Threats go both ways in the management of volcanic protected areas

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ABSTRACT

Volcanoes are true wonders of the planet. Managers of volcanic protected areas face the dual challenge of protecting the volcanic landscape from overuse and damage, and protecting visitors and local residents from the range of geophysical risks presented by volcanic activity. Without clear recognition of how the volcano works, there is the potential that the risk of hazardous conditions (e.g., eruptions, gas emissions, fumarolic activity, landslides, seismic activity, and other volcanic hazards) may not be adequately addressed in the site's management plan. Two examples illustrate current best practice in response to this management challenge. Managers at Mount St. Helens National Volcanic Monument face a decision on what civil engineering measures to take in response to a large lake formed by a debris avalanche during the 1980 eruption that poses catastrophic flood and debris flow risks to more than 50,000 downstream residents. Managers of Hawai'i Volcanoes National Park in Hawai'i faced imminent threats to residents of the island during eruptions of Kīlauea volcano in 2018 and 2020, which also destroyed a research observatory and park visitor facilities. The management response was to fully close the area near the volcanic vent and move the research center to the city of Hilo, 30 miles northeast of the Kīlauea summit.

INTRODUCTION

Active volcanoes are among the most spectacular examples of geoheritage. They are also central to the

Lava flow from Kīlauea volcano, Hawai'i, 2018 US GEOLOGICAL SURVEY

formation, evolution, and sustenance of biological systems; they form some of our deepest and most significant cultural attachments to the land; and they attract large numbers of visitors for their aesthetic appeal. Volcanic landscapes demonstrate geological and geomorphological processes fundamental to understanding how the dynamic earth works, from the global to the local scale, and also link processes in the earth's interior with those on its surface. In addition to their core geoscience values, volcanoes provide one of nature's most dynamic stages, which has expressions in the great biodiversity found in many volcanic landscapes, the cultural connections between people and their environment, and as a record of human developments on every continent (Casadevall et al. 2019).

In general, because of their large size, long eruptive lifetimes (usually spanning many hundreds of thousands of years), and inherent dangers, the most active volcanic systems are relatively undisturbed and little influenced by human behavior. On many occasions the interaction between humans and volcanoes is the reverse of that influencing other natural systems, because volcanoes pose substantial hazards to life and property, and indeed to the conservation of important geological, biological, and cultural features. Nevertheless, human activity also poses threats to many volcanic protected areas, such as through illegal dumping, pollution of groundwater, inappropriate highway development, erosion of wilderness quality, commercial tourism (including ski area development), recreational overuse, off-road driving, and mineral extraction (Crofts et al. 2020).

SITE MANAGEMENT PRINCIPLES AND GUIDELINES

Management of some protected areas does not recognize that beautiful volcanic features may be active. Therefore, there is the potential that the risk of hazardous conditions may not be adequately addressed in the site's management plan. Drawing visitors to active geophysical areas carries a responsibility to monitor volcanic activity and develop risk contingency plans as essential parts of the management process. Many volcanic protected area managers help coordinate civil protection monitoring, communication, and emergency response systems designed for area residents. However, the application of civil defense measures directly to protected area visitors, such as a warning system and an orderly method for evacuation, may be missing entirely or else fail to address specific hazards of the site. Protected areas offer a good venue for providing such information to visitors, but it is frequently omitted from management planning. There is also an educational value to raising awareness of volcanic hazards in a scientifically valid manner.

A good example of a successful hazard reduction scheme in a volcanic World Heritage Site is New Zealand's Tongariro National Park (Keys and Green 2008). Threat of lahars (mud flows) caused by water spillage from Mount Ruapehu's summit lake has been of particular concern for the safety of skiers and ski infrastructure on its slopes, and for surrounding roads, farmland, and settlements. A sophisticated crater-lake monitoring system and lahar warning system have been installed, and these proved to be of vital importance in reducing loss of life and property damage during a recent lahar.

In addition to working with scientists to document the possible threats from a volcano, as noted above managers often must also work with the civil and emergency authorities and the local communities to prepare a contingency plan in the event of a serious incident happening. Contingency planning is now recognized to be very important in safeguarding the public in a wide range of risk situations, although in addition to public safety concerns managers of volcanic protected areas will also wish to understand and mitigate the risks to natural assets of high conservation value. Japan's Mount Fuji has such management plans and managers there have conducted evacuation drills (Chakraborty and Jones 2018).

Looking at threats from the other perspective, in which people endanger volcanic geoheritage, it is important that protected area plans and management provide adequate protection of the complete volcanic system, including evidence of its eruption styles, products, and landforms. While there is general belief that volcanic geology is generally quite robust to high levels of visitation, many young volcanic features, such as hydrothermal deposits and delicate eruptive products, are quite fragile. Some human-made threats to geological values may require management intervention. In most cases, these threats also affect the site's ecology and cultural values, and where these

values are strong the sites should be managed as integrated systems.

Volcanic sites frequently have ecological, cultural, and aesthetic resources that depend upon special factors of terrain. The ecology of a volcano will be influenced by, or in some cases depend upon, the rock type, soil, geomorphology, and such features as micro-terrain, aspect, altitude, aridity, and sometimes even volcanic disturbance. Indeed, as exemplified by the Surtsey World Heritage Site off the southern coast of Iceland (Moore and Jackson 2020), active volcanoes are the only places on Earth where new land is created—an ecological clean slate, or *tabula rasa*—and their protection and monitoring over time enables insights into the processes of biological colonization. Volcanoes also frequently have strong cultural importance, such as Mount Vesuvius and the burial of Pompeii in what is now Italy, or the complex religious traditions of native Hawaiian people and their volcanic home.

The rest of this paper looks at two examples of best practice in managing volcanic protected areas.

SPIRIT LAKE OUTFLOW SAFETY IMPROVEMENT PROJECT, MOUNT ST. HELENS NATIONAL VOLCANIC MONUMENT, USA

The eruption of Mount St. Helens on May 18, 1980, was unusually well monitored and observed and subsequently studied by scientists from around the world. Our current understanding of several important eruptive processes such as volcano sector collapse, the dynamics of pyroclastic surge and flows, the mechanics of debris flows and mudflows, and degassing of continental stratovolcanoes all originated with observation and studies of the 1980 eruption. With 57 fatalities, the 1980 eruption was the deadliest and most economically destructive volcanic event in the history of the United States. In 1982, the landscape around the volcano was protected as Mount St. Helens National Volcanic Monument to preserve the volcano and allow for the eruption's aftermath to be scientifically studied: a new gift to

Surtsey World Heritage Site, Iceland: A new island dedicated to long-term research of ecosystem dynamics, and closed to visitation. © ROGER CROFTS

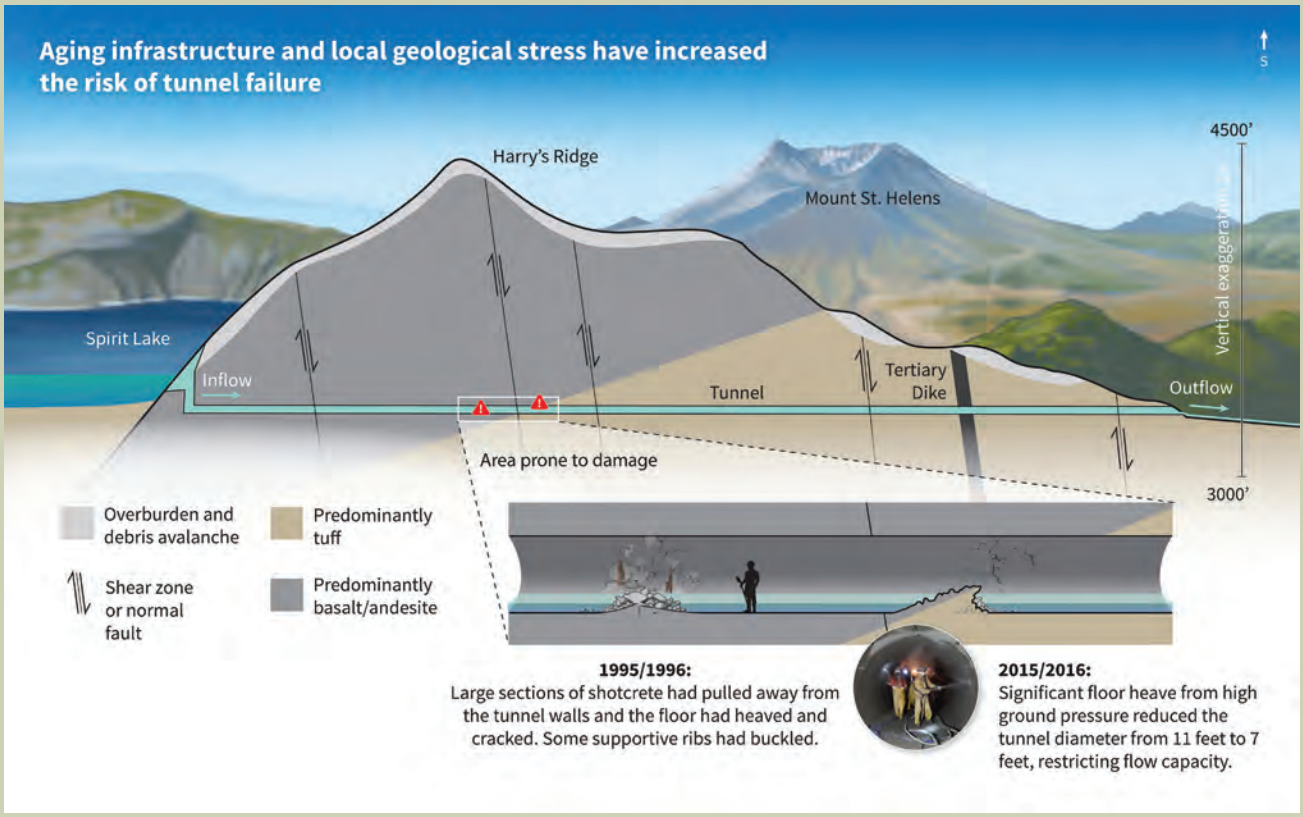
ecological systems science. The establishment of the monument protects and preserves different types of values, and at times management of this protected area must include decisions that balance impacts on public safety, geoheritage, biodiversity, and culture.

The 1980 eruption destroyed the summit of the volcano, sending large amounts of debris into the North Fork of the Toutle River and blocking the sole means of drainage from Spirit Lake. Rising lake levels could cause failure of the debris blockage, putting the downstream population of approximately 50,000 people at risk of catastrophic flooding and mudflows. Furthermore, continued transport of sediment to the river from volcanic debris deposits surrounding the mountain reduces the flood-carrying capacity of downstream river channels and leaves the human population vulnerable to chronic flooding. Spirit Lake is also the centerpiece of the national monument, a talisman of the landscape changes wrought by the 1980 eruption, and managing its outflow is an ongoing maintenance and safety concern whose engineering design and retrofit must be addressed.

Any major federal action conducted in this context draws focused attention and critical legal scrutiny. Engineering measures were implemented in the 1980s to manage both catastrophic and chronic risks associated with the debris blockage of Spirit Lake and sediment loads in the rivers. These included construction of a 1.56-mile tunnel at Spirit Lake to drain the lake and control lake levels. Engineering measures now in place, however, do not represent long-term solutions to the region's risk management challenges. Because the outflow tunnel serves as the only drainage for Spirit Lake, disruption of tunnel operations leaves the debris blockage vulnerable to breaching. The tunnel has required major repairs and is not operating optimally. Additional expensive repairs are necessary, and, as for any constructed facility, continued costly maintenance will be needed.

In 2014, Gifford Pinchot National Forest, a unit of the US Forest Service (USFS), commissioned the National Academies of Science, Engineering, and Medicine (NASEM) to develop *Decision Making Framework for Managing the Spirit Lake and Toutle River System*; a

Schematic representation of the outflow tunnel at Spirit Lake, with descriptions of engineering problems managers now face.



Mount St. Helens in 1982, showing the active volcano, a new lahar, and Spirit Lake (lower left). US GEOLOGICAL SURVEY / THOMAS CASADEVALL

multi-criteria decision-making approach was specified (NASEM 2018). In 2019, USFS commissioned the William D. Ruckelshaus Center of the University of Washington and Washington State University to develop a report titled *Situation Assessment for the Long-Term Management of the Spirit Lake/Toutle– Cowlitz River System* (Ruckelshaus Center 2019). The purpose was to engage a broad spectrum of stakeholders in order to identify and clarify key issues to be considered within a multi-criteria decision-making framework.

USFS is now implementing the guidance resulting from the situation assessment to engage stakeholders for the Spirit Lake Outflow Safety Improvement Project. The Spirit Lake outflow tunnel is a case of deferred maintenance that at present does not meet risk reduction goals. One of USFS's aims during the engagement process is to communicate to stakeholders the effects on resources of concern of different options in the situation assessment.

The Spirit Lake Outflow Safety Improvement Project will lead to decisions for the optimum long-term engineering solutions to be installed. In their assessment of the Spirit Lake and Toutle River System, NASEM (2018) clearly framed the need for multi-criteria decision-making:

> Given the uncertainties associated with potential moderate intensity and catastrophic events, as well as the analytic uncertainty associated with incomplete or outdated information, an analytic decision process that establishes risk management as an organizing principle is needed. But, given the competing values of interested and affected parties in the region; the lack of agreement on planning time frames; the overlapping but sometimes competing management responsibilities and authorities in the region; and the limited budgets of those authorities, that process needs to promote communication and trust among agencies and the public so that technical decisions effectively and satisfactorily incorporate the priorities of those interested and affected parties.

The NASEM 2018 report went on to outline a multi-criteria decision-making process designed to understand and act on public engagement. Planning and design about how to improve the safety, integrity, and function of the Spirit Lake outflow have been ongoing since 2014. During this planning period, the level of interest from stakeholders, and their varied goals, have indicated a need for mindful public participation.

USFS has also initiated an engineering study to assess the feasibility of safety improvement options that will provide information on the engagement and decision-making process and provide substantive content for outreach. Robust and credible review of the different options for addressing outflow from Spirit Lake is essential to support Gifford Pinchot National Forest managers in their evaluation of project options, as well as the required public outreach program.

The diverse interests and missions of stakeholders in a technically complex project such as this can create external challenges between the needs of USFS, the research community, downstream communities, and the broader group of stakeholders. Although it is not the responsibility of the outreach program to craft a solution, to be successful it must create an environment of dialogue and information exchange so that the multi-criteria decision-making process can be built on a comprehensive factual foundation.

MANAGEMENT RESPONSE TO KĪLAUEA VOLCANO ERUPTION OF 2018 AND 2020, HAWAIʻI VOLCANOES NATIONAL PARK, USA

Hawai'i Volcanoes National Park (HAVO) is located on the island of Hawai'i, the largest island of the Hawaiian archipelago. The park comprises more than 21 square miles and includes two historically active volcanoes, Kīlauea and Mauna Loa, within its boundaries. The area was designated a national park in 1916. Owing to its unique geological features and biodiversity, the park was further designated as a UNESCO biosphere reserve in 1980, and was inscribed on the World Heritage List in 1987 under criterion viii for its unique geological features.

Aerial view of lava flow invading housing subdivisions in the Lower East Rift Zone, Kīlauea volcano, Hawaiʻi, May 2018. US GEOLOGICAL SURVEY

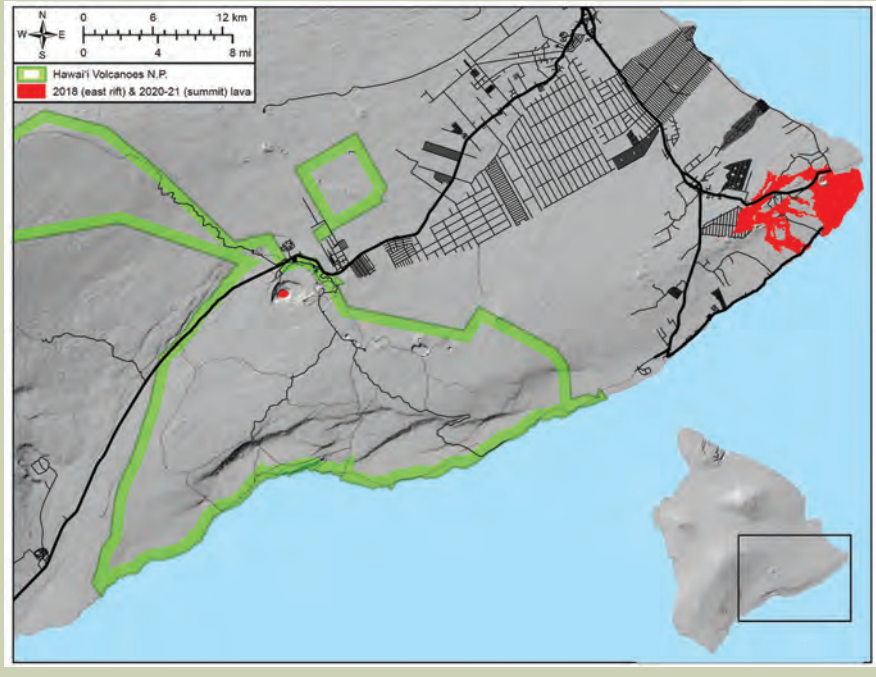
Since the start of 2018, HAVO managers have faced several unique and difficult challenges. These include the long-lived and especially dynamic 2018 eruption at both the summit and on the East Rift Zone of Kīlauea volcano, and the COVID-19 pandemic starting in March 2020.

Arguably both the principal attraction of HAVO and its main challenge to managing visitation is the ongoing volcanic eruption that began in January 1983. From 1983 through 2020, much of the newest lavas at Kīlauea were erupted outside the boundaries of HAVO and covered more than half of the middle and lower East Rift Zone of the volcano. Much of this land is held privately and is home to nearly half of the residents of Hawai'i County. Since the start of the current activity in 1983, HAVO park management has adapted to the challenges of managing visitation to the Kīlauea summit area and the adjacent upper East Rift Zone and the Southwest Rift Zone. The focus of these visitor management plans has been to safeguard visitor safety and to protect life and property.

The most wide-reaching management action taken by the National Park Service during the 2018 summit collapse activity was to institute a blanket closure order for the summit caldera and the upper reaches of the Southwest Rift Zone. This closure remains in effect at this time (October 2021). Visitors may still visit the Kīlauea Visitor Center and view the Kīlauea summit area from the Volcano House overlook, and access is still permitted to the Kīlauea Iki and Thurston Lava tube sites immediately east of the main summit caldera. The most notable sign of the impact of the 2018 eruption was a decline in visitation to the national park: in 2017, HAVO welcomed 2,016,702 visitors, while in 2018 there was a significantly reduced visitor count of 1,116,891.

A challenge for HAVO is that some of the more attractive eruption sites—such as the middle and lower East Rift Zone of Kīlauea volcano—lie outside the boundaries of the national park. Visitation to these areas, which lie closer to the main city of Hilo, is managed locally by officials from the state of Hawai'I, including the Department of Civil Defense. Guidance to visitors and residents of the East Rift Zone area is provided by the Hawai'i Department of Health, the Hawai'i County Civil Defense Agency, and local police jurisdictions. A variety of local tourism agencies, flight and boat charters, and other entrepreneurial outlets provide information to visitors. Such information varies in level of detail, timeliness on eruption activity, and the amount of care and caution needed when visiting sites of active lava flows and associated hazards such as toxic gas emissions, unstable ground, and dense tropical vegetation, which might all be unfamiliar to visitors.

Monitoring and management of Hawaiian volcanoes. The 2018 volcanic activity at Kīlauea included a series of large-scale collapses in the summit caldera centered on the Halema'uma'u pit crater, and on a series of more than 50 eruptive vents and associated fissures along the lower East Rift Zone (Neal et al. 2019). The only activity located within Hawai'i Volcanoes National Park was related to the summit collapse and production of a small volume of new lava. All of the eruptive vents and fissures were located outside



Map of Kīlauea volcano, Hawai'i, showing lavas produced in the 2018 and 2020–2021 eruptions (in red) and the boundaries of Hawai'i Volcanoes National Park (in green). Note that most of the eruptive activity is outside the park boundaries, and therefore not included in park management eruption response planning.
USGS HAWAIIAN VOLCANO OBSERVATORY / M. ZOELLER

of the national park on either private landholdings or state-managed lands. All collapse activity and eruptive activity at both the summit and in the lower East Rift Zone ended by August 2018.

The responsibility for monitoring the behavior of Hawaiian volcanoes lies with the Hawaiian Volcano Observatory (HVO), managed by the US Geological Survey. Since its establishment in 1911, HVO has a nearly continuous record of the behavior of Kīlauea and Mauna Loa volcanoes. Modern geophysical and geochemical monitoring of Hawai'i's volcanoes forms the backbone of the HVO effort. Consistent, timely, and accurate information—provided at public meetings in an understandable form, including reports and maps— ensures that managers have the information they need to make decisions about visitor access.

Until 2018, the main infrastructure and facility for HVO was located inside the park at Uēkahuna Bluff directly overlooking Kīlauea caldera and the Halema'uma'u pit crater. Kīlauea caldera includes the summit region of the volcano and forms the centerpiece of HAVO. When originally established, having HVO in close proximity to park staff was essential so that decisions could be made in a timely fashion when there were indications of a change in the behavior of Kīlauea or Mauna Loa volcanoes.

During the unprecedented geophysical activity at Kīlauea caldera in May and June of 2018, the main elements of the HVO infrastructure were damaged and deemed unfit for future use. In the fall of 2018, the decision was made by the National Park Service and the US Geological Survey to relocate the HVO operation and offices to Hilo, approximately 30 miles to the northeast from Kīlauea caldera. This relocation meant that for the first time in its 110-year history, scientists would no longer be making direct field observations from the edge of Kīlauea summit (Williams et al. 2020).

The responsibility for managing the response to volcanic activity within the boundaries of HAVO falls to the National Park Service. Typically such actions are made on a consultative basis with HVO and with state and local agencies. Outside of HAVO, eruptive vents and movement of lava flows may take place on private lands and lands managed by the state and/or Hawai'I County. In these instances, decisions about evacuation of people, management of road access, and decisions affecting businesses are often made in a consultative manner with scientists of HVO.

CONCLUSION

Drawing visitors to active or potentially active geophysical areas carries a responsibility to monitor volcanic activity and develop risk contingency plans as essential parts of the management process. The examples provided for managing hazards at Mount St. Helens National Volcanic Monument and Hawai'i Volcanoes National Park illustrate the benefits of transparent decision-making processes that seek to engage interested parties. Management decisions that restrict visitor access or have the potential to impair non-geological resources in the protected area will not get universal support, but the goal is to at least gain a generally accepted factual foundation upon which to make management decisions in a transparent manner.

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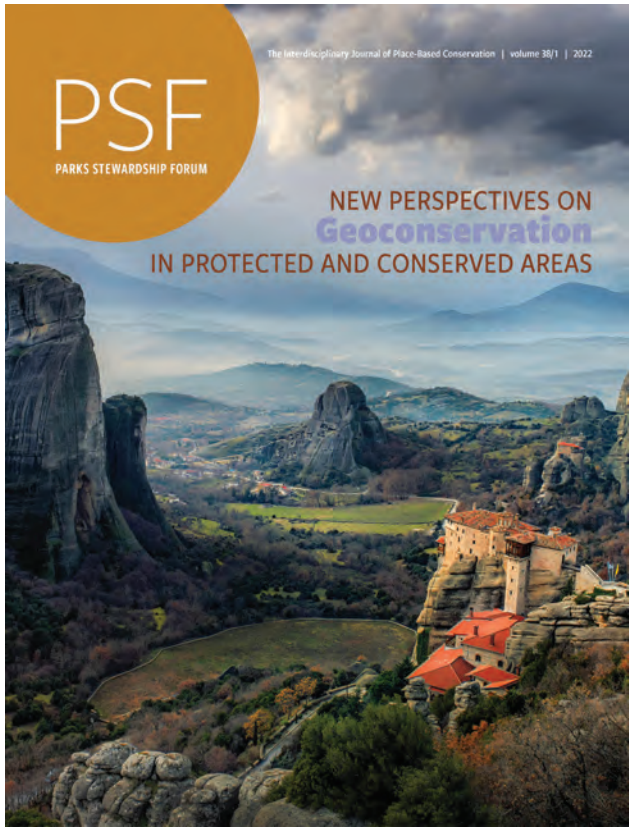

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