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Five-Year Management Plan for Establishing and Operating NVEWS: The National Volcano Early Warning System

Open-File Report 2021–1092

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

Cover. Mount Shasta, a very high threat volcano in northern California, looming over the town of Weed in the evening. Photograph by Mark Stensaas; used with permission.

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By Peter F. Cervelli, Charles W. Mandeville, Victoria F. Avery, and Aleeza M. Wilkins

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Abbreviations

ANILCA	Alaska National Interest Lands Conservation Act
ANSS	Advanced National Seismic System
ARRA	American Recovery and Reinvestment Act
AVO	Alaska Volcano Observatory
BLM	Bureau of Land Management
CalVO	California Volcano Observatory
CNMI	Commonwealth of the Northern Mariana Islands

CVO	Cascades Volcano Observatory
FAA	Federal Aviation Administration
FISMA	Federal Information Security Modernization Act of 2014
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GPS	global positioning system
HVO	Hawaiian Volcano Observatory
IMW	Intermountain West
IRIS	Incorporated Research Institutions for Seismology
IT	information technology
MOU	memorandum of understanding
NASA	National Aeronautics and Space Administration
NEIC	National Earthquake Information Center
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
NVDC	National Volcano Data Center
NVEWS	National Volcano Early Warning System
%	percent
R&D	research and development
RFP	request for proposals
UNAVCO	University NAVSTAR Consortium
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VHP	Volcano Hazards Program
VSC	Volcano Science Center
VWO	Volcano Watch Office

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Introduction

On March 12, 2019, Congress passed the John D. Dingell, Jr., Conservation, Management, and Recreation Act (Public Law 116–9; 133 Stat. 580; herein referred to as "the act"), in which Title V, §5001 (43 U.S.C. 31k) authorized the establishment of the National Volcano Early Warning and Monitoring System (NVEWS). Conceived by the U.S. Geological Survey (USGS) Volcano Hazards Program, NVEWS (herein also referred to as "the System") is designed to be a proactive, fully integrated national-scale volcano monitoring effort to ensure that volcanoes in the United States are monitored commensurate with the threat they pose. The act directed the Secretary of the Interior to submit to Congress a five-year management plan for establishing and operating the System, and stipulated that the plan include "(I) annual cost estimates for modernization activities and operation of the System; (II) annual milestones, standards, and performance goals; and (III) recommendations for, and progress towards, establishing new, or enhancing existing, partnerships to leverage resources" (43 U.S.C. 31k(b)(3)(A)(ii)). The first USGS NVEWS five-year management plan was presented to Congress on March 12, 2020. The core of this report is that plan, which details the principal elements of NVEWS. The objectives of the plan are to (1) build the components of NVEWS outlined in the act, (2) modernize and augment the monitoring networks on 34 of the Nation's most threatening volcanoes, (3) develop effective, low-cost methods to monitor the less threatening volcanoes at the level prescribed in the act, and (4) establish a long-term strategy for operating and maintaining the System. While the plan description below is presented in the indicative, the plan will be implemented as dedicated Congressional appropriations for NVEWS allow.

The foundation of NVEWS is the monitoring network, which consists of hundreds of instruments spread across regions of volcanic interest to measure, record, and transmit the imperceptible ground movements and other phenomena associated with volcanic unrest. The remaining components of NVEWS that are identified in the act are listed below.

- A National Volcano Data Center (NVDC), which will curate and distribute data collected by the volcano monitoring network and will be operational 24 hours per day, 7 days per week ("24/7"), incorporating a watch capability to monitor volcanic unrest.
- External grants that will fund NVEWS-related applied research and development through a competitive, proposal-driven process.
- An Advisory Committee, which will be established to assist the Secretary of the Interior in implementing NVEWS. The USGS Volcano Hazards Program (VHP) will work with the USGS Director and the Secretary to nominate and appoint representatives from the relevant Federal agencies listed in the act, as well as possibly other Federal agencies and the scientific community.
- The five USGS volcano observatories and their cooperative partners, which already compose a core component of NVEWS through previous national investments. A more formalized and permanent Implementation Committee will be initiated from this core component, and expanded through new partnerships, to establish NVEWS requirements, implementation steps, and performance standards of the System. The Implementation Committee will report to the USGS Volcano Science Center Director on requirements, progress, and challenges in NVEWS implementation. This committee will leverage resources where and when applicable, and oversee the long-term implementation, operation, and maintenance of the System.

Background and Strategy

The United States has 161 volcanoes within its borders that are considered potentially active (Venzke, 2013) in that they have had eruptive activity in the Holocene Epoch, defined by the International Commission on Stratigraphy as 11,650 calendar years before 1950, when precise geologic dating methods were developed (Walker and others, 2009). Twenty-nine of these erupted between 1980 and 2017, some repeatedly (table 1 in Ewert and others, 2018). Based on a 2018 USGS assessment (Ewert and others, 2018), 106 of these volcanoes pose at least a moderate threat. Volcanoes create

a wide range of destructive processes, including lava flows, ash falls, debris flows, toxic gases, and powerful explosions. Unlike earthquakes, eruptions of most well-monitored volcanoes can be forecast well before their occurrence, and their locations are well known beforehand. Advance warning allows for preparation, which often can mitigate the worst effects of an eruption. Timely and accurate eruption forecasts require high-quality ground-based monitoring data and expert scientific analysis and interpretation, both of which depend on solid and reliable infrastructure.

Over the last 35 years, the USGS has considerably improved its ability to monitor the Nation's threatening volcanoes. Notable advances were made in Alaska between 1996 and 2005, and nationwide between 2009 and 2011 using $15.2 million provided by the American Recovery and Reinvestment Act (ARRA). ARRA funds paid for a complete modernization of the seismic network of the Hawaiian Volcano Observatory (HVO), and for major improvements to the networks of the Alaska, Cascades, and Yellowstone Volcano Observatories. At present, however, a significant fraction of the Nation's volcano monitoring infrastructure is inadequate or obsolete. This leaves many communities and vital sectors of the economy vulnerable to the harmful effects of active volcanism.

In fiscal year (FY) 2018, the USGS VHP was appropriated $14.5 million in one-time infrastructure funds above baseline to complete 180 analog-to-digital station conversions in Alaska ($13.0 million) and to develop and install a next-generation lahar detection system ($1.5 million) in all the major drainages of Mount Rainier in Washington. Sixteen stations remain to be converted in Alaska through the FY2022 field season, and installation of the lahar detection system at Mount Rainier is expected to be completed by October 2025, barring delays in funding, permitting, and fieldwork. Moreover, new digital telemetry infrastructure is now in place on volcanoes in Alaska to accommodate the addition of multiple sensor types (global positioning system [GPS], web cameras, gas sensors, and infrasound sensors) required for bringing these networks up to NVEWS standards. The complete installation of the lahar detection system at Mount Rainier will significantly improve the monitoring network by widening the seismic aperture with arrays of digital broadband seismometers, infrasound sensors, and web cameras in all major drainages.

In 2005, the USGS published the results of a systematic study of the Nation's potentially active volcanoes in a report entitled "An assessment of volcanic threat and monitoring capabilities in the United States: Framework for a National Volcano Early Warning System" (USGS Open-File Report 2005–1164 [Ewert and others, 2005]). This assessment examined the eruption history and the range of possible hazards from each volcano, along with the approximate scope of impact to population and infrastructure should any of these hazards occur. Taken together and quantified, the hazards and their impact compose a volcano's overall threat score. Because our understanding of hazard and impact change over time, the threat score is a dynamic quantity subject to periodic update as new data become available. Indeed, any eruption of a volcano can immediately, if temporarily, raise its threat score, up to very high threat level if the volcano is close enough to population, aviation routes, and (or) critical infrastructure. In October 2018, the USGS published the revised version of the NVEWS threat assessment, which incorporated the latest scientific research, updated information on land use and demographics, and new data and observations from recent volcanic eruptions (USGS Scientific Investigations Report 2018–5140 [Ewert and others, 2018]).

The revised version of the NVEWS threat assessment provides objective criteria for establishing threat levels for each potentially active volcano. Using this methodology, the USGS has determined that the Nation's current volcano monitoring infrastructure at volcanoes posing at least a moderate threat is, in total, about 25 percent complete compared with the infrastructure recommended in the act. Our strategy for satisfying the requirements in the act is twofold. First, we plan a concerted, five-year effort to establish the components of NVEWS, while simultaneously deploying about 200 instruments at 34 of the Nation's most threatening volcanoes. Second, for moderate- and lower-threat volcanoes we recommend several approaches for achieving the monitoring standards proposed in the act, all of which have proved successful in the past. These are:

- Expanding existing partnerships with the USGS Earthquake Hazards Program's Advanced National Seismic System (ANSS) and with the National Earthquake Information Center (NEIC) and its university- and State-run regional affiliate seismic networks, which will be supported by long-term cooperative agreements for operating monitoring networks around lower-threat and isolated volcanoes.
- Collaborating with researchers funded by the National Science Foundation (NSF) or other external sources.
- Working with other Federal agencies that operate in remote, volcanically active regions, either by sharing costs or by entering into fee-for-service relationships.
- Partnering with industry through cooperative research and development agreements to create new volcano monitoring technology and strategies.
- Leveraging new remote sensing capabilities and other emerging technologies to complement sparse ground-based instrumentation.

Constraints, including short field seasons in Alaska and the Pacific Northwest, complex permitting processes, and weather contingencies, will likely preclude the USGS from fully implementing NVEWS as outlined in the act within five years. Consequently, many volcanoes will still remain under-monitored at the end of the first five-year implementation period. In the interim, the USGS will establish and maintain a dedicated cache of rapidly deployable monitoring instruments

in the event of unrest at under-monitored volcanoes. This rapid-response strategy will be an interim measure destined to be replaced by longer-term NVEWS monitoring infrastructure. The USGS VHP has scientifically sound, long-term plans for improving monitoring networks on moderate-threat volcanoes. Moreover, there will be opportunities to do instrument installations on moderate-threat volcanoes, which serves the dual purpose of improving the ANSS network locally and also making the regional volcano monitoring networks more resilient while eliminating single points of failure.

Prioritization

Several factors will influence the pace and sequence of NVEWS implementation, including volcano threat score, existing monitoring levels, current volcanic activity, logistical constraints (including COVID-19 pandemic safety measures), public interest, funding availability, and land use regulations. Because some of these factors are outside of USGS control, our approach to NVEWS implementation will have to be flexible and opportunistic, allowing us to take advantage of favorable conditions as they arise. NVEWS implementation plans should therefore be regarded as blueprints, not timetables.

Of the 106 volcanoes that pose at least a moderate threat, 53 lie entirely or partly within wilderness areas operated by the Bureau of Land Management (BLM), the U.S. Forest Service (USFS), the U.S. Fish and Wildlife Service (FWS), and the National Park Service (NPS). Notable among these are many of the very high threat volcanoes of the Pacific Northwest, including Glacier Peak, Mount Rainier, and Mount Baker in Washington, Mount Hood and Three Sisters in Oregon, and Mount Shasta in California. Acquiring permits to install and operate volcano monitoring instruments in wilderness areas near active volcanos is costly and time consuming, and the outcome can be uncertain. Legal questions from citizen groups concerning activities in wilderness areas are also on the rise. Because of these uncertainties, it is difficult to predict when (or if) volcanoes within wilderness areas will have monitoring levels commensurate with those outlined in the act. Nevertheless, the USGS has developed scientifically sound plans for making improvements to monitoring networks in these areas. The USGS Volcano Hazards Program will ensure effective engagement with the above-named agencies through ongoing partnerships. Because of provisions in the Alaska National Interest Lands Conservation Act (ANILCA), permitting of instrumentation on volcanoes in wilderness areas in Alaska to forecast eruptions and warn of hazards is less challenging.

System Components

Monitoring Network

The buildout and modernization of the instrumentation network will involve the installation of about 200 new or refurbished stations distributed over the 34 active and most threatening volcanoes (table 1). Most existing monitoring stations have only a seismometer, as they were established in the 1980s and 1990s when this was the most practical monitoring system. Because of new wireless technology and significant reductions in instrument power consumption, most of the new installations will be multiparametric. That is, they will contain several instrument types, including seismometers, GPS receivers, infrasound sensors, gas sensors, and cameras sensitive to both visual and nonvisual wavelengths. Multiparametric stations can detect and characterize a broad range of volcanic phenomena, which leads to more timely and accurate eruption forecasts. They also make good economic sense, because the utility of additional instruments greatly exceeds the marginal cost increase of their installation.

Following the buildout and modernization, the volcano monitoring network will generate about 1 terabyte of data per day. Moving this volume of data from the point of origin (the volcanoes) to the point of analysis (the observatories) will require a robust and reliable data telemetry system spanning an area three times larger than the continental United States (fig. 1). Data security is a fundamental design constraint, and the completed telemetry system will be required to comply with all applicable Federal Information Security Modernization Act of 2014 (FISMA) and National Telecommunications and Information Administration (NTIA) regulations and authorizations for use of radio frequency spectrum allocations and standards.

Table 1. List of the 34 volcanoes that will be prioritized for additional monitoring infrastructure during the first five years of implementation of the National Volcano Early Warning System (NVEWS). The threat score is derived by quantifying each volcano's unique hazards and impact to population and infrastructure.

[Colors correspond to the very high (red) and high (orange) threat categories as defined by the 2005 and 2018 threat assessments (Ewert and others [2005, 2018]). At present, the volcanoes in the Commonwealth of the Northern Mariana Islands (CNMI) lie within the Alaska Volcano Observatory's area of responsibility. Volcano observatory abbreviations: AVO, Alaska Volcano Observatory; CalVO, California Volcano Observatory; CVO, Cascades Volcano Observatory; HVO, Hawaiian Volcano Observatory]

Name	Location	State	Volcano Observatory	Threat Score
Very High Threat				
Kilauea	Hawaii	HI	HVO	263
Mount St. Helens	Washington	WA	CVO	235
Mount Rainier	Washington	WA	CVO	203
Redoubt Volcano	Cook Inlet	AK	AVO	201
Mount Shasta	Northern California	CA	CalVO	178
Mount Hood	Oregon	OR	CVO	178
Three Sisters	Oregon	OR	CVO	165
Akutan Island	Aleutian Islands	AK	AVO	161
Makushin Volcano	Aleutian Islands	AK	AVO	161
Mount Spurr	Cook Inlet	AK	AVO	160
Lassen Volcanic Center	Northern California	CA	CalVO	153
Augustine Volcano	Cook Inlet	AK	AVO	151
Newberry Volcano	Oregon	OR	CVO	146
Mount Baker	Washington	WA	CVO	139
Glacier Peak	Washington	WA	CVO	135
Mauna Loa	Hawaii	HI	HVO	131
Crater Lake	Oregon	OR	CVO	129
High Threat				
Mount Okmok	Aleutian Islands	AK	AVO	117
Iliamna Volcano	Cook Inlet	AK	AVO	115
Aniakchak Crater	Alaska Peninsula	AK	AVO	112
Hualalai	Hawaii	HI	HVO	109
Mount Katmai	Alaska Peninsula	AK	AVO	106
Mount Veniaminof	Alaska Peninsula	AK	AVO	102
Korovin Volcano	Aleutian Islands	AK	AVO	102
Clear Lake Volcanic Field	Northern California	CA	CalVO	92
Mount Adams	Washington	WA	CVO	92
Hayes Volcano	Cook Inlet	AK	AVO	90
Mount Churchill	Eastern Alaska	AK	AVO	82
Kanaga Volcano	Aleutian Islands	AK	AVO	81
Kaguyak Crater	Alaska Peninsula	AK	AVO	79
Pagan Island	Northern Mariana Islands	CNMI	AVO	79
Kasatochi Island	Aleutian Islands	AK	AVO	75
Mount Moffett	Aleutian Islands	AK	AVO	73
Seguam Island	Aleutian Islands	AK	AVO	73

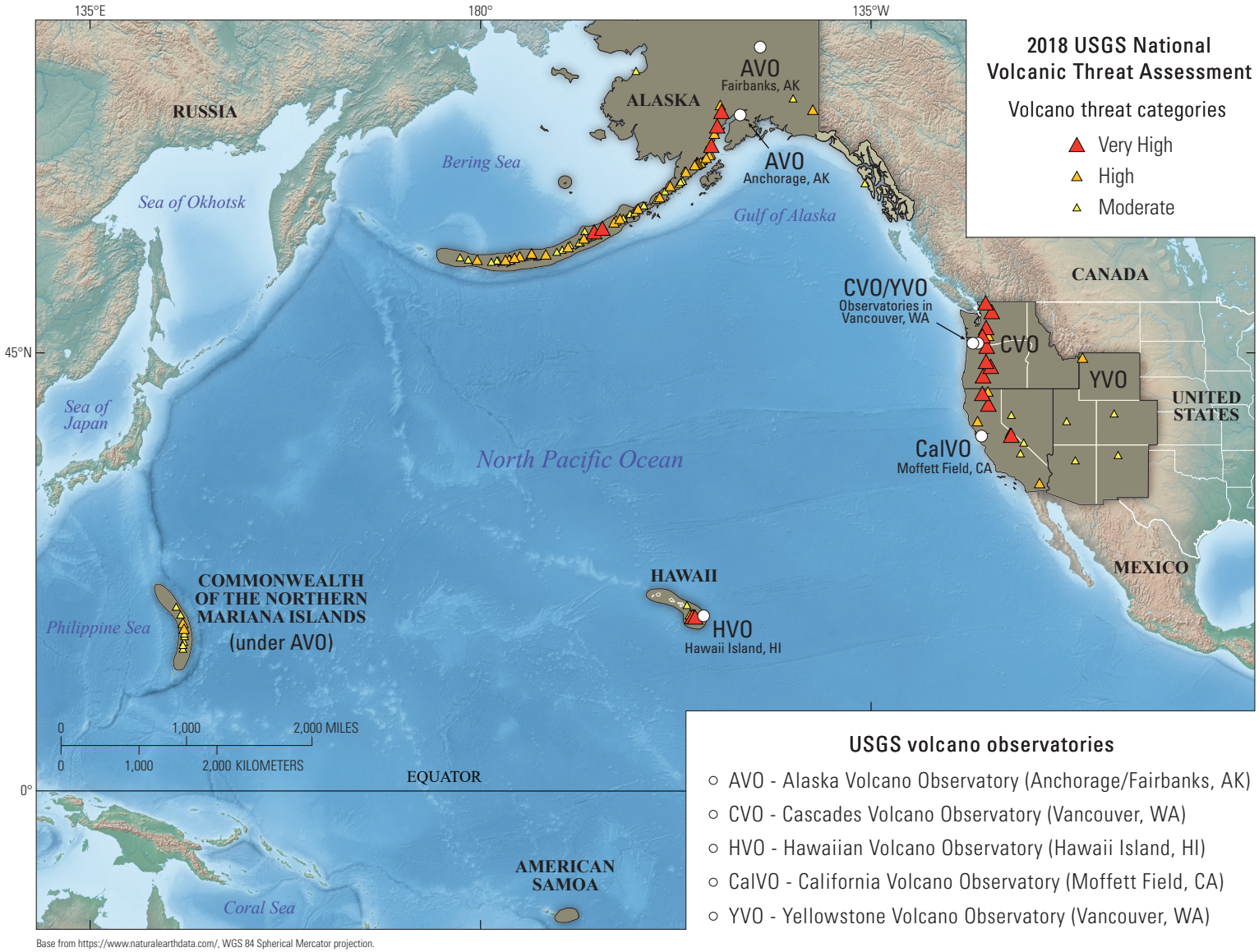

Figure 1. Map of the 106 NVEWS volcanoes in the United States that pose at least a moderate threat according to categories defined by the 2018 volcano threat assessment (Ewert and others, 2018). Volcanoes in the low and very low threat categories are not shown.

National Volcano Data Center (including a "watch office" capability)

In addition to the dedicated infrastructure described above, a variety of other sources create data that will be useful for volcano monitoring at the proposed National Volcano Data Center (NVDC). Among these are satellites operated by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) (including the NISAR mission scheduled for launch in 2022; see https://nisar.jpl.nasa.gov), geospatial imagery from commercial and government sources, university-operated lightning detection networks, and NSF-funded projects such as the EarthScope Transportable Array and successors. The proposed NVDC can (1) facilitate prompt analysis and interpretation as well as curation and long-term storage of all volcano data recorded by the USGS and partners assisting with volcano monitoring in the United States, and (2) provide a centralized mechanism by which USGS partners, academic colleagues, and the public can more easily access and use the data.

Owing to the continued rapid pace in the development of information science and technology, machine learning, and tools for remote team collaboration, we propose to merge the activities of the USGS Volcano Watch Office as described in the act into the NVDC. Operating a 24/7 watch schedule requires ready access to incoming monitoring data along with a set of standardized software tools created specifically for the real-time analysis of signals indicative of volcanic hazards. NVDC computer scientists will develop these tools side-by-side with the analysts who use them. In our judgment, incorporating the volcano watch component of NVEWS into the NVDC will both lower costs and improve the overall effectiveness of the NVDC.

The main functions of the NVDC will be to partner with existing USGS volcano observatories to:

- Build and operate a unified system that collects, aggregates, stores, and distributes all incoming data, which will be made accessible to all observatory staff, partner agency scientists, and the public.
- Create and track internal alarm systems that integrate disparate data streams from all sensor types.
- Develop software tools for monitoring, visualizing, and analyzing volcano monitoring data.
- Monitor incoming data streams 24/7 for anomalous volcanic activity.
- Report anomalies to the appropriate USGS volcano observatory, which will retain the authority to issue public warnings of volcanic activity through its messaging and through partner agencies such as NOAA's National Weather Service, the Federal Aviation Administration (FAA), and the U.S. Air Force's 557th Weather Wing.
- Track system state of health by documenting data flow rates and signal quality over time.
- Provide general assistance to the USGS volcano observatories as needed.
- Maintain and improve methods of product generation, standardization, and distribution.

The NVDC will also curate, archive, and serve all data created by the VHP through a commercial cloud-based service or via dedicated, NSF-supported facilities. Data will be managed and made available to the public according to the standards and best practices recommended by the Federal Chief Information Officer of the United States. Current archiving of geodetic and seismic data through the University NAVSTAR Consortium (UNAVCO) and the Incorporated Research Institutions for Seismology (IRIS), respectively, will continue.

Many of the challenges and goals of the NVDC are the same as or similar to those of the NEIC, located in Golden, Colorado. Although volcano and earthquake monitoring are fundamentally different and constitute two distinct elements of the public safety mission of the USGS, they have enough in common for the NVDC to leverage the facilities and expertise already present at the NEIC to speed development and avoid duplication of effort.

External Grants

To make the most from the NVEWS data, the USGS will launch an external grants competition that will promote applied research and development across an assortment of topics, ranging from volcanic processes to instrument design and emerging technologies. Using the longstanding and successful USGS Earthquake Hazards Program external research support component as a model, the NVEWS equivalent will be widely inclusive, inviting proposals from academia; nonprofit organizations; State and local agencies; unaffiliated scientists; scientists in underrepresented groups in science, technology, engineering, and mathematics (STEM) fields; and international organizations. Awards will be distributed based on recommendations from independent review panels drawn from this same community.

NVEWS grants could go into effect during the third year of implementation of the five-year management plan after planning activities conclude in year 2, provided that funding availability is sufficient to justify the grant activity's operational costs. On the basis of existing USGS grants systems, we estimate that the minimum level of funding for an established grants activity is about $500,000 per year above current program baseline funding enacted by Congress (~$30.266 million).

External Representation and Governance

Advisory Committee

The act (Section (3)(B)) directs the Secretary of the Interior to create a high-level advisory committee (NVEWSAC) to assist with the implementation and operation of NVEWS. The members will be appointed by the Secretary and will include of heads of Federal agencies (or their designees) named in the act: Department of Transportation, FAA, NOAA, and the Federal Emergency Management Agency. Representatives of other relevant Federal agencies, such as NSF, NASA, and the National Institute of Standards and Technology, as well as industry and the scientific community, will also be considered for membership. The committee's purview will be to assist the Secretary with implementation of the System and to provide constructive comment and vetting of NVEWS implementation plans as developed by the USGS and its partners. The advisory committee will submit an annual report to the Director of the USGS that describes its activities and makes recommendations on policy issues and other matters that affect NVEWS operations.

Implementation Committee

The USGS Volcano Science Center will assemble a permanent Implementation Committee composed of partners either directly involved in NVEWS operations or otherwise involved in operations essential to the success of NVEWS. Members will be selected from the scientific community and industry, and from among land managers and emergency responders at the Federal and State levels. The committee's scope will include the respective roles and responsibilities of the committee members, as follows: data acquisition and analysis, dissemination of volcano hazard information products such as alerts and warnings, emergency response to eruptions, and the development of plans for access to Federal lands for the installation and maintenance of volcano monitoring instruments. Within these disciplines, the Implementation Committee will form working groups composed of subject-matter experts external to the committee to optimize design of the System. Working-group membership will include staff from the five USGS volcano observatories and their cooperative partners that already compose a significant core component of NVEWS, as well as new partnerships or enhanced existing partnerships with academia, industry, and State and Federal agencies as needed. The committee will suggest topics for external grant proposal solicitations and internal VHP activities. The Implementation Committee will inform the long-term implementation, operation, and maintenance of the System and will prepare annual reports to the Volcano Science Center Director on progress and challenges to NVEWS implementation.

Cooperative agreements can also be implemented in later phases of NVEWS implementation to improve monitoring of moderate- and low-threat volcanoes. An excellent example of this is a group of potential cooperators within the Intermountain West (IMW), defined here as the area comprising the States of Arizona, Colorado, Idaho, Nevada, New Mexico, Utah, and Wyoming. This region is home to more than a dozen potentially active volcanoes, including four that have erupted within the last 1,000 years. Apart from Yellowstone, none of the IMW volcanoes currently has a dedicated monitoring network. However, a variety of State agencies and universities operate seismometers and other instruments close enough to IMW volcanoes to be useful for detecting the kinds of anomalous activity that typically precede volcanic eruptions. Establishing cooperative agreements with some or all of these agencies and universities in later phases of NVEWS implementation can satisfy NVEWS monitoring requirements, while also leveraging and saving resources and expanding the geographic scope of the ANSS/NEIC.

Annual Cost Estimates

Based on the parameters in the NVEWS authorization, we have developed cost estimates with two primary goals in mind: (1) to improve the Nation's volcano monitoring at 34 prioritized volcanoes to the level outlined in the act, and (2) to build the NVEWS components outlined in the act. We have also emphasized partnerships, both internal and external, to leverage NVEWS resources. The plan below (table 2) represents our best effort to implement NVEWS on prioritized volcanoes over a five-year interval, given the potential constraints mentioned above.

Annual Milestones

The management section of the act directs the VHP to develop "annual milestones, standards, and performance goals." Table 3 summarizes a possible sequence of milestones, that is, distinct, significant achievements toward meeting the requirements of the act. The milestones assume funding of about $11 million per year.

Table 2. Five-year plan for NVEWS implementation.

[Figures are in thousands of 2019 dollars as they appear in the Congressional Report. The U.S. Geological Survey will invest approximately $24 million in permanent volcano monitoring infrastructure. Once built, NVEWS will require an annual operations and maintenance expenditure of about $11.4 million above the current level. Note that operations and maintenance costs of new monitoring stations (Instruments and Telemetry row) increase steadily from year to year as more stations are installed. However, the new stations should not require maintenance for several years after their installation—hence the difference between the instruments and telemetry operations and maintenance costs in the Totals and Recurring columns. Abbreviation: —, no applicable costs]

	Cost Category	Year 1	Year 2	Year 3	Year 4	Year 5	Totals	Recurring
Capital Investment	Network Installation	$4,200	$6,300	$5,250	$3,150	$2,100	$21,000	—
	Station Permits	$390	$390	$330	$130	$70	$1,310	—
	Emergency Equipment Cache	$1,750	—	—	—	—	$1,750	—
Operations and Maintenance	Instruments and Telemetry	$1,326	$2,164	$2,806	$4,486	$5,286	$16,066	$7,086
	Data Center/Watch Office	$1,215	$1,857	$2,055	$3,025	$3,025	$11,175	$3,025
	External Data	$150	$150	$150	$150	$150	$750	$150
Coordination and Partners	Research Grants	$150	$300	$500	$750	$1,000	$2,700	$1,000
	Committee Activities	$20	$30	$50	$60	$80	$240	$170
Totals	Capital Investment:	$6,340	$6,690	$5,580	$3,280	$2,170	$24,060	—
	Operations and Maintenance:	$2,690	$4,170	$5,010	$7,660	$8,460	$27,990	$10,260
	Coordination and Partners:	$170	$330	$550	$810	$1,080	$2,940	$1,170
		Yearly Totals					Five Year Total	Annual Costs
		$9,200	$11,190	$11,140	$11,750	$11,710	$54,990	$11,430

Table 3. Possible milestones for the first five years of implementation of the National Volcano Early Warning System (NVEWS) at a funding level of about $11 million per year. First section (Current Program Status) shows activities performed out of current program base funding.

[VSC, Volcano Science Center; NVDC/VWO, National Volcano Data Center/Volcano Watch Office; MOU, memorandum of understanding; R&D, research and development; IT, information technology; 8/5, 8 hours per day, 5 days per week; RFP, request for proposals; 12/7, 12 hours per day, 7 days per week; VHP, Volcano Hazards Program; 24/7, 24 hours per day, 7 days per week; USGS, U.S. Geological Survey]

Network	Committees / Partnerships	System Components
Current Program Status		
Modernize and maintain existing single-parameter and multiparameter sites as baseline resources allow. Identify sites for future expansion at prioritized, undermonitored volcanoes. Plan to acquire permits necessary for site expansion. Continue working toward completion of buildout of Mount Rainier lahar detection system.	Maintain existing cooperative agreements as needed and beneficial for leveraging resources. Hold periodic meetings to discuss current state of VSC monitoring network and identify priorities for modernization. Continue participation in interagency working groups. Continue partnerships with academia and others to support program goals.	Develop generalized framework for NVDC/VWO. Meet with representatives from the Office of the Associate Chief Information Officer familiar with cloud-hosted data storage and computational environments to discuss requirements (security, latency, capacity) and system design. Refine NVEWS instrumentation plan.
Year 1—25 percent complete		
Begin hiring the operational staff necessary to augment and maintain the growing network. Upgrade instrumentation and add new components to existing single-parameter sites. Hire permitting specialists and estimate likely permit latencies. Focus on improvements to the networks of the most accessible volcanoes.	Hold workshops to establish the scope, responsibilities, and means of governance for the Advisory Committee and Implementation Committee. Review existing cooperative agreements and MOUs for expansion opportunities (for example, university networks for monitoring Intermountain West volcanoes).	Develop position descriptions for the Director of the NVDC/VWO and the manager of the Grants Program. Recruit and hire appropriate personnel. Identify the required facilities and resources for the NVDC/VWO and Grants Program and begin the procurement and acquisition process.
Year 2—55 percent complete		
Finish design of a secure, digital telemetry system capable of handling the data throughput required by NVEWS. Focus on high-threat volcanoes having the lowest levels of monitoring (for example, Hualalai, Adams, Seguam Island).	The Advisory Committee and Implementation Committee have begun forming; membership of Advisory Committee is under consideration. Implementation Committee is working to modernize and update existing interagency agreements to reflect the results of NVEWS network augmentation.	Stand up the NVDC/VWO, starting with real-time data. Begin hiring and training development personnel and watch office personnel. Solicit input from academic and R&D communities to define the scope and topics of the Grants Program.
Year 3—75 percent complete		
Most field engineers and IT specialists have been hired. Digital telemetry system is mostly complete. Focus on completing very high threat volcanoes (for example, Lassen Volcanic Center, Redoubt, Makushin, Mauna Loa) and other targets of opportunity.	Meetings to establish and define standards and expected performance levels have been held or are underway. MOUs and cooperative agreements are up to date; Advisory Committee and Implementation Committee charters are complete and their annual or periodic products are defined.	NVDC/VWO is operating 8/5 and software development has begun. NVDC schema design is well underway, and a variety of real-time datasets are coming in. Grants Program is running a pilot RFP focused on data and findings from newly installed instrumentation.

Table 3. Possible milestones for the first five years of implementation of the National Volcano Early Warning System (NVEWS) at a funding level of about $11 million per year. First section (Current Program Status) shows activities performed out of current program base funding.—Continued

[VSC, Volcano Science Center; NVDC/VWO, National Volcano Data Center/Volcano Watch Office; MOU, memorandum of understanding; R&D, research and development; IT, information technology; 8/5, 8 hours per day, 5 days per week; RFP, request for proposals; 12/7, 12 hours per day, 7 days per week; VHP, Volcano Hazards Program; 24/7, 24 hours per day, 7 days per week; USGS, U.S. Geological Survey]

Network	Committees / Partnerships	System Components
Year 4—90 percent complete		
Operational staff hiring is nearly complete. Digital telemetry system is fully operational. Focus on difficult-to-permit volcanoes like Glacier Peak, Three Sisters, Mount Shasta.	Proposed standards and performance levels are in external review. Interagency agreements are up to date; Advisory Committee and Implementation Committee evaluate progress so far and make recommendations for remaining work.	NVDC/VWO is almost fully staffed and is operating watches 12/7; most VHP and partner data are coming in. Grants Program begins first year of full operation with continued focus on the growing network.
Year 5—100 percent complete		
All operational staff are on board. Maintenance cycles for Year 1 have begun. Focus on remaining volcanoes and re-engineering of poorly performing stations and (or) telemetry links.	Standards and performance levels are published in the Journal of Research of the National Institute of Standards and Technology (or similar publication) and are officially in effect. Advisory Committee and Implementation Committee are holding regularly scheduled meetings and issuing annual reports.	NVDC/VWO is operating 24/7; watch capabilities are largely operating with NVDC-designed software. NVDC is working with USGS toward integration of volcano data into general systems.

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