruption should be included in and/or directly involved in long-term planning processes. Not only will this allow community members to express their needs and desires for their futures, but it may also help planners envision new ways of working with the natural and built environment through exposure to ideas that come from traditional or local knowledge. Community members should also be engaged in community-based long-term monitoring of physical/mental health, air quality, ecosystem health, and infrastructure recovery. This engagement can act as another means of communication and can empower local communities who may have historically been excluded in science, management, and planning activities and strengthen and foster new support networks that emerged spontaneously during the response period. Collaborations in planning and monitoring will serve to forge new connections across disciplines, institutions, and groups.

Conclusion

The alert level for the 2018 Kīlauea eruption was reduced to Warning on August 17, 2018, allowing officials, residents, and responders to make the transition from response to recovery. Many complicated questions surround the recovery process: what lessons can be learned from the 2018 eruption? In an area prone to multiple types of hazards including lava, vog, hurricanes, tsunamis, wildfires, sea level rise, and subsidence, how should multi-hazard risk be assessed and mitigated? How can future risk mitigation measures account for different socio-economic status and land use practices? How can policies best be developed to honor the cultural importance of the volcano and to incorporate native Hawai'i residents' input in the recovery process? What innovations can be incorporated into the rebuilding process? If implemented, how will these perform during the next extreme event – whether it is another Kīlauea eruption, a Mauna Loa eruption, a hurricane, or some other combination of hazards?

For the DOI SSG, the 2018 Kīlauea eruption was its first official activation since its support of Hurricane Sandy recovery in 2013. This activation presented the opportunity to test new methods, including for the first time, working directly with local and regional stakeholders (in addition to DOI) before, during, and after deployment. Upon reflection, the reconnaissance trip proved to be a useful tool for collecting information.

The on-site SSG briefing to stakeholders in Hilo was useful for sharing immediate insights directly with responders and decision makers. While the SSG has traditionally operated “off the radar” of other agencies in order to ensure that the information it delivers to the Department is unfettered, many of the SSG findings are relevant to agencies beyond the Department. Therefore, direct interaction between the SSG and local stakeholders provides a unique opportunity to ensure that actionable insights are quickly and broadly disseminated to those who can use them for response and/or recovery. If the SSG will interact with non-DOI stakeholders in the future, SSG deployments should include a stakeholder briefing at the *outset* of the deployment *and at the end* of the deployment to facilitate communication and mutual understanding of interests, limitations, and capabilities. Briefings to the Department and multiple stakeholders after the SSG’s meeting helped to disseminate additional information from the meeting. Future deployments would benefit from an evaluation of these interactions to improve the efficacy of the SSG’s methods and briefings.

The 2018 Kīlauea eruption was a geologically, socially, and culturally historic event with long-lasting social, economic, and environmental consequences. The recovery process will take years to decades. While challenging, expensive, and emotionally-taxing for affected residents, it represents the opportunity to implement new ideas, practices, and programs, some of which are presented in this report. The SSG’s work in Hawaii allowed for some of these ideas to be explored and hopefully utilized to the benefit of those impacted by this eruption.

Acknowledgements

The SSG staff thanks the following individuals for their support throughout this activation of the SSG. The SSG Kilauea Team (Appendix 3) generously volunteered their time and expertise to be a part of this activation. DOI SILC Liaisons Pat Mangan, Jonathan Rosen, and Jason Marineau provided critical situational awareness and connections to stakeholders in Hilo and Hawai'i Volcanoes National Park. USGS Volcano Science Center Director Tom Murray provided useful connections prior to the SSG deployment and provided input on follow-on briefing materials. HVO Scientist in Charge Tina Neal generously provided input and connections during the reconnaissance trip and feedback on briefing materials. USGS colleagues Dave Ramsey and Larry Mastin provided key connections during the reconnaissance trip. Gordon Tribble, Director of the USGS Pacific Island Ecosystems Research Center, provided key insights into ecological issues of concern and arranged for the time and expertise of Jim Jacobi to join the SSG Kīlauea Team. USGS Emergency Management Specialist Anna Stull provided critical on-the-ground support in Hilo and arranged for the SSG Kīlauea Team to tour the Kīlauea Caldera on July 17, 2018. HAVO Superintendent Cindy Orlando provided the time and expertise of Rhonda Loh and Keola Awong to join the SSG Kīlauea Team. FEMA Deputy Federal Coordinating Officer (DFCO) Ryan Brown provided input during the July 19, 2018, stakeholder meeting and arranged for the time and expertise of Forrest Lanning to join the SSG Kīlauea Team. Hawai'i Emergency Management Agency’s David Lopez provided useful information on the State’s needs and delivered a seminar to the SSG Kīlauea Team prior to deployment. The Air National Guard provided the SSG Kīlauea Team with a tour of Leilani Estates on July 18, 2018. We thank Hawai'i County for their interest and meeting with us on July

11, 2018, in Hilo to share insights from the County perspective. We also thank Fenix Grange of Hawai'i Department of Health for contacting the SSG to exchange information about public health concerns of vog. USGS Natural Hazards Mission Area staff including Roberta Chaves and Linda Huey quickly acted to support travel and logistics needs.

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Appendix 1: Background on the Department of the Interior Strategic Sciences Group

Mission & Leadership

The mission of the SSG is to provide the Department of the Interior (DOI, hereafter also referred to as "the Department") with the capacity to rapidly assemble teams of experts to conduct science-based interdisciplinary scenarios of environmental crises affecting DOI resources and provide actionable results to DOI leadership. When deployed, the SSG rapidly convenes multidisciplinary teams of experts to assess the short- and long-term environmental, social, and economic consequences of the crisis and identify actionable interventions.

The SSG is co-led by a representative from the U.S. Geological Survey (USGS) and a representative from one other DOI bureau and is staffed by the USGS. The SSG Co-Leaders are responsible for developing procedures and methods, managing activities, leading operational response teams during deployment, providing results to the Secretary and DOI leadership, and coordinating with other Federal agencies and the scientific community. The Co-Leaders report directly to the Science Advisor to the Secretary, currently (2018) the Director of the USGS.

An Advisory Council comprised of DOI bureau and office representatives ensures coordination among DOI bureaus, advises on key issues, and communicates the activities of the SSG to bureau leadership. The SSG is intended to be "an arrow in the quiver" to support the Department in its response to crisis events: it is not part of Incident Command.

History

The SSG was created as an experiment during the 2010 Deepwater Horizon oil spill. As part of its response to the spill, DOI leadership temporarily created an interdisciplinary Strategic Sciences Working Group (SSWG), involving scientists from Federal, academic, and non-governmental organizations. SSWG participants were selected and their expertise applied during an intense period of national environmental crises (Machlis and McNutt, 2010). The SSWG held two scenario-building sessions during the Deepwater Horizon Oil Spill and produced two progress reports outlining impacts, cascading effects of those impacts, and recommendations to improve long-term recovery. The SSWG progress reports included the recommendation that the DOI create a standing capacity to conduct strategic science activities during future environmental crises. The SSWG was replaced by the Strategic Sciences Group established within the Office of the Secretary by Secretarial Order 3318 issued January 3, 2012. This Order was replaced by Part 305, Chapter 4 of the DOI Departmental Manual in 2016.

To date, the SSG has been deployed to support response to the Deepwater Horizon oil spill (2010) and recovery from Hurricane Sandy (2013). Following the Sandy deployment, DOI leadership directed the SSG to develop an evaluation process to help prioritize projects proposed for $300M in DOI Hurricane Sandy supplemental mitigation funds.

Criteria for Deployment

The Secretary of the DOI is responsible for deploying the SSG. The following "triggering" criteria identify crises for which the SSG may be deployed: an acute event of immediate, significant impact and of relatively defined duration; an event for which the SSG can add value, using a strategic approach of scenario development to assist decision makers; unanticipated, improbable events with multiple, synergistic or cascading environmental, economic, and social consequences; and events with a potential high degree of social/economic/environmental risk or loss. The Secretary may direct the SSG to assist other Federal, State, local, or tribal agencies, and may direct the SSG to provide international assistance, subject to applicable authorities and availability of appropriations.

Operational Response Teams

When deployed, the SSG convenes a multidisciplinary operational team of experts suited for the specific crisis. The SSG uses a network of 23 professional societies and academic center partners to expedite the formation of its teams. Experts may be recruited from the government, academic, non-governmental, or private sector.

The SSG has been deployed to support response to the Deepwater Horizon oil spill (2010) and recovery from Hurricane Sandy (2013). Following the Hurricane Sandy deployment, DOI leadership directed the SSG to develop an evaluation process to help prioritize projects proposed for $300M in DOI Hurricane Sandy supplemental mitigation funds.

Technical Assistance & Training

The SSG also provides technical assistance to DOI bureaus and other groups to examine the cascading consequences of real and hypothetical events. To date, the SSG has provided technical assistance on topics including drought, Zika virus, risk on DOI lands, and wildlife disease.

Between deployments, the SSG participates in tabletop exercises, explores new applications of its methods, evaluates previous efforts to improve the effectiveness of future deployments, and contributes to an emerging community of practice focused on science during crisis.

Appendix 2: Charge from SSG Co-Leader

United States Department of the Interior

U. S. GEOLOGICAL SURVEY
12201 Sunrise Valley Drive, Mail Stop 111
Reston, Virginia 20192

MEMORANDUM

July 13, 2018

To: Kris Ludwig and Alice Pennaz, DOI Strategic Sciences Group Staff

From: Dave Applegate, Associate Director for Natural Hazards and Co-Leader, DOI Strategic Sciences Group

Subject: SSG Technical Support for the Kīlauea Eruption

On July 3, the Department of the Interior (DOI) Strategic Sciences Group (SSG) received direction from U.S. Geological Survey (USGS) Director Jim Reilly, serving as science advisor to the Secretary of the Interior, to stand up a technical support team in support of the Department's role in the ongoing Kīlauea eruption. As it is able and appropriate, the team's activities should also support the needs of the Hawai'i Emergency Management Agency, Hawai'i Civil Defense, and the Federal Emergency Management Agency.

Pursuant to that direction, the purpose of this memorandum is to describe the charge that is being given to the team that will be meeting July 17-19, 2018, in Hilo, Hawai'i. I am tasking you to lead this team activity and be responsible for development of reports and other materials.

Background: Established in 2012 by Secretarial Order 3318 and subsequently incorporated into Departmental Manual Chapter 305-4, the SSG provides the Department with a standing capacity to rapidly assemble teams of experts to construct interdisciplinary scenarios of environmental crises affecting DOI resources. The SSG is designed to complement ongoing response efforts by providing strategic science to inform decision makers of the potential consequences and possible interventions within the coupled human and natural systems impacted by the crisis event. While tactical response efforts are underway, the SSG can provide a distinct, complementary perspective focused on the identification and analysis of short- and long-term chains of consequences, potential interventions that can accelerate recovery and restoration, and expert-informed insights to support decisions during and following the crisis.

Charge: The team will examine the short- and long-term (present to next ten years) social, economic, and environmental cascading consequences of this eruption. Geographic areas to consider include the lower East Rift Zone, as well as the eruptive and seismic activity at the summit of Kīlauea. Scenarios should include: (1) consideration of the closure and potential relocation of DOI resources and (2) the short- and long-term social, economic, and ecological impacts of the eruption. Potential interventions should consider actions to mitigate social/psychological distress, ecological disruptions to the sensitive island ecosystem, impacts to critical and DOI infrastructure, and provide usable knowledge to inform decisions during the immediate response and long-term recovery effort.

Roles: As the SSG staff, you are responsible for forming the temporary technical support team, which shall be organized, engaged, and then dissolved when its tasks are complete. The SSG should engage the best available experts with a diverse set of talents appropriate to the SSG mission. The team shall include necessary support staff and approximately 10-15 experts from government, academic institutions, non-governmental organizations, and the private sector, as appropriate. This team will develop and prepare the scenarios of cascading consequences and identify actionable interventions through discussions facilitated by the SSG staff. Ideas, discussion and comments contributed by individual team members are for informational purposes only.

Deliverables and Communication

The SSG staff will work with the technical team to prepare and deliver the following:

- *Scenarios:* qualitative chain-of-consequences scenarios illustrating the short- and long-term impacts of the eruption on the environment, economy, and people of the affected region.
- *A list of interventions/*institutional actions that support and/or inform response and recovery efforts. Efforts should be made to connect interventions to either Emergency and/or Recovery Support Functions.
- *Issue Papers:* Using scenarios, the SSG Crisis Science Team will identify information gaps. Following deployment, team members will be asked to deliver additional information on specific issues of concern.
- *Briefings:* During deployment, the SSG staff will provide written daily briefing reports to the Secretary’s Science Advisor and SSG Co-Leader. Onsite and post-deployment briefings will be scheduled as requested and in consultation with the SSG Co-leader.
- *Technical Report:* A peer-reviewed report detailing scenario results and interventions will be completed within three months of deployment and published as soon as possible thereafter.

Appendix 3: SSG Kīlauea Team Participants

Below is a list of participants and staff in the 2018 SSG Kīlauea July 17-19, 2018 Hilo meeting.

Participants:

David Abramson, PhD MPH, Clinical Associate Professor of Public Health, New York University

Keola Awong, Area Manager of the Hawai'i Volcanoes National Park Kahuku Unit

Michael R. Boswell, PhD, AICP, Department Head and Professor of City & Regional Planning at California Polytechnic State University

Tamar Elias, PhD, Gas Geochemist, Hawai'ian Volcano Observatory, U.S. Geological Survey

Bruce Houghton, PhD, Hawai'ian State Volcanologist, Science Director at the FEMA-funded National Disaster Preparedness Training Center at University of Hawai'i

Jim Jacobi, PhD, Biologist, Pacific Islands Ecosystem Research Center, U.S. Geological Survey

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Appendix 4: Issue Papers

Following deployment, SSG Kīlauea Team members were asked to quickly write short “issue papers” highlighting different issues the group did not have time to discuss during the meeting but agreed were important to capture and communicate. The SSG sought to provide information on these topics to stakeholders as quickly as possible via briefings. Authors were asked to draw on their expertise and knowledge of each topic to give a sketch of the issues at hand. Each issue paper describes the state of knowledge in August 2018, and includes suggestions for near-term and long-term actions extending beyond two years into the future. Where possible, authors were asked to provide lists of additional resources for further reading.

Utility of arts community in healing

Author: Sara K. McBride

What we know now: The expressive arts (painting/drawing, sculpture, dance, theatre, and music) are a fundamental component of the human experience, both in ancient and contemporary times. The arts are used by artists as forms of expression to communicate emotional and internal complexities and issues. This includes grief, struggles, and confrontation, particularly in the modern arts movements, where extreme colors, shapes, and forms have diverted from more classical images. The arts also create connections to our heritages.

The arts community is a critical but often overlooked component of successful recoveries. In disasters, often arts can suffer because artists loose artistic spaces (studios, theatres, venues) to perform or engage in the creation of their arts. Further, these losses rarely get financial support because these may be perceived as “secondary” needs of a community to recover. Housing, building, and infrastructure rebuilds often receive more focus, funding, and attention because of the immediacy of these needs. However, recovery for the arts community is critical as well because it assists in building more social capital, which may have been impacted due to evacuations and loss of communities.

Expressive arts can be grouped into a larger concept of social capital, as it helps create cohesion to a sense of place, self, heritage, and cultural identities. These aspects of identity and sense of place are critical to recovery; if a community is involved in their own recovery, they are more likely to recover faster than if they feel excluded.

In the non-disaster context, we know that arts and musical therapy are known psychological therapy techniques and theories to help people process, cope, and create new futures for themselves post-trauma. In the limited case studies that examine arts in recovery, we understand that this is a critical component of mourning, healing, and rebuilding communities post disaster.

Hawai’ian context (Author: Keola Awong): What we understand about *Hawai’ian* communities and cultures is the power of the arts, whether through hula (dance), oral histories, arts, and expression. These art forms have ensured the Hawaiian language and culture has continued despite adversity and colonialism to oppress part or all its expressions. Today, chant and hula are considered an art form. Traditionally, their function was much more practical, and they served as history books. In a culture that did not have a written language, chant and hula was a way to record current events. Performing these chants and hula assured that these events would be remembered. There are hundreds of chants that were passed down generationally that recorded volcanic activity.

Case studies: There are several important case studies regarding the importance of arts as social connectors, some of these are directly related to disasters while others focus on merging diverse communities utilizing arts.

> *Christchurch, New Zealand*
> With the Central Business District and large parts of the city destroyed, several community movements arose. Two of these: GapFiller and Ministry of Awesome, are examples of bringing communities together through arts, music, dance, and theatre. The GapFiller project took over spaces in the city that formerly had buildings (then demolished) and put pianos, moveable dance floors, and art spaces for people to enjoy. The concept was simple: to enjoy the "gap" between when the city would be rebuilt fully, so that people felt connected during the process of the rebuild (which has taken more the eight years). The Ministry of Awesome was similarly activities, creating hackathons and creative exercises to help inform the design of the future city.
>
> *New Orleans, L.A. (Hurricane Katrina)*
> Music is a critical cultural aspect to New Orleans. Post-Hurricane Katrina, the re-emergence of the music and art scene helped re-establish a sense of place for both old and new residents. The first Mardi Gras, post Katrina, was smaller and more contained, but also was a time of celebration and connection for residents (Burnett, 2006; "Katrina 5 Years Later: Healing and Rebuilding Through Art," 2010)

What we need to know and knowledge gaps: The gaps in our knowledge regarding the artistic endeavor in Hawai'i is manageable through engaging with artists, musicians, and writers living in these areas. As the areas affected were mostly suburbs rather than townships, it is likely that most artistic spaces were largely untouched. However, in these communities, there were some smaller but influential art galleries that could have been impacted.

Why this is important: The rebuilding of the impacted communities may take some time and discussion. During this period, community members can face many challenges including loss of some communities (due to people not choosing to return or rebuild) and uncertainty about whether or how the rebuilding process may occur.

Potential actions:
Present – 6 months: Engage with community to understand what art spaces need to be developed or rebuilt. Potential suggestions could be arts gatherings, music evenings, and memorial type gatherings for mourning what was lost. Develop artistic grants and funding to support the beginning of artistic response.

6 months – 2 years: Support the ongoing development of art spaces. One-year anniversary of the beginning of the volcanic unrest and activities.

2+ years: Continued supporting of artists and their connection to the eruption.

Resources:

- “Katrina 5 Years Later: Healing and Rebuilding Through Art,” Public Broadcasting Service, August 3, 2010, accessed May 14, 2019 at https://www.pbs.org/newshour/arts/katrina-5-years-later-healing-through-art
- Burnett, J., 2006. Mardi Gras Adjusts to Post-Katrina New Orleans, *Morning Edition*, National Public Radio, February 27, 2006, accessed May 14, 2019 at https://www.npr.org/templates/story/story.php?storyId=5234970
- “Disaster Art: The emergence of a trend,” New Statesman America, November 7, 2012, accessed May 14, 2019 at https://www.newstatesman.com/cultural-capital/2012/11/disaster-art
- Ganapati, N.E., 2012. In good company: Why social capital matters for women during disaster recovery. *Public Administration Review*, *72*(3), pp.419-427.

Communicating Uncertainty

Author: Sara K. McBride

What we know now: Throughout much of the 2018 Kīlauea eruption, there was no known estimate for how long the eruption may last. In one communication to the public, the HVO stated that the eruption may continue for many months or years (USGS, 2018). Several aspects that contributed to this uncertainty were not knowing: when the eruption will end; where else the eruption will impact (for example, new fissures or deformation at the summit); where people can rebuild; when rebuilding can begin; what costs will be covered for damage and rebuilding; if managed retreat is a viable solution and if so, how would this be coordinated. Given this list of uncertainties, it is understandable that people who were directly impacted may continue to be frustrated and/or experience compromised mental health.

Case studies: Kīlauea and the uncertainty of the 2018 eruption is not without some analogues. These case studies can provide an informed perspective on what unique challenges may be in events with high levels of uncertainty and have some social science studies related to them, specifically regarding communication or adaptation.

- *Monserrat (Caribbean Island, Lesser Antilles):* Volcanic crisis, which is ongoing and involved more than half the island being placed in an “exclusion zone”, where no one can build permanent homes. Towns were destroyed during pre-exclusion zone and people were injured or killed. (1990s – present activity.)
- *Eldfell (Iceland):* Volcanic crisis on an island south of the main island of Iceland. Caused social disruption on island and mass evacuations. (1973)
- *Eyjafjallajökull (Iceland):* Volcanic crisis, known for causing disruption to air travel due to ash plumes. (2010) (Carlsen 2012).
- *Previous Hawai’ian eruptions:* Eruptions on Kīlauea are not novel, with several eruptions occurring in the last 30 years that have impacted human settlement. (1970s – present).
- *Ambae (Vanuatu):* Ongoing with current eruptions causing evacuations from the island. (Ongoing) (Cronin, 2004)
- *Canterbury Earthquake Sequence (New Zealand, 2010 – present):* Aftershock sequences can last years, a present example being the Canterbury Earthquake Sequence, which has been ongoing for more than eight years (2010 – present) (Wein, 2014).

Examining literature from these major eruptions and earthquakes, several themes emerged from the social science conducted during and after these events.

Creating and maintaining trust during times of uncertainty: locals first
Publicly-distributed information on science and planning should come from well-known and respected local scientists and policy makers, either from the local university, government agencies or local governments. In Monserrat, trust in the science observatory was ranked higher than trust in political figures or external parties (for example, military from the U.K. to help manage the emergency). "Outside" groups making decisions, without consultation with residents, were met with distrust and anger, as well as poor decision making by those outside groups (for example, tent cities that were built blew away during the frequent high winds that battered Monserrat).

Communicating probabilities and percentages
Scientific information of what will happen next is often framed in terms of probabilities using percentages or chances (for example, 1 in 100). Much of the literature suggests that it can be difficult for many people to fully grasp their risks, when framing it probabilistically using numbers alone. Scenarios "tell the story" of what could happen next, comparing one scenario with another. This type of communication is frequently used by volcanologists during eruptions. It is important to highlight which scenario is most likely and which is least likely, without diminishing the impact of the less likely, but more impactful event. The use of narrative (story) combined with numbers, maps, tables, and charts can be useful in providing a whole picture to different people.

Empowering affected communities
In the Canterbury Earthquake Sequence, the "Share an Idea" platform was a popular concept which encouraged residents to share their thoughts on what should happen to land that was no longer occupiable due to liquification or land instability. The project encouraged residents to place their priorities for the rebuild on magenta colored post-it notes. The notes were posted, en masse, in public spaces, and were generally met with positivity. Despite the intention of public empowerment, the project's ideas were not greatly utilized during the planning of the rebuild; this then further diminished trust among residents that the government was listening to their concerns and desires for a new city. If these types of events are utilized, it is best to continue with follow-up and to illustrate how these ideas were incorporated in decision making over the long term.

Cultivating empathy
Empathy is an important component of crisis and recovery communication. Messages should be local, based on the experience of the impacted people to increase trust. Empathy for residents impacted by Kīlauea is two-fold: the length of time this event lasted and that residents knowingly built their homes in the LERZ. With most disasters, external empathy wanes in a matter of days to months if no further events occur. Evidence indicates that once the media becomes disinterested, so do people not directly impacted. Kīlauea has followed a similar trajectory.

Initially, the media interest in these events was high, with constant reporting on the volcano and its destruction of homes. As the eruption continued, media interest waned. This can lead to a lowered sense of interest in the fate of residents and homeowners who are impacted by the eruption. In a cursory analysis of social media, some people stated that those impacted were aware of the risks of building a home near the volcano and therefore should receive either minimal official help. It is unknown whether these commentators were aware of the lack of affordable housing on the island or cultural/community ties to these communities that may have led homebuyers to settle in these areas.

Knowledge gaps:
There are several critical areas for which we do not have official or reliably collected data, data that are ethically sourced and peer reviewed. These are:

- Levels of trust from affected residents and various science and government agencies
- Risk perception (for example “it will happen again here”) among potential new residents or residents returning near the area
- Social cohesion of the evacuated residents
- Vision for future rebuilding and adaptation, among residents
- Preferred channels of communication
- Empathy for impacted residents
- Where the directly impacted residents have relocated and preferences among those residents for future developments, and
- Financial support from insurance companies to rebuild in the Lower Rift Zone.

Understanding these gaps, from an analytical perspective, can assist any group in developing a thorough and comprehensive communication strategy for the months and years ahead.

Potential research actions

Present – 6 months: conduct a study of attitudes and needs assessment of residents. Visioning activities for example “Share an Idea” with communities so there is hope in future activities. Updated regular Kilauea updates that include scenarios and probabilities (this has happened but only infrequently and not on a regular schedule), may be useful.

6 months – 2 years: Action visioning suggestions that are achievable in shorter time frames for example provide more public green or recreational activities, create an arts festival honoring the volcanic activity and residents lost or other ideas the communities may have.

2+ years: Conduct another study to determine if interventions outlined by the baseline (conducted in the first six months) has shifted, and if community expectations have been partially or wholly met.

Resources:
“Communicating in Recovery” Australian Red Cross accessed on May 14, 2019 at https://www.redcross.org.au/get-help/emergencies/resources-about-disasters/help-for-agencies/communicating-in-recovery

Botan, C. H., and Taylor, M. 2005, The role of trust in channels of strategic communication for building civil society. *Journal of Communication, 55*(4), 685.

Broome, B. J.,1991, Building shared meaning: Implications of a relational approach to empathy for teaching intercultural communication. *Communication education, 40*(3), 235-249.

Carlsen, H. K., Gislason, T., Benediktsdottir, B., Kolbeinsson, T. B., Hauksdottir, A., Thorsteinsson, T., and Briem, H., 2012, A survey of early health effects of the Eyjafjallajökull 2010 eruption in Iceland: a population-based study. *BMJ open, 2*(2), e000343.

Cronin, S. J., Gaylord, D. R., Charley, D., Alloway, B. V., Wallez, S., and Esau, J. W., 2004, Participatory methods of incorporating scientific with traditional knowledge for volcanic hazard management on Ambrae Island, Vanuatu. *Bulletin of Volcanology, 66*(7), 652-668.

Wein, A. M., Potter, S., Becker, J. S., Ratliff, J. L., and Hudson-Doyle, E. E., 2014, *Aspects of Decision-Making for Risk Reduction during the Prolonged Earthquake Sequence in Canterbury, New Zealand.* Paper presented at the AGU Fall Meeting Abstracts.

Potential socioeconomic impacts of the Kīlauea eruption

Authors: Ruben Juarez and Mark Kimura

What we know now: The 2018 Kīlauea eruption has and will continue to have a significant socioeconomic impact on families and businesses from lower Puna to Hilo and beyond. It will also have severe financial consequences on the federal, state and local governments. Estimated direct financial losses have already reached several hundreds of millions of dollars, but this does not include indirect impacts on businesses, or direct and indirect socioeconomic and health impacts on individuals for years to come. Families of low socioeconomic conditions are disproportionately affected.

What we need to know: Quantify the short- and long-term impact of Kīlauea on individuals, businesses, local communities, and governments. At the individual level, such assessments should include the financial, social and health (such as employment, education, psychological, and physical) impacts on individuals and families, potentially cascading beyond directly affected areas to the entire big island and the state. The financial impacts on businesses and their implication on the local and state communities must be measured. There is also a need to assess the impact on communities, including roads, schools, hospitals, jobs, and their effects on individuals, businesses and other communities. More accurate metrics are needed for the impact of Kīlauea on revenues for park services, the tourism industry, the agriculture sector, and their impact on federal, state and local revenues. When monitoring the socioeconomic impacts, monitoring should be done locally (both geographically, by industry or by socioeconomic group) rather than at island's average.

Knowledge gaps:

- How should short- and long-term financial support for affected families and businesses be determined to maximize their benefits?
- How can non-profit community organizations (who know the needs of their constituents better) play a role in a more efficient distribution of resources in their communities?
- How can social and economic networks be used to provide more precise measures of the impact of Kīlauea and maximize the benefits of limited resources allocated to affected individuals?
- How should non-financial effects (for example, education and health) be incorporated into financial models of decision making? There is a need to develop more comprehensive models that interconnect social and health with economic modeling.
- How can the knowledge acquired by the data collected be used to build more resilient communities that are less impacted by future natural disasters?
- How can new technologies (for example, widely spread access to phones/smartphones) play a role in measuring and minimizing the impact of natural disasters?

Why this is important: The data collected should help evaluate action plans to mitigate the effect of Kīlauea and future natural disasters inside and outside of Hawai'i. In particular, these data should be used for optimal decision making to address the displacement of affected individuals and to rebuild a more resilient community.

Potential actions:

Present - 6 months: Assemble multidisciplinary teams of scientists (for example, economists, public health, engineers, geologists, etc.) and community members to design comprehensive data-collection tasks (for example, economic, health, geological, etc.) that evaluate impacts on individuals and communities at large.

6 months – 2 years: Along with decision makers that include community partners, use data collected (see present - 6 months) to design long-term solutions for affected individuals and businesses.

2 +years: Study the long-term socioeconomic and health impacts of a disaster on individuals and their families, for instance, by recruiting a cohort of individuals that will be followed over several years. Study alternative ways to diversify the economy to minimize the effect of future Kīlauea eruptions and other natural disasters. Evaluate other communities at risk for natural disasters (from volcanic eruptions to global warming), their expected impact if a disaster occurs, and alternative solutions for such communities.

Resources:

Coffman, M., and Noy, I., 2012, Hurricane Iniki: Measuring the long-term economic impact of a natural disaster using synthetic control. *Environment and Development Economics*, 17(2), 187-205. doi:10.1017/S1355770X11000350

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., and Webb, J., 2008, A place-based model for understanding community resilience to natural disasters. *Global environmental change*, 18(4), 598-606.

Huan, T. C., Beaman, J., and Shelby, L., 2004, No-escape natural disaster: Mitigating impacts on tourism. *Annals of Tourism Research*, 31(2), 255-273.

Jaeger, P. T., Shneiderman, B., Fleischmann, K. R., Preece, J., Qu, Y., and Wu, P. F., 2007, Community response grids: E-government, social networks, and effective emergency management. *Telecommunications Policy*, 31(10-11), 592-604.

Rose, A., 2004, Economic principles, issues, and research priorities in hazard loss estimation. In *Okuyama, Y. and Chang, S.E. [eds] Modeling spatial and economic impacts of disasters* (pp. 13-36). Springer, Berlin, Heidelberg.

Biosecurity and invasive species issues

Author: Jim Jacobi

What we know now: The 2018 Kīlauea eruption activity had some significant impact on native species and ecosystems, particularly those found along the LERZ of Kīlauea volcano. While lava flows also happened regularly in this area during pre-human history, the impacts of those eruptions were relatively minor since they occurred across landscapes that were completely dominated by native species. However, when lava flows, such as those in 2018, now cover native ecosystems in this area, the impacts are magnified since much of the lowland habitat in Hawaiʻi, including the Puna District, has been heavily altered by human land-use practices as well as impacted by invasive species, with only remnant native patches remaining.

What we need to know and knowledge gaps:

- Conduct new surveys of native ecosystems and rare species in eruption impacted areas to provide a more current assessment of the status of these resources.

- Conduct a study to assess the impact and recovery potential by native plants and animals to short-term and chronic exposure to sulfur dioxide fumes.

Why this is important: Hawai'ian ecosystems evolved in relative isolation for millions of years before humans first arrived in these Islands. Due to the location if this archipelago near the middle of the Pacific Ocean, it was extremely rare for plant and animal species from surrounding island chains and continents to disperse to and become established here. As a result, Hawai'ian ecosystems are renowned for the evolution of a very unique diversity of species of plants and animals, most of which are found nowhere else in the world. However, the isolation and associated evolution of species diversity also resulted in very high vulnerability of Hawai'ian ecosystems to invasive species brought by humans to these islands. Since western contact, starting in 1778, thousands of non-native species of both plants and animals have been introduced into Hawaiʻi and many have had severe impacts on the native ecosystems. Invasive species, combined with human land-use impacts, have resulted in the extinction or endangerment of over 500 Hawai'ian plants or animals.

Potential actions:
present – 2 years: Intensify searches for the transport of invasive species from the impacted areas in the LERZ into new areas on Hawaiʻi Island and elsewhere in the state. For example, there is potential for Hawaiʻi National Guard vehicles and gear used to support the LERZ efforts to have been contaminated by invasive species, such as coqui frogs or little fire ants, which could then be transported to new sites in Hawaiʻi.

6 months – 2 years: Intensify searches for new invasive species that have been brought into areas adjacent to the lava and fume impacted areas in the LERZ. Expand efforts by the state and federal endangered species programs to collect propagules from extremely rare species of plants that are in areas threatened by the current eruptive activity.

2+ years: Monitor recovery of native plant and animal species in plant communities impacted by the current eruption activity.

Resources:

Daehler, C.C., Denslow, J.S., Ansari, S. and Kuo, H., 2004, A risk assessment system for screening out invasive pest plants from Hawai'i and other Pacific Islands. *Conservation Biology* 18: 360-368.

Ellsworth, L.M., Litton, C.M., Dale, A.P. and Miura, T., 2014, Invasive grasses change landscape structure and fire behavior in Hawai'i. *Applied Vegetation Science* 17: 680-689.

Loope, L.L., Hughes, R.F. and Meyer, J.-Y., 2013, Plant invasions in protected areas of tropical Pacific Islands, with special reference to Hawai'i. In: Foxcroft, L.C., Pysek, P., Richardson, D.M. & Genovesi, P. (eds.) *Plant Invasions in Protected Areas: Patterns, Problems and Challenges*, pp. 313-348. Springer, Dordrecht, Heidelberg, New York, London.

Staples, G.W. and Cowie, R.H., 2001, *Hawai'i's Invasive Species: A guide to invasive plants and animals in the Hawai'ian Islands*. Mutual Publishing and the Bishop Museum Press, Honolulu, HI.

Warshauer, F.R., 1998, Alien species and threats to native ecology. In: Juvik, S.P., Juvik, J.O. & Paradise, T.R. (eds.) *Atlas of Hawai'i*, pp. 146-149. University of Hawai'i Press, Honolulu, HI.

Disasters and Mental Health: Mental Health Implications for Adults and Children

Author: David Abramson

What we know now: Acute collective stressors, whether of natural origins (such as hurricanes or earthquakes), man-made events (such as terrorism) or technological sources (such as the Deepwater Horizon oil spill or the Chernobyl nuclear accident), have been associated with short- and long-term mental health effects among adults and children. The primary psychological and behavioral impacts associated with these acute catastrophic events include post-traumatic stress disorder (PTSD), major depressive disorders (MDD), generalized anxiety disorders, mental health distress, and substance use disorders. As Bonanno and others (2010) have noted, it is generally only a minority of disaster-exposed individuals who experience short- and long-term mental health effects, and of those many are time-limited. Bonanno and others (2010) have also noted that population mental health incidence as a result of a disaster rarely exceeds 30% of the exposed population; an earlier meta-analysis of disasters and psychopathology found that, on average, 17.4% of disaster exposed populations experience mental health effects (Rubonis and Bickman, 1991).

Of course, these estimates vary greatly by the nature of the disaster, the types of consequences experienced by those individuals exposed to the disaster, and their pre-disaster strengths and vulnerabilities. In a Hurricane Katrina study of 1,079 randomly sampled displaced and greatly impacted individuals in Louisiana and Mississippi, many of whom were socio-economically disadvantaged before the hurricane struck, over half of the respondents reported significant mental health distress in the first year. Similarly, over 40% of the children among this Katrina cohort experienced mental health distress within the first year after the hurricane, and 35% of children had serious emotional disturbance five years later, a rate five times greater than the norm for Gulf Coast children (Abramson and others, 2008). In a population study conducted among 1,000 randomly sampled household in New Jersey after Hurricane Sandy, a far more economically-advantaged group than in Katrina, 16% of adults reported mental health distress two years after the event, although parents reported that 37% of their children had experienced mental health effects of Sandy (Abramson and others, 2015).

Among the most common models used to describe behavioral health impacts is the one illustrated in Figure 7, the stress-mediated model of mental health effects. “Disaster exposure” can refer to direct contact with the disaster agent itself – such as being injured by floodwaters, or to the cascading consequences of the disaster – such as displacement from one’s home, secondary injuries or illnesses, and economic losses. Three primary behavioral health outcomes are listed on the right: an increase in substance use disorders; depression, anxiety, or distress; and PTSD. Some of the factors leading to these psychological outcomes may have pre-dated the disaster, such as prior mental health issues or prior substance use.

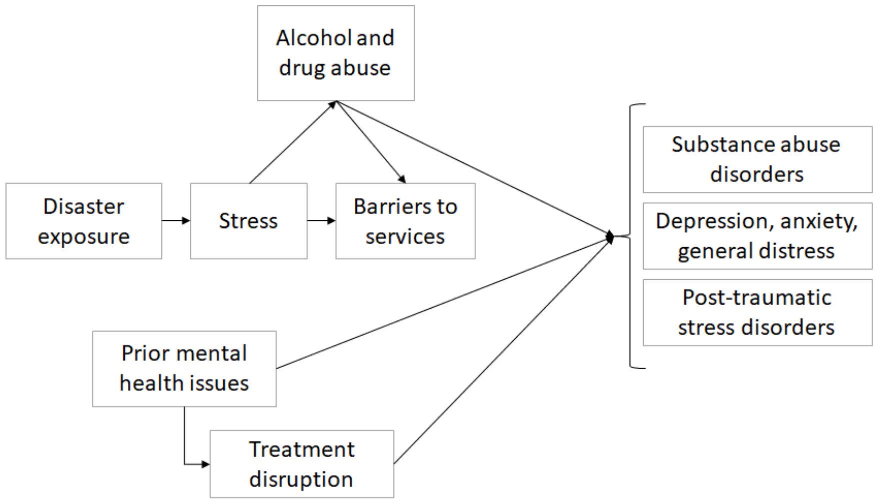

Figure 7: Post-disaster behavioral health conceptual framework

Central to this model is the role played by stress, which essentially serves as the mechanism through which a disaster produces mental health distress. One way to think about this is that many individuals, who we may consider resilient or resistant to such stressors, experience the disaster exposure but do not progress to mental health pathophysiology. This may be because of their access to key resources that help them buffer the effects of the exposure (such as a strong social support system, or financial assets and insurance) or because of their psychological traits of self-efficacy, hardiness, or a strong ability to cope, among others. One key trait that has been cited often as a significant buffer is a strong religious belief system.

Fundamentally, if the stress is not buffered by these traits and assets it is experienced as a loss of control or certainty about one's future and one's environment. These could be the result of "existential" threats to an individual's livelihood, housing, or social roles in the community; to significant disruptions to familial, social, or educational routines; or to economic and physical harms to oneself, one's family, or one's pets or animals. These stresses may lead to alcohol or drug use, and secondarily to more serious substance use disorders, or they may lead directly to psychopathologies, particularly if there are limited therapeutic services available to intervene.

One important thing we know about Hawai'i is that, according to the Centers for Disease Control and Prevention's Behavioral Risk Factor Surveillance System, in 2011 the state reported the lowest rate of Depressive Disorders of any state (10.6%, compared to the median of 17.5%) (CDC, 2011). This may suggest a hardier or more psychologically-resilient population.

What we need to know and knowledge gaps: The greatest stressor to the population on Hawai'i is the lava eruption in the LERZ where the lava flows have disrupted or destroyed populated areas of the island. Regarding the behavioral health impacts of the lava eruption, what we need to know are:

- The proportion of all exposed populations (adults and children) who have experienced increases in substance use, or who have experienced depression, anxiety, or PTSD;
- Access and availability of therapeutic services;
- The geographical, social, cultural, economic, and psychological factors associated with increased likelihood of mental health distress, and those factors associated with greater resilience.

The greatest “unknown” is the extent to which cultural beliefs by native Hawai'I residents in the Goddess Pele buffer the stresses caused by the eruptions. This, as well as other population characteristics such as self-sufficiency, experience with prior eruptions, and even a slower pace of life, may account for both historical mental health resilience among Hawai'i residents as well as their resistance to the current acute stressor.

Why this is important: Addressing these knowledge gaps is critical, since they can help inform potential programmatic and policy efforts. The problem may not require simply deploying teams of mental health professionals to engage in therapeutic activities, but rather interventions such as transitional housing, disaster case management, continuity of educational, social, and cultural services, and financial counseling and planning, all of which may be better positioned to help alleviate concerns associated with loss of control about one’s future and environment. Furthermore, it will be important to identify issues among children, who may not readily confide their emotional or psychological problems to parents (often, so as not to “burden” them when they are already dealing with so many financial or housing stressors), and for whom such psychological impacts can have long-term effects on educational and health outcomes.

Potential actions:
Present – 6 months: Immediately assess the behavioral health status of the exposed population. This includes those who have evacuated, been displaced, or voluntarily moved. Consider the ways that community-based organizations can be immediately deployed to offer multiple supports to the exposed population.

6 months – 2 years: Based on survey data and discussions with subject matter experts, consider programmatic activities such as coordinated disaster case management, transitional housing options that lead to stable housing, and financial counseling and planning. Consider developing youth programs to cultivate resilience through promotion of pro-social behaviors (see the SHOREline Project, https://ncdp.columbia.edu/microsite-page/shoreline/shoreline-home/, as an illustration of such a project).

2+ years: Consider repeat (longitudinal) surveys of the exposed population to determine change over time.

Resources:

Abramson, D., Stehling-Ariza, T., Garfield, R. and Redlener, I., 2008, Prevalence and predictors of mental health distress post-Katrina: findings from the Gulf Coast Child and Family Health Study. *Disaster Medicine and Public Health Preparedness*, *2*(2), pp.77-86.

Abramson, D.M., Park, Y.S., Stehling-Ariza, T. and Redlener, I., 2010, Children as bellwethers of recovery: dysfunctional systems and the effects of parents, households, and neighborhoods on serious emotional disturbance in children after Hurricane Katrina. *Disaster Medicine and Public Health Preparedness*, *4*(S1), pp.S17-S27.

Abramson, D.M., Van Alst, D., Merdjanoff, A., Piltch-Loeb, R., Beedasy, J., Findley, P., Peek, L.A., Mordy, M., Moroso, S., Ocasio, K. and Park, Y.S., 2015. The hurricane sandy person report: disaster exposure, health impacts, economic burden, and social well-Being. The Sandy Child and Family Health Study. Rutgers University School of Social Work, New York University Global Institute of Public Health, National Center for Disaster Preparedness at Columbia University, Colorado State University, Briefing Report 2015_2. (Release date 3 June 2015)

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New challenges for staying healthy with Kīlauea's air pollution

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What we know now: Volcanic eruptions are not new to Hawaiʻi. Hawai'i residents have lived with these volcanoes for hundreds of generations. There are countless chants that record volcanic activity over time that describe different gases *uahi awa* (sulphur gas), *uahi pele* (volcanic smoke), *māhu* (steam water vapor), etc. Scientists currently use the term "vog" to describe volcanic air pollution in Hawai'i.

Only a limited number of studies have examined health effects from volcanic air pollution worldwide. Studies on vog at Kīlauea have identified adverse health effects associated with both low and high exposure (scientific literature on the Hawai'i Interagency Vog Information Dashboard, 2018; Longo 2013) These studies used a variety of research designs to measure frequency of diseases or symptoms, test for associations between exposure and health outcomes, or describe lived experiences from informants. Adverse effects identified include acute cardiorespiratory and ocular self-reported symptoms, clinical signs, and diagnosed illnesses. Development of chronic diseases from long-term exposure to vog was not investigated and remains unknown. Yet, there is sufficient causal evidence from urban studies on adverse health effects from pollutants found in vog. These studies identified increased acute and chronic cardiorespiratory morbidity and mortality in populations exposed to finely-sized particulate matter ($PM_{2.5}$) and anthropogenic-sourced sulfur dioxide (SO_2) (Rajagopalan and Brook, 2018; Sun and Wold, 2010). Most at risk for adverse effects of the pollution were sensitive members of the population (for example, infants and children, elderly, pregnant women, persons with preexisting cardiorespiratory disease, or those with low socioeconomic status).

What we need to know: There is biological plausibility for development of chronic disease from vog. Hence, it is imperative to investigate causal relationships between vog and chronic disease or late sequelae, and to identify population sub-groups most susceptible to its effects. Probable chronic diseases include: (1) adult-onset cardiorespiratory, cerebrovascular and endocrine diseases (for example chronic obstructive pulmonary disease, reactive airway dysfunction syndrome, diabetes, and various cardiovascular diseases), and (2) pediatric airway, allergic and cardiovascular diseases.

There is also a need to empirically test and enhance existing interventions for vog. Are the interventions evidence-based, culturally appropriate and feasible to reduce gas/vog/ash exposure, with consideration for economically disadvantaged residents? Are the current school-based interventions for vog and ashfall effective in reducing absenteeism and illness, especially asthma exacerbations?

Why this is important: Chronic disease has adverse outcomes and burdens that affect the economic status, social structure and psychological health of the people. In the face of a natural-source air pollutant, abatement is not an option. Therefore, efforts should focus on 1) reducing exposure on sensitive populations across settings; 2) improving overall health status of the population through health promotion; 3) detecting disease early by ensuring access-to-care and screening programs, thereby enabling prompt initiation of treatment; 4) providing chronic disease maintenance programs to slow progression and maintain quality of life; and 5) epidemiologic monitoring using geospatial exposure data. To reduce disparity and inequity, efforts and services should focus on rural/underserved communities across the island.

Potential actions:
present – 6 months:

- Identify and fund island-wide health promotion and screening initiatives that are culturally appropriate.
- Initiate school interventions using a team-based participatory approach.
    - Put emphasis on teacher education about hazards and health impacts, as well as their frontline participation in student health.
    - Ensure school safety officers are equipped to test air quality.
    - Conduct outdoor/indoor penetration measures for classrooms and identify rooms for sensitive students.
    - Track absenteeism and illnesses related to vog.
    - Encourage schools with previous experience to mentor newly affected schools.
    - Conduct six-month evaluation of interventions and make necessary adjustments.
- Conduct epidemiologic monitoring for incidence (new cases) of chronic diseases in the population by public health.
- Continue community education across all the state on protection from emissions, vog and ashfall via the Hawai'i Interagency Vog Information Dashboard (2018).

6 months – 2 years:

- Begin health promotion initiatives in schools, senior centers, daycares, etc.
- Present training programs for healthcare personnel in affected areas to improve quality of care delivery (goal by end of year 1).
- Begin disease screening of affected populations performed by public health nursing and healthcare agencies.
- Launch health studies using designs to test causal relationships. Additional epidemiologic and qualitative studies with community participation are encouraged.
- Share effective school interventions with all Hawai`i Island schools and eventually across the state (goal by end of 2018/19 school year).
- Modify school and senior center buildings to decrease indoor penetration of vog/ashfall if necessary.
- Identify rural healthcare delivery needs and address them as possible.

2+ years: evaluation and reassessment of knowledge gleaned from health studies and interventions by a multi-disciplinary team, with informants from the affected communities. Consider environmental health planning for long-term intermittent exposure of volcanic air pollution across the state.

Resources:

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Long term effects of daily earthquakes and ground deformation on buildings and infrastructure

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What we know now: Since the first of the summit crater pressure explosions at Kīlauea Volcano in early May of 2018, there were almost daily pressure explosions giving off the energy equivalent of approximately a magnitude-5.2 earthquake. These internal crater explosions created surface ground accelerations up to approximately 0.2g within Volcano Village and the area of the main facilities of the National Park Service property.

In addition to the ground accelerations, there were considerable amounts of ground deformation due to the volcano deflating. This ground deformation comes in the form of lateral ground spreading and differential settlement. At this time, the amount of ground deformation in Volcano Village is not known, but there are visible effects of it (for example, cracks and depression to Highway 11, voids in and around HVO and Jaggar Museum buildings). There was also structural damage due to lateral spreading and differential settlement to HVO and the Jaggar Museum buildings.

An earthquake creating up to 0.2g in ground accelerations normally would not create any damage to timber-framed houses in itself. However, daily events for the term of months to years can create structural damage. It is possible with constant shaking to loosen the structural connections (nailed or bolted wooden members, etc.). When the connections loosen, the house can have greater deflections under subsequent earthquakes than was intended. Greater deflections in turn could damage the external weatherproofing and internal architectural elements (drywall, doorways, windows frames, etc.).

What we need to know/knowledge gaps:

- The amount of ground settlement in Volcano Village over the course of time since the start of the current eruption.
- Existence of architectural and/or structural damage to the housing stock in Volcano Village and other buildings in the National Park from both ground deformation and daily ground accelerations (earthquake shaking).
- Verification of the existence of damage to underground utilities (waterlines, etc.)

Why this is important: It is possible with daily ground accelerations for the connections in timber buildings and structures to loosen. This in turn can cause the building to be more flexible and create knock-on damage (cracking of drywall, doorways deforming and jamming, windows jamming or cracking). Housing using the post and pile type of construction where the ground floor is elevated from grade (crawl space) can be more vulnerable to this type of damage.

Knowing the rate of ground deformation over time, it is possible to estimate if or when there will be damage to the housing stock and utilities. Ground deformation can be uneven creating a condition called differential settlement. Small amounts of differential settlement (+/- 20mm) can create structural damage to buildings. Differential settlement can also create uneven floors and separation of building sections (usually at construction joints or changes in building geometry). Unlike ground accelerations that act momentarily, differential settlement is permanent and cumulative.

Potential actions: Damage assessments by professional engineers to verify the existence of architectural and/or structural damage to the housing stock in and around Volcano Village. If there is damage, take protective action (shoring/propping/bracing) to stop or minimize further cumulative damage which over the course of a year, could make the housing uninhabitable.