U.S. Geological Survey 2018 Kilauea Volcano Eruption Response in Hawai‘i—After-Action Review

Open-File Report 2020–1041

U.S. Department of the Interior
U.S. Geological Survey

Cover: U.S. Geological Survey scientist documenting an approximately 50-meter-high lava fountain at fissure 7 of the Kilauea Volcano, Island of Hawai'i, Hawai'i. Photograph by Brett Walker, volunteer with U.S. Geological Survey, May 27, 2018.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
	Volume	
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Flow rate	
gallon per second (gal/s)	3.78541	liter per second (L/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	Acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
square meter per second (m^2/s)	10.7639	square foot per second (ft^2/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F – 32) / 1.8.

Abbreviations

CERT	Community Emergency Response Team
CISM	Crisis Incident Stress Management
CONUS	Continental United States
COOP	Continuity of Operations
DISC	Deputy Scientist-in-Charge
DOI	Department of the Interior
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
ESM	Event Support Team
FAQ	frequently asked questions
FCO	Federal Coordinating Officer

Abbreviations—Continued

FEMA	Federal Emergency Management Agency
FOB	Forward Operating Base
GAR	Green-amber-red alert system
GIRT	Geospatial Information Response Team
GIS	geographic information system
GSA	General Services Administration
HAVO	Hawai'i Volcanoes National Park
HCCD	Hawai'i County Civil Defense
HiEMA	Hawai'i Emergency Management Agency
HING	Hawai'i National Guard
HREC	Hazard Response Executive Committee
HVO	Hawai'ian Volcano Observatory
ICS	Incident Command System
IMAT	Incident Management Assistance Team
IMT	Incident Management Team
IT	Information Technology
JIC	Joint Information Center
LERZ	Lower East Rift Zone
lidar	light detection and ranging
M	Magnitude
NASA	National Aeronautics and Space Administration
NCAC	National Civil Applications Center
NGP	National Geospatial Program
NHMA	Natural Hazards Mission Area
NPS	National Park Service
OCAP	Office of Communications and Publishing
OEI	Office of Enterprise Information

Abbreviations—Continued

OEM	Office of Emergency Management
OMS	Office of Management Services
PIERC	Pacific Islands Ecological Research Center
PPE	personal protective equipment
SIC	Scientist-in-Charge
SO_2	sulfur dioxide
SSG	Strategic Sciences Group
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UHH	University of Hawai'i Hilo
USGS (or “the Bureau”)	U.S. Geological Survey
VHP	Volcano Hazards Program
VSC	Volcano Science Center

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Executive Summary

Americans are more at risk from cascading natural hazard events than ever before, and volcanoes hold high potential for catastrophic loss. The response of the U.S. Geological Survey (USGS) Hawai'ian Volcano Observatory (HVO) to the 2018 Kīlauea Volcano eruption (hereinafter Kīlauea eruption) vividly demonstrates that dedicated civil servants play an indispensable role in mitigating natural hazards and making our society a safer place to live. The HVO, through its core staff and extended support network, responded to the Kīlauea eruption by courageously working through dangerous and exhausting conditions to save lives; reduce economic losses; and mitigate local, national, and international impacts with a variety of adaptive hazard monitoring and emergency response activities.

The 2018 eruption lasted 107 days, and now ranks as Kīlauea's most destructive event since 1790, and as one of the most costly volcanic disasters in U.S. history. Multiple simultaneous hazard events unfolded, including sustained seismic activity leading to collapse at the summit of Halema'uma'u crater and severe damage to the HVO facility, with additional eruption of lava in Kīlauea's Lower East Rift Zone that progressively grew to a total of 24 fissure openings. Eruptive activity became focused at fissure 8, where lava fountains reached heights of about 80 meters and formed a channel that ultimately entered the ocean at Kapoho Bay. The lava flow devastated surrounding communities, forcing approximately 2,500 people to evacuate their homes.

Eleven HVO scientists were positioned 24 hours per day, 7 days per week (24/7), at the County Emergency Operations Center in Hilo. HVO also staffed the State Emergency Management Agency facility on O'ahu, and the Federal Emergency Management Agency (FEMA) Incident Management Assistance Team in Hilo. As considerable assistance arrived from beyond Hawai'i, the "extended HVO" expanded to involve other components of USGS and the Department of the Interior (DOI) to ensure continuity of operations and hazard management in

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[1]USGS, Alaska Regional Office (Team Lead)
[2]USGS, Volcano Hazards Program
[3]USGS, Alaska Volcano Observatory
[4]USGS, Science Application for Risk Reduction
[5]USGS, Northwest Regional Office
[6]USGS, Earthquake Science Center in Menlo Park
[7]USGS, Western States Office of Communications
[8]USGS, Cascades Volcano Observatory

near real time. Over time the USGS response team increased to include 29 personnel from Hawai'i and 83 personnel from elsewhere across 17 different program offices, plus 31 USGS volunteers and 52 personnel from other DOI operations. The response team handled nearly 700 media inquiries from outlets all over the world, and more than 1.5 million people viewed daily video updates from HVO scientists. In recognition for such meritorious public service, the HVO scientist-in-charge and the extended HVO team were honored for selection as a 2019 finalist for the prestigious Samuel J. Heyman Service to America Medal. Finalist achievements are considered eloquent testimony to the many ways civil servants make a difference for our country every day (see https://servicetoamericamedals.org/about/).

This report builds on a wide variety of prior documents (situational reports, published articles, technical reviews, small team "hot wash"[9] exercises) that have already been generated by USGS activities concerned with the 2018 Kīlauea Volcano eruption and goes beyond preexisting sources by using two different survey instruments to gather direct input from the USGS team members who participated in the response action. The first survey collected interim commentary from 65 respondents in July 2018 while the eruption was still ongoing, and the second survey collected retrospective commentary from 32 respondents in December 2018 after the eruption had ended. Their aggregated feedback was consolidated into about 100 pages and then systematically analyzed and synthesized by the After-Action Review team, which focused on two basic questions: (1) what went well, and why?; and (2) what can be improved, and how?

This report compiles and summarizes the most notable themes of successful accomplishments (alternately viewed as "best practices") into six main categories: (1) General Crisis, (2) Incident Command System (ICS), (3) Safe Science Planning and Coordination, (4) Data Acquisition and Management, (5) Application of Unmanned Aircraft Systems (UAS) Technology, and (6) Communications. Likewise, this report compiles and summarizes the most notable themes of suggested improvements into four main categories: (1) Planning, (2) Training, (3) Communications, and (4) Equipment and Resources. Across those four categories, the report identifies 12 main issues in need of improvement.

Survey respondents conveyed a strong consensus in the overall view that the USGS response to the Kīlauea eruption was primarily impressive and inspiring. Suggestions for improvement generally were offered in the context of targeted adjustment to an otherwise highly effective response operation. Excerpt findings from small team reflective exercises that occurred external to the survey effort also are included in the section, "Discussion." This report then draws collectively from the wide assortment of all received input to advance a refined set of recommendations for targeted adjustments that focus on each of the following topics:

- Develop more comprehensive planning documents.
- Create a more customized fit within the ICS.
- Establish a Regional Hazards Coordinator.
- Initiate science leadership early.
- Prioritize safety in all response operations.
- Formalize incident response training protocols.
- Enhance interoperability within the Volcano Science Center (VSC).

[9] "Hot wash" has become a common term for the practice of providing immediate evaluation of performance by a team or an agency following a major trial event. It apparently derives from the practice used by some soldiers of dousing their weapons in hot water to remove debris after firing as a preliminary step to more thorough cleaning.

- Establish a Hazard Response Communication Plan.
- Improve situational awareness throughout the entire VSC.
- Initiate media procedural guidelines early.
- Consolidate community outreach opportunities from 2018 experiences.
- Ensure facility access and renewed coordination with the National Park Service .
- Improve collection and dissemination of field data.
- Expand UAS operations within the VSC.
- Enhance flexible administration of human resources during disasters.

Introduction

Globally, there are about 1,500 active volcanoes, and about 800 million people living within range of eruptive activity. Population growth and economic development are twin drivers that put more people close to volcanic hazards, but visitors and homeowners also are increasingly drawn voluntarily to spectacular landscapes and volcanic activity (Brown and others, 2017). Multiple social and environmental factors contribute to a reality where increases in disaster losses tend to outpace population growth and other demographic changes. In short, as risk creation continues largely unchecked by society, people and assets become more exposed to disaster-related losses that affect the socio-economics, health, culture, and environment of local communities (Brown and others, 2017; Vahedifard and AghaKouchak, 2018; National Oceanic and Atmospheric Administration, 2019). This steady global growth of disaster risk, whether volcanic or otherwise, compels the USGS to fortify disaster preparedness capabilities, and to ensure that institutional capacities are in place to optimize effective planning, response, and mitigation. The 2018 Kīlauea Volcano eruption offers a prime opportunity to review, assess, and improve on those capacities for potential replication both domestically and abroad.

The purpose of this After-Action Review is to identify priorities for programmatic or policy improvements that the USGS could feasibly implement to advance strategic preparation for future disasters, and thereby reduce public vulnerabilities. Specifically, the report is intended to help the USGS respond even better than before to the next eruption in Hawai'i or elsewhere by advancing any of the following goals:

- Design better planning scenarios;
- Enhance response team effectiveness;
- Assist local decision-makers;
- Promote new areas of strategic research; and
- Streamline administrative, finance, and Incident Management Team (IMT) support functions during a crisis to secure continuity of operations and essential records management.

Description of the Event

Kīlauea is the youngest volcano in Hawai'i and one of the world's most active volcanoes, with lava erupting from vents in largely uninhabited areas since 1983, and a lava lake present at the summit since 2008. Those conditions changed on May 3, 2018, when lava began erupting from fissures in the Leilani Estates in the Puna District of the Island of Hawai'i (fig. 1), and the summit lava lake drained, precipitating the largest Kīlauea summit caldera collapse in about 200 years. The initial eruption was followed on May 4 by a Magnitude (M) 6.9 earthquake, and subsequently was accompanied by a sustained rate of more than 40 M3+ shallow earthquakes per day. The 2018 eruption lasted 107 days, pausing on August 17 with the last live lava visible on September 5, and ranks as Kīlauea's most destructive event since 1790. Hawai'i County officials estimate by some accounts that the economic costs for long-term recovery could exceed $800 million, including public infrastructure projects, purchases of lava zone property, and housing assistance (Dayton, 2018).

Figure 1. Photograph showing lava advancing west from fissure 7 of the Kīlauea Volcano on Leilani Avenue, with lava fountain in background, Puna District, Island of Hawai'i, Hawai'i. U.S. Geological Survey, public domain, May 27, 2018.

As the eruption progressed, a total of 24 fissures opened along the Lower East Rift Zone (LERZ). The fresh lava flows covered more than 35 km^2 and flowed at dangerous rates of as much as 5 m per minute, covering 58 mi of road, causing about $28 million in farm losses, and destroying more than 700 homes and dozens of structures including damage to the Puna Geothermal Venture energy plant, which previously supplied about 22 percent of the island power grid. The lava flow extended more than 12 mi across before meeting the ocean at Kapoho Bay, where it established a new lava delta of about 875 acres. The lava flow devastated surrounding communities, with about 2,500 people forced to evacuate their homes. A public shelter at the Pahoa Community Park was open for 137 days, with a daily population that ranged from 100 to more than 500 people. An additional shelter opened at the Kea'au Community Center to serve about 50 more people.

Ash plumes at the summit extended as high as 32,000 ft. above sea level and threatened air traffic, and air quality was compromised to an unhealthy level on many occasions by a local record release of sulfur dioxide (SO_2) gas (averaging more than 50,000 tons per day and for some time exceeding 100,000 tons per day based on preliminary analyses). Upon contact with oxygen, water, and air particulate matter, the gas emissions produce volcanic smog (or "vog") and acid rain, which can aggravate respiratory problems, damage crops, and contaminate household water supplies. As lava comes into contact with ocean water, a deadly acid steam is formed (lava and haze) known as "laze" that can extend for a distance of as much as 15 mi. The dangerous mix also produced ballistic projectiles that resulted in serious injuries to both coastal residents and dozens of tour boat passengers.

Frequent earthquakes and collapse events led to significant damage to infrastructure and roads throughout Hawai'i Volcanoes National Park (HAVO). Within the HAVO, the USGS Pacific Islands Ecological Research Center (PIERC) closed because of the threat of ashfall and seismic activity. The Hawai'ian Volcano Observatory (HVO), vulnerably perched on the northwest rim of the summit caldera in HAVO, sustained such damage from seismic activity that the facility was permanently closed and condemned, creating numerous technical and administrative challenges to maintain continuity of operations. HVO and PIERC employees relocated to a temporary emergency site provided by the University of Hawai'i at Hilo (UHH).

Despite all the dangers, through close coordination between HVO and Hawai'i County Civil Defense, there were no fatalities on the island even though the vents erupted in the middle of a rural subdivision. Losses were reduced and mitigated through effective hazard monitoring and emergency operations. What made this response so successful, and what can be gleaned from the experience to further advance and improve USGS preparations for a future event? These are the two basic questions on which this report will focus.

Event Timeline

Prior to May of 2018, the Kīlauea Volcano was characterized by two active eruption vents: a lava lake within the summit of Halema'uma'u crater and the Pu'u Ō'ō cone with associated fissures along the East Rift Zone from 20 to 50 km to the southeast. The 2018 eruption proved unusually complex because it involved a summit caldera collapse and a flank fissure eruption. Because the event already has been thoroughly described by Neal and others (2018) in the December issue of *Science*, we provide here a succinct account of the chronology of key events.

Timeline by Date

2018

March 23:	The HVO sent their first email to Hawai'i County Civil Defense (HCCD) about the gradual growth of deformation at Pu'u Ō'ō cone and the potential for a new eruption.
April 17:	After observing the continued growth of deformation at Pu'u Ō'ō cone, the HVO issued a public warning because of concern that a new eruptive vent might form to relieve pressure from accumulating magma.
April 21:	Accumulating magma caused the summit lava lake to rise and overflow onto the floor of Halema'uma'u crater.
April 30	Indications of new seismic activity occurred as the Pu'u Ō'ō cone collapsed and magma began to migrate eastward, down rift toward the lower Puna District.
May 1:	The HVO issued a public warning that an eruption was possible down rift of Pu'u Ō'ō somewhere in the Lower Puna area. Lava lake levels at Halema'uma'u crater began to drop as magma drained and the caldera summit began to deflate.
May 3:	The first of 24 eruptive fissures opened in Leilani Estates subdivision. Initial fissure eruptions extended several hundred meters and lasted for minutes to hours (fig. 2). The initial lava was viscous, suggesting long-term storage prior to eruption. The Kīlauea Volcano Alert Level was raised to WARNING.
May 4:	A M6.9 earthquake occurred, the strongest to hit the island in more than four decades, centered 19 km southwest of Leilani Estates, followed by sustained aftershocks from hundreds of daily M3–4 summit earthquakes.

May 8: The VSC Director began to distribute briefing memorandums and daily situational reports.

May 10: Halema'uma'u crater lava lake disappears from view (fig. 3). The HVO issued a status update to warn that more lava outbreaks were likely. Sporadic eruptions of ash and rock reached heights of about 2,000 m above the summit vent. Because of building closures, HVO and PIERC employees began to use the temporary emergency site provided by the UHH.

Figure 2. Photograph showing lava fountains as high as about 70 meters (230 feet) erupted from a new fissure on the Kīlauea Volcano, Puna District, Island of Hawai'i, Hawai'i. U.S. Geological Survey, public domain, May 5, 2018.

Figure 3. Photograph showing Halema'uma'u crater rim and walls continue to slump inward and downward with ongoing subsidence at the Kīlauea Volcano summit, Island of Hawai'i, Hawai'i. U.S. Geological Survey, public domain, June 12, 2018.

As the eruption progressed through mid-May, two simultaneous hazard events unfolded: sustained seismic activity leading to collapse at the summit of the crater by the end of May and an additional eruption of lava in the Kīlauea Lower East Rift Zone that progressively increased to a total of 24 fissure openings.

May 11:	Most of HAVO closed, contributing to a significant decrease in tourism.
May 15:	The HVO issued a Volcano Observatory Notice for Aviation, increasing the aviation threat level from ORANGE to RED, because of increased ash venting at the summit.
May 17:	The highest ash plume occurred at the summit, reaching 8,100 m (about 26,500 ft) above ground level. SO_2 emission rates intensified, exceeding 50,000 tons per day at peak rate .
May 18:	Hotter and less viscous lava began erupting to create fast-moving lava flows at an unusually high effusion rate (fig. 4). The HVO began producing rapid preliminary lava-flow path forecasts. The USGS Alaska Regional Office initiated daily USGS internal coordination calls with participating offices across the Bureau.
May 19:	Lava entered the ocean near MacKenzie State Recreation Area.

Figure 4. Photograph taken from helicopter overflight of Lower East Rift Zone, Kīlauea Volcano, Island of Hawai'i, Hawai'i. U.S. Geological Survey, public domain, May 19, 2018.

May 28:	Eruptive activity was focused at fissure 8, where lava fountains reached heights of about 80 m and formed a channel that ultimately entered the ocean at Kapoho Bay on June 4, about 12 km to the southeast.
May 29:	Caldera down drop accelerated, with onset of near-daily summit collapse events that each released energy equivalent to about a M5 earthquake. Lava flow overran Hawai'i Route 132, blocking an important access road between Kapoho and Pāhoa.
June 3:	Lava erupting from fissure 8 reached the ocean at Kapoho Bay (fig. 5).
June 4:	The northeastern flow of lava quickly advanced and destroyed the subdivision of Vacationland.

Figure 5. Photograph showing acid-and-steam lava-haze ("laze") plume where lava entered the Pacific Ocean at Kapoho Bay resulting from the fissure 8 lava flow from Kīlauea Volcano, Island of Hawai'i, Hawai'i. U.S. Geological Survey, public domain, June 9, 2018.

June 24:	Aviation Color Code was lowered to ORANGE because collapse events no longer produced ash.
July 16:	A total of 23 passenger tourists on a commercial tour boat were injured by an ocean entry explosion, underscoring the challenges of safeguarding residents and tourists throughout the eruption.
July 17–19:	The Department of the Interior (DOI) Strategic Sciences Group (SSG) convened a multidisciplinary team of 13 experts in Hilo to consider cascading consequences of the eruption.
August 4:	High eruption rates diminished abruptly, and large summit subsidence events ended.
August 17:	Eruption at fissure 8 paused and the HVO lowered the alert level of Kīlauea Volcano from WARNING to WATCH.
August 21:	Ocean entries of lava became inactive.
September 1–4:	Lava activity at fissure 8 were observed to be weak.
September 20:	The last activity report was filed for the USGS eruption response.
September 22:	HAVO partially reopened.
December 5:	After 3 months of inactivity, the eruption event entered technical cessation, although the HVO continued to monitor for any changes. The Volcano Alert Level changed to ADVISORY (YELLOW).

2019

March 26:	The HVO lowered the Volcano Alert Level for ground-based hazards from ADVISORY to NORMAL. This means that the volcano was at a non-eruptive, background state. The Aviation Color Code was also lowered from YELLOW to GREEN.

U.S. Geological Survey Response Overview

Although planning is always essential, USGS staff demonstrated that a successful response also requires dedication, adaptability, creativity, and effective communication. The 29 personnel members resident at the HVO quickly set up 24/7 operations and established a presence in the local Emergency Operations Center to advise the County Civil Defense. The initial response was greatly complicated by aftershocks from the M6.9 earthquake on May 4. These aftershocks caused stress for HVO staff and resulted in the damage to the HVO facility that eventually led to its evacuation. Meanwhile, staff at other USGS volcano observatories were organized to remotely assist monitoring during evenings and nights, supplementing the HVO staff to ensure continuity of operations and hazard management. This "extended HVO" that expanded to involve other components of USGS, including 83 personnel across 17 different program offices and the Department of the Interior, simultaneously addressed three crisis events: (1) the collapse of the summit caldera with sustained seismic activity, (2) the lava eruption in the Kīlauea Lower East Rift Zone, and (3) the loss of the HVO facility.

Given the complex situation, the extended HVO had to develop creative solutions to new challenges as they occurred. The team came together to (1) monitor the volcano and develop hazard assessments, (2) work closely with emergency managers, (3) respond to media inquiries as local authorities coordinated public evacuations, (4) conduct essential scientific fieldwork, (5) provide daily situation reports and briefings to a large body of decision-makers, and (6) organize and participate in public town-hall meetings. The team accomplished this under dangerous and exhausting circumstances, all while preparing a back-up HVO facility forced by evacuation.

The team worked continuously under adverse conditions while maintaining tremendous flexibility to adapt to rapidly changing circumstances. After evacuating their home base of operations, they quickly adjusted and almost seamlessly continued to monitor the volcano and communicate with emergency managers from a temporary facility at the UHH. They found creative ways to use new technology pathways, resulting in more efficient communications and data sharing between scientists, emergency managers, news media, and the public. In support of emergency evacuation operations, the extended HVO used Unmanned Aircraft Systems (UAS) to help track lava flows and guide evacuations, including the rescue of a local resident.

In response to the complex and uncertain nature of the 2018 Kīlauea eruption, USGS team activities tended to coalesce around several interrelated core functional areas: science, emergency management and administration, and external communications.

Science

Science was the foundation of the USGS response to the 2018 eruption. Scientific activities were interwoven throughout all aspects of the response, so much so that it is difficult to distinguish between activities that were purely scientific and those that were purely operational. The overarching goals of the 2018 scientific response were to (1) collect information, data, images, analyses, and interpretations necessary for hazard monitoring and assessment; and (2) record as many aspects of the eruption as possible to enable post-eruption research into processes underlying various aspects of the 2018 eruption.

In 2018, USGS scientists met these goals through a variety of activities, including the following:

1. Closely monitoring data streams from real-time instruments (seismometers, Global Positioning System receivers, tilt meters, cameras, gas sensors, infrasound, radar, and UAS-based video streams when available) for indications that hazardous conditions might increase;
2. Collecting, processing, and analyzing data from ground-based monitoring networks as well as from satellites, UAS and (or) helicopter-based surveys (gas, photogrammetry, thermal maps), and a wide range of field observations at the summit and in the LERZ;
3. Augmenting instruments and the telemetry network for monitoring activity in the LERZ; and
4. Collecting lava and ash samples for laboratory analysis to better determine what was happening inside Kīlauea Volcano.

Although much of the emphasis was on real-time or near real-time data collection and interpretation, scientists also deployed non-telemetered instruments (for example, fig. 6) to collect various types of data (seismic, geodetic, gas, cameras, and ash-collection buckets) for subsequent retrospective analysis.

Figure 6. Photograph showing Hawai'ian Volcano Observatory geologist measuring a temperature of 103 degrees Celsius (218 degrees Fahrenheit) at a crack in Leilani Estates, Island of Hawai'i, Hawai'i. The asphalt road was described as "mushy" from the heat. U.S. Geological Survey, public domain, May 9, 2018.

Notably, the 2018 Kīlauea eruption was the first time the Federal government used UAS to assist in a volcano eruption response in the United States. UAS provided the ability to survey areas otherwise inaccessible or too hazardous for field crews or manned aircraft, collect multiple types of data, and provide 24/7 real-time situational awareness. As fissure openings multiplied, the UAS team was mobilized to work with geologists in tracking fissure activity and the advance of flows. Information passed rapidly among team members and then was relayed in a timely manner to emergency managers. The continuous preparation and dissemination of map products (for example, figs. 7 and 8), sometimes multiple times daily, for the duration of the event achieved unprecedented performance standards.

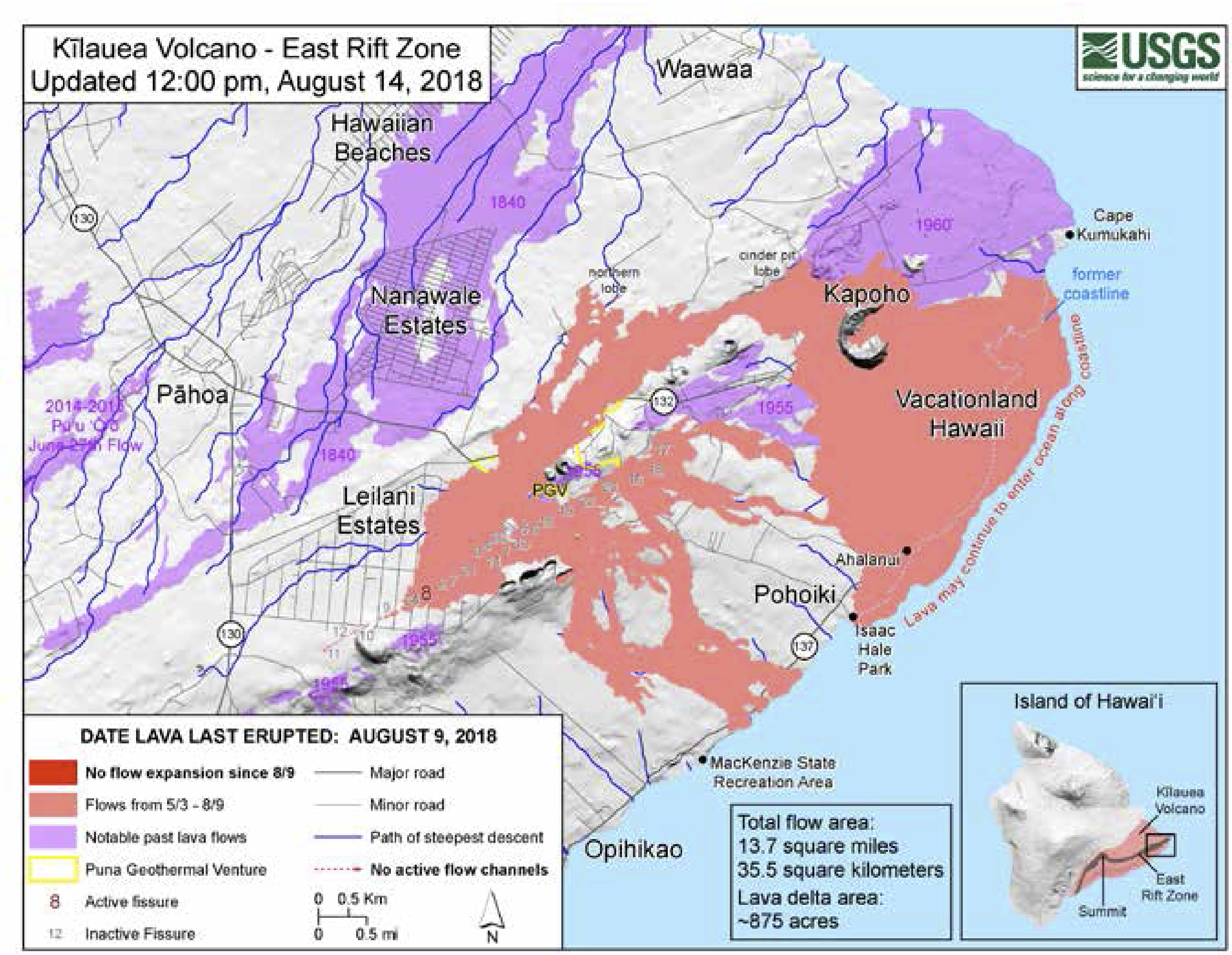

Figure 7. Image showing lava flow coverage from Kīlauea Volcano, Island of Hawai'i, Hawai'i, as reported through August 20, 2018. U.S. Geological Survey, public domain, August 20, 2018.

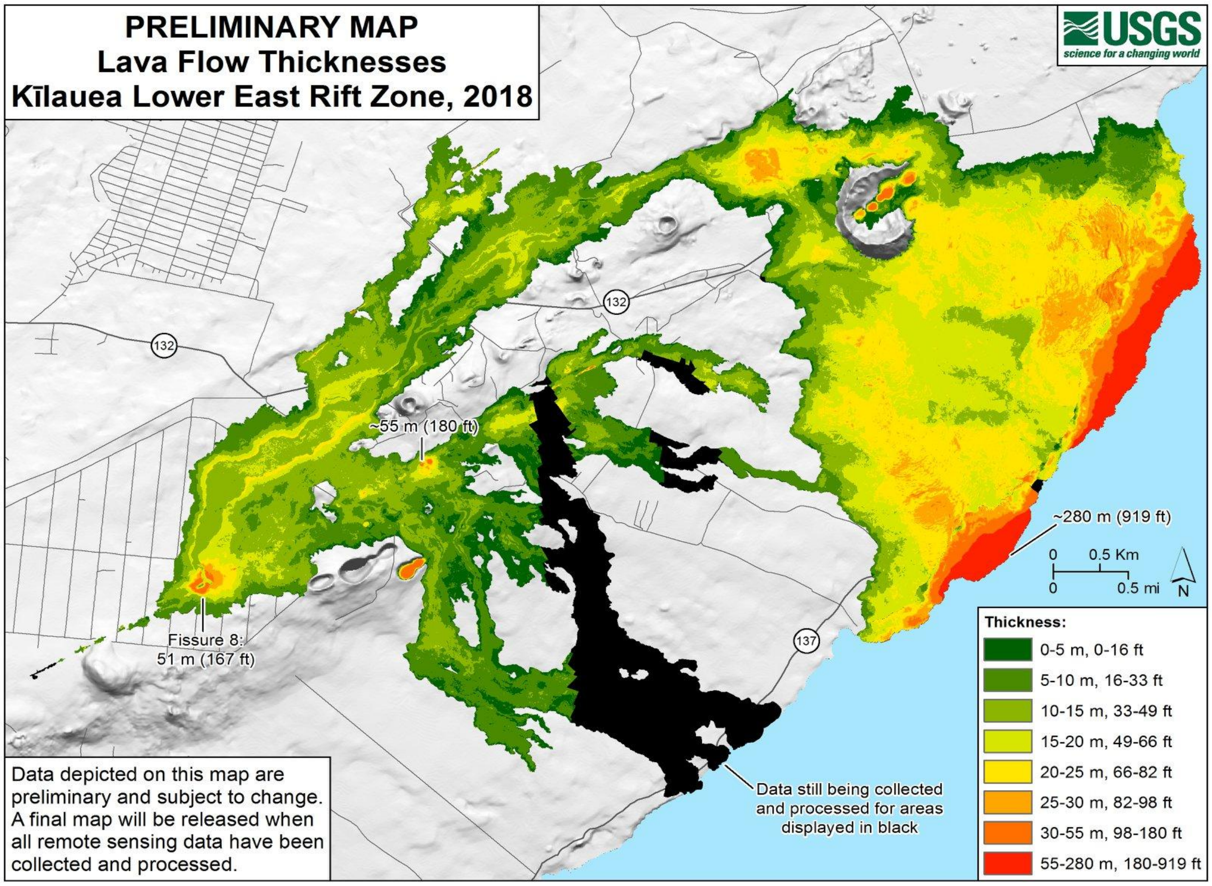

Figure 8. Preliminary image showing estimated lava thicknesses across the flow field, from Kīlauea Volcano, Island of Hawai'i, Hawai'i. Areas in green are thin flows, often occurring at the margins, and areas in red represent the greatest lava-flow thicknesses. m, meters; ft., feet. U.S. Geological Survey, public domain, February 19, 2019.

During the eruption, UAS cameras collected about 2,800 aerial photographs that were used to calculate a rough estimate of the total volume of lava erupted and added to the land surface—about 0.8 km^3 (more than 1 million yd^3). When corrected for voids in the lava and divided by the duration of the eruption, this yields a minimum eruption rate of about 50–200 m^2/s (13,000–53,000 gal/s), which is substantially larger than most, if not all, known sustained Kīlauea eruption rates.

Supplementing the work of HVO personnel through the duration of the event, a group of 12–15 volunteers also assisted in the performance of core functions that were critical to a successful eruption response, including lava-flow sampling, dispatch activities, and food preparation for HVO staff. Likewise, a group of 6–10 collaborators from Hawai'ian universities conducted important scientific work following their own specific expertise.

Emergency Management and Administration

Another core functional area involved actively facilitating emergency management, both internal and external to USGS. Over the course of the Kīlauea eruption, the HVO made use of established close working relationships with numerous collaborating agencies and partners to prepare for continued outbreak and flow of lava that could threaten people and infrastructure. These collaborating agencies included the following:

- HCCD,
- Hawai'i State Emergency Management Agency (HiEMA),
- The National Park Service (NPS),
- The Federal Emergency Management Agency (FEMA),
- National Weather Service,
- National Aeronautics and Space Administration (NASA),
- The DOI Office of Aircraft Services,
- The UHH, and
- Others.

By May 8, two senior USGS volcanologists also began working with the Region 9 FEMA Incident Management Assessment Team (IMAT) in Oakland, California, that formed in support of the response. By May 12, a USGS subject-matter expert was mission-assigned to the FEMA IMAT that had already relocated to Hilo. On or about May 16, the HVO positioned a scientist 24/7 at the County Emergency Operations Center in Hilo and another scientist to work at the HiEMA facility on O'ahu (Honolulu).

Internal to USGS, the Natural Hazards Mission Area (NHMA) and the Alaska Regional Office played a ubiquitous role in the daily management of the eruption response on a national scale. Working within that broad management structure, there were many vital USGS internal emergency management entities, and their adapted roles for this response are outlined as follows:

- **Scientist-in-Charge (SIC), Hawai'ian Volcano Observatory.** The person in this role provided overall senior management of the on-site response. It included situational awareness reporting to external partners (local, State, and Federal emergency managers), active participation in public meetings, management of responding Continental United States (CONUS) science staff, and oversight of all local administrative aspects of the HVO facility relocation. The SIC also provided a crucial role in recovery planning efforts with local, State, and Federal authorities.
- **Deputy Scientist-in-Charge (DSIC), Hawai'ian Volcano Observatory.** The DSIC was the primary backup for the SIC and led management of operational aspects of eruption response including aviation support, safety, some aspects of FEMA reporting, interface with NPS in the conduct of the green-amber-red alert (GAR) system. The DSIC also was the primary HVO spokesperson at more than a dozen community meetings in Pahoa during the eruption.

- **Director and staff, Volcano Science Center (VSC).** The VSC is based in the Alaska Region, yet it manages the five U.S. volcano observatories and about 200 employees throughout the West Coast, including the HVO in Hilo; the Alaska Volcano Observatory in Anchorage; the Cascades Volcano Observatory and Yellowstone Volcano Observatory in Vancouver, Washington; the California Volcano Observatory in Moffett, California; and the internationally scoped Volcano Disaster Assistance Program. The VSC worked closely with the Alaska Regional Office to play a vital role in facilitating the required managerial pivot from normal operations to disaster response. This involved ensuring substantial reassignments of personnel throughout the observatories to support the HVO, advancing the creation and dissemination of a wide variety of situational reports and media communications, and coordinating geospatial map products and Information Technology (IT) services to meet the needs of FEMA and other response partners. The VSC also provided knowledge and skills to physically move HVO operations to an alternate office location and storage facility.
- **Emergency Management Coordinator, Reston, Virginia.** The person in this role designed and managed the activity reporting process with the DOI Office of Emergency Management (OEM) that established Essential Elements of Information for volcanic eruptions for the DOI and FEMA. The Emergency Management Coordinator coordinated the process, administration, and application of FEMA mission assignments related to the eruption and conducted several Hazard Response Executive Committee (HREC) emergency meetings to provide USGS leadership with situational awareness and coordinate response and recovery actions.
- **Emergency Management Specialist, on-site.** The person in this role served as Continuity of Operations (COOP) coordinator and liaison to the NPS HAVO IMT, FEMA Response and Recovery, and the Hawai'i County Civil Defense IMT. With Regional and HREC direction, the COOP provided the overall execution of HVO/PIERC hazardous waste and chemical clean-up and removal, provided drone management support and aviation coordination of light detection and ranging (lidar) missions, and coordinated with the various response components to address emerging issues.
- **Hazard Response Executive Committee (HREC).** This group provided executive direction, oversight, and support to USGS managers in response to the Kīlauea eruption without interfering with the activities of programmatic or response teams.
- **Volcano Hazards Program (VHP) Office.** The Volcano Hazards Program Coordinator, Associate Program Coordinator, and one scientific assistant served as volcano subject-matter experts within USGS Headquarters and the DOI as well as to other relevant Federal agencies at the national level. The VHP office provided high-level briefings to the Secretary of the DOI, the Assistant Secretary for Water and Science, the National Security Council, the President’s Office of Science and Technology Policy, the Federal interagency Subcommittee on Disaster Reduction, and FEMA Headquarters. VHP Office staff also helped coordinate the leveraging or monitoring of assets from NASA and National Science Foundation-funded Principal Investigators, and additionally conducted live interviews with national news media and answered media questions by email.

- **USGS/DOI Drone Team.** This group deployed an assortment of rotor and fixed-wing Unmanned Aircraft Systems (UAS) and sensors to support the remote sensing data acquisition needed for monitoring the Kīlauea Volcano eruptions at the summit and LERZ. They provided situational life-saving information and scientific information to Hawai'i County Civil Defense (HCCD) Emergency Operations Center (EOC), Hawai'i State EOC, FEMA, DOI Interior Operations Center, and other internal USGS partners.
- **USGS Advanced Systems Center.** This group was the hub of operations for the National Civil Applications Program, which provided for the acquisition, dissemination, and use of remote sensing systems and data in support of mission responsibilities for land and resource management, including response to hazards and natural disasters. This group also provided high-quality, lava-flow shapefiles with the format and frequency conducive to operational monitoring, and more generally helped to compensate for lack of geographic information system (GIS) staffing at the HVO.
- **Geospatial Information Response Team (GIRT).** USGS established GIRT within the National Geospatial Program to ensure that timely geospatial data are available for use by emergency responders, and land and resource managers, and for scientific analysis during a disaster event. This group provided the Event Support Map, coordinated space-based and UAS imagery collection during daily calls, and facilitated access to data archived in the Hazards Data Distribution System.
- **Office of Management Services (OMS).** This group helped evaluate the structural integrity of the damaged HVO facility and management of the search and acquisition details of securing replacement facilities and the transfer of property to interim and permanent locations. The unfolding plan to reestablish USGS facilities in HAVO through shared space and services between HVO and PIERC is expected to require 3 years to complete the design, construction, and occupancy.
- **Office of Enterprise Information (OEI).** This group provided the critical information management and technology foundation for the USGS science mission. It managed data storage solutions, software applications, web infrastructure, SharePoint® and cloud-hosting services, disposition of Federal records, and other critical information. This group played a vital role in maintaining continuity of operations for data flow and storage throughout the disaster response and facility transfer.
- **Office of Administration.** This group provided direction related to business administration, financial accounting, and general support services. This group made it possible to rapidly mobilize the "extended HVO" both into and out of Hawai'i in a controlled, yet efficient, manner. This group also helped troubleshoot many accounting complications related to travel, safety, purchasing, and overtime pay.

External to USGS, there were many entities that played key roles in the Kīlauea eruption emergency management structure. A schematic showing the configuration of the emergency management structure for the Kīlauea eruption, including brief descriptions of the various responsibilities of key roles, is provided in figure 9.

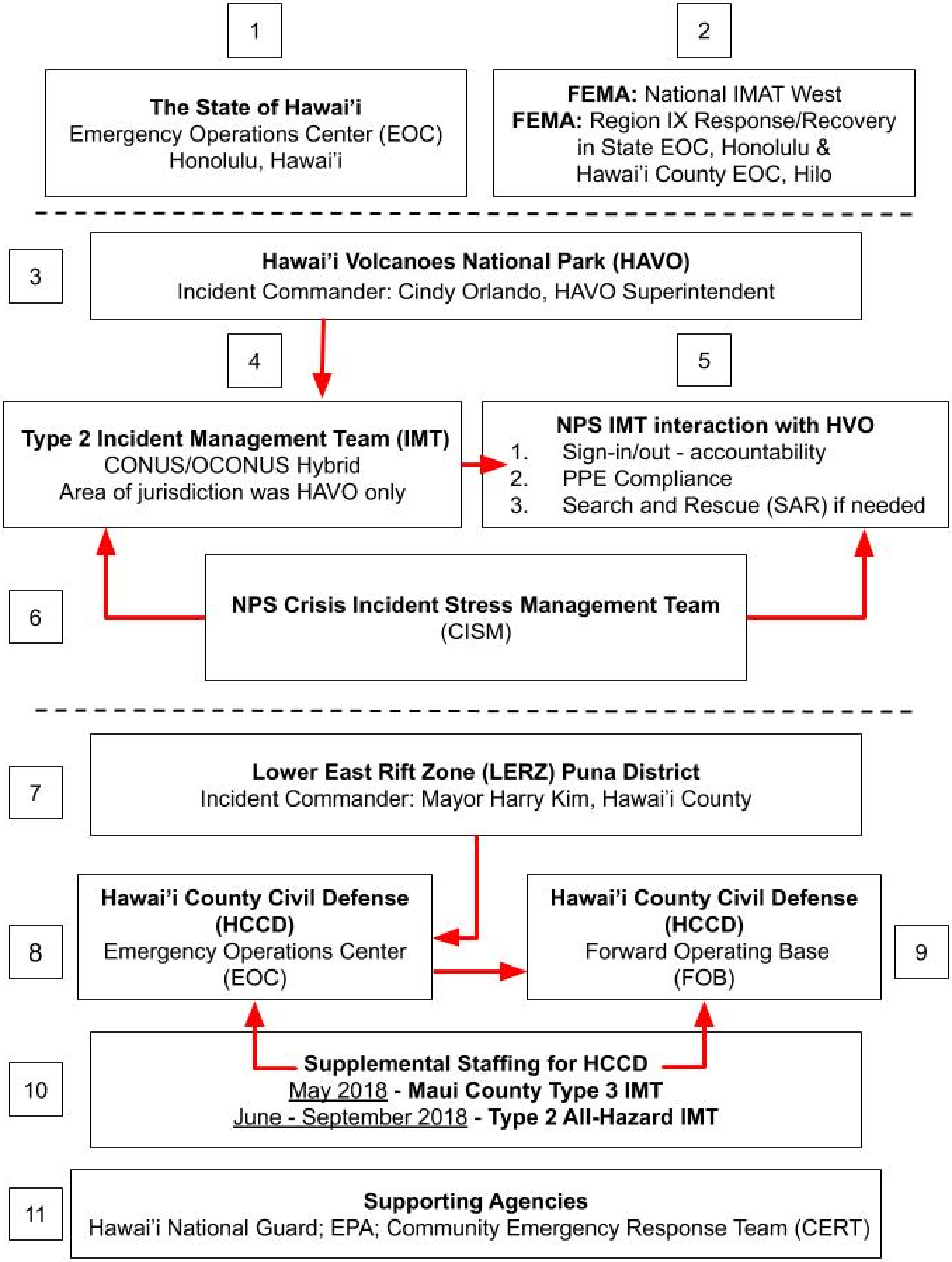

Figure 9. Schematic showing configuration of the emergency management structure for the Kīlauea Volcano eruption, including brief descriptions of the various responsibilities of key roles 1–11, Island of Hawai'i, Hawai'i, 2018.

DESCRIPTION OF RESPONSIBILITES OF KEY ROLES:

1. **Hawai'i State Emergency Management Agency (HiEMA):** Responded to Hawaii County requests for State assistance. Once the State was unable to support the request in full, HiEMA recommended to the Governor to declare a State Emergency Proclamation, which then cascaded into FEMA-4366-DR, Hawai'i Disaster Declaration. USGS staffed a geologist as a science liaison to the State and Federal Emergency Management Agency (FEMA) at HiEMA Emergency Operations Center (EOC) for 12-hour day shifts from 18 May to 22 June.
2. **FEMA:** National Incident Management Assistance Team (IMAT) West originally was dispatched to HiEMA EOC in Honolulu, but eventually sent some team members forward to the Island of Hawai'i, Hawai'i County Civil Defense EOC. The team improved coordination to the overall response efforts. At the end of the IMAT West rotation, the FEMA mission was handed off to FEMA Region IX coordinating authorities.

   FEMA Federal Coordinating Officer (FCO) and Deputy Officers from Region IX were integral to the assessment of the overall disaster needs and supporting the county and State in implementation of recovery efforts. The FCO established a disaster field office in Hilo in concert with a Disaster Recovery Center in Pāhoa and then Hilo.

3. **Hawai'i Volcanoes National Park (HAVO):** The Kīlauea eruption event and associated hazards occurred in two separate locations—the Kīlauea caldera summit in HAVO and the Lower East Rift Zone (LERZ) in Lower Puna District. The National Park Service (NPS) HAVO had command and control of everything inside the NPS boundaries.
4. **NPS Type 2 Incident Management Team (IMT):** The NPS quickly deployed an IMT composed of local assets. However, once the eruption period passed 15 days, the HAVO Park Superintendent, functioning also as the Incident Commander, called in a Continental United States (CONUS) NPS Type 2 IMT. This team consisted of primary Incident Command System positions (operations, finance, and logistics section chiefs, along with 2–4 safety officers).
5. **NPS IMT interaction with Hawai'ian Volcano Observatory (HVO) staff:** The NPS IMT implemented sign-in/sign-out personnel accountability protocol and personal protective equipment (PPE) evaluation at the Volcano EOC within HAVO. Accountability and PPE was required for anyone entering HAVO. The NPS also was responsible for Search and Rescue if required.
6. **NPS Crisis Incident Stress Management (CISM) deployment:** The NPS has a cadre of staff trained in CISM intervention. At the request of the Scientist-in-Charge, owing to the duration of the event, the NPS deployed two CISM team members twice to HAVO and HVO for responding to staff needs. CISM is a highly structured, professionally recognized form of peer-to-peer support to mitigate the impact of the event.
7. **LERZ, Lower Puna District:** The second location of the Kīlauea event took place in the Lower Puna District, specifically east of State Route 130. Command and control of this area was under the authority of the Hawai'i County Civil Defense, at the direction of County Mayor, Harry Kim.
8. **Hawai'i County Civil Defense (HCCD) EOC, Hilo:** HCCD used their main headquarters as the EOC for the duration of the eruption event. Mayor Kim held a daily overall briefing for all to attend at 07:00 hours, followed by a HCCD multidisciplinary operational team meeting at 08:30 hours. The USGS staffed a geologist liaison position at the EOC for the duration of the event, in two 12-hour shifts, and later in three 8-hour shifts, for nominal 24/7 coverage during most of the response. This proved to be an enormous service to HCCD, FEMA, and other partners.
9. **HCCD Forward Operating Base (FOB):** At the early signs of volcanic activity in Lower Puna, HCCD used the Pāhoa Fire Department as a staging area for first responders. It was used to check response personnel in and out of restricted zones, as an immediate information hub, and a location for food and water and some PPE for police and fire responders. As the volcanic activity increased and fissures began to open in the Leilani Estates neighborhood, HCCD and Mayor Kim deployed a designated Forward Operating Base on State Route 130 and relinquished the fire department facility (fig. 10).
10. **Supplemental Staffing of the FOB and HCCD headquarters.** As the event grew larger, Mayor Kim and HCCD called in a Type 3 IMT from Maui County. Their job was to transition staging from the Pāhoa Fire Department to the newly created FOB. After a 2-week rotation, HCCD used the National IMT registry to staff the incident with CONUS Type 2 teams until the event was declared terminated.
11. **Supporting agencies:**
    - **Hawai'i National Guard (HING):** Responsible for maintaining evacuation zones and manning checkpoints. HING also staffed 24/7 helicopter search and rescue units at Hilo airport; conducted spot measurements of SO_2 concentration upon request; and completed some night flying that, with more advanced coordination, could potentially have provided useful footage.
    - **Environmental Protection Agency (EPA)**: Responsible for real-time air-quality monitoring for the public. The EPA also assisted with PIERC and HVO hazardous waste and chemical removal from HAVO.
    - **Community Emergency Response Team (CERT):** A FEMA program of trained volunteers, responsible for patrolling Leilani Estates and assisting HING with checkpoint duties, they also coordinated and disseminated information to and from public meetings to residents unable to attend in person. The CERT team went door-to-door in some areas to ensure that residents were situationally aware, including those with no internet or cell phone communication.

Figure 9.—Continued.

Figure 10. Photograph showing Hawai'i County Civil Defense Forward Operating Base check-in station in Puna, Island of Hawai'i, Hawai'i. Photograph by Brett Walker, Hawai'ian Volcano Observatory volunteer, June 14, 2018.

External Communications

Another core functional area involved public outreach and communications. The local, national, and international media interest in the eruption remained high throughout the response period. The USGS participated in weekly public meetings held in Pahoa (fig. 11) that were organized by HCCD, as well as daily briefings for the news media. USGS teams also routinely communicated with the public by fielding direct inquiries and by providing continuously updated information on public websites. The USGS also initiated an around-the-island series of meetings with communities to discuss ashfall and vog hazards, as well as meetings in Volcano Village to discuss summit-collapse activity. Team activities also produced daily situation reports and briefings that the VSC Director compiled, synthesized, and circulated to many decision-makers, both internal and external to the USGS.

The improvised coordination and communication between field operations, dispatch, the EOC, and the extended HVO team proved to be timely, effective, and noteworthy. One astute reporter from *Forbes* magazine accurately observed "… very few people have been injured. The reason? The extraordinary work of the United States Geological Survey, its scientists, and the outstanding communication spearheaded by the Hawai'ian Volcano Observatory…." (Siegel, 2018). Indeed, the team responded to nearly 700 media inquiries from outlets all over the world, and more than 1.5 million people viewed daily video updates from HVO scientists.

Figure 11. Photograph showing one of a series of community meetings held in Pahoa High School cafeteria to brief residents from the District of Puna about the Lower East Rift Zone eruption of the Kīlauea Volcano, Island of Hawai'i, Hawai'i. Photograph by Steve Brantley, U.S. Geological Survey, May 4, 2018.

Public and professional feedback to USGS has been overwhelmingly positive, including direct input from the White House, Congress, other Federal agencies, the State of Hawai'i, external media outlets, and the affected communities.

Since the cessation of eruption activities, there have been several notable ongoing public outreach and communication activities. The HVO staff continues to engage with communities affected by the 2018 eruption to directly share information, as well as to inform residents of the continuing presence of HVO scientists and technicians in the lava-flow area as they rebuild, restore, and harden monitoring stations and conduct post-eruption field studies. For example, on March 16, HVO staff provided an update on the Kīlauea Volcano status and prognosis, and described ongoing HVO work along the Lower East Rift Zone to members of Leilani Estates Community Association, which proved to be ground zero for much of the eruptive activity. On April 26, two HVO scientists presented a similar update to board members of the Nānāwale Estates Community Association. Nānāwale Estates was affected by poor air quality during the protracted eruption and could have been affected by lava flows if the flow field had evolved differently. Helicopter noise also was a critical concern for these residents because of frequent flights over the 2018 lava flows.

Discussion

After-Action Review Methods

This report builds on a wide variety of documents that already have been generated by the USGS during and after the 2018 Kīlauea Volcano eruption. The most relevant prior documents include the following:

- Sixty-three situational reports that briefed USGS leadership on a near-daily basis from May 10 to August 20, 2018;
- A technical report produced by the DOI SSG after convening a multidisciplinary group of 13 experts in Hilo from July 17 to 19, 2018, to evaluate the short- and long-term social, economic, and environmental impacts of the Kīlauea eruption;
- A summary of action items generated by immediate “hot wash” group discussions that occurred on November 13, 2018, between HVO managers and key staff, and NPS managers of HAVO;
- A summary of reflective notes generated post-response within the Office of Communications and Publishing (OCAP);
- A summary of action items generated in November 2018 by immediate “hot wash” group discussions among managers and staff at HVO and the Hawai'i County Civil Defense; and
- A summary report of action items generated by the SIC at HVO.

This report combines insights from these documents with responses to confidential survey instruments administered to individuals involved in the response during and shortly after the eruption, to develop new insights that can be applied to future events. Given the large number of individuals and geographic distances separating USGS participants in the Kīlauea response, it is clearly challenging to achieve a single all-encompassing group reflection on actionable “lessons learned”. Rather than attempt to convene a forum to bring everyone together in a common physical space, the Bureau has come to rely primarily on the use of confidential survey instruments to systematically organize the broad array of individual commentary about response activities into a collective team assessment.

Two different survey instruments were circulated internally among all USGS members of the multifaceted response team at different stages of the event. Survey 1 was developed by the USGS Emergency Management staff and VSC leadership. It was piloted with several people who already had been involved in the response and was revised based on their feedback. The revised survey 1 then was circulated by the USGS Emergency Management group on July 18, before eruption activity ended, to collect interim input and commentary from individuals who had actively participated in the disaster response. A version of this survey also was adapted to be shared with volunteers or individuals outside the USGS who were involved in response, as they were unable to access the online survey form. A total of 65 people responded to the survey 1 instrument.

Survey 2 was developed jointly between the USGS OEM with direct input from the Alaska Regional Office, and distributed on December 2, after the eruption response officially ended. Survey 2 allowed for additional input from anyone who had previously responded to survey 1, but explicitly requested input from those individuals who had been closely involved in the response action yet had not previously completed the survey 1. A total of 32 people responded to the survey 2 instrument. The relative distribution of survey respondents by home office is shown in the pie diagram in figure 12. A snowball sampling method was used for this survey, as those initially contacted to complete these forms were asked to share the form with others who were involved in the response. Response data from both surveys was treated as confidential; it was collected, anonymized, and aggregated using standardized protocols developed by the USGS Emergency Management group.

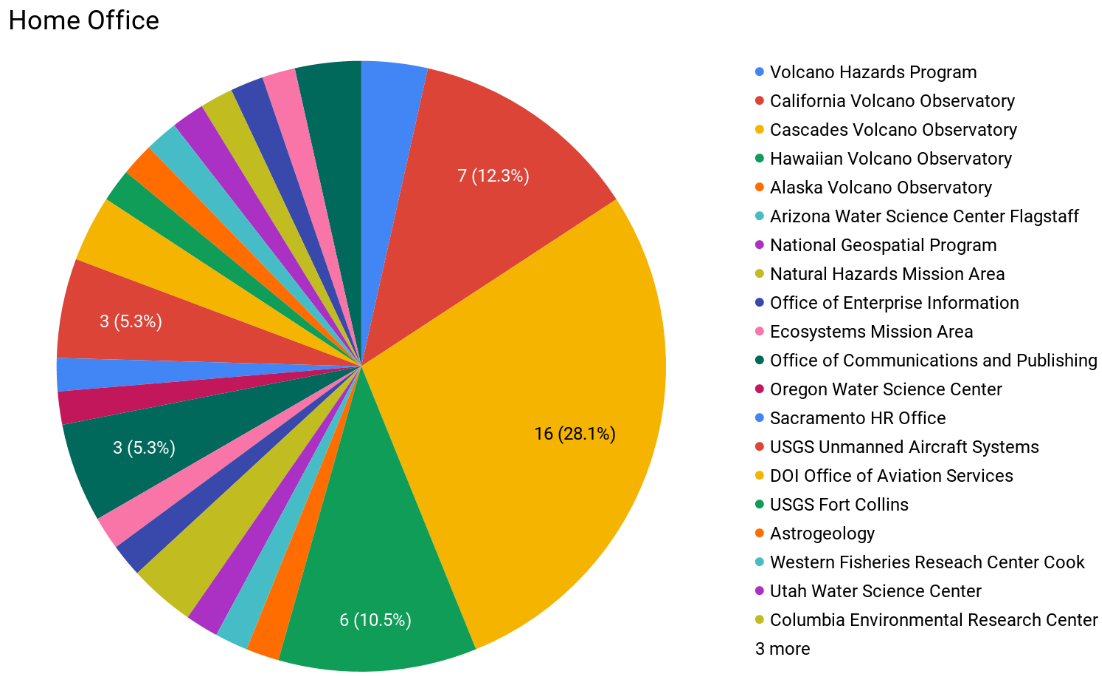

Figure 12. Pie diagram showing relative distribution, by home office, of respondents to survey of the U.S. Geological Survey response to the 2018 Kīlauea Volcano eruption on the Island of Hawai'i, Hawai'i. %, percent.

While the survey 2 response data was gathered, the Alaska Regional Office assembled an After-Action Review team and launched their first deliberations on February 8, 2019 (delayed more than 1 month by a partial Federal government shutdown).

Survey responses were analyzed separately, but were consistently organized into three major respondent categories by functional role: (1) science operations, (2) emergency management/administration, and (3) media and communications. The relative distribution of survey respondents by the functional role they played in the response office is shown in the pie diagram in figure 13.

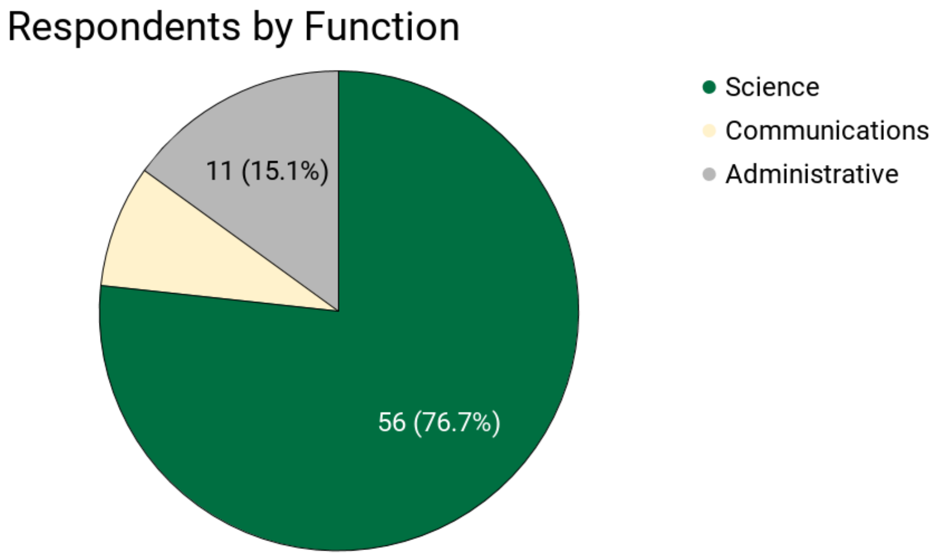

Figure 13. Pie diagram showing relative distribution of respondents, by the functional role they played in the response office, to survey of the U.S. Geological Survey response to the 2018 Kīlauea Volcano eruption on the Island of Hawai'i, Hawai'i. %, percent.

The After-Action Review team organized into four separate work groups to sort through the response data, grouping comments by functional role and by theme, then summarizing comments into succinct statements of best practices, lessons learned, and (or) recommended actions.

One of the work groups used NVivo®, a qualitative data analysis computer software package to facilitate observation of patterns and response correlations within text-based and (or) multimedia information. The NVivo® program allowed the review team to quantify the response themes by frequency and co-occurrence as well as sentiment valence. It also facilitated awareness of any notable differences in thematic response between the survey instruments. For example, it allowed the team to determine that the order of thematic concerns in survey 1 heavily emphasized planning, followed by communications, followed by equipment and resources, followed by training; whereas those concerns in survey 2 completely reversed order, with almost equal emphasis given to training and equipment/resources, followed by almost equal emphasis between communications and planning. However, relative concern over the Incident Command System (ICS) increased strongly within the second survey, as did relative concern over staff safety and burnout, as well as relative concern over internal communication and the need for more local orientation.

It is not clear why substantive differences emerged between the two surveys. We hypothesize that each survey captured somewhat different types of respondents who occupied different functions during the response; it is also likely that any repeating respondents wanted to highlight different topics the second time around, or perhaps over time, agency staff simply developed alternative narratives about the event.

After analyzing the survey response data, the After-Action Review team expanded the scope of their analysis to specifically incorporate relevant USGS documents that identified recommendations as generated by other response review teams. These recommendations have been summarized separately and incorporated in this report under the section, "Excerpted Findings from Other Sources." They are ultimately synthesized and merged with survey input to yield our list of recommended actions.

A draft internal report was completed on April 30 and circulated to managers of relevant program offices for review comments and the opportunity for additional input. The review period lasted from May 1 to May 28. The draft report then was edited to accommodate received input during the review period. Upon completion of a revised draft by the After-Action Review team, this report was orally presented and formally delivered to the Hazard Response Executive Committee (HREC) on September 18. The HREC formally validated the internal report on October 8 and then referred it to executive leadership within the NHMA, the VSC, and the Alaska Regional Office to assess the suite of recommendations, establish priorities, and convey all endorsed actions to responsible parties for implementation and (or) further solution development. The HREC will continue to monitor the ongoing status of these actions through regular briefings. Because of the broad scientific and hazard management interest in the Kīlauea eruption response, the internal report was prepared for public distribution in November 2019.

Survey Instrument Insights: What Went Well and Why?

"Wow, does HVO have superb staff! Every one of them has done heroic work, and they've all given us reason to be proud. And it's been awesome to see the huge response across the VSC in support of HVO. The response to the crisis has been highly successful, and it's made me even prouder than I've been to work for such an organization." (**Note:** All italicized quotations from here through the remainder of the report are excerpted from statements of survey respondents, 2018.)

"The HVO staff was unwaveringly resilient in the face of this monumental challenge."

This section synthesizes the variety of comments that were collected through the formal survey instruments about what worked well during the event. These insights may be alternately construed as "best practices." Survey respondents conveyed a strong consensus in the overall view that the HVO and broader USGS response to the Kīlauea eruption primarily was impressive and inspiring (fig. 14). Respondents frequently used superlatives to assess their own personal experiences and observations; the two quoted comments above are representative.

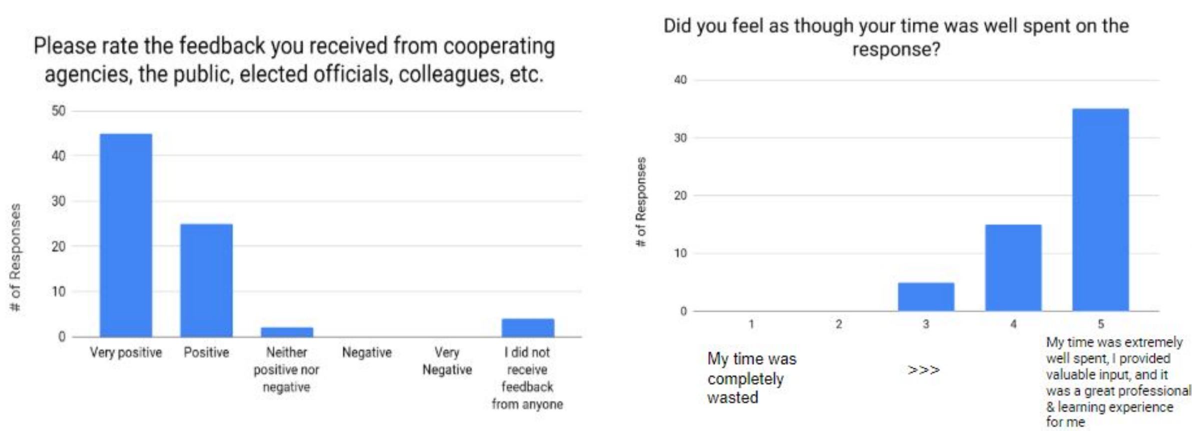

Figure 14. Graphs showing summary of clearly positive consensus of data responses to survey of the U.S. Geological Survey response to the 2018 Kīlauea Volcano eruption on the Island of Hawai'i, Hawai'i.

Summary of Survey Data Responses

This report compiles the most notable themes of successful accomplishment into six main categories: (1) General Crisis Management at HVO and the VSC, (2) Working within the ICS, (3) Safe Science Planning and Coordination, (4) Data Acquisition and Management, (5) Adaptable Application of UAS Technology, and (6) Communications.

General Crisis Management (23 comments)

"The scientific knowledge and collaboration were impressive, along with the accurate forecasts. Methodical and diligent work by all really felt like a team... and the main objective, no matter how tired, was to provide accurate science and observations."

The HVO and the entire VSC performed exceptionally well in reacting to a challenging and uncertain situation. The success was due to several factors, including the following:

- HVO staff rose to the occasion in many ways despite facing evacuation. They tirelessly worked to do their jobs, often at great personal expense, and showed admirable willingness to give each other the benefit of the doubt under such stressful conditions. Additionally, the relationships that HVO staff had established with the Hawai'i community and other Federal agencies over the previous several decades established a primary reason for the successful response—HVO staff were highly trusted.
- The integration of VSC staff from outside the HVO went well. This indicated a strong camaraderie and showed that VSC staff maintain a good understanding at an organic level of what needs to be done, and getting it done in a professional manner. It also indicated good cross-observatory familiarity that stemmed from past rotations with the HVO, as well as VSC Director efforts to improve interoperability by centralizing several VSC functions and by forming VSC-wide working groups to address various issues that affect all observatories. It also indicated a mostly effective onboarding process, which was achieved through guidance documents provided by the VSC, HVO, and other groups, as well as on-site mentoring by experienced staff.
- The rapid and universal adoption of the open-source messaging/data distribution tool, Mattermost® (implemented with help from the Alaska Volcano Observatory), as a primary inter-observatory communication tool was one of the hallmarks of the eruption response. Mattermost® made it remarkably straightforward for HVO staff working from home and in the field, and VSC staff working at five different office locations and on the mainland, to stay up-to-date on developments.
- The Event Support Map (ESM) provided important situational awareness data and was used by resource managers in the office and the field (fig. 15). The ESM is mobilized by the GIRT for major disaster events and used to provide a coordination and communication structure for USGS teams managing the USGS response. The ESM is a "one-stop" landing and reference page for spatial data, applications, team notes, reports and other agency information that can easily be accessed and used during the event.

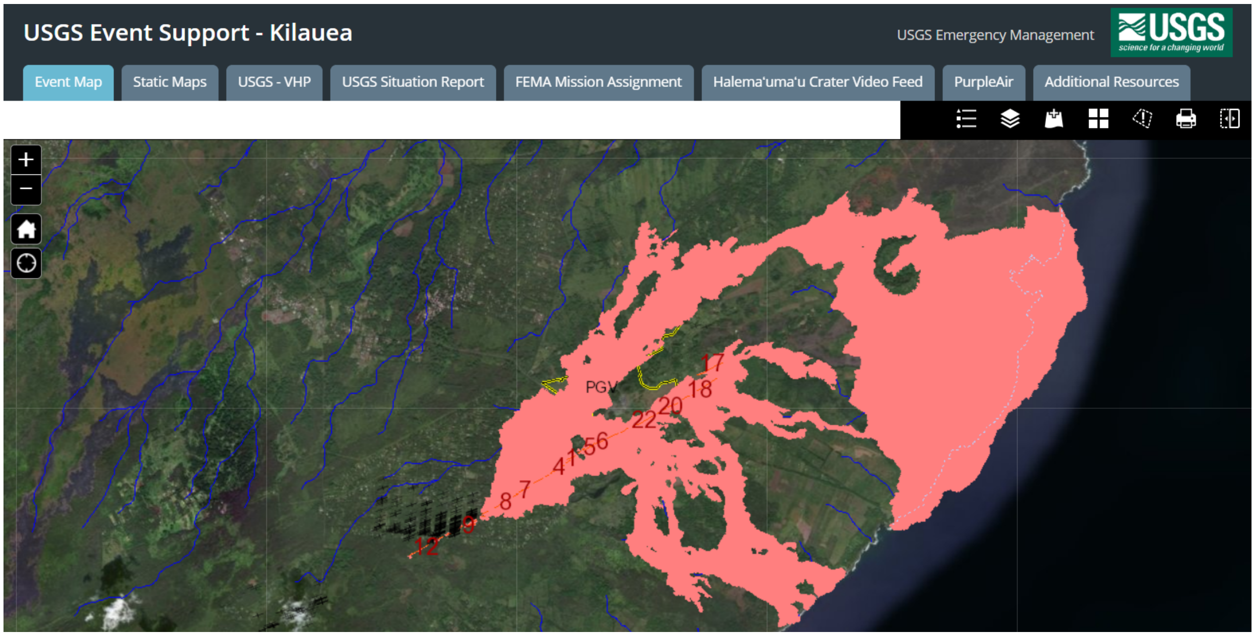

Figure 15. U.S. Geological Survey Event Support Map landing and reference page for spatial data, applications, team notes, reports and other response information. U.S. Geological Survey, public domain.

Incident Command System (5 comments)

"Public and professional feedback to USGS has been overwhelmingly positive, including direct input from FEMA [and many other agencies]."

The VSC performed well in the ICS that was established during the first week of the eruption. This was especially remarkable given that this was the VSC's first experience working in a full-scale ICS. The success was due to many factors, including the following:

- Outstanding performances by many who worked at the various EOCs and who interacted with ICS workers at the Forward Operating Base (FOB) and Pahoa Fire Department.
- The ability of USGS staff to quickly react and adapt to fast-changing situations through the initial stages of confusion as the response structure was established.
- Many of the VSC staff had ICS training and were familiar with ICS structure.
- Mattermost® made it easy for USGS scientists in multiple ICS locations to coordinate their efforts and work at same level of situational awareness.
- The strong relationships fostered by HVO over the last several decades with local response agencies including the Hilo County EOC and the Pahoa Fire Department, which placed all USGS scientists in a position where they were implicitly and explicitly trusted by local emergency responders.

Safe Science Planning and Coordination (5 comments)

"I was impressed with USGS management's response to the situation. It seems like we were given just about any resource we needed. That allowed us to keep working, with minimal impact to our health and well-being."

The overall safety record during the response was very good, especially considering the collective number of hours worked in the field, the quantity of miles driven through compromised roads and infrastructure, and the hundreds of helicopter sorties flown, many involving pilots unfamiliar with Hawai'ian airspace. A desire to provide accurate science, observations, and forecasts drove all VSC scientists to perform diligently, methodically, but also creatively. An outgrowth of this desire was an abundance of rather organic planning and collaboration that occurred. The success of the scientific response can be attributed in part to the following factors:

- The role of senior scientists with decades of geologic experience on Kīlauea.
- The event-tree analysis process was familiar to, and accepted and used by members of the response team. It was also effective in sharing information and understanding, in addition to developing forecasts.
- LERZ field geology shifts were managed efficiently and staff were willing to participate.
- The capacity to use infrasound monitoring and develop new alarms.
- The application of UAS to data gathering.
- The generous budget for helicopter flights, which vastly increased the density of observational and other data acquisition.

Data Acquisition and Management (9 comments*)*

"Timely geospatial data is pure gold in this response—especially when lava flows are moving quickly, and the evacuation situation is shifting accordingly."

There were several notable achievements during the eruption response regarding data. The testing and development of an online data distribution tool (Mattermost®), which could be seen and accessed by multiple users from multiple devices, worked very well. The quick adoption of Mattermost® showed a transformative adaptation in our ability to move information around the observatory, to the emergency managers, and to social media. Mattermost® allowed for uploading of real-time images and data, including obtaining weather reports from other field crews. The VSC also successfully established a dedicated service for sharing preliminary map data on the internet that could be accessed and used in geospatial software or other online tools. The continuity of operations in geophysical monitoring also was remarkable. The OEI group stepped up and helped HVO technical staff avoid any stoppage in real-time monitoring. The technical team also achieved rapid and critical installations and upgrades to allow for monitoring capability of the LERZ. The success was due to many factors, including the following:

- The OEI office worked with Amazon Web Services to provide backup devices to move data from the HVO to cloud-hosting services.
- The HVO had accumulated much experience over the previous decade dealing with prolonged concurrent eruptions and a persistent low-level crisis mode since the 2008 onset of summit activity. Through a series of recurring crises, HVO staff became accustomed to delivering GIS shapefiles and lava-flow forecasts as needed by emergency managers, while continually practicing and improving methods for monitoring and measuring activity.
- The HVO benefitted from working with very skilled pilots who had prior familiarity with monitoring requirements.
- The HVO benefitted from the gradual refinement of methods for communicating with the public about threatening lava flows.

- The HVO benefitted tremendously from a long-standing collaborative relationship with the National Civil Applications Center (NCAC), which provided high-quality lava-flow shapefiles in a manner conducive to operational monitoring.

Application of UAS Technology (6 comments)

"Our UAS team was able to contribute so much to the response in terms of science and hazards research, as well as public safety."

UAS proved to be an incredibly valuable tool during the eruption—to such a degree that the VSC probably should develop its own dedicated drone response team. UAS operations played a critical role in providing near real-time scientific data and situational awareness to emergency managers, and demonstrably contributed to public safety in direct ways. The success was attributable to many factors, including the following:

- The UAS and HVO staff proved highly adaptable and nimble while operating in a volatile field situation. A total of 38 different UAS operators and data processors across three departmental agencies proved they could function safely and work well together.
- Safety was a high priority for all involved. The team was very methodical in planning and executing missions through an efficient "go-slow and test" manner.
- The team established good benchmark launch and recovery locations for effectively mapping the most affected areas on a regular basis.
- The Emergency Certificate of Authorization provided the authority to use innovative technologies and flight lines that will continue to benefit the proof of concept for emergency response.
- Key individuals showed a willingness to lead and maintained a positive attitude throughout the mission.

Communications (18 comments)

"The daily teleconference media briefings were hugely successful to keep media informed, who in turn, helped keep the public informed. Media depended on and greatly appreciated those briefings."

The USGS provides subject-matter expertise, data, and information through various public mediums during natural hazard events. This information must be communicated in a timely, relevant, accessible, understandable, and accurate manner to our local, State and national response partners and to the public, both within and beyond the framework of the National Incident Management System. The success was due to many factors, including the following:

- The HVO performed incredibly well working with the OCAP to inform people about what could happen, what was happening, and what to expect moving forward.
- The VSC assembled and digitally delivered daily situation reports by 7:00 a.m. Eastern Time, in advance of morning briefings for USGS and DOI management. The VHP Office referenced the situation reports in reporting to the White House National Security Council, the Office of Science and Technology Policy, Congress, and DOI upper management.
- Daily telecommunications media briefings were successful in keeping the media informed. The community and USGS partners noticed that the agency worked very hard to provide good information despite great adversity.

- The capacity to provide graphical details of continuous adjustments of Kīlauea through updated images, videos, and graphics built public confidence that the USGS knew what it was doing, while leading the government response to an uncontrollable natural hazard.
- Regular internal coordination calls among various USGS offices outside Hawai'i, led by Alaska Region management, directly supported the eruption response. Participants included upper-level management from Facilities, UAS, the VSC (but not the HVO), the VHP Office, Office of Administration, OCAP, OEI, Land Resources, Science Application for Risk Reduction, NCAC, National Geospatial Program (NGP), National Earthquake Information Center, Emergency Management, and Safety. These meetings enhanced collaboration, reduced duplication of effort, and revealed how broad the USGS response was Bureau-wide. They also focused on issues not reported in situation reports, such as details relevant to continuity of operations.
- The SSG also contributed to DOI response activities and community outreach by identifying expertise, coordinating travel, holding local workshops and stakeholder meetings, and documenting those interactions in a cooperator and open-file reports.

Survey Instrument Insights: What Can Be Improved and How?

This section synthesizes the diverse and thoughtful input collected through the survey instruments about suggestions for improvement. The synthesis imposes organizational structure and consolidation on incoming suggestions to provide context and background information for the formal recommendations that later emerge from this report. Not every suggestion for improvement is necessarily translated into a discrete actionable recommendation by the report authors. Instead, the process calls for sorting, compiling, and shaping received input into a coherent summary for the potential attention of responsible decision-makers within the Bureau.

Many survey respondents emphasized how their suggestions were offered in the context of modest adjustment to an otherwise impressive response operation. In the interests of clarity and consistency with preestablished after-action reporting structure, this report compiles the most notable themes of targeted improvement into four main categories: (1) Planning, (2) Training, (3) Communications, (4) Equipment and Resources.

Planning (181 comments)

Survey respondents consistently identified the great need for improvement in several aspects of planning for the HVO (and all volcano observatories), both to facilitate operations during crisis response and to reduce overall stress.

Issue 1: Absence of a Clear VSC Internal “Response Structure”

The most predominant feedback from survey respondents points to challenges of understanding both internal and external roles and responsibilities with our response partners in times of crisis. This lack of clarity contributed to confusion, conflict, ill-defined expectations, and stress at different times during the response.

In retrospect, it seems advisable that the HVO and VSC should both have moved from a normal management structure to an explicit and predetermined “response structure.” It is difficult to know when to shift to such a structure as an event is unfolding, and the HVO was facing an extraordinary number of crises all at once, which made it extremely difficult to consider changing management schemes. HVO and VSC staff adapted primarily by identifying what needed to be done and then finding the means to get it accomplished.

There is always a tension between the need to have a response plan with roles, responsibilities, and chain of command clearly defined and to allow the flexibility to react and respond as the situation requires. The latter was a positive hallmark of the Kīlauea eruption and a primary reason why the response was so effective. However, the lack of a clear response plan contributed to confusion and stress at different levels during the event, and thereby became a reason why the scientific response may not have been as fully complete or effective as it might ideally aspire to be.

A more formal response plan needs to be prepared, circulated, and practiced before a disaster event occurs. However,, a response plan also needs to allow for flexibility, particularly in the field, and to acknowledge the value of people being allowed to respond to unanticipated situations as they occur without spending valuable time obtaining approvals from up the chain of command.

Issue 2: Better Integration of Volcano Science Center Staff into Response

Survey respondents frequently commented about challenges in coordinating actions within and across the ICS. HVO staff generally lacked awareness about who was coming and going (visitors were doing so at a fast pace), and what role they were serving. Onboarding was done as a collateral duty split amongst several HVO and VSC staff, which led to confusion at times. Having to train and integrate new people also was sometimes a strain, as it required several HVO insiders to divert their attention from other duties. More effective and structured communication on what was expected by whom, what projects were ongoing, and what opportunities existed to join in group efforts (to name a few items) would have helped ensure that everyone had the same level of situational awareness, that the right people and skill sets were matched to the tasks at hand, and that no one was excluded.

Issue 3: Lack of Understanding of Incident Command System and Federal Emergency Management Agency

Interacting with FEMA was initially a challenge because of limited understanding within the USGS of the administrative functions within an ICS, particularly on the financial side. Furthermore, many people brought in by FEMA had little to no experience with volcano events; much of their experience was with wildfires, which did not fully prepare them for an eruption crisis. Additionally, at times there was confusion amongst USGS staff embedded within county and State EOCs with respect to communications. For example, it was unclear when it was or was not appropriate to make information requests through Mattermost®. More fundamentally, the priorities and pathways for third-party communications were not always clear, and briefings at State and county levels were not necessarily synchronized. For example, HiEMA held their own briefings, including a presentation from the USGS liaison that HCCD did not attend. This seemed inefficient, as the HVO-HCCD liaison also provided a situational briefing each morning.

Issue 4: Enhanced Workforce Planning

HVO management externally delegated the role of determining rotations for visiting VSC staff during the response, which provided useful flexibility. However, that delegation created management challenges in knowing the availability of relative skill sets and the degree of interest to assist in the eruption response across the VSC. It also created management challenges in ensuring compliance with applicable laws and regulations, such as designating an Essential Records liaison and coordinating with the Records Officer on the appropriate handling of Federal records, including data.

There was some concern that overtime rules were not properly followed or communicated by supervisors for both exempt and non-exempt staff. There was some concern about striking a proper balance between long work shifts (often done at the discretion of the employee) and time off for necessary rest and recharge, pointing to a need for crews to allow more time between long shifts. There was also some concern over perceived tension in tasking people appropriately to balance among science operations, EOC duties, and social media coverage.

Because so many staff came from outside HVO, newcomers often had an imperfect idea of what was needed. This occurred with the UAS group, where it became apparent that a data manager and UAS coordinator were needed. People brought in often had an imperfect understanding of their charge, and some respondents noted that a prior UAS crew did not always know what was required with these new positions, which produced some fairly significant misunderstandings.

Issue 5: Enhanced Safety

Survey respondents expressed multiple concerns about reinforcing safety protocols. HVO did not have a safety officer present at the beginning of the response. Individuals were responsible for acquiring their own personal protective equipment (PPE), yet guidelines for this PPE were not always made clear to incoming personnel. A job hazard analysis for the LERZ was not complete until July, 2 months after the eruption began. The resulting analysis covered more than 20 activities and provided mitigation steps for each risk, which improved safety protocols and procedures considerably through the remainder of the eruption. To the degree practical, it is advisable to initiate the job hazard analysis sooner and designate an Essential Records liaison to ensure compliance with applicable laws and regulations.

There also were some issues at the summit and the LERZ where USGS scientists were not allowed to access field sites because of safety concerns. At the summit, there was no access to conduct field work in the caldera until June 5, and limited provision thereafter. Virtually all science was conducted remotely. At the LERZ, particularly in the last few months of the eruption, FOB personnel became increasingly concerned that USGS personnel were taking too many risks, particularly with respect to gas exposure. On one hand, this was due largely to FOB personnel having no experience or knowledge of volcanic hazards and falling back on overly restrictive Occupational Safety and Health Administration limits. However, some HVO staff and others placed themselves in high-risk areas. The HVO discussed these matters at staff meetings, appealing to good judgement instead of establishing rigid guidelines. It may be that guidelines tailored to the HVO need to be formalized.

Many people commented that UAS safety procedures and protocols were not followed as much as they needed to be, especially during the first few weeks of the response. The initial UAS crew was very busy with the emergency response nature of the first weeks of the eruption and lacked dedicated time for proper flight and safety briefings. Subsequent crews instituted safety standards and briefings in accordance with DOI Operational Procedures Memorandum-11 guidelines.

Issue 6: Enhanced Science Coordination

Some scientists expressed frustration over lack of access to traditional field work opportunities; however, several scientists thought that the USGS response was very effective from a crisis-management and science communication perspective, but less so from the perspective of capturing ephemeral data. At the summit, there was little on-the-ground monitoring of cracks; at the LERZ, there was no systematic approach to activities such as taking temperature measurements at cracks, nor was there a systematic way of recording of such measurements, other than through field notebooks and *ad hoc* reports in Mattermost®. There were no systematic plans for collecting and documenting thickness of ash/cinder deposits at either site. This likely indicates the initial heavy emphasis on monitoring large changes during the initial stages of the eruption, as well as safety concerns. The alternate view presented is that HVO management considered whether to acquire such data but made a reasoned decision that such data collection did not warrant the safety risk or the overhead expenses.

Some scientists perceived a general disconnect between GIS and field geology, with no systematic effort in place to organize field observations into a GIS. Tension was reported in the UAS group about prioritizing flights for response rather than for gathering science information. The gas project was understaffed, which had a direct impact on the ability of the team to respond. For example, the available staff could not take measurements at both the summit and LERZ, process data, and communicate findings to the broader response team in a timely manner, despite everyone working extremely long hours every day and on weekends. There was a perceived need to establish a protocol for SO_2 measurements with respect to public health hazards with continuous sensors and a method for consistent flow of data back to the EOC.

Other survey respondents noted that citizen scientists were very involved in the response, but that staff could do better highlighting their activities, publicly thanking them, and ensuring that they also have what they need during the response, as they play a valuable role in our science infrastructure.

Training (108 comments)

Training processes varied widely among USGS responders. Although some responders brought existing skill sets (human resources, records storage protocols, VDP Event Trees) and relationships with major players, others had to be trained quickly for their roles. The latter could be hindered by lack of training documents stating clear roles and responsibilities at the beginning of the response, which evolved during the response. On-site training tended to range from accessing reading materials, shadowing predecessors for a short time period, or talking with staff already involved in the eruption response. Consistent systems, protocols, and reporting tools shared by all observatories; former work experience at HVO; and individual initiative helped VSC responders ramp up quickly.

Issue 7: Enhanced Onboard Training

Survey respondents consistently commented about the need to improve the onboarding processes of visiting staff. Each observatory should develop their own “best-practices” briefing document (for all to read and sign) that addresses region-specific topics such as volcano safety, call-down procedures, data/photograph sharing, archiving procedures, behavior while in the field, cultural sensitivities, and other best practices. Some respondents thought that more attention during orientation is needed to ensure that biosecurity considerations are included into disaster-response protocols, especially for non-Hawai'ian residents.

The EOCs need to have on-hand useful training materials specific to their unique roles and responsibilities. People assigned to EOCs need to expect shifts to last as long as 11 hours and be prepared to adapt to changing situations with new protocols. Incoming personnel need to join Mattermost® discussions ahead of arrival to gain knowledge of EOC liaison duties and how they relate to USGS personnel.

Issue 8: Promote Deliberate Mentorship

There is a perceived need to make allowances for personnel with extensive experience to work more closely with those who have less experience. There is an expressed need to have more overlap of senior field-oriented physical-volcanologists with next-generation scientists to maintain basic research on highly hazardous past eruptive phenomena. For persons assigned to EOC duty within the State and county, there is a perceived need to allow for at least 1 day of overlap with personnel who are rotating out.

Communications (160 comments)

Communication across all disciplines and partners is critical to keep all responders speaking as one voice and working toward a common purpose.

Issue 9: Improve Standardization of Communications

Internal to the USGS, there is a need to adopt a uniform communications platform that (1) everyone in the response can use, including external collaborators; (2) enables 24/7 distribution of data; (3) allows for archival functions; (4) provides defined pathways for vertical communications within disciplines; and (5) works independently of cell towers, which can be destroyed by lava. There also is an expressed need to improve coordination among regional and national USGS communication staff. There is a perceived need to establish more regular HVO internal conference calls, including remote response participants, to facilitate information-sharing with HVO management and keep everyone informed of developments.

External to the USGS, survey respondents expressed a perceived need to establish a proper debriefing order among various ICS entities (such as FOB, and county and State EOCs) so that eruption status information is delivered on time from the field for daily scheduled briefings. Other respondents expressed a need to adopt a more structured approach that establishes and maintains a tracking list of very important person engagement and Congressional visits to the site of a disaster. There is need to establish protocols for communications in the field between the USGS and the FOB, including the use of consistent radio frequencies and specific devices (radios instead of inReach phones), with enough radios on hand and FOB personnel trained in using them.

There is also a need to improve visual materials for public consumption. In the case of Kīlauea, this would include a labeled map of the summit area that includes significant features−road names, HVO and Park Service sites, overlooks, caldera rim, current and new outlines of the crater, the Volcano House, and cardinal direction. Photographs also should be labeled accordingly. One problem that emerged after the response was that photographs posted in Mattermost® were stripped of their exchangeable image file (EXIF) format headers, which included coordinates of the photographer. For drone footage, captions should describe the direction of travel. Survey respondents also expressed a need to improve website materials to provide better orientation and better explanations on the deformation page.

Given that social media increased in importance throughout the eruption, there is a need to be more attentive to resident concerns and feedback to enhance USGS credibility. It was suggested that on-the-ground photography and video footage should be more inclusive of the human element, yet with due regard for honoring privacy concerns. Progress toward improved standardization in communications also would tend to improve compliance with regulations under records management.

Equipment and Resources (124 comments)

Many survey respondents indicated the need to use the Kīlauea experience to determine what equipment and crew resources are most essential to provide the type of emergency support and data products that are required from the USGS to promote real-time situational awareness. Several different topics emerged around this concern.

Issue 10: Ensure Data Quality and Records Management

Survey respondents expressed concern over data consistency and quality control. There tended to be too much variability in the type of observations and amount of data placed in various logs.

Although a few geologists were using some mobile GIS in the field, there was no systematic effort to organize and store all the spatial data being generated by the field crews. Furthermore, there was no good unitary system for computing, data storage, backup, and uploading, primarily because people relied on their personal work computers from other projects, or personal phones and Wi-Fi hotspots, using alternate email accounts because the enterprise system would prohibit some participants from being able to access important Google Docs™ and shared folders. There also was no defined method in place to quickly convey geospatial data to emergency management partners, and because of previous years of chronic understaffing at the HVO, there was no one at HVO specifically tasked to gather geospatial data and accomplish this during a crisis. Despite awareness of the need, a dedicated GIS position did not exist at the HVO, forcing a few dedicated employees to fill the void and adapt to a lead role on GIS during the eruption response.

Mattermost®, although serving a vital function as an excellent communication tool, became for some people the only path through which they reported observations. This has proven problematic for long-term record keeping because of inadequate archival functions and because using the software as a service requires documentation for "authority to operate." Identifying metadata is a records-management requirement that needs to be maintained even in the event of a disaster. In a crisis, there often is only time to file one detailed report, so there should be more thought put into how scientists report observations and codify them. Other respondents noted that people sometimes seemed to be more interested in taking images and posting them immediately on Mattermost® than in observing, thinking, and taking notes during the observations. Data archiving remains a big problem, with negative implications for both response coordination and subsequent scientific work, so the VSC needs to consider using professional assistance for this purpose. Each group used their own approach, with varying degrees of success.

Improved coordination across all USGS observatories is a critical and essential next step forward in volcano monitoring for safeguarding people and communities. Having a permanent USGS staff member at the HVO dedicated to managing geospatial data will help address this gap.

Issue 11: Administration of Human Resources

Many survey respondents expressed a need to better optimize staffing to confront persistent challenges that resulted from the constant stress of filling gaps in coverage and extremely long work shifts. The USGS response team was stretched too thin by the event, having a direct effect on their ability to perform. Some respondents thought that the VSC needs a larger team of field people in general, and geologists in particular. Other respondents thought the VHP office needs an additional full-time employee to help handle media, meeting notes, and reporting tasks during eruption responses, as most regular work (data calls, cooperative agreements) cannot be placed on hold. Some expressed the idea that an external grants program could potentially enhance our ability to bring in science partners from other research agencies for help during a crisis.

There was substantial concern expressed about stress management and staff burnout. It was also noted that difficulties with implementing interagency travel agreements translated into lost expertise and insights. Resolving such administrative challenges needs to happen prior to the activation of an emergency response. Other staff were not always used in the most efficient manner. For example, some respondents suggested that full staffing support was not regularly needed for most meetings, and that time might be better spent for some participants if questions were addressed as a task item sent afterwards.

Issue 12: Advanced Preparation for Equipment and Gear

There was concern that safety equipment should be inventoried and updated regularly to prevent any shortfalls or gaps in distribution. Having an easy-to-move and well-tracked cache of equipment would be an improvement for future eruption responses.

There is a clear need for redundant sensor arrays and rapid-deployment sensors. Redundant channels of telemetry communication also are needed, along with serious vulnerability analysis.

Clothing also became an issue when very few people had appropriate USGS or DOI visual identity and no one had sufficient visual identity to be properly representing the agency every day in the field. FEMA, NPS, and other agencies seemed to have an endless supply of visual identity gear that enabled their employees to conspicuously represent their respective agencies. Several people commented that a logistics manager should be mobilized to an event site to handle the various challenges associated with lodging, gear, safety supplies, and other logistic items.

Excerpted Findings from Other Sources

This section highlights excerpts of findings that were derived from numerous sources external to the survey instruments. The bulleted lists that follow capture specific suggestions for action derived from structured after-action group discussions (“hot wash” exercises) that warrant explicit reiteration in this report. However, not every suggestion here is carried through with identical phrasing into the final set of recommendations advanced by this report.

Department of the Interior Strategic Sciences Group

The DOI SSG developed a technical report (U.S. Department of the Interior, 2018) that explained in detail many examples of potential actions that likely would help mitigate adverse effects in a future eruption. Some of the specific suggestions for action from that report that pertain most directly to the USGS VHP include the following key concepts:

- Seize opportunities to develop new partnerships within and outside DOI to address facilities issues caused by seismic damage and park closure.
- Support ongoing efforts to create redundancy for HVO instrumentation through alternate instrumentation or siting.
- Educate community members and workers to increase early detection of invasive species and establish new wash stations at the entrance of Volcanoes National Park to address biosecurity threats posed by increased commuting from more distant Hilo locations.
- Create a "vog officer" position to ensure better coordination and consistency in communication about vog hazards across Federal, State, and county agencies.
- Use lava-flow risk maps to facilitate discussions between the NPS and local landowners about the possible creation of public lava viewing areas for use in future eruptions.

Office of Communications and Publishing

The OCAP developed an internal document after team discussion on the Kīlauea response. Some of the specific suggestions for action from that report are summarized here:

- Visiting staff should be more aware of local sensitivities and adopt a supportive and deferential role toward local staff.
- Two vital communication functions should begin right away and not await external initiative—organizing a coordinated news media response and organizing community meetings.
- Plan to deploy a strong public affairs presence early on, and then reduce activity later if not needed.
- Establish clear buy-in from the SIC and the resident media specialist about the types of roles and responsibilities needed to fulfill national media needs. Each visitor should arrive with an invitation and full awareness by the SIC, and work within a defined space.
- Assert early control over media interactions by dictating procedures through tactics such as using out-of-office voicemail directing callers to join collective media calls, establishing a website template for tracking the status of media inquiries, dividing event email traffic into national and local inquiries, and streamlining review and approval processes for social media posts.
- Establish a clear policy that defines the circumstances under which media can be permitted to shadow scientists in the field, and then coordinate specific field trip opportunities with FEMA and other relevant agencies.

Hawai'i Volcano Observatory Interactions with the National Park Service

After-action "hot wash" activities specific to HVO interactions with the NPS also resulted in a collection of lessons learned, which are summarized here:

- The HVO should develop a written plan of interaction between the USGS and NPS that summarizes roles, responsibilities, and protocols during a response.
- The HVO should plan for a formal liaison position at NPS Incident Command. This person would need awareness of ICS protocol, the USGS mission, HVO operations, and local Hawai'ian culture.
- USGS observatories should increase general awareness of ICS principles and procedures by accessing free online annual training courses on DOI Talent.
- The USGS needs to tighten control of employee tracking and reporting in dangerous conditions, while preventing rogue activities. This might be handled through more extensive use of radios, phone applications, or badges with embedded trackers.
- The HVO should adopt the GAR Operational Risk Assessment Model used by the NPS to improve situational awareness and mitigate safety risk during an eruption. Risk calculation worksheets can be used to align risk decisions with appropriate managerial levels.
- The HVO should work with the NPS to simplify gate lock combinations and park maps for easier use by approved non-NPS partners during an emergency.
- The HVO should make more use of NPS radio communications by adding call names, shared frequencies, training, and standard operating procedures.
- The HVO should join the rapid message methodology SENDWORDNOW to share urgent messages with the NPS.
- The HVO should work with the NPS to streamline management of aviation vendors.
- The HVO should coordinate with the NPS to allow participation in NPS all-hands meetings to receive and share monthly updates.
- The HVO should coordinate with the NPS about sharing social media responsibilities during the next eruption.
- The HVO should coordinate with the NPS to conduct half-day realistic eruption scenarios for small teams.
- The HVO should coordinate with the NPS to establish proper orientation briefings for all visiting staff.
- The HVO should coordinate with the NPS to develop local hazard maps that are consistent with USGS products.
- The HVO should coordinate with the NPS to develop a master map of roads in HAVO, with possible redesignation of the summit road as an emergency route.
- The HVO should determine with the NPS how UAS footage can and cannot be used.
- The HVO should coordinate with the NPS how to attain research permits during a response.

Hawai'i County Civil Defense Debrief

The HVO also conducted a thorough after-action debrief with HCCD in November 2018. A summary of key suggestions (arranged by topic) from that "hot wash" exchange is presented here.

On the topic of Communications:

- The start of weekly HVO communications to HCCD on March 23 was well-timed and sufficiently informative, allowing HCCD to be proactive in response preparation. However, the HVO should alert HCCD earlier about possible rare events such as summit explosions.
- The HVO should subscribe to HCCD text alert messaging for specific categories of interest.
- The HVO should run early public messaging text by HCCD for review. Expert help in hazard communication would be valuable in the beginning of a crisis. Public messaging should include any uncertainties in forecasting.
- HCCD should strengthen early messaging to improve public compliance. Investigate methods of tracking messaging effectiveness, possibly through social media by HiEMA.
- HCCD messaging should focus on the hazards present by area (for example, Leilani Estates was not going to have the ashfall mentioned in more general messaging). Investment in more complex messaging by area will relieve HVO staff of responding to public confusion over which hazard to expect. Investigate developing an online tool that would allow the public to learn about hazards specific to their location, with on-camera testimony and a tailored frequently asked questions (FAQ) document.
- HVO and HCCD should establish a Joint Information Center (JIC) to facilitate HCCD participation in USGS-moderated media calls that reach local, national, and international media outlets. A JIC also could coordinate planning of smaller community meetings. A possible location for a JIC is in a complex across the road from HCCD.
- HVO and HCCD should pursue a combination of local in-person briefings and media calls to reach the widest audience. Community meetings were very popular with the public and are very effective at mitigating misinformation. However, they need more consistent messaging and better workload balance among presenters, shorter briefings, consistent HCCD presence, and NPS presence for meetings in communities near the park. The use of local moderators to focus meetings and mitigate tensions should be continued. Expand messaging about specific eruption scenarios at community meetings, jointly reviewed by HCCD and the HVO.
- Nā Leo TV® was a valuable partner in recording community meetings. Request their advice on meeting frequency, and how to livestream future meetings on Facebook to reach a wider audience and increase trust in authorities.
- Establish a HCCD-HVO education working group to develop new, multi-audience materials to educate HCCD staff, USGS non-VHP staff, and the public on volcanic and earthquake hazards. Write volcanic preparation pamphlets at two different levels (for kids and adults). Work with Nā Leo TV® to develop a documentary about the community experiences and effects of this event.
- HVO and HCCD should offset social media misinformation disseminated by grassroots organizations over which responders have little influence. Suggestions include coordinating with Nā Leo TV® as a trusted local entity to send out more targeted daily local reports; recruiting upper levels of responders to better monitor social media; updating more frequently the availability of public information at HCCD shelters; and using dedicated misinformation correction threads on social media, such as a Microsoft smart algorithm for scrubbing.

- HCCD should use established Community Emergency Response Teams (CERT) to better empower citizens to reach evacuation decisions on their own through direct information dissemination.
- HVO should send a scientist as liaison to the HCCD EOC at the beginning of activation. This position is critical in allowing HVO to reach HCCD through cell phone and Mattermost® texting capability.

On the topic of Operations:

- The HVO should work with HCCD to implement a formal ICS *tailored to Hawai'i County* to enable information flow from HCCD back to the HVO. This may help in defining a common crisis response terminology. Use the Incident Action Plan to deconflict and schedule various briefings ahead of time for a logical response flow. Analyze timing of HVO briefings and revise as needed.
- Revive the old HVO call-down list for the start of different crisis events and revise as necessary, using the expertise of the USGS Emergency Management Office.
- Insert daily virtual policy/logistics meetings with select HVO (as needed) and HCCD personnel. The meetings would inform HVO of HCCD-specific response actions, such as evacuation routes and use of sirens that would influence HVO fieldwork.
- Early in the response, mobilize someone who understands FEMA mission assignments who can act as a FEMA liaison and a USGS Safety officer. The HVO should refine their workflow to complete ICS Form 214—daily log reporting of significant events—to HCCD to support FEMA reimbursement.
- Ask FEMA if future geology interpreter liaisons stationed at the HiEMA could come from the University of Hawai'i system to relieve the HVO of that duty.
- Develop a common operating picture platform with elements such as a dashboard, Mattermost®, and someone to create visualizations from reporting. Determine which agencies/personnel would have access. HCCD can ask FEMA to be the lead in data collection, delivery, and standardization across agencies, particularly for maps, including those of the HiEMA.
- Consider HCCD opening the EOC earlier, prior to the EOC being formally activated, for initial closed-door partner briefings, so that all partners have the same level of situational awareness.
- Investigate HVO adopting the free "collector" application for gas and crack data, photographs, and videos. HCCD uses this application and can train the HVO. Investigate incorporating a web form that feeds into the collector application database so that the public also can contribute to it.
- The HVO and HCCD should define systems, standards, and workflow about collecting, archiving, distributing, and using gas data, as well as public education on gas hazards. Define standards for gas mask type and use that are unique to *each agency* and train accordingly. Work with the Hawai'i Department of Health to define mask type and use standards for the public.
- Plan ahead of time which resources (fuel, food, water, and sleeping quarters) will be available to HVO personnel at an FOB. Arrange for the HVO to access help with instrument deployment, storage space at the FOB, a camper van for sleeping after shifts in the field, and installation of temporary cell towers during response.

- HVO should develop a lava-flow cooling model that will feed HCCD criteria for allowing citizens and businesses back into flow areas, especially where lava will be removed from driveways and roads.
- HVO should continue to develop UAS live feed capability to the EOC, increasing IT capability as needed. Talk with the UHH about technologies to process UAS footage in real time in the field for quicker georeferencing of the footage.
- HVO should ensure that sufficient information is passed to HiEMA (maximum of 4–5 Microsoft PowerPoint™ slides), and that it matches information provided to the HCCD.

On the topic of Safety and Training:

- Develop first responder baseline safety standards. Develop and train separate safety standards for the HVO that address the HVO unique mission, which requires a higher risk tolerance than HCCD.
- Radios with locators and satellite phones with trackers would facilitate HVO accountability and safety without reliance on cell towers.
- ICS training for all partners would improve many coordination and communication issues. Determine which HVO staff to train in the use of Incident Action Plans as part of ICS training. High-level volcano hazards training is needed for ICS and other responders coming from off-island.
- Hold HVO-HCCD biannual meetings with briefings on different eruption scenarios and forecasting tools such as event trees.
- HCCD should include the HVO in future liaison training.
- Maintain the policy of having the HING accompany the media into the field. This has freed up HVO and HCCD resources while preserving the necessary safety precautions.

Recommendations

"This event was a wake-up call for all USGS offices. A bigger event will leave USGS scrambling and unable to conduct our mission unless we can take advantage of this learning moment."

This report draws collectively from the wide assortment of received feedback, as identified and discussed in the section, "Discussion," to advance a concise set of recommendations for targeted adjustments that might improve the USGS response to future events. It is anticipated that USGS leadership will further assess these recommendations, prioritize them, and then refer the endorsed actions to appropriate responsible parties for implementation and (or) further solution development. A summary of these recommendations is shown in table 1, located at the end of this section.

Consolidated Recommendations by Topic

PLANNING

Topic 1.0: Develop More Comprehensive Planning Documents (Aligns with Issues 1,10,11, and 12)

1.1 Update Continuity of Operations (COOP) planning.

The scale of the Kīlauea eruption brings into sharp focus the ongoing need for updated COOP planning, not only at the Bureau level but also at the local level of each science center and, in the case of the VSC, each observatory. Each COOP should follow the template established by FEMA, with all the integral component parts, including (1) identification and prioritization of mission essential functions, (2) order of succession and delegation of authority specifications, (3) continuity of facilities, (4) continuity of communications through physical hardware and procedural guidance, (5) essential records-management, (6) continuity of personnel, (7) training and drills, and (8) reconstitution of operations.

Following direct “lessons learned” from the Kīlauea event, each local COOP plan should include the following elements:

- Clearly identify who has decision-making authority, and how decisions will be made.
- Include a strategy to relocate or duplicate the core functions of vital equipment so that each observatory could abandon a facility during an emergency yet still perform critical functions elsewhere.
- Consider the feasibility of increasing the mobility of operations using trailers, steel shipping containers, or mobile homes that would allow for rapid relocation of laboratories and communication resources to support incident command centers.
- Confirm that personnel are set up with virtual private network (VPN) accounts for remote DOI access.
- Beware of the cumulative effect of multiple COOP plans using the same backup resources during a crisis.

Potential Action Office: Scientists-in-Charge and Regional Safety Manager

1.2 With specific regard to continuity of facilities, following direct “lessons learned” from the Kīlauea event, the COOP plan for each observatory should include the following elements:

- Develop a full Reconstitution Plan for those facilities operating in areas of high hazard risk, with discussion of options and future space needs related to rebuilding and leasing.
- Outline when a building must be evacuated and under what circumstances it is safe to return.
- During an event, establish a dedicated point of contact early in the process (within 2 weeks) who would have authority to make decisions regarding space and funding, and could obtain training in Emergency Space Acquisition.
- Under conditions of evacuation, contact partners and use Cooperative Agreements and Interagency Agreements where possible to maintain continuity of operations. If Federal space is not available, the OMS should coordinate with General Services Administration (GSA) to expedite the process through procurement vehicles such as Emergency Leases

and Justification for Other than Full and Open Competition; consideration may also turn to the use of Categorical, Special Purpose, and Delegation space authorities.
- Coordinate with the Office of Acquisition and Grants for short-term blanket emergency contracts (such as Moving Services) to provide manpower to relocate personal property, historic artifacts, and other valuable items.
- Maintain awareness that in an emergency, normal market forces change unexpectedly, and rental space can escalate in cost during the acquisition process.

Potential Action Office: Scientists-in-Charge and Office of Management Services

1.3 With specific regard to continuity of communications, following direct "lessons learned" from the Kīlauea event, the COOP plan for each observatory should include the following elements:

- Identify how to maintain priority service for cellular and landline communications, including "waiver use" of university or National Oceanic and Atmospheric Administration networks as backup in times of emergency to allow for more redundancy.
- Identify redundant configurations for each data center, identifying viable backup options using cloud-hosting services, another observatory, or the USGS Earth Resources Observation and Science Center.
- Consider new opportunities to better leverage sensor to cloud technologies.
- Consider new opportunities to better leverage local cloud-hosting solutions during disaster recovery.
- Identify a prescribed GIS tool (such as Mattermost®) for consistent use across the VSC and the Natural Hazards Program that establishes a sanctioned IT solution with formal "authority to operate" for sharing files internally and with external partners.

Potential Action Office: Scientists-in-Charge and Office of Enterprise Information

1.4 Draft an internal Incident Response Plan.

In close association with an updated COOP plan, each volcano observatory needs to prepare an internal Incident Response Plan that predefines staff roles and responsibilities, as well as capabilities, during an eruption response. This would help reduce confusion and redundancy of effort during a crisis. The plan can be informed by past efforts, such as the 2006 Augustine eruption, the Yellowstone Volcano Observatory response plan, and the 2018 Long Valley eruption VSC tabletop exercise.

The Incident Response Plan should address the following specific concerns:

- Backup power and fuel supplies,
- Backup communications equipment,
- Accountability for staff,
- Safeguarding hazardous materials,
- Continuing the best practice of establishing telemetry redundancies across monitoring networks,

- The identification of predefined backup observatory facilities in coordination with GSA, and
- The identification of critical IT systems and plans for mandatory reporting outages to DOI.

Additionally, the Incident Response Plan should include:

- A clear definition about when unrest phenomena would activate the response plan;
- Criteria for engaging USGS scientists outside the VSC;
- An expedited purchasing capability for supplies and equipment;
- Dedicated internal communication platforms by activity;
- Provision for a centralized database of observations;
- Regular internal VSC coordination calls; and
- Identification of appropriate leads for all the necessary components of a large coordinated response (scheduling, logistics, administrative functions, finance and acquisitions, science collaborations, IMT liaisons, geospatial data services, and information technology and data management). This may lead to additional Full-Time Equivalent positions or redefinition of some position descriptions.

For example, the scheduling component of the Incident Response Plan should strategize how to:

- Identify gaps in staffing;
- Vet available personnel from outside the primary responding observatory in a fair manner;
- Onboard external personnel with a briefing on their duties so as to manage their expectations;
- Develop onboarding training materials covering local concerns, consider cultural sensitivities, messaging standardization, and predictable complications;
- Maintain a running list of downtime tasks for personnel;
- Maintain tracking of USGS and DOI staff whereabouts on the island (modelled on the Fukunaga Google sheet); and
- Maintain a personnel roster so that everyone knows names, affiliations, and assignments of the visiting staff.

The scheduler would give HVO staff priority in assignments for which they have the relevant skill set.

The logistics component should strategize how to coordinate money, resources, lodging, vehicle, and travel needs, while interacting directly with each IMT. The administrative component should strategize how to track the status of time and attendance for all deployed personnel, exempt and nonexempt employee designation, comp time instead of overtime eligibility and consecutive days worked so that potential violations of the Fair Labor Standards Act are avoided. The finance component should strategize how to optimally coordinate with FEMA over mission assignments, overtime pay, hazard pay, and purchasing needs. The science collaboration component should strategize how to evaluate and facilitate external research collaborations and project requests in advance of an eruption. The IMT liaison component should strategize how to vet FEMA requests, assist with mission control, and possibly draw salary through FEMA mission assignment. It would also establish protocols for communications in the field between USGS and the FOB, including use of consistent radio frequencies and specific devices (radios instead of inReach phones), with enough radios on hand and FOB personnel trained in using them.

The geospatial data services component of the Incident Response Plan should strategize how to bring in, distribute, and catalog all the latest lava-flow mapping, drone data, forward looking infrared, instrument and observation station positions, and lidar from a centralized system that can be accessed by multiple users from multiple devices. The Incident Response Plan should assess needs for different map formats ahead of time and facilitate the release of information in shape files and suitable metadata. It would also further evaluate the capacity of ScienceBase as a data repository. The USGS GIRT of the NGP should be included as a support component of the geospatial data services plan, with explicit coordination planning.

The IT/data management component should strategize how to address the collection, preservation, organization, and disposition of Federal records, including data, in accordance with existing laws, regulations, and policies. The OEI is available to help in this effort, with specific regard to telecommunications, cloud and data storage (including communication logs) for future studies and the scientific record with a dedicated data processing unit, centralized storage area, and staff who are authorized to release data. The data management component also should strategize how to:

- Facilitate access to new computers,
- Fast-track experimental software (in-house code and internet tools),
- Test freeware tools that might be useful but are not allowed on DOINet,
- Facilitate access to data from mobile devices,
- Facilitate access to non-DOINet computers for instrument-dependent data download tools that have been erroneously identified as malware, and
- Establish a central repository for all documents.

The Incident Response Plan should explain who is in charge of what; and, roles and responsibilities should be clearly defined and communicated, with frequent reiteration, especially as changes occur in management structure. Yet, the planning should not be overly rigid, as there needs to be flexibility for people to respond to situations as they occur, especially when circumstances are changing quickly.

Potential Action Office: Scientists-in-Charge and the Volcano Science Center, with input from the Regional Safety Manager

Topic 2.0: Create a More Customized Fit Within the Incident Command System (Aligns with Issues 2, 3, and 4)

The VSC will be interacting with an ICS during any future eruption crisis at a volcano with hazards affecting major population centers and critical infrastructure. To plan better for such interactions, the VSC should do the following:

2.1 Ensure that more VSC staff are trained with ICS.

2.2 Establish closer ties with the IMT community, in addition to the traditional focus on community preparedness.

2.3 Establish several dedicated liaison positions at the start of a crisis, including a position to help the VSC navigate the financial aspects of a FEMA-involved response, and to act as a liaison between various IMTs and the USGS.

2.4 At the start of a crisis, diagram how communication flow should occur between USGS staff at different IMT posts, particularly regarding anticipated requests for information.

2.5 Identify triggering criteria for scientists embedded in EOCs to be replaced by a dedicated contact at the local volcano observatory; for example, as waning or steady-state is established.

2.6 Establish protocols for communications in the field between USGS and the FOB, including use of consistent radio frequencies and specific devices (radios instead of inReach phones), with enough radios on hand and FOB personnel trained in using them.

2.7 The USGS liaison to the ICS should establish a proper debriefing order among various ICS entities (FOB, county and State EOCs) so that eruption status information is delivered on time from the field for daily scheduled briefings. Such briefings should plan to incorporate improved visual materials for public consumption.

2.8 In the absence of a full-time employee, assign a Geospatial Data Manager, who would ensure during a crisis that data received from the drone team or field crews are quickly used to generate maps for internal and external distribution through a streamlined ScienceBase-like approval process. This manager would establish a single web-based location to direct individuals and agencies for access to USGS spatial data. For example, a ScienceBase web service was eventually created during the Kīlauea response to serve data as a cartographic product that could be incorporated in web-based mapping programs, Google Earth™, and desktop GIS applications. This vision could be expanded to streamline and improve future efforts. This assigned manager would also ensure that large-volume datasets are managed appropriately, with IT infrastructure that meets the needs for UAS-generated and other field-based data. The role would also facilitate management of relevant satellite data.

Potential Action Office: Natural Hazards Mission Area and the Alaska Regional Office

Topic 3.0: Establish a Regional Hazards Coordinator (Aligns with Issues 2, 3, and 4)

The multiple tasks of disaster response require action that will exceed the ordinary capacity of a science center or observatory, requiring support from the Regional Office in the form of a USGS "Regional Hazards Coordinator" who will support science centers with an understanding of all the natural hazards within their region. The coordinator would communicate with local and regional responders within and outside the USGS, complementing and augmenting the work that the volcano observatories already do in these areas. The coordinator would support the science center and observatories by engaging with the various EOCs to assure that mutual protocols, roles, responsibilities, and guidelines are clearly communicated between the USGS and EOC personnel. The coordinator would introduce USGS personnel and products, as well as science capabilities to assure understanding and usefulness, during crisis and non-crisis time frames.

A key role of the Regional Hazards Coordinator would be to work with science centers to develop a customized Hazard Response Communication Plan (see Topic 8.0) that establishes internal and external roles between USGS subject-matter experts, OCAP, and the emergency response community through the National ICS protocols.

A Regional Hazards Coordinator would be trained in the National Incident Management System (ICS-100 and -200-course level, minimum) and regularly participate in FEMA, State and interagency steering committees, and preparedness events. The coordinator would participate in and suggest mock exercises with the USGS and the local, State, and national response communities for each natural hazard within their region. The location, time zone, remoteness, population/infrastructure of each threat will make each response unique.

The Regional Hazards Coordinator and OCAP lead would assume responsibility for coordinating public as well as internal and interagency communications. The coordinator would assume responsibility for engaging with and onboarding outside communications assistance. Onboarding activities would include introductions to USGS subject-matter experts on the response team and among other agencies, familiarization with the communication plan, and promotion of situational awareness to local sensitivities. The size of the response team could be adjusted, depending on the situation, although the idea is to come in quickly with strong support and reduce support later, rather than catching up later.

Potential Action Office: Alaska Region, with Natural Hazards Mission Area, OCAP

Topic 4.0: Initiate Science Leadership Early (Aligns with Issues 5 and 6)

4.1 Each observatory should establish a plan to (1) quickly identify scientific priorities for a response; (2) communicate those priorities to all involved; (3) develop an approach to address those priorities (including any systematic observations that need to be taken); (4) systematically evaluate priorities and change them, if necessary; and (5) perform periodic quality-assurance checks to ensure that the science is addressing the priorities. This could be done through a single science coordinator, discipline-specific coordinators, or geography-based science coordinators. This tasking should remain separate from, but in close communication with, operational leadership.

4.2 Each observatory should develop a more systematic process and format for internal project coordination during an event with clear specification of (1) what products are expected by whom and when; (2) what projects are ongoing and in need of external assistance; and (3) what types of training/skills are required to participate in the projects requiring additional staff.

4.3 It is advisable to establish a more deliberate process to evaluate and facilitate outside research. A standing steering committee could be organized at the center level to evaluate outside requests, identify gaps within USGS that could be filled by others, and then proactively reach out to coordinate such efforts.

4.4 It is advisable to incorporate more scenario-based planning in future hazard assessments. Advance preparation of event-tree scenarios with associated reference materials may well promote improved science delivery. Likewise, it is advisable for observatories to prepare new regional hazard assessments that include not only a long-term analysis (for example, for land-use planning), but also with anticipation for use during a crisis response. In short, the VSC should work in a more deliberate manner to better understand and use the linkages between long-term and short-term hazard analysis. One important aspect of this strategy involves the development and practice with scenario-based event trees.

Potential Action Office: Scientists-in-Charge

Topic 5.0: Prioritize Safety in All Response Operations (Aligns with Issues 5 and 12)

The VSC and each observatory need to take additional measures to ensure that the established culture of safety is not subordinated by science or data gathering, even during a crisis.

5.1 At the onset of a disaster response, a dedicated full-time safety officer should be on site, and should remain for the duration of the response. The USGS safety officer, at the onset of and throughout the duration of the eruption, should perform the following functions: (1) work with FEMA and each ICS to establish a job-hazard analysis for all field-based activities; (2) ensure that safety orientation and training requirements are met for all activated employees; (3) manage the distribution and use of PPE and other safety gear; and (4) document proper limits for SO_2 exposure and other safety protocols ahead of time. The safety officer would also assume responsibility to ensure better coordination and consistency in communication about vog hazards across Federal, State, and county agencies. The safety officer also would explain how PPE should be selected, what exposures were measured or estimated, and how employees and volunteers would know if and when PPE might become insufficient. For prolonged events where safety officers are on rotation, a hand-off of information should take place. The response plan should specify whether a tool is developed or if there will be staff overlap to allow for in-briefings and debriefings.

5.2 Additionally, a UAS safety officer and (or) airspace coordination expert also may be desirable, depending on the response activities. This officer should establish a clear internal and external chain-of-command and define roles and responsibilities, including identification of who sets the schedule for the day, who has the authority to modify the mission, and who has responsibility for the mission and safety of the team. All members of the UAS team should be made aware of this structure during mandatory orientation sessions given to all crews before they deploy to the field for the first time.

5.3 The VSC should further develop an ash hazards response strategy with rapid response protocols and establish partnerships in this area with the National Weather Service, Federal Aviation Administration, and Washington Volcanic Ash Advisory Center.

5.4 Safety equipment should be inventoried and updated regularly. Prepare in advance an easy-to-move and well-tracked cache of equipment for use in future eruption responses.

Potential Action Office: Volcano Science Center and Regional Safety Manager

TRAINING

Topic 6.0: Formalize Incident Response Training Protocols (Aligns with Issues 6 and 7)

The anticipated implementation of an internal Incident Response Plan will involve increased annual training on ICS principles and procedures. Such individual training currently is available on DOI Talent (free of charge) through the National Park Service.

6.1 It is advisable to conduct joint NPS/HCCD/HVO ICS training exercises, and VSC-wide ICS training events so that ICS roles and protocols are better understood, response interactions go smoothly with minimal misunderstandings, and time is well-managed. ICS training should include response operations with multiple ICS teams. In the training, explore ICS response situations unique to volcanic eruptions.

6.2 At the beginning of a disaster response, it is advisable for the USGS to provide some degree of training for on-site safety personnel at the FOB as to the role and capacities of USGS personnel; and to provide a better understanding of how volcanoes work, the various hazards that can be expected, and how USGS operates in the hazardous environment.

6.3 It is advisable for each observatory to incorporate a process that ensures safety orientation and training requirements are met for all activated employees. Establish onboarding briefing materials on volcanic hazards for ICS staff and encourage the ICS leadership to enforce its use (ICS responders will not always listen to USGS). Materials should differentiate between fire and volcano hazards, which do not present as often as fire hazards, and may not be familiar to all responders. Key personnel should maintain compliance with all required training, such as A-100, respirator clearance, first-aid, and other safety equipment/training so that they can respond in a timely manner to an event with the proper PPE.

6.4 It is advisable for each observatory to develop their own "best-practices" briefing document for all to read and sign that addresses region-specific topics such as volcano safety, call-down procedures, data/photograph sharing, archiving procedures, behavior while in the field, cultural sensitivities, and other relevant topics.

6.5 In the event of evacuation, it is advisable to initiate training for the facilities management point of contact and the leasing contracting officer to work efficiently within an ICS.

Potential Action Office: Scientists in Charge

Topic 7.0: Enhance Volcano Science Center Interoperability (Aligns with Issues 6, 7, 8, and 9)

7.1 It is advisable to increase cross-training and interoperability among geophysical monitoring network staff in volcano observatories, but with recognition that different observatories will always have some unique challenges and solutions.

7.2 The EOCs should have on-hand useful training materials specific to their unique roles and responsibilities. People assigned to EOCs should expect shifts to last as long as 11 hours and should be prepared to adapt to changing situations with new protocols. Incoming personnel need to join Mattermost® discussions ahead of arrival to gain knowledge of EOC liaison duties and how they communicate with USGS personnel.

7.3 Onboarding orientations should include clear instructions about proper use of Mattermost® within the ICS.

7.4 Each observatory should try to promote mentorship moments in the field, to reaffirm safety, but also to maintain continuity of operations and enhance interoperability. For example, people assigned to EOC duty within the State and county should have at least 1 day of overlap with the person rotating out.

Potential Action Office: Volcano Science Center

COMMUNICATIONS

Topic 8.0: Establish a Hazard Response Communication Plan (Aligns with Issue 9)

The USGS Hazard Response Communication Plan should detail who is deployed, who is taking media inquiries, and how to manage the opportunities and challenges associated with managing a high volume of information requests from traditional and social media.

8.1 The Hazard Response Communication Plan should identify how best to reach different audiences (media, public, homeowners, landowners, emergency responders, science community, and cooperators). Natural hazard events can easily become a 24/7 full-time affair. They can disrupt the regular order of science center business and stress our staff. A Hazard Response Communication Plan should be devised to plan for this intensive and long-term involvement to reduce stress on science center management, identify alternate facilities, and develop "on-call" subject-matter experts to support USGS personnel who may be negatively affected by the event.

8.2 A Hazard Response Communication Plan should clearly detail roles, responsibilities, and protocols in line with the National Incident Management System.

8.3 Social media allows us to communicate with our constituents in real time. However, an *ad hoc* approach can be unsustainable. It is advisable to develop an FAQ document for broad use in answering public inquiries about the natural hazard and the response.

8.4 To implement such a plan, there should be focused media training for key subject-matter experts and public affairs officers, including training in the National Incident Management System (ICS-100 and -200), training in use of media inquiry tracker, how to effectively use social media, where to send inquiries (volcanomedia@usgs.gov), and how to update the active FAQs.

8.5 The Hazard Response Communication Plan should identify preestablished triggers that will call for the immediate deployment of a strong response team to include the Regional Hazards Coordinator, OCAP lead, videographer, pre-identified subject-matter experts, and alternates at the scene to support center management and USGS personnel. The plan will reside in the cloud and include preestablished products, including the following:

- USGS Response and Communication Plan Schematic,
- FAQ Template with Pre-Identified Themes,
- Shared Event Calendaring System,
- B-Roll (Still and Video),
- Social Media Team Members Contacts,
- Daily Press Briefing Instructions (teleconference and EOC),
- Facebook Live Instructions,

- Community Meetings Format and Instructions to Emphasize Practical Information,
- Congressional Outreach Contacts, and
- Media Inquiry tracker.

Potential Action Office: Office of Communications and Publishing

Topic 9.0: Improve Situational Awareness Throughout the Entire Volcano Science Center (Aligns with Issues 6 and 9)

9.1 It is advisable to start internal coordination calls immediately when the eruption response starts so that issues can be addressed and reporting can be conveyed up the chain-of-command as necessary.

9.2 Ensure that call attendees are on the mailing list for dedicated daily internal reports. Pre-meeting materials should include a daily internal USGS report on various topics (including IT needs), all housed on a shared drive.

9.3 When reporting response activities, it is advisable to include home office designations of USGS staff outside the responding observatory so that cross-program assistance can be documented.

9.4 VSC management should hold occasional all-VSC conference calls during a disaster response for major events.

9.5 VSC management should share with all VSC staff the situation reports that are written for upper USGS/DOI management.

9.6 Extend Mattermost® training and read access to participants of the internal coordination calls to keep them better linked to eruption response events, with dedicated channels to topics, if possible.

Potential Action Office: Volcano Science Center

Topic 10.0: Initiate Adaptive Traditional and Social Media Procedural Guidelines Early (Aligns with Issue 9)

10.1 It is advisable to assert early control over media interactions by dictating procedures through tactics such as (1) using out-of-office voicemail directing callers to join collective media calls; (2) establishing a website template for tracking the status of media inquiries; (3) dividing event email traffic into national and local inquiries; and (4) streamlining review and approval processes for social media posts.

10.2 It is advisable to establish a JIC to facilitate external partner participation in USGS-moderated media calls that reach local, national, and international media outlets. Such a center could also coordinate planning of smaller community meetings. A possible location for a JIC is in a complex across the road from HCCD.

10.3 Investment in more complex messaging by geographic area could relieve HVO staff of responding in those community meetings to public confusion over which hazard to expect.

Potential Action Office: Office of Communications and Publishing

Topic 11.0: Consolidate Community Outreach Opportunities from 2018 experiences (Aligns with Issue 9)

11.1 It is advisable to work with Nā Leo TV® to develop a documentary about community experiences and effects from this event.

11.2 It is advisable to coordinate with HCCD to ensure that future hazards messaging will allow the public to learn about hazards specific to their location, perhaps with an online tool that includes on-camera testimony and tailored FAQs.

11.3 It is advisable for each observatory to improve the utility of visual materials for public consumption, with proper labels and orientation. Future events need to be more attentive to resident concerns and feedback to enhance USGS credibility.

Potential Action Office: Hawai'ian Volcano Observatory and Office of Communications and Publishing

EQUIPMENT AND RESOURCES

Topic 12.0: Ensure Facility Access and Better Coordination with the National Park Service (Aligns with Issues 1, 2, 4,and 6)

12.1 Ongoing USGS and NPS discussions over reconstruction of HVO facilities should include a comprehensive facility usage and access agreement in HAVO so that any future management changes do not adversely affect USGS access.

12.2 The HVO should develop a written plan of interaction between the USGS and NPS that summarizes roles, responsibilities, and protocols during a response.

12.3 The HVO should coordinate with the NPS to simplify lock combinations and gate maps in HAVO to facilitate more efficient USGS access during emergency response.

12.4 The HVO should coordinate with the NPS to improve radio communication, including additional call names, shared frequencies, standardized operating procedures, and improved mutual training opportunities.

12.5 The HVO should join the SENDWORDNOW network to share emergency messages more quickly with the NPS.

Potential Action Office: Hawai'i Volcano Observatory and Hawai'i Volcanoes National Park

Topic 13.0: Improve Collection and Dissemination of Field Data (Aligns with Issues 6, 9, and 10)

It is necessary to include GIS in the collection of field data. We need a system that can be viewed by multiple personnel at different locations, receive data from multiple sources, and facilitate the collection of field data in a way that is useful to geologists. This system should allow data to be entered and updated in a central location either through network connectivity or through disconnected editing.

It is necessary to ensure that technologies are robust and redundant so that field personnel can be connected and can upload data/observations 24/7. The USGS needs to develop a system for reporting observations that allows access by USGS and their cooperators (not limited to DOI only). It is also necessary to develop protocols for data management that allow for some degree of review and oversight on the efficacy of measurements.

13.1 It is a high priority that the VSC work with the OEI to decide on a communications platform that everyone can use and that meets requirements for archiving communications. If Mattermost® is the preferred solution moving forward, then the application needs to be properly documented in such a way that the VHP acquires a formal authority to operate. The OEI has expressed interest to be engaged and will require that the data and the network are properly secure, and that the application be adopted for standardized use throughout the Natural Hazards Mission Area.

13.2 The VSC should invest in short message service as a standard messaging service component to enable most telephone, internet, and mobile device systems to exchange text messages.

13.3 Scientists should work to develop a lava-flow cooling model that would provide information to emergency managers as they determine when to allow citizens and businesses back into flow areas, especially where lava will be removed from driveways and roads.

Potential Action Office: Volcano Science Center

Topic 14.0: Expand Unmanned Aircraft Systems Operations Within the Volcano Science Center (Aligns with Issues 2, 4, 5, 6, 10, and 11)

Because the UAS team was able to contribute so much to the response in terms of science, hazards research, and public safety, it is advisable that the VHP evaluate whether and how to develop its own dedicated UAS response team. It is also advisable to continue to develop UAS live feed capability to the EOC, increasing IT capability as needed. In advance of the next eruption, the VSC should work to establish a clear a list of what can and cannot be achieved with UAS footage.

Potential Action Office: Volcano Science Center

Topic 15.0: Enhance Flexible Administration of Human Resources During Disasters (Aligns with Issues 11 and 12)

15.1 It is advisable for the VHP to document more efficient methods to transfer money between agencies during emergencies so that team members are not prevented from rotation simply because it is difficult to pay them.

15.2 The VHP should improve the ability to track and report the whereabouts of staff working in dangerous settings and isolated locations. Rogue field efforts should not occur.

15.3 The VHP should ensure that all supervisors understand the rules surrounding overtime. Moreover, some comprehensive strategy should be developed across the Bureau that, during a crisis, will help properly balance the accommodation for rules, coverage of duty, and employee choice.

15.4 It is advisable for the VHP to develop more efficient methods to transfer money between agencies during emergencies. For example, adjust the Interagency Travel Agreement procedures to allow for more flexible implementation during a crisis.

15.5 The VHP needs to better manage the distribution and use of PPE and other safety gear. Response plans must acknowledge the necessity to provide adequate breaks for staff. There is also a need to develop minimum temporary duty length (perhaps 2 weeks) to minimize operational inefficiencies.

Potential Action Office: Natural Hazards Mission Area and the Office of Administration

Table 1. Summary of recommendations

[**Abbreviations:** COOP, Continuity of Operations; EOC, Emergency Operation Center; FAQ, frequently asked questions; FOB, Forward Operating Base; GIS, geographic information system; HAVO, Hawai'i Volcanoes National Park; HCCD, Hawai'i County Civil Defense; HVO, Hawai'ian Volcano Observatory; ICS, Incident Command System; IMT, Incident Management Team; JIC, Joint Information Center; NPS, National Park Service; NHMA, Natural Hazards Mission Area; OEI, Office of Enterprise Information; OMS, Office of Management Services; SIC, Scientist-in-Charge; UAS, Unmanned Aircraft Systems; VSC, Volcano Science Center]

Proposed recommendation		Actors
PLANNING		
Topic 1	Develop more comprehensive planning documents. Update COOP planning with regional safety manager. Establish continuity of facilities with OMS. Establish continuity of communications with OEI. Draft an Incident Response Plan for each observatory.	SIC
Topic 2	Create a more customized fit within the ICS. Ensure that more VSC staff are trained with ICS. Establish closer ties with the IMT community. Establish several dedicated liaison positions. Map out communication flow with different IMT posts. Identify triggering criteria for staffing at EOC. Establish field communication protocols with the FOB. Establish a proper debriefing order among various ICS entities. Assign a geospatial data manager.	NHMA
Topic 3	Establish a Regional Hazards Coordinator. Develop new position to interface among emergency responders during a crisis.	Region
Topic 4	Initiate science leadership early. Establish a plan to quickly identify scientific priorities for a response. Establish a more deliberate process to evaluate and facilitate outside research. Perform periodic quality-assurance checks to ensure that science is addressing the priorities. Incorporate more scenario-based planning into future hazard assessments.	SIC
Topic 5	Prioritize safety in all response operations. Assign a dedicated full-time safety officer for the duration of the response. Establish a UAS safety officer and (or) airspace coordination expert. Further develop an ash hazards response strategy. Regularly inventory and update safety equipment.	VSC

Proposed recommendation		Actors
TRAINING		
Topic 6	Formalize incident response training protocols. Conduct joint NPS/HCCD/HVO ICS training exercises Provide training for on-site safety personnel at the FOB. Incorporate a process that ensures safety orientation. Develop observatory specific "best-practices" briefing document for all to read and sign. Initiate ICS training for facilities management points of contact.	SIC
Topic 7	Enhance VSC interoperability. Increase cross-training and interoperability among geophysical monitoring network staff. Develop useful training materials for each EOC role. Develop clear instructions about proper use of Mattermost® within the ICS. Promote more mentorship opportunities.	VSC
COMMUNICATIONS		
Topic 8	Establish a Hazard Response Communication Plan. Identify how best to reach different audiences. Detail roles, responsibilities, and protocols within the National Incident Management System. Develop a FAQ document for public inquiries about the hazard and response. Provide focused media training for key subject-matter experts. Identify preestablished triggers for immediate deployment of a strong response team.	OCAP
Topic 9	Improve situational awareness throughout the entire VSC. Start internal coordination calls immediately as eruption response begins. Ensure that call attendees are on the mailing list for dedicated daily internal reports. Include home office designations of USGS staff outside the responding observatory. Hold occasional all-VSC conference calls during the disaster response. Share the Situation Reports with all VSC staff. Extend Mattermost® training and read access to participants of internal coordination calls.	VSC
Topic 10	Initiate media procedural guidelines early. Assert early control over media interactions by dictating some procedures. Establish a JIC to facilitate external participation. Invest in more complex messaging by geographic area.	OCAP
Topic 11	Consolidate community outreach opportunities from 2018 experiences. Work with Nā Leo TV® to develop a documentary. Coordinate with HCCD to ensure that future hazard messaging is location-specific. Improve the utility of visual materials for public consumption.	HVO

	Proposed recommendation	Actors
EQUIPMENT AND RESOURCES		
Topic 12	Ensure facility access and better coordination with the NPS.	HVO
	Achieve facility-use and access agreement in HAVO.	
	Develop a plan of interaction to summarize protocols during a response.	
	Coordinate with the NPS to simplify lock combinations and gate maps in HAVO.	
	Coordinate with the NPS to improve radio communications.	
	Join the SENDWORDNOW network.	
Topic 13	Improve collection and dissemination of field data.	VSC
	Work with the OEI to develop a GIS communications platform that all can use.	
	Standardize use of short message service for emergency text messaging.	
	Work to develop a lava-flow cooling model.	
Topic 14	Expand UAS operations within the Volcano Hazards Program.	
	Develop a dedicated response team for immediate deployment of UAS technology.	
Topic 15	Enhance flexible administration of human resources during disasters.	NHMA
	Document more efficient methods to transfer money between agencies during emergencies.	
	Improve ability to track and report whereabouts of staff.	
	Ensure that supervisors understand rules surrounding overtime.	
	Develop more efficient methods to transfer money between agencies during emergencies.	
	Improve management of the distribution and use of safety gear.	

Final Thoughts

The 2018 Kīlauea Volcano eruption was a remarkable and highly destructive event that has prompted much discussion and rethinking in various fields, spanning the science of volcanology to emergency management operations and land-use planning. Hawai'ian Volcano Observatory scientists and the extended network of support throughout the U.S. Geological Survey (USGS) The Volcano Science Center will continue with the effort to better understand the eruption and its significance for years to come.

One prominent observation emerged as a frequent theme of sobering concern among many survey respondents with this After-Action Review: the USGS does not seem to be properly prepared to respond to more than one volcano in such a substantial level of unrest or eruption at any given time. This one eruption tasked most USGS resources, leaving no reserves for any simultaneous large event. Hopefully, all the energy that has been generated to learn and adapt from this event will prove decisive in expanding our institutional capacity to respond in the future.

The suite of recommendations developed from this review process will only prove worthwhile if the entire USGS is vested in improving the USGS response to future volcano eruptions and other hazards. Adaptive approaches to planning, training, communications, and equipment must be developed and implemented to prepare the USGS workforce for additional challenges certain to develop. It is imperative that we all play our part in translating these inventories of observations and lessons learned into actionable improvement.

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