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An Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System

NVEWS

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Cover photo: Mount St. Helens, Washington, reawakens on October 1, 2004. USGS photo.

EXECUTIVE SUMMARY

NVEWS – a **National Volcano Early Warning System –** is being formulated by the Consortium of U.S. Volcano Observatories (CUSVO) to establish a proactive, fully integrated, national-scale monitoring effort that ensures the most threatening volcanoes in the United States are properly monitored in advance of the onset of unrest and at levels commensurate with the threats posed. Volcanic threat is the combination of hazards (the destructive natural phenomena produced by a volcano) and exposure (people and property at risk from the hazards).

The United States has abundant volcanoes, and over the past 25 years the Nation has experienced a diverse range of the destructive phenomena that volcanoes can produce. Hazardous volcanic activity will continue to occur, and – because of increasing population, increasing development, and expanding national and international air traffic over volcanic regions – the exposure of human life and enterprise to volcano hazards is increasing. Fortunately, volcanoes exhibit precursory unrest that if detected and analyzed in time allows eruptions to be anticipated and communities at risk to be forewarned with reliable information in sufficient time to implement response plans and mitigation measures.

In the 25 years since the cataclysmic eruption of Mount St. Helens, scientific and technological advances in volcanology have been used to develop and test models of volcanic behavior and to make reliable forecasts of expected activity a reality. Until now, these technologies and methods have been applied on an ad hoc basis to volcanoes showing signs of activity. However, waiting to deploy a robust, modern monitoring effort until a hazardous volcano awakens and an unrest crisis begins is socially and scientifically unsatisfactory because it forces scientists, civil authorities, citizens, and businesses into "playing catch up" with the volcano, trying to get instruments and civil-defense measures in place before the unrest escalates and the situation worsens. Inevitably, this manner of response results in our missing crucial early stages of the volcanic unrest and hampers our ability to accurately forecast events. Restless volcanoes do not always progress to eruption; nevertheless, monitoring is necessary in such cases to minimize either over-reacting, which costs money, or under-reacting, which may cost lives.

Volcano monitoring in the U.S. is conducted by five volcano observatories, supported primarily by the USGS Volcano Hazards Program. Under the Stafford Act, the USGS is responsible for issuing timely warnings of potential volcanic disasters to the affected populace and civil authorities. To make maximum use of the Nation's scientific resources, the USGS operates the observatories with the help of universities and other governmental agencies, through formal partnerships. At present, about half of the most threatening U.S. volcanoes are monitored at a basic level with real-time sensors (primarily seismic arrays), and a few are well monitored with a suite of modern instrument types and methods. However, monitoring capabilities at many hazardous volcanoes are known to be sparse or antiquated, and some hazardous volcanoes have no ground-based monitoring whatsoever.

Recognizing that there are potentially dangerous volcanoes within the United States and its Territories that have inadequate or no ground-based monitoring, the USGS Volcano Hazards Program, with CUSVO, is preparing a plan for a **National Volcano Early Warning System (NVEWS).** NVEWS is based on a systematic assessment of various hazard and exposure (risk) factors that are used to calculate a threat score for each U.S. volcano. The resultant scores permit a relative ranking of U.S. volcanoes into five threat groups from very high to very low. (The threat scores presented in this report are subject to change as new data on past eruptive activity appear and/or as unrest develops and exposure factors change.) The level of monitoring called for by the threat assessment is compared to the current monitoring coverage at each volcano to identify those volcanoes with significant monitoring gaps that require improvements. The improvements should be implemented well in advance of the escalation of unrest with the aim of providing early detection of unrest and reliable forecasting of likely hazards.

Based on the NVEWS analysis and volcanic activity as of April 2005, the highest priority targets for monitoring improvements are:

- *5 volcanoes that currently are erupting (Mount St. Helens in Washington, Anatahan in the Mariana Islands, Kilauea in Hawaii) or exhibiting precursory unrest (Mauna Loa in Hawaii, Mount Spurr in Alaska*).
- *13 very-high-threat volcanoes with inadequate monitoring (9 in the Cascade Range and 4 in Alaska).*
- *19 volcanoes in Alaska and the Mariana Islands that have high aviation-threat scores and <u>no</u> real-time ground-based monitoring to detect precursory unrest or eruption onset.*

An additional 21 under-monitored volcanoes in Washington, Oregon, California, Hawaii, Alaska, the CNMI, and Wyoming also are priority NVEWS targets. The physical aspects of NVEWS involve installation of modern instrumentation arrays with data links to the volcano observatories and facilities of the CUSVO partners. Monitoring improvements at these volcanoes would entail new capital costs for equipment as well as recurring expenses for operation and maintenance and take several years to implement, requiring a substantial investment beyond the current resources of the USGS Volcano Hazards Program and its affiliated partners.

Along with enhancing instrumentation capabilities, NVEWS proposes to institute a National 24x7 Volcano Watch Office to improve alerting and forecasting capabilities and provide authoritative information on volcanic activity. Duties at the Watch Office would be shared among all the observatories in a distributed fashion. Implementing NVEWS and a National Volcano Watch Office will require significant investment in IT hardware and software to handle continuous archiving and sharing of data from monitoring networks. The IT system would increase inter-operability among observatories and permit all data streams from monitored volcanoes to be accessed in real time at multiple locations.

A fully implemented NVEWS, when combined with current monitoring capabilities, will provide:

- A much richer body of observations and data on volcanic activity, as the basis for more reliable eruption forecasts and a range of derived information products from real-time graphical and map depictions of data to peer-reviewed research papers.
- Minimized risk of a surprise eruption at a dangerous volcano.
- Real-time hazard analysis and rapid event notification during periods of escalating unrest and eruption at well-monitored volcanoes, aiming for 5-minute notification by volcano observatories to the FAA of major explosive eruptions.
- The hardware, software, and networking infrastructure to enable scientists to view and analyze all data streams from monitored volcanoes in real time at multiple locations.
- A National 24X7 Volcano Watch Office for full alerting capabilities and authoritative information about unrest and eruptive activity throughout the U.S. and more general situational awareness of volcanic activity globally.
- A National Volcano Data Center to archive all the diverse kinds of NVEWS data.
- An NVEWS web site with a daily status report covering all monitored volcanoes.
- Efficient coordination of volcano-monitoring resources across agencies and institutions.

As a next step, the USGS Volcano Hazards Program will convene workshops to review and refine the proposed implementation framework. A workshop will be held with the full CUSVO membership and other scientific stakeholders to establish data and operational policies and launch topical working groups. At another workshop, a broader group including other Federal agencies, State and County emergency management agencies, and business and private organizations, will be consulted about their specific information requirements.

> One ought never to turn one's back on a threatened danger and try to run away from it. If you do that, you will double the danger. But if you meet it promptly and without flinching, you will reduce the danger by half.
>
> *Sir Winston Churchill*

INTRODUCTION

This report presents an assessment of the Nation's volcano monitoring needs based on the threats posed by the 169 geologically active U.S. volcanic centers listed in the global volcanism database of the Smithsonian Institution (Simkin and Siebert, 1994). In the past, the Volcano Hazards Program has measured its progress in volcano monitoring and hazard assessment against an estimate of 70 volcanoes that represent significant hazards to people and property. Results of this report constitute a major improvement to that earlier estimate by providing a comprehensive analysis of all U.S. volcanoes and determining the appropriate level of monitoring based on a systematic measure of the threats posed to lives and property. Although the total number of volcanoes representing the most significant hazards remains similar to the earlier estimate, this report identifies critical gaps in the Nation's monitoring capability that should be used as a basis for charting the course and measuring the performance of the Volcano Hazards Program.

Volcanoes produce many kinds of destructive phenomena. In the U.S. over the past 25 years, communities have been invaded by lava flows, a powerful explosion has devastated huge tracts of forest and killed people miles from the volcanic source, debris avalanches and mudflows have choked major river ways, destroyed bridges, and swept people to their deaths, noxious gas emissions have given rise to widespread lung ailments, airborne ash clouds have caused hundreds of millions of dollars of damage to aircraft and nearly brought down passengers jets in flight, and ash falls have disrupted the lives and businesses of hundreds of thousands of people. The growing potential for such severe threats to communities, property, and infrastructure down stream and down wind of volcanoes drives the need to decipher the past eruptive behavior, monitor the current activity, and mitigate the damaging effects of these forces of nature.

Volcanic eruptions can be anticipated in time to take preparatory actions. Unlike most other natural hazards, eruptions herald their coming over periods of days to years with various physical and chemical indicators (called "unrest") related to the rise of magma toward the surface of the Earth. Modern instrumentation and data-processing techniques, combined with an understanding of the previous eruptive activity of a volcano, provide a means to monitor and interpret precursory signals – seismicity, ground deformation, gaseous emissions, thermal changes, and hydrothermal flux – and make forecasts of the expected hazards. Moreover, because the locations of volcanoes are known, the sources of the hazardous events can be anticipated well ahead of time.

If a hazardous volcano is properly monitored with a diverse suite of instruments and methods *in advance of the onset of unrest*, it is possible to forewarn communities at risk of an impending eruption with reliable information and in sufficient time to implement specific response plans and mitigation measures. Waiting to deploy a proper monitoring effort until a hazardous volcano awakens and an unrest crisis begins means that scientists, civil authorities, businesses, and citizens are caught in a reactive mode of "playing catch up" with the volcano, trying to get instruments and civil-defense measures in place before the unrest escalates and the situation worsens. Precious time and data are lost in the weeks it can take to deploy a response to a reawakening volcano – time and data that the public needs and should have to prepare for the hazards they may be confronted with. A worst-case example of a failed "catch-up" scenario occurred in 1985 during the response to the unrest and eruption of Nevado del Ruiz in Colombia. At Ruiz, volcanologists were scrambling to install monitoring systems on the volcano, prepare hazards assessments, and educate the authorities and public about the looming danger. Ultimately, there was public notification that an eruption was in progress, yet over the course of the next several hours more than 23,000 people lost their lives, needlessly, because adequate pre-event monitoring did not exist and linkage had not been established between scientists, public officials, and the community at risk (Voight, 1996).

Volcanoes operate on individual time scales, some progressing to eruption very quickly (days to weeks), others needing months to a year or more. Not all unrest leads to eruptions, and interpreting the significance of unrest on a sustained basis is important so that communities and businesses can make informed choices without being either too apprehensive or too complacent about potential volcanic hazards. A fundamental benefit of long-term volcano monitoring is that by providing sound, long-baseline, scientific information to the public and emergency managers throughout unrest episodes, the twin problems of either over-reacting or under-reacting are minimized.

The United States has abundant volcanism, both in terms of recent eruptions and episodes of unrest (Table 1). Based on the global volcanism database of the Smithsonian Institution (Simkin and Siebert, 1994; modified where new data are available), the U.S. is home to 169 geologically active volcanoes – i.e., those that are erupting, have erupted recently or, if dormant, are young enough to be capable of reawakening (Figure 1). U.S. volcanoes occur in diverse tectonic settings and present a range of potential dangers depending on the manner in which they erupt and the communities and infrastructure within their reach.

Volcano monitoring in the U.S. is conducted by five volcano observatories, supported primarily by the USGS Volcano Hazards Program (Figure 1). The observatories are located in distinct volcano-tectonic areas of the U.S., but staff and resources are shared among them. Under the Stafford Act (Public Law 93-288), the USGS has the responsibility to issue timely warnings of potential volcanic disasters to the affected populace and civil authorities. As part of this responsibility, the volcano observatories issue notices and warnings of conditions at monitored U.S. volcanoes on a regular basis or as often as warranted during eruptive periods (see http://volcanoes.usgs.gov/update.html).

To make maximum use of the Nation's scientific resources, the observatories partner with academia and other governmental agencies through various formal agreements. The Consortium of U.S. Volcano Observatories (CUSVO) was established in 2001 to promote scientific cooperation among the Federal, academic, and State agencies involved in observatory operations. The principal CUSVO members are the USGS, University of Washington, University of Alaska, University of Utah, University of Hawaii, Advanced National Seismic System, National Science Foundation's Plate Boundary Observatory, Alaska Division of Geology and Geophysics, and Yellowstone National Park. (Details of CUSVO's charter and membership are given in Appendix 1).

Other agencies contribute to volcano studies. NSF funds installation of geophysical instruments at some volcanoes for research projects, through its EarthScope Initiative as well as through its regular geoscience proposal process. Meteorological satellites operated by the National Oceanic and Atmospheric Administration (NOAA) provide important, near-real-time, remote-sensing data used by the volcano observatories, and NOAA operates two Volcanic Ash Advisory Centers – in Washington DC and in Anchorage, Alaska – to track the dispersion of volcanic-ash clouds hazardous to aircraft. The Smithsonian Institution's Global Volcanism Program supports volcano monitoring activities by maintaining a comprehensive database on the eruptive histories of volcanoes throughout the world, providing data that are critical input to forecasting the likely future activity of restless volcanoes.

Table 1. 45 eruptions and 15 cases of notable volcanic unrest have occurred at 33 U.S. volcanoes since 1980.

VOLCANO	ERUPTION YEAR	UNREST EPISODE
Kilauea, Hawaii	1983-present	
Mauna Loa, Hawaii	1984	2002-2004, inflation and deep seismicity
Mt. St. Helens, Washington	1980-1986, 2004-2005	1989-2003, occasional earthquake bursts, minor phreatic explosions, small mudflows
Mt. Hood, Oregon		Occasional earthquake swarms
Three Sisters, Oregon		Uplift began 1997; earthquake swarm March 2004
Long Valley, California		Recurrent earthquake swarms and uplift since 1980, CO_2 emission from ground since 1989.
Medicine Lake, California		1988-1989 earthquake swarm
Yellowstone National Park		Recurrent earthquake swarms and ground deformation (uplift & subsidence), changes in hydrothermal features
Redoubt, Alaska	1989-1990	
Spurr, Alaska	1992	2004-2005 earthquake swarms and melt pit at summit
Augustine, Alaska	1986	
Iliamna, Alaska		1996 earthquake swarm and elevated gas emission
Veniaminof, Alaska	1983-1984, 1993-1995, 2004-2005	
Pavlof, Alaska	1980, 1981, 1983, 1986-1988, 1996-1997	
Shishaldin, Alaska	1986-1987, 1995-1996, 1999	2004-2005 earthquakes and tremor, thermal anomalies
Westdahl, Alaska	1991-1992	
Dutton, Alaska		1984 earthquake swarm; 1988 earthquake swarm and intrusion
Shrub Mud Volcano, Alaska		1996-1999 carbon dioxide/mud eruption
Becharof Lake, Alaska		1998 earthquake swarm
Chiginigak, Alaska		1997-1998 fumarolic activity
Akutan, Alaska	1980, 1987, 1988, 1992	Intense earthquake swarm and intrusion with ground cracks in 1996.
Makushin, Alaska	1980	
Bogoslof, Alaska	1992	
Okmok, Alaska	1981, 1983, 1986-1988, 1997	
Cleveland, Alaska	1986, 1987, 1994, 2001	
Amukta, Alaska	1987, 1996?	
Seguam, Alaska	1992, 1993	
Korovin, Alaska	1987, 1998	
Kanaga, Alaska	1993-1995	
Gareloi, Alaska	1980, 1982	
Kiska, Alaska	1987?	
Pagan, Mariana Islands	1981-1996	
Anatahan, Mariana Islands	2003-2005	

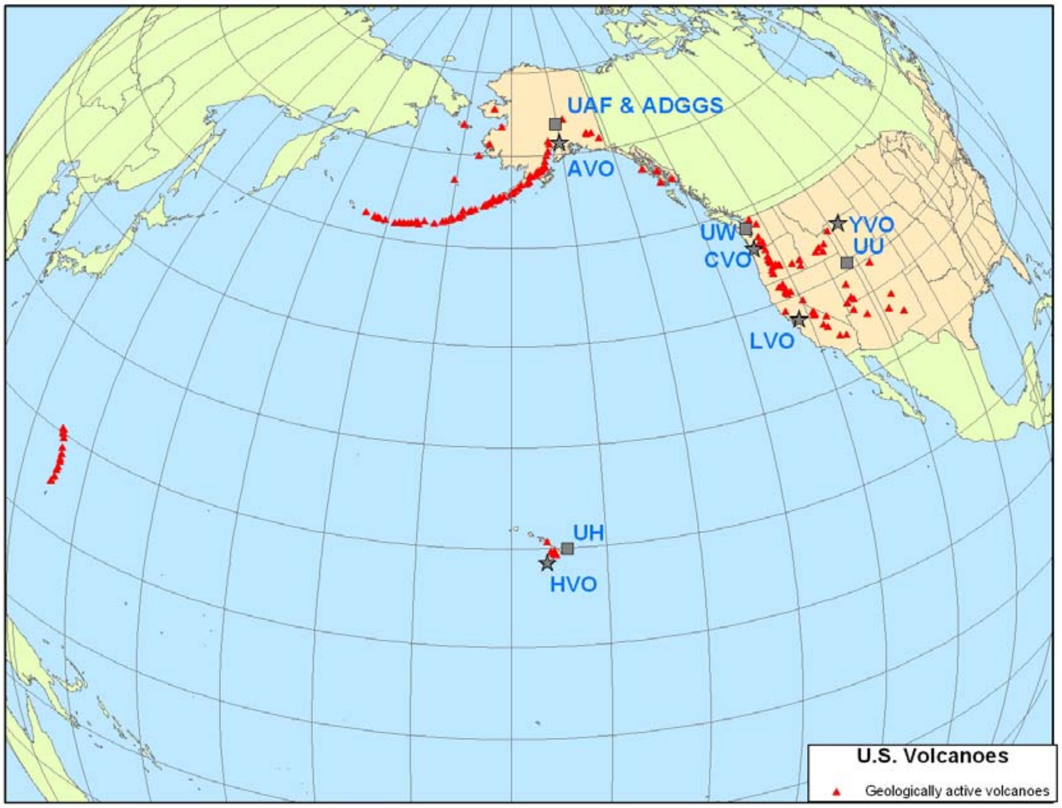

Figure 1: Locations of volcanoes (red triangles), volcano observatories (gray stars), and affiliated cooperators (gray squares). Eruption styles, hazards, and risk vary greatly from place to place, and communication of natural hazards information to the public and local civil authorities is most effective when it comes from locally accessible scientists with credible expertise. The observatory concept works well because it is at this regional or local level that volcanic systems can be adequately monitored and the complex issues attendant to hazards mitigation can be addressed. The nation's first volcano observatory, the Hawaiian Volcano Observatory (HVO), was founded in 1912 atop Kilauea Volcano on the island of Hawaii; currently, HVO and its affiliated partner the University of Hawaii are tracking Kilauea's 22-year-long eruption. After the devastating eruption of Mount St. Helens in 1980, the USGS Cascades Volcano Observatory (CVO) in Vancouver, Washington, was established in 1982 to continue long-term monitoring and hazard assessment for Cascade Range volcanoes, in partnership with the University of Washington Geophysics Program and the USGS Northern California Seismic Network. Recurring unrest began in 1980 at the large Long Valley caldera in east-central California, and research and monitoring conducted by the USGS and university community eventually led to formal organization of the Long Valley Observatory (LVO) in 1999. After the 1986 eruption of Augustine Volcano, near Alaska's major population center in the Cook Inlet, the Alaska Volcano Observatory was created as a partnership of the USGS, University of Alaska Fairbanks Geophysical Institute, and the Alaska Division of Geological and Geophysical Surveys. Beginning in 1996, with new Congressional funding, AVO began an ambitious and unprecedented effort to increase the number of monitored volcanoes in the remote Aleutian volcanic islands so that the aviation sector can be quickly informed of potential ash-cloud hazards. The Yellowstone Volcano Observatory (YVO) was established in 2001 by the USGS, University of Utah, and Yellowstone National Park. YVO formalizes the long-term monitoring and geologic mapping of Yellowstone caldera, the largest volcanic system in North America and the world's first National Park. Since the eruption in 2003 of Anatahan Volcano in the Mariana Islands (a U.S. Commonwealth), monitoring of data telemetered from the volcano is shared by CVO, HVO, and LVO.

At present, about half of the most threatening U.S. volcanoes are monitored at a basic level with real-time sensors (primarily seismic arrays), and a few are well monitored with denser networks involving a variety of instrument types. However, monitoring capabilities at many hazardous volcanoes are known to be sparse or antiquated, and some hazardous volcanoes have no ground-based monitoring whatsoever.

Optimum volcano monitoring is achieved by integrating a combination of approaches employing ground-based, airborne, and remote-sensing techniques, rather than relying on any single method or class of methods. Real-time data from ground-based geophysical sensors, telemetered to a regional observatory, provide the continuous all-weather data required to correctly interpret volcanic unrest and accurately forecast the consequences. Satellite-based remote sensing can be useful in detecting long-term changes in conditions at a volcano and confirming eruptive activity. Integrating the various data streams that pertain to detecting and diagnosing volcanic activity nationally is one of the goals of this framework.

Globally, institutions with the responsibility to monitor volcanic hazards and mitigate impacts face growing demand for rapid hazard analysis and real-time eruption reporting. This demand is exemplified by the aviation sector's stated need that air traffic control centers be notified by a volcano observatory of an ash-producing eruption within five minutes of the start of the eruptive event (Salinas and Watt, 2004). This ambitious goal was met by the Cascades Volcano Observatory when Mount St. Helens reawakened in October 2004 because sufficient monitoring infrastructure was in place at the volcano (see Sidebar 1). In contrast, at Anatahan volcano in the Mariana Islands no real-time monitoring capability existed when the volcano unexpectedly erupted in 2003, and a distressingly long period of several hours elapsed before the eruption could be confirmed using images from meteorological satellite (Guffanti and others, 2005).

Recognizing that there are potentially dangerous volcanoes within the United States and its Territories that have inadequate or no ground-based monitoring, the USGS Volcano Hazards Program and its CUSVO partners are preparing a plan for a **National Volcano Early Warning System (NVEWS)** to move beyond a reactive mode of mitigating volcanic risk and toward a proactive, fully integrated approach. NVEWS is based on a systematic assessment of the threats posed by each volcano coupled with an evaluation of its current monitoring capability. The assessment has identified which volcanoes in the U.S. need monitoring improvements. The improvements should be commensurate with the risks posed by a particular volcano and should be implemented well in advance of precursory unrest with the aim of providing early detection of unrest and reliable forecasting of likely hazards.

Twenty-five years of scientific and technical accomplishments provide us with a solid base for such an assessment:

- We have established five volcano observatories (Figure 1) in the U.S. to carry out a partnered program of long-term monitoring, and we have worked with USAID's Office of Foreign Disaster Assistance to respond to numerous volcanic crises and build monitoring capabilities in other countries.
- We have gained scientific experience with numerous episodes of volcanic unrest both foreign and domestic, many culminating in eruption, some not. We also have gained practical experience by interacting with emergency-management agencies as they make decisions affecting their constituencies.
- Through detailed geologic field investigations, we have greatly expanded our knowledge about eruptive histories of major volcanoes in Alaska, Hawaii, and the Cascade Range.

- We have identified new, acutely hazardous phenomena – such as the airborne-ash hazard to aviation, carbon-dioxide degassing from soils and lakes, far-reaching lateral blasts – and we have documented the full catastrophic scope of volcanic mudflows.
- With this broader understanding of eruptive hazards, we have improved our ability to evaluate volcanic risk at different kinds of volcanoes in a variety of settings.
- Technological advances, developed and proven at erupting volcanoes in the U.S. and abroad, have provided us with a rich variety of new volcano monitoring tools. Also, improvements in telemetry now permit large amounts of data to flow in real time from remote volcanoes to observatories for analysis and interpretation (Figure 2).

This combination of diverse programmatic partnerships, greatly enhanced knowledge about the hazards and eruptive histories of U.S. volcanoes, global experience with volcanic unrest and eruptions, and technological advancements have set the stage for a more effective, proactive approach to living with volcanic hazards. In the following sections of this report, we explain our methodology for assessing volcanic threat, for rating the adequacy of monitoring currently in place at U.S. volcanoes, and for identifying the most serious monitoring gaps that should be filled as part of an effective National Volcano Early Warning System.

The NVEWS methodology was developed at a series of meetings in 2004, convened by the USGS mostly as CUSVO meetings (Appendix 1). Non-USGS participants who reviewed the methodology in its formative stages are John Eichelberger (Univeristy of Alaska Fairbanks), Michael Jackson (UNAVCO), Steven Malone (University of Washington), Christopher Nye (Alaska Division of Geological and Geophysical Surveys), David Schmidt (University of Oregon), Robert B. Smith (University of Utah), and Donald Thomas (University of Hawaii).
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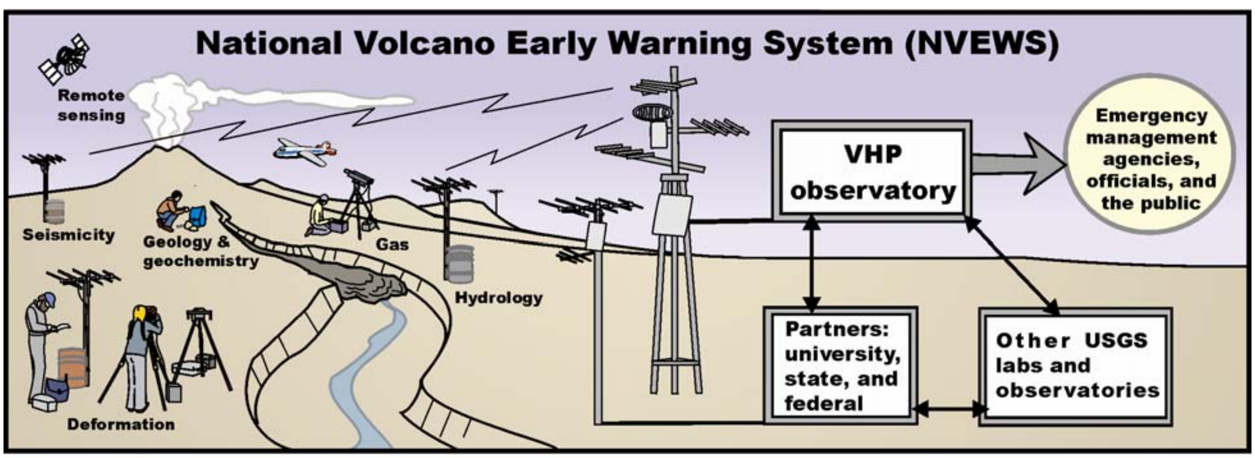


Figure 2: Volcano-monitoring methods are designed to detect changes in the state of a volcano caused by magma movement beneath the volcano. Rising magma typically triggers swarms of earthquakes and other types of seismicity, causes swelling or subsidence of a volcano's edifice, and leads to the emission of volcanic gases. By monitoring these and related phenomena, scientists can anticipate an eruption days to weeks ahead of time. Transmission of monitoring data occurs via radios, phone lines, internet, and/or satellites from instruments installed at volcanoes to scientific facilities for processing and analysis. Automatic, computer-based data processing systems make most data available in real to near-real time for analysis by scientists that may be located in different facilities. Interpreting monitoring data and assessing the future behavior and eruptive potential of a restless volcano, however, is far from automatic and requires complex analysis by a variety of volcanological experts as soon as the data are received.

SIDEBAR 1

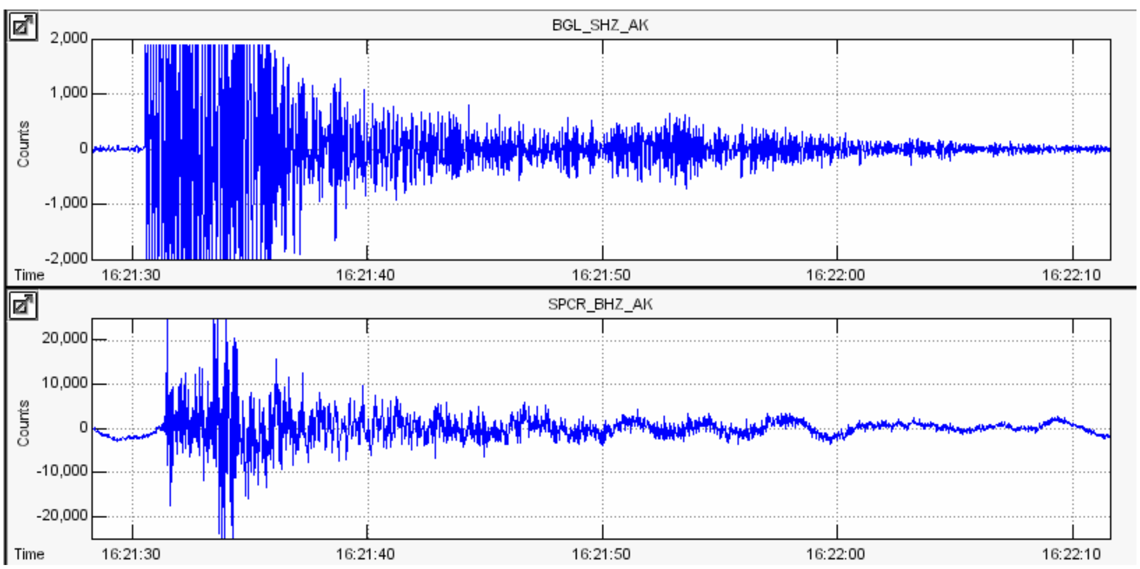
MOUNT ST. HELENS REAWAKENS

Scientists prepare to fly into the crater of Mount St. Helens (background, right), 3 Jan. 2005. (USGS photo)

8 March 2005 eruption of Mount St.Helens, Washington. (USGS photo)

After lying in repose for 18 years, Mount St. Helens volcano reactivated on 23 September 2004 with a swarm of earthquakes and rapid deformation of the crater floor. Within days the volcano was producing small steam and ash eruptions that led to the closure of a popular U.S. Forest Service visitor center, and after only 18 days the first lava reached the surface. Although sufficient monitoring was in place to detect the obvious onset of unrest, much of the instrumentation and telemetry infrastructure had been installed more than 20 years previously, and their limitations soon became evident. For example, as earthquake activity increased many seismic signals went off scale, which limited their diagnostic capabilities. Broadband seismometers for use at other restless volcanoes were borrowed and hurriedly installed; however, data from these instruments was not available in real time because the telemetry infrastructure for these new instruments was lacking. A single telemetered GPS station located 8 km north of Mount St. Helens recorded far-field deformation that accompanied the onset of the initial earthquake swarm. Although additional instruments were installed in cooperation with the NSF-EarthScope program, they could not be installed quickly enough to catch the deformation event, precluding our ability to determine with confidence the volume of magma potentaily involved with the current eruptive event.

As additional instrumentation was installed at Mount St. Helens, the Cascades Volcano Observatory and CUSVO-partner University of Washington were in the position of playing catch up with the volcano while a potentially hazardous situation unfolded under the scrutiny of the National media. Even though working in a largely reactive mode at Mount St. Helens, scientists still had the advantages of responding to initial mildly explosive activity at a well-characterized volcanic system with basic instrumentation already in place and in mild, early fall weather. These advantages cannot be counted on should other U.S. volcanoes awaken, particularly in deepest winter. In those cases, playing catch up will be very difficult.



<u>Two seismograms from the same earthquake measured by different instruments.</u> Top panel is a clipped seismogram from a traditional short-period instrument where the amount of ground shaking has exceeded the range of the instrument. Bottom panel is from a modern broadband instrument (at a slightly greater distance from the earthquake) which is responsive to a much larger range of shaking and thus less likely to clip. The broadband also can sense ground tremors that are too fast or too slow for the older short-period instruments. While short-period instruments are capable of locating earthquakes, broadbands are required to understand the physical processes at the source of the seismic signal.

VOLCANIC-THREAT ASSESSMENT: ANALYSIS OF HAZARD AND RISK FACTORS

An underlying principle of NVEWS is that the degree and type of early-warning monitoring at a particular volcano should be commensurate with the threat it poses. Volcanic threat is the combination of hazards (the dangerous or destructive natural phenomena produced by a volcano) and exposure (the people and property at risk from the volcanic phenomena). Accordingly, our first step is a systematic assessment of various hazard and exposure factors – defined herein – at each U.S. volcano in order to have a consistent, objective basis for prioritizing an early warning system on a national scale. We calculate an overall threat score for each volcano by first assigning numerical values to the hazard and exposure factors; the individual factors are summed into a hazard score and an exposure score which are then multiplied to generate the volcano's overall threat score. The resultant scores produce a relative ranking of U.S. volcanoes that we use to group them into five threat categories from very high to very low.

A total of 169 US volcanic systems are evaluated. We have used the Smithsonian's Global Volcanism Program's (GVP) volcano reference file, which is the on-line successor to Simkin and Siebert (1994), as the source listing of geologically active volcanic centers in the United States. (http://www.volcano.si.edu/gvp/world/index.cfm). The GVP file includes volcanoes that currently are in an eruptive phase, have erupted in historical time, and those that have not erupted recently but are young enough (eruptions within the past 10,000 years) to be capable of reawakening. Among exceptions to the 10,000-year criterion in the GVP file is the large Yellowstone caldera system, which has not produced a purely magmatic eruption in the past 10,000 years but shows obvious signs of unrest, has had geologically recent large steam explosions in areas that now have high visitor density, and has a large magmatic source at depth.

Based on some recent radiometric dating results, we have omitted several volcanoes from the Smithsonian list. The omitted volcanoes are Ko`olao and Kaho`olawe, Hawaii, and Saddle Buttes, Oregon. Also omitted from our consideration are four deep submarine volcanoes off the Washington and Oregon coast and Loihi Volcano, Hawaii, whose great depths of more than 900 m (3000 ft) below sea level negate most potential threats. Of these submarine volcanoes, Loihi which lies close by the Big Island of Hawaii is the subject of cooperative research endeavors by numerous groups; the USGS will continue to inform the broader research community of notable seismic activity at Loihi when detected by the HVO monitoring network.

The NVEWS threat assessment is not a formal risk assessment of U.S. volcanoes. The latter requires that probabilities of particular hazards occurring at individual volcanoes within a set time period be calculated and that the vulnerability of people and property to the hazards be estimated as expected losses in dollars. Such an analysis for so many volcanoes is beyond the scope of this work, especially because our knowledge of eruptive histories of many U.S. volcanoes is not sufficient to determine solid probabilities of eruption-recurrence intervals.

The approach taken in this report uses hazard and exposure factors that are general enough to be applied easily to most of the volcanoes. Also, there are sufficient factors such that the absence of data for one or two factors will not have an inordinately large effect on final individual scores. Table 2 lists the hazard and exposure factors used in the NVEWS threat assessment. The 15 hazard factors include volcano type, occurrence of unrest, the general frequency of past eruptions, and the tendency toward explosivity. Unrest factors include seismicity within 20 km of a volcano, deformation in response to magma intrusion or gross changes to an existing hydrothermal system, and degassing (e.g., fumaroles, thermal features, cold degassing of magmatic gases). The 10 exposure factors include population (both permanent and transient; Ewert and Harpel, 2004), aviation exposure, power generation/transmission, etc. A more detailed explanation of the factors is given in Appendix 2.

Table 2. List of the 15 hazard and 10 exposure factors used in the NVEWS threat assessment and their scoring ranges. Detailed explanation of the factors is given in Appendix 2.

Hazard Factors	**Scoring Ranges**
Volcano type	0 or 1
Maximum Volcanic Explosivity Index	0 to 3
Explosive activity in past 500 years?	0 or 1
Major explosive activity in past 5000 years?	0 or 1
Eruption recurrence	0 to 4
Holocene pyroclastic flows?	0 or 1
Holocene lahars?	0 or 1
Holocene lava flow?	0 or 1
Hydrothermal explosion potential?	0 or 1
Holocene tsunami?	0 or 1
Sector collapse potential?	0 or 1
Primary lahar source?	0 or 1
Observed seismic activity	0 or 1
Observed ground deformation	0 or 1
Observed fumarolic or magmatic degassing	0 or 1
Total of Hazard Factors	
Exposure Factors	
Log_{10} of Volcano Population Index (VPI) at 30 km	0 to 5.4
Log_{10} of approximate population downstream or downslope	0 to 5.1
Historical fatalities?	0 or 1
Historical evacuations?	0 or 1
Local aviation exposure	0 to 2
Regional aviation exposure	0 to 5.15
Power infrastructure	0 or 1
Transportation infrastructure	0 or 1
Major development or sensitive areas	0 or 1
Volcano is a significant part of a populated island	0 or 1
Total of Exposure Factors	
Sum of all hazard factors X Sum of all exposure factors = Relative Threat Ranking	

Scoring of hazard and exposure factors used to generate the threat scores is tabulated in Appendix 3. In addition to the overall threat score, the factors also are subtotaled to give a hazard score, exposure score, and an aviation-threat score for each volcano. The aviation score, which we use to help define threat groups, is the product of four hazard factors (maximum VEI, explosive activity in the past 500 years, major explosive activity in the past 5000 years, and eruption recurrence) and the local and regional aviation exposure factors.

The overall threat score for each volcano is given in Table 6 in a later section of this report. The threat scores presented here are subject to revision as more information becomes available. How much we know about individual volcanoes varies greatly from one to another. The individual scores and hence the overall ranking are subject to change as new data on past eruptive activity appear and/or as unrest develops and exposure factors change. The ranking represents minimum scores for many volcanoes where past behavior and ages of explosive eruptions are poorly known. It also is important to keep in mind that the NVEWS threat ranking is a tool to guide long-term monitoring plans and is not a prediction of which volcano is most likely to awaken or erupt next.

The distribution of overall threat scores, shown in Figure 3, is more informative than any individual score alone. The distribution exhibits a generally exponential decrease, from a value of 324 to 0. In Figure 3, the corresponding unrest score for each volcano is superimposed on the overall threat sequence. The maximum score possible for unrest at a volcano is 3; scores less than 3 may be the result of no data at un-instrumented volcanoes. The distribution of overall scores with aviation-threat scores superimposed is shown in Figure 4. Using these figures, we divide the distribution into five threat groups, from very high to very low:

- 18 volcanoes comprise a group having **VERY HIGH** overall threat scores (324 to 123 points, volcanoes 1 through 18 in the ranking sequence). This segment of the distribution has a steep exponential rise in scores from point 18 to point 1. Two volcanoes in this group are erupting (Mount St. Helens in Washington and Kilauea in Hawaii), and all others have shown some signs of unrest since last erupting.

- 37 volcanoes comprise a group having **HIGH** scores (113 to 64 points, volcanoes 19 through 55 in the sequence). At point 19 in the sequence, there is a step decrease in scores from the very-high group. In the high group, all but two volcanoes have shown signs of unrest since last erupting, and most of them have high aviation-threat scores. The lower bound of the group is defined by a change in slope of the distribution (less steep) after point 55 and an overall drop in aviation scores.

- A group of 48 volcanoes comprise a group having **MODERATE** scores (63 to 30 points, volcanoes 56 through 103 in the sequence). The aviation threat scores remain significant on the whole; the lower bound of the group is defined by a marked decline in aviation-threat scores after number 103 in the sequence.

- A group of 34 volcanoes comprise a group having **LOW** scores (30 to 6, volcanoes 104 to 137 in the sequence); this is a transitional group between Moderate and Very Low scores. Aviation-threat scores continue to decline in this group. A few volcanoes in this group show one component of unrest (score of 1).

- A group of 32 volcanoes comprise a tail of **VERY LOW** scores (6 to 0, volcanoes 138 through 169 in the sequence. No unrest is observed in this group, and aviation scores are zero.

Figure 3. Distribution of overall threat scores for 169 U.S. volcanoes (red) with unrest scores (blue) superimposed. See text for explanation of scoring and threat groupings.

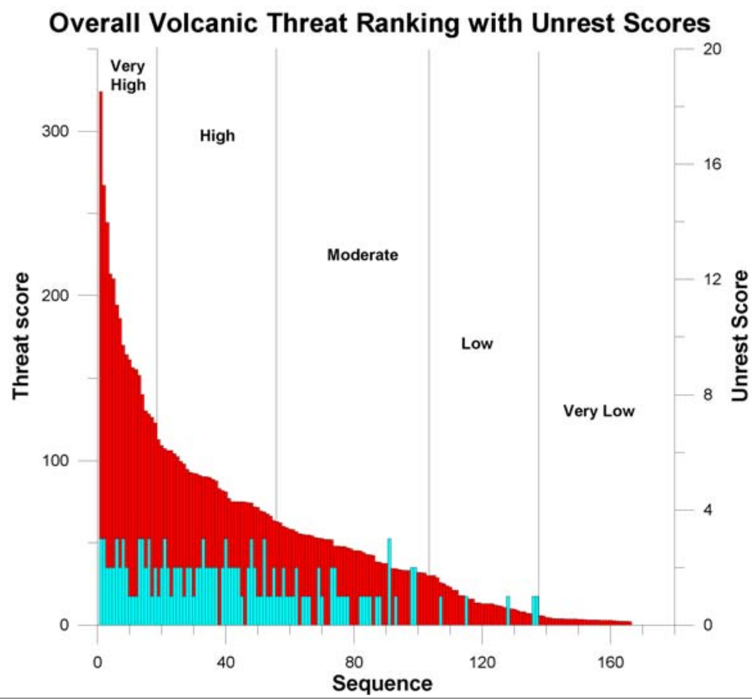


Figure 4. Distribution of overall threat scores for 169 U.S. volcanoes (red) with aviation scores (open diamonds) superimposed. See text for explanation of scoring and threat groupings.

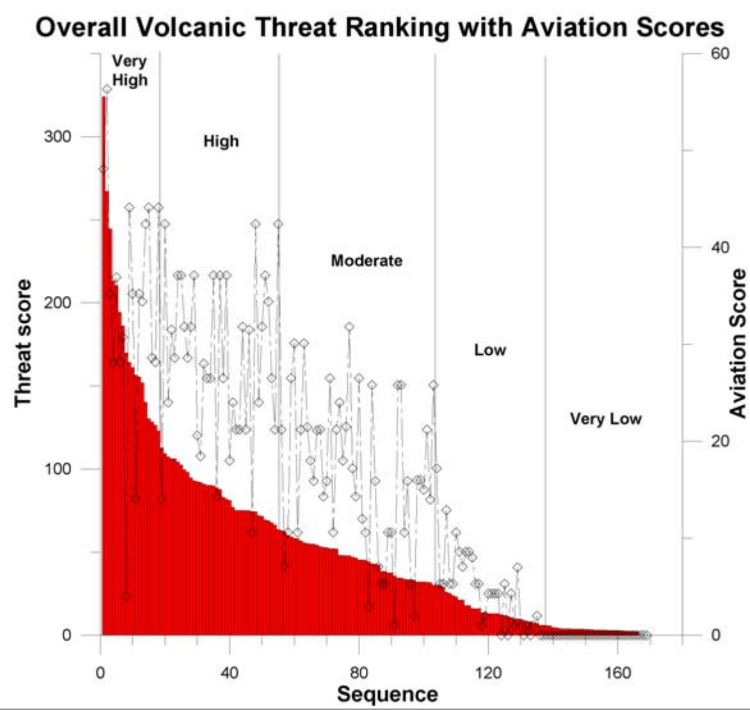


Table 3 gives an analysis of threat scores by state. The volcanic threat in the U.S. is generated by volcanoes in 12 states and the Commonwealth of the Northern Mariana Islands (CNMI). All the volcanoes in the very high and high threat groups are found in Alaska, California, Washington, Oregon, Hawaii, the CNMI, and Wyoming. Hawaii, Washington, and Wyoming are further noteworthy for having volcanoes that predominantly fall in the very high and high threat groups; some of these volcanoes lie in heavily visited National Parks (Hawaii Volcanoes National Park, Mt. Rainier National Park, and Yellowstone National Park). Alaska is notable for being home to about half of U.S. volcanoes, including the most volcanoes that erupt frequently and explosively.

Table 3. Summary of volcanic threat by state. N is number of volcanoes; %N is percentage of the total of 169 volcanoes.. For each state, the number of volcanoes in each of the five threat groups (very high, high, moderate, low, very low) is given; the percentage of a state's volcanoes that have a very high (VH) or high (H) threat level also is calculated. Recur=4 is the code for an eruption-recurrence interval of 1-99 years and indicates the most frequently erupting volcanoes. Number of volcanoes in each state with eruptions having a volcanic explosivity index (VEI) greater than 3 in the past 500 years is tabulated in the last column.

STATE	N	%N	VERY HIGH	HIGH	(VH+H)/N as %	MOD	LOW	VERY LOW	RECUR =4	VEI>3/500 YR
AK	90	53.3	5	26	34	31	22	6	22	29
CA	19	11.2	3	4	37	4	0	8	0	2
WA	7	4.1	4	1	71	0	2	0	1	1
CNMI	13	7.7	0	4	31	4	3	2	4	2
OR	19	11.2	4	0	21	2	2	11	0	0
HI	5	3.0	2	1	60	2	0	0	2	1
WY	1	0.6	0	1	100	0	0	0	0	0
UT	4	2.4	0	0	0	1	1	2	0	0
ID	4	2.4	0	0	0	0	4	0	0	0
NM	3	1.8	0	0	0	1	0	2	0	0
AZ	2	1.2	0	0	0	1	0	1	0	0
NV	1	0.6	0	0	0	1	0	0	0	0
CO	1	0.6	0	0	0	1	0	0	0	0
Total	**169**	**100**	**18**	**37**	**N/A**	**48**	**34**	**32**	**29**	**35**

Table 4 lists volcanoes alphabetically by state, in the five threat groups. The very high threat group includes 10 Cascade Range volcanoes in Washington, Oregon, and California – Baker, Crater Lake, Glacier Peak, Hood, Lassen, Newberry, Rainier, Shasta, South Sister, St. Helens – whose explosive behavior and lahar potential can impact both large populations and extensive development on the ground as well as heavily traveled air-traffic corridors. In Alaska, the highest threat volcanoes are represented by Augustine, Redoubt and Spurr, which are located near the state's major population center of Anchorage and its international airport, and Makushin and Akutan, which are near towns, regional airports, and important fishing ports in the Aleutian Islands; all five volcanoes pose major hazards to busy air-traffic routes in the North Pacific. Kilauea and Mauna Loa on the Island of Hawaii, which are frequently active and capable of producing far-reaching and damaging lava flows, rate as very-high-threat volcanoes; Kilauea's hazards also include the potential for explosive eruptions. The large Long Valley caldera system, which has exhibited recurring signs of unrest for more than two decades and is close to major resort development and transportation infrastructure, also falls in the very-high-threat group.

The high-threat group includes numerous Alaskan volcanoes located throughout the State. Most pose a significant threat to aviation because of their frequent explosive behavior; many are also near smaller population centers and power or transportation infrastructures. The high threat group also includes four volcanoes in the Mariana Islands; one of those, Anatahan volcano, has been erupting intermittently since 2003. Yellowstone caldera also fall~~s~~ in the high-threat group, as do Hualalai volcano in Hawaii, Mount Adams in Washington, and Clear Lake, Medicine Lake, and Inyo Craters and Mono Craters in California.

Volcanoes in the moderate threat group are spread throughout nine states and the Mariana Islands. Again, numerous Alaskan volcanoes fall in this group, primarily because of the ash-cloud hazard to aviation. Volcanoes in the low- and very-low-threat groups are also are dispersed among several states; although eruptions at these volcanoes would not constitute a significant threat to people and property, the reawakening of any of them would present a valuable and unique scientific opportunity for volcanology, as well as a target for intense media and public attention.

Table 4 also indicates for each threat group the commensurate level of monitoring that should be in place before the onset of an unrest crisis or eruptive activity. The most threatening volcanoes, those near communities and transportation infrastructure (ground and air) and with a history of frequent and violent eruptions, need to be well monitored in real time (Level 4) with an extensive suite of instrument types to detect the earliest symptoms of unrest and to reliably forecast behavior of the volcano. Waiting until unrest escalates to augment monitoring capabilities at these high-threat volcanoes puts people (including scientists in the field) and property at undue risk. Remote, isolated, or less frequently erupting volcanoes that nevertheless can pose hazards to air-traffic corridors require sufficient ground-based instruments to detect and track unrest (Level 3: basic real-time monitoring) so that other agencies responsible for enroute flight safety (elements of the Federal Aviation Administration and National Oceanic and Atmospheric Administration) can be kept apprised of the potential for explosive, ash-cloud-forming eruptions. Volcanoes that are unlikely to erupt in the near future and that pose little threat on the ground or in the air can be monitored by sparser networks and satellite surveillance (Levels 2 and 1).

In the next section, we compare the monitoring capability currently in place at each volcano to the level of monitoring required by its threat score, with the objective to systematically ascertain where there are gaps in monitoring and to identify those volcanoes – in addition to currently erupting or restless ones – that are most in need of additional monitoring resources.

Table 4. U.S. volcanoes listed alphabetically by state in five threat groups, with required level of monitoring indicated. Threat groups are defined in the text using Figures 3 and 4. A fuller description of monitoring levels is given in Appendix 4.

<table>
<tr><th>THREAT GROUP</th><th>REQUIRED MONITORING LEVEL</th></tr>
<tr><td>
VERY HIGH THREAT VOLCANOES
<u>Alaska</u>
Akutan, Augustine, Makushin, Redoubt, Spurr,
<u>California</u>
Lassen, Long Valley Caldera, Shasta
<u>Hawaii</u>
Kilauea, Mauna Loa
<u>Oregon</u>
Crater Lake, Hood, Newberry, South Sister
<u>Washington</u>
Baker, Glacier Peak, Rainier, St. Helens

HIGH THREAT VOLCANOES
<u>Alaska</u>
Aniakchak, Atka, Churchill, Dutton, Gareloi, Great Sitkin, Griggs, Hayes, Iliamna, Kaguyak, Kanaga, Katmai, Mageik, Martin, Novarupta, Okmok, Pavlof, Pavlof Sister, Seguam, Semisopochnoi, Shishaldin, Trident, Ugashik-Peulik, Veniaminof, Westdahl, Wrangell
<u>California</u>
Clear Lake, Inyo Craters, Medicine Lake, Mono Craters
<u>Hawaii</u>
Hualalai
<u>Mariana Islands</u>
Agrigan, Alamagan, Anatahan, Pagan,
<u>Washington</u>
Adams
<u>Wyoming</u>
Yellowstone
</td><td>
<u>LEVEL 4: WELL MONITORED IN REAL TIME</u>
Monitoring should provide the ability to track detailed changes in real-time and to develop, test, and apply models of ongoing and expected activity.

<u>Seismic</u>: 12-20 stations within 20 km of vent, including several near-field sites. Network includes numerous three-component stations and mix of other instrument types, including digital broadband stations, acoustic sensors, and accelerometers. Borehole instruments where practicable.
<u>Deformation</u>: Routine surveys along with sufficient continuous stations (GPS, tiltmeters, and/or borehole dilatometers) to track closely geodetic changes in space and time and do detailed source modeling.
<u>Gas</u>: Frequent airborne or campaign gas measurements. Arrays of continuous sensors and other types of gas measurements as appropriate for the volcano.
<u>Hydrologic</u>: Level-3 coverage along with real-time monitoring of hill-slope soil moisture, stream discharge, etc., as appropriate. AFM systems for lahar detection where warranted.
<u>Remote sensing:</u> Level 3 coverage along with other data from pertinent satellite sensors (e.g., daily multi-channel, high-resolution thermal-infrared images and frequent, high resolution, multi-channel visible images). Where practicable, continuous ground-based thermal imaging and Doppler radar coverage.

</td></tr>
<tr><td>
MODERATE THREAT VOLCANOES
<u>Alaska</u>
Adagdak, Amak, Amukta, Black Peak, Bogoslof, Chiginigak, Cleveland, Dana, Denison, Douglas, Edgecumbe, Emmons Lake, Fisher, Frosty, Kasatochi, Kialagvik, Kiska, Kukak, Kupreanof, Little Sitkin, Moffett, Recheschnoi, Roundtop, Sanford, Snowy Mountain, Steller, Tanaga, Ukinrek Maars, Vsevidof, Yantarni, Yunaska,
<u>Arizona</u>
Sunset Crater
<u>California</u>
Coso Volc. Field, Mono Lake Volc Field, Red Cones, Ubehebe Craters
<u>Colorado</u>
Dotsero
<u>Hawaii</u>
Haleakala, Mauna Kea
<u>Mariana Islands</u>
Asuncion, Farallon de Pajaros, Guguan, Sarigan
</td><td>
<u>LEVEL 3: BASIC REAL-TIME MONITORING</u>
Monitoring should provide the ability detect and track pre-eruptive and eruptive changes in real-time, with a basic understanding of what is occurring.

<u>Seismic</u>: Network with 3-4 near-field stations and a total of at least six within 20 km of vent.
<u>Deformation</u>: Routinely repeated surveys. At least six continuous stations (GPS and/or tiltmeters) in vicinity of volcano. LIDAR-derived images available for active features.
<u>Gas</u>: Frequent airborne or campaign measurements of gas emissions (annually to monthly, as appropriate) along with support of 1-2 telemetered continuous sensors.
<u>Hydrologic</u>: Level-2 coverage along with continuous-sensing probes in features of primary interest, including water wells. LIDAR-derived DEMs for lahar-runout modeling. cont'd.

</td></tr>
</table>

(Moderate threat cont'd.) Nevada Steamboat Springs New Mexico Valles Caldera Oregon Bachelor, North Sister Field Utah Black Rock Desert	• Remote sensing: Level 2 coverage along with routine use of multi-channel thermal-infrared data from ASTER-class satellite. Thermal and/or SAR overflights, as indicated by other monitoring data. Where practicable, remote video camera in operation.
LOW THREAT VOLCANOES Alaska Bobrof, Buldir, Buzzard Creek, Carlisle, Chagulak, Davidof, Duncan Canal. Fourpeaked, Herbert, Ingakslugwat Hills, Isanotski, Kagamil, Koniuji, Nunivak Island, Segula, Sergief, Stepovak, St.Michael, Table Top-Wide Bay, Takawangha, Uliaga, Unnamed Idaho Craters of the Moon, Hell's Half Acre, Shoshone Lava Field, Wapi Lava Field Mariana Islands Esmeralda Bank, Maug Islands, Ruby Oregon Belknap, Blue Lake Crater Utah Markagunt Plateau Washington Indian Heaven, West Crater	**LEVEL 2: LIMITED MONITORING FOR CHANGE DETECTION** **Monitoring should provide the ability to detect and track activity frequently enough in near-real time to recognize that anomalous activity is occurring.** • Seismic: Regional network with 1-2 near-field stations in place (within ~10 km of volcano). • Geodetic: Two or more surveys for establishing baseline. InSAR observations possible on summer-to-summer basis. At least three continuous stations (GPS or tiltmeters) in vicinity of volcano. • Gas: Baseline of carbon-dioxide emission rate (or other gas as appropriate to the volcano). • Hydrologic: Comprehensive database on temperatures and chemistry of springs and fumaroles. Remote-Sensing: Regular processing and review of near-real-time meteorological satellite images (AVHRR, GOES), and/or review of non-real-time research satellite images (e.g., MODIS) by an observatory. Baseline inventory of air photos and/or satellite images with high spatial resolution (1 m).
VERY LOW THREAT VOLCANOES Alaska Behm Canal-Rudyerd Bay, Gordon, Imuruk Lake, Kookooligit Mountains, St. Paul Island, Tlevak Strait-Suemez Island Arizona Uinkaret Field California Amboy, Big Cave, Brushy Butte, Eagle Lake Field, Golden Trout Creek, Lavic Lake, Tumble Buttes, Twin Buttes Mariana Islands Ahyi, Supply Reef New Mexico Carrizozo, Zuni-Bandera Oregon Cinnamon Butte, Davis Lake, Devils Garden, Diamond Craters, Four Craters Lava Field, Jackies Butte, Jefferson, Jordan Craters, Lava Mountain, Sand Mountain Field, Washington Utah Bald Knoll, Santa Clara	**LEVEL 1: MINIMAL MONITORING** **Monitoring should provide the ability to detect that an eruption is occurring or that gross changes are occurring/have occurred near a volcano.** • Seismic –Volcano lies within a regional network; no near-field stations are in place but at least one station is within 50 km of the volcano. Or, a single near-field station is present, but no regional network exists. • Remote sensing - Baseline inventory exists of Landsat-class satellite images. Routine scans for eruption clouds are conducted by meteorological agencies.

GAP ANALYSIS FOR A NATIONAL VOLCANO EARLY WARNING SYSTEM

The NVEWS gap analysis – the method for determining the difference between the current level of monitoring at a volcano and the level called for by its threat score – is intended to be a tool for prioritizing monitoring targets in advance of the onset of unrest or eruption so that future instances of playing high-stakes catch up with a restless volcano are minimized.

Current monitoring capabilities at U.S. volcanoes are rated on our ability to characterize ongoing and expected activity during a potential unrest crisis based on the types, numbers, and proximity of monitoring instrumentation now in place at each volcano. Each of the primary monitoring methods – seismic, deformation, gas, hydrologic, and remote-sensing – is rated for each volcano using a scale from 0 to 4 (details of the scale are given in Appendix 4). Based on those ratings (which are tabulated in Appendix 5), an overall current monitoring level for each volcano also is assigned, again using a scale from 0 for no real-time ground-based monitoring to 4 for well monitored in real time.

A breakdown of current overall monitoring levels by threat group (Table 5) gives a general indication that inadequacies in monitoring capabilities exist. Only three U.S. volcanoes (17% of the 18 very-high-threat volcanoes) are well-monitored in real-time at Level 4: Mount St. Helens, Washington, which erupted catastrophically in 1980 and began a new eruptive phase in 2004; Kilauea, which has been erupting since 1983; and Long Valley caldera, California, which is a site of recurring unrest and also is the focus of many topical research studies utilizing instrument arrays. Nearly one quarter of the 37 high-threat volcanoes have minimal to no ground-based monitoring (11% at Level 1; 13% at Level 0). Moderate-threat volcanoes also have a significant proportion (33%) with no ground-based monitoring. The high percentages of low- and very-low-threat volcanoes with Level 1 and Level 0 monitoring (85% and 100%, respectively) is reasonable, given their negligible threat potential.

Table 5. Summary of current overall monitoring levels at U.S. volcanoes by threat groups. Percentages based on the number of volcanoes (N) in each threat group.

	Level 4 Well monitored	**Level 3** Basic real time	**Level 2** Limited	**Level 1** Minimal	**Level 0** No ground based
Very High Threat (N=18)	17%	33%	39%	11%	0%
High Threat (N=37)	0%	54%	22%	11%	13%
Moderate Threat (N=48)	0%	11%	29%	27%	33%
Low Threat (N=34)	0%	6%	9%	32%	53%
Very Low Threat (N=32)	0%	0%	0%	69%	31%

To pinpoint which volcanoes are most in need of additional monitoring resources, the existing monitoring capability at each volcano is compared to the level of monitoring called for by its threat score. For each volcano, the value of the current overall monitoring level is subtracted from the value of the required level indicated in Table 4; the resulting number is a measure of the monitoring gap at that volcano. For example, the current overall monitoring level at Lassen Volcanic Center is at 2 but the needed level for such a high-threat volcano is 4, giving a monitoring gap of 2. Results of this monitoring-gap analysis for all U.S. volcanoes are given in Table 6.

It should be noted again that the gap analysis is a tool for prioritizing monitoring targets in advance of the onset of unrest crisis or eruption. Accordingly, activity at the volcanoes that currently are erupting (Mount St. Helens, Kilauea, and Anatahan) or exhibiting heightened unrest (e.g., Mauna Loa, Mount Spurr) supersedes their particular monitoring gap analysis. An erupting or highly restless volcano will require a heightened monitoring response regardless of its ranking in the gap analysis; even a volcano with a low overall threat score may warrant a strong response to address a specific local threat or because scientific investigations there may reveal insights about eruptive behavior and hazards elsewhere. Moreover, as demonstrated by intense public and media interest in the recent reawakening of Mount St. Helens, eruptions are undeniably fascinating events that compel the attention of scientists and the public alike. Eruptions, particularly those in accessible locations, will not be ignored.

Table 6: Results of NVEWS gap analysis. The monitoring gap for each volcano is determined by subtracting the value of the current monitoring level from the required monitoring level. Threat groups are color coded: very high threat is red, high is orange, moderate is yellow, low is blue, and very low is green. Gray highlighting indicates volcanoes that currently are erupting or showing heightened unrest (as of April 2005).

Volcano	State	Aviation-Threat Score	Threat Score	Required Monitoring Level	Current Monitoring Level	Monitoring Gap
Kilauea	HI	48	324	4	4	Eruption
St. Helens	WA	56	267	4	4	Eruption
Rainier	WA	35	244	4	2	2
Hood	OR	28	213	4	2	2
Shasta	CA	37	210	4	2	2
South Sister	OR	28	194	4	2	2
Lassen Volcanic Center	CA	31	186	4	2	2
Mauna Loa	HI	4	170	4	3	Unrest
Redoubt	AK	44	164	4	3	1
Crater Lake	OR	35	161	4	1	3
Baker	WA	14	156	4	2	2
Glacier Peak	WA	35	155	4	1	3
Makushin	AK	34	152	4	3	1
Akutan	AK	42	140	4	3	1
Spurr	AK	44	130	4	3	Unrest
Long Valley Caldera	CA	29	128	4	4	0
Newberry Volcano	OR	28	126	4	2	2
Augustine	AK	44	123	4	3	1

Adams	WA	14	113	4	2	2
Veniaminof	AK	42	109	4	3	1
Yellowstone	WY	24	107	4	3	1
Iliamna	AK	32	106	4	3	1
Inyo Craters	CA	29	106	4	2	2
Shishaldin	AK	37	104	4	3	1
Kanaga	AK	37	102	4	3	1
Wrangell	AK	32	100	4	2	2
Mono Craters	CA	29	98	4	1	3
Pavlof	AK	32	95	4	3	1
Ugashik-Peulik	AK	37	93	4	3	1
Hualalai	HI	21	92	4	2	2
Medicine Lake	CA	18	92	4	2	2
Pagan	CNMI	28	91	4	0	4
Trident	AK	27	90	4	3	1
Katmai	AK	27	90	4	3	1
Great Sitkin	AK	37	90	4	3	1
Clear Lake	CA	14	89	4	1	3
Aniakchak	AK	37	88	4	3	1
Churchill	AK	27	83	4	1	3
Gareloi	AK	37	82	4	3	1
Anatahan	CNMI	18	81	4	2	Eruption
Agrigan	CNMI	24	77	4	0	4
Martin	AK	21	75	4	3	1
Mageik	AK	21	75	4	3	1
Novarupta	AK	32	75	4	3	1
Griggs	AK	21	75	4	3	1
Hayes	AK	32	75	4	1	3
Dutton	AK	11	74	4	2	2
Westdahl	AK	42	74	4	3	1
Alamagan	CNMI	24	72	4	0	4
Atka	AK	32	71	4	3	1
Semisopochnoi	AK	37	69	4	0	4
Okmok	AK	34	69	4	3	1
Kaguyak	AK	27	68	4	2	2
Pavlof Sister	AK	21	66	4	3	1
Seguam	AK	42	64	4	0	4
Chiginagak	AK	21	63	3	1	2
Steamboat Springs	NV	7	62	3	2	1
Snowy Mountain	AK	11	60	3	3	0
Dana	AK	27	59	3	1	2
Kiska	AK	30	58	3	0	3
Roundtop	AK	11	58	3	1	2
Tanaga	AK	21	57	3	3	0
Vsevidof	AK	30	56	3	0	3
Mono Lake Volcanic Field	CA	21	55	3	1	2
Valles Caldera	NM	18	55	3	2	1
Kupreanof	AK	16	55	3	1	2

North Sister Field	OR	21	54	3	1	2
Edgecumbe	AK	21	53	3	1	2
Coso Volcanic Field	CA	14	53	3	2	1
Douglas	AK	16	53	3	1	2
Yantarni	AK	27	52	3	0	3
Frosty	AK	11	52	3	2	1
Ukinrek Maars	AK	21	52	3	3	0
Guguan	CNMI	24	48	3	0	3
Sarigan	CNMI	18	48	3	1	2
Little Sitkin	AK	22	48	3	0	3
Fisher	AK	32	48	3	3	0
Recheschnoi	AK	17	47	3	0	3
Ubehebe Craters	CA	14	46	3	1	2
Black Peak	AK	27	45	3	1	2
Dotsero	CO	12	45	3	0	3
Kukak	AK	11	45	3	2	1
Haleakala	HI	3	44	3	2	1
Cleveland	AK	26	43	3	0	3
Emmons Lake	AK	16	43	3	2	1
Bachelor	OR	7	42	3	2	1
Moffett	AK	5	38	3	2	1
Adagdak	AK	5	38	3	2	1
Denison	AK	11	38	3	2	1
Steller	AK	11	38	3	2	1
Red Cones	CA	1	36	3	3	0
Amukta	AK	26	34	3	0	3
Bogoslof	AK	26	34	3	0	3
Kialagvik	AK	11	34	3	0	3
Amak	AK	16	33	3	0	3
Sanford	AK	5	33	3	1	2
Mauna Kea	HI	2	33	3	2	1
Farallon de Pajaros	CNMI	16	32	3	0	3
Asuncion	CNMI	16	32	3	0	3
Sunset Crater	AZ	15	32	3	2	1
Kasatochi	AK	21	32	3	0	3
Black Rock Desert	UT	14	32	3	1	2
Yunaska	AK	26	30	3	0	3
Carlisle	AK	17	30	2	0	2
Fourpeaked	AK	5	30	2	2	0
Isanotski	AK	5	29	2	3	-1
Kagamil	AK	13	26	2	0	2
Takawangha	AK	5	25	2	3	-1
Bobrof	AK	5	24	2	2	0
St. Michael	AK	11	23	2	0	2
Segula	AK	9	21	2	0	2
Blue Lake Crater	OR	7	21	2	1	1
Ingakslugwat Hills	AK	9	18	2	0	2
Nunivak Island	AK	9	18	2	0	2

Maug Islands	CNMI	8	16	2	0	2
Koniuji	AK	5	16	2	0	2
Sergief	AK	5	16	2	0	2
Hell's Half Acre	ID	1	14	2	1	1
Stepovak	AK	2	14	2	0	2
Buldir	AK	4	13	2	0	2
Chagulak	AK	4	13	2	0	2
Herbert	AK	4	13	2	0	2
Uliaga	AK	4	13	2	0	2
Craters of the Moon	ID	0	12	2	2	0
Unnamed	AK	5	12	2	0	2
Indian Heaven	WA	0	11	2	1	1
Davidof	AK	4	11	2	0	2
West Crater	WA	1	10	2	1	1
Markagunt Plateau	UT	7	10	2	1	1
Shoshone Lava Field	ID	1	10	2	1	1
Belknap	OR	0	9	2	1	1
Table Top-Wide Bay	AK	1	8	2	0	2
Wapi Lava Field	ID	0	8	2	1	1
Duncan Canal	AK	1	7	2	0	2
Buzzard Creek	AK	2	7	2	1	1
Ruby	CNMI	0	6	2	1	1
Esmeralda Bank	CNMI	0	6	2	1	1
Carrizozo	NM	0	6	1	0	1
Zuni-Bandera	NM	0	6	1	0	1
Santa Clara	UT	0	5	1	1	0
Jordan Craters	OR	0	4	1	0	1
Gordon	AK	0	4	1	0	1
Eagle Lake Field	CA	0	4	1	1	0
Big Cave	CA	0	4	1	1	0
Twin Buttes	CA	0	4	1	1	0
Davis Lake	OR	0	4	1	1	0
Tumble Buttes	CA	0	4	1	1	0
Lavic Lake	CA	0	4	1	1	0
Brushy Butte	CA	0	4	1	1	0
Washington	OR	0	3	1	1	0
Amboy	CA	0	3	1	0	1
Sand Mountain Field	OR	0	3	1	1	0
Jefferson	OR	0	3	1	1	0
Bald Knoll	UT	0	3	1	1	0
Cinnamon Butte	OR	0	3	1	1	0
Uinkaret Field	AZ	0	3	1	1	0
St. Paul Island	AK	0	3	1	1	0
Tlevak Strait-Suemez Is.	AK	0	3	1	1	0
Four Craters Lava Field	OR	0	3	1	1	0
Imuruk Lake	AK	0	3	1	1	0
Lava Mountain	OR	0	3	1	1	0
Devils Garden	OR	0	3	1	1	0

Diamond Craters	OR	0	2	1	1	0
Jackies Butte	OR	0	2	1	0	1
Golden Trout Creek	CA	0	2	1	1	0
Kookooligit Mountains	AK	0	2	1	0	1
Behm Canal-Rudyerd Bay	AK	0	0	1	0	1
Ahyi	CNMI	0	0	1	0	1
Supply Reef	CNMI	0	0	1	0	1

Based on the NVEWS analysis summarized in Table 6 and volcanic activity as of April 2005, the **HIGHEST PRIORITY TARGETS** for monitoring improvements are:

- 5 volcanoes that currently are erupting (Mount St. Helens, Anatahan, Kilauea) or exhibiting heightened unrest (Mauna Loa, Mount Spurr).
- 13 very-high-threat volcanoes with some but inadequate monitoring: This group includes 9 volcanoes in the Cascade Range that are significantly under-monitored (gaps of 2 or 3; *viz.* Rainier, Hood, Shasta, South Sister, Lassen, Crater Lake, Baker, Glacier Peak, Newberry). Cascade volcanoes do not erupt frequently, but they threaten major populations and development. Winter is harsh at the elevations of these volcanoes, making an unplanned response to unrest very difficult much of the year. Also in this group are 4 volcanoes in Alaska with monitoring gaps of 1 (*viz.* Redoubt, Makushin, Akutan, Augustine).
- 19 high- and moderate-threat volcanoes in Alaska and the CNMI that have high aviation-threat scores (>15) and **no** real-time ground-based monitoring at the present time: USGS notices of escalating unrest or eruption are part of an international system to avert encounters of aircraft with dangerous volcanic-ash clouds (Miller and Casadevall, 2000). With no real-time ground sensors at a volcano, timely evidence of a volcano's precursory unrest will be lacking. Depending on the remoteness of the volcano, even eruption reports may be delayed, as was the case with the surprise eruption in 2003 of Anatahan volcano in the Mariana Islands. Hours elapsed from the eruption's onset to the issuance of the first warning to aviation of ash in the atmosphere; luckily, no damaging encounters of aircraft occurred during that dangerous period. The 19 targeted volcanoes are Semisopochnoi, Seguam, Kiska, Vsevidof, Yantarni, Little Sitkin, Recheschnoi, Cleveland, Amukta, Bogoslof, Amak, Kasatochi, and Yunaska in Alaska, and Pagan, Agrigan, Alamagan, Guguan, Farallon de Pajaros, and Asuncion in the CNMI.

Additional **HIGH PRIORITY TARGETS** include:

- 11 high-threat volcanoes with that are significantly under-monitored (gaps of 2 and 3). This group includes Mount Adams in Washington; Inyo Craters and Mono Craters in California; Hualalai in Hawaii; Medicine Lake and Clear Lake in California; Wrangell, Churchill, Hayes, Dutton and Kaguyak in Alaska.
- 9 moderate-threat volcanoes that have high aviation-threat scores and minimal ground-based monitoring (gaps of 2 in Table 6). These are Dana, Black Peak, Chiginigak, Edgecumbe, Kupreanof, and Douglas in Alaska, Mono Lake Volcanic Field in California, North Sister Field in Oregon, and Sarigan in the CNMI.
- 1 under-monitored high-threat caldera system that also experiences large tectonic earthquakes, specifically Yellowstone caldera. The magnitude 7.5 Hebgen Lake earthquake occurred on the periphery of the Yellowstone volcanic system in 1959. The fact that this system also hosts earthquake hazards not strictly of volcanic origin indicates the need for close collaboration between NVEWS and the Advanced National

Seismic System. (Another caldera with large tectonic earthquakes is Long Valley caldera in California; four magnitude 6 earthquakes occurred on its periphery as recently as 1980. Long Valley caldera is a very-high-threat center but currently is considered to be well monitored.)

Low- and very-low-threat volcanoes are not NVEWS priorities at this time. Such volcanoes should at least be covered by a regional seismic network (28 are not; monitoring level of 0 in Table 6), but given that the threats posed are minor and resources are limited, response to any signs of reawakening would be on a case-by-case basis.

NVEWS priority volcanic targets are dispersed throughout the United States and the Mariana Islands (Figure 5). The requisite monitoring improvements would be achieved most efficiently by proceeding on multiple regional fronts each year, thus spreading the work out among the various volcano observatories. On an annual basis, specific work plans must be developed that take into account various factors. Technological constraints (e.g., telemetry infrastructure in remote locations) may limit monitoring options or require considerable advance planning. Permits for access to Wilderness Areas and National Parks must be obtained in advance from land managers. Physical terrain and weather (e.g., on high, glacier-clad stratovolcanoes) can alter scheduled instrument installation and maintenance. A cluster of volcanoes may be efficiently monitored as a unit, even if some of the individual volcanoes are of lower threat. Occasionally, opportunities arise to partner efficiently with another group (e.g., NSF-funded scientists) working at a particular volcano. Certainly, volcanoes showing new/escalating unrest or eruptive activity would become high-priority targets. And it is important to note that some volcanoes not listed as priorities nevertheless still require an investment of monitoring resources for routine maintenance and upgrades.

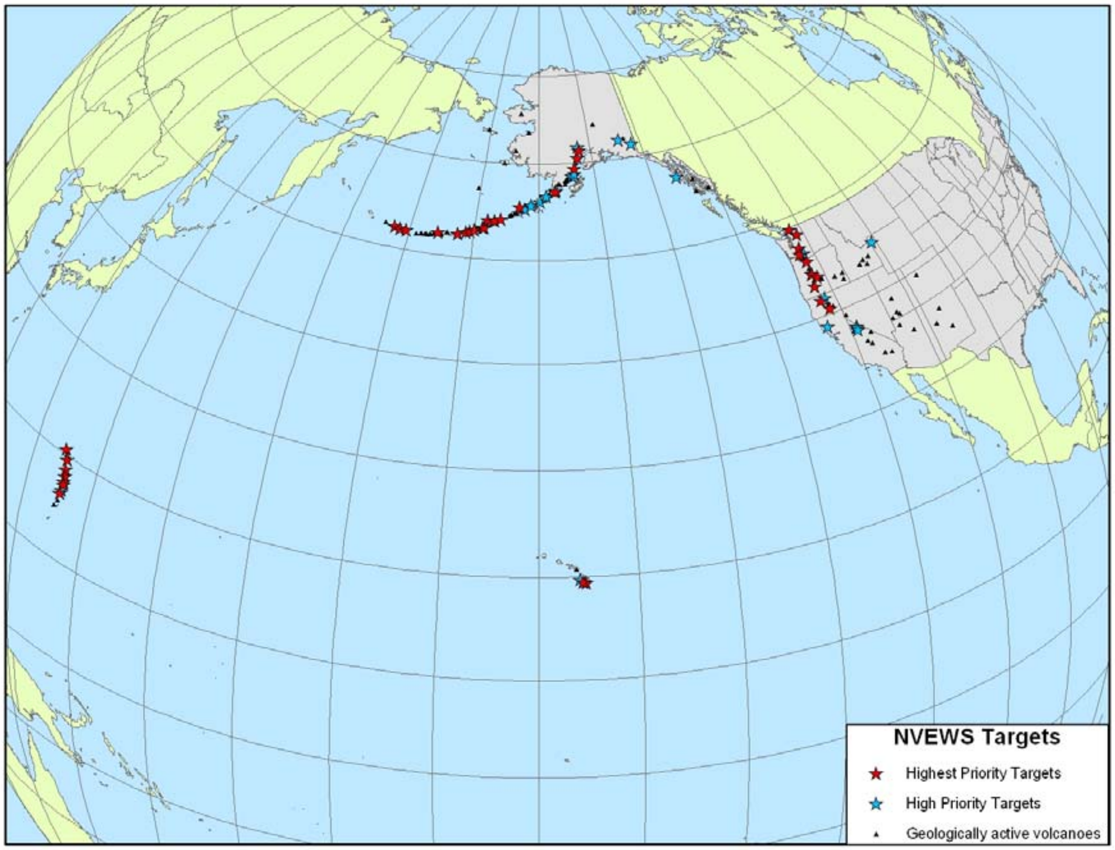


Figure 5. Locations of volcanoes that are NVEWS priority targets for monitoring improvements. See text for volcano names.

IMPLEMENTATION FRAMEWORK

A proposed framework is outlined here to give an overview of the issues related to future implementation of a National Volcano Early Warning System.

Products and Outcomes of NVEWS

The physical aspects of NVEWS involve installation of modern monitoring arrays with data links to observatory facilities of the USGS and CUSVO partners. In addition, NVEWS would create a common information technology (IT) infrastructure for coordinating the collection and dissemination of data among all relevant federal agencies, academic partners, and the general public.

A fully implemented NVEWS, when combined with current monitoring capabilities, would provide:

- A much richer body of observations and data on volcanic activity, as the basis for more reliable eruption forecasts and a range of derived information products from real-time graphical and map depictions of data to peer-reviewed research papers.
- Minimized risk of a surprise eruption at a dangerous volcano.
- Real-time hazard analysis and rapid event notification during periods of escalating unrest and eruption at well-monitored volcanoes, aiming for 5-minute notification by volcano observatories to the FAA of major explosive eruptions.
- The hardware, software, and networking infrastructure to enable observatory and affiliated scientists to view and analyze all data streams from monitored volcanoes in real time at multiple locations.
- A National 24X7 Volcano Watch Office for full alerting capabilities and authoritative information about unrest and eruptive activity throughout the U.S. and more general situational awareness of volcanic activity globally.
- A National Volcano Data Center to archive all the diverse kinds of data produced by NVEWS.
- An NVEWS web site with a daily status report covering all monitored volcanoes, with graphics and plots of monitoring data and links to other related sites.
- Efficient coordination of volcano-monitoring resources across agencies and institutions.

NVEWS Organizational Structure

NVEWS would be implemented under the existing observatory-based structure of the USGS Volcano Hazards Program and affiliated CUSVO partners. The observatories would continue to be the focal points for data gathering and analysis, information dissemination, and forecasting activity, just as they are now. The strength of the current system is that observatory staff meets directly with local emergency-response officials to explain the pertinent data and ensure that all parties understand the significance of hazard assessments and forecasts; the importance of face-to-face professional relationships for such matters cannot be overestimated.

NVEWS is an opportunity to develop a higher degree of inter-operability between scientific groups than currently exists. Using recent advances in IT and high-speed data transmission, NVEWS would institute the hardware, software, and networking infrastructure to permit data streams from monitored volcanoes to be accessed with a common suite of data-analysis tools in real time at multiple locations. We propose that development of data-analysis and data-management tools be guided by a CUSVO IT working group under a broader NVEWS coordinating committee. Enhanced inter-operability will greatly aid both crisis response and research as scientists from different locations and specialties will be able to collaborate more easily on projects or form small teams to address larger issues.

General Equipment Needs of NVEWS

Volcanoes are complex systems that are monitored with a variety of geophysical, geochemical, and geospatial sensor systems (such as seismometers, GPS stations, tiltmeters, borehole strainmeters, microbarometers, gas sensors, lahar detectors, Doppler RADAR, stream and precipitation gauges, weather satellites, etc.). Addressing inadequacies and gaps in monitoring would require a substantial investment over the next decade beyond the current resources of the USGS Volcano Hazards Program and its affiliated partners. The needed monitoring improvements would entail new capital costs for equipment and recurring expenses for operation and maintenance and take several years to implement.

Some equipment needs of NVEWS can be met by instrument arrays funded by the National Science Foundation as part of its Earthscope Program. As part of Earthscope's Plate Boundary Observatory (PBO) projects, installation of strain-measuring instruments (GPS stations, tiltmeters, borehole strainmeters, and borehole seismometers) is planned at a few volcanoes that are also NVEWS targets. Already, PBO accelerated the planned deployment of GPS stations to augment the monitoring effort at Mount St. Helens when the volcano resumed activity in 2004. Wherever there are joint interests, NVEWS plans will be closely coordinated with plans of PBO (or similar groups) to eliminate duplication and ensure efficient use of government-funded resources.

Improvements to telemetry infrastructure also must occur along with an increase in monitoring instrumentation. Robust, broadband data transmission infrastructure is necessary to reliably carry data from the various instrument types at the volcanoes to the observatories and partner institutions. For example, in areas without straightforward terrestrial radio telemetry or access to telephone lines, more use of Very Small Aperture Terminal (VSAT) satellite communications systems will be needed to carry large volumes of data generated by seismic and other sensors. Over the next few years, we can expect to see new technological developments in telemetry systems that should be exploited for volcano monitoring.

In the event that an under-monitored volcano becomes restless before NVEWS can be fully implemented, or an eruption occurs at an unlikely volcano, a cache of instruments needs to be available for immediate deployment. A limited cache of instruments was used to help with the recent monitoring response at Mount St. Helens, but a much more extensive cache is needed to deal with volcanoes that reawaken but lack adequate monitoring infrastructure. Some equipment in the cache would be rotated into permanent installations and then directly replaced; other items in the cache would be one-of-a-kind instruments to be deployed as needed then returned to the cache (e.g., portable Doppler RADAR, certain kinds of airborne gas sensors). Deploying instruments from a cache wastes time and does not fulfill the basic NVEWS goal of optimal data collection and earliest warning, but it does serve as a critical safeguard for monitoring capability when needed.

NVEWS Information Technology

The advances in Information Technology (IT) over the past 10 years are staggering. Raw computing power and storage capabilities combined with lower costs provide, what were until recently, improbable amounts of data and analytical computational power to a scientist. Equally impressive are the advances in data transmission that make it possible to view data in almost real-time, almost anywhere on the planet.

NVEWS proposes to take advantage of these IT advances by implementing a framework to store and access NVEWS data, which will require enhancing efforts to establish common data formats and common database schemas, as well as acquiring the hardware and software for the system. As this framework is established, software programmers will work with scientists to develop the next generation of visualization and analysis tools. These tools will encompass tasks from the routine (displaying simple time-series data from a seismometer, for instance) to the complex (real-time modeling of deformation data). NVEWS data come from a wide variety of sources including field instruments operated by the volcano observatories, field instruments operated by groups outside the observatories, maps compiled by a variety of sources over decades, existing reports and photographs, and remote sensing data collected by satellites, to name just a few sources. NVEWS would organize these disparate data in such a way that they are readily and reliably available for scientific analysis.

With the implementation of standard formats, techniques, and tools – as recommended by the National Research Council review in 2000 of the USGS Volcano Hazards Program – the observatories would become the basis of a national system of inter-operating nodes such that resources can be quickly focused where needed during crises and teams of scientists can easily create formal or informal work groups no matter where they are geographically located. A conceptual model of the proposed NVEWS IT system is presented in Figure 6.

Data storage – in terms of both the quantity and the diversity of data collected – is a major issue for NVEWS. Each observatory-related data center now collects on the order of 10 gigabytes of data each day, and under NVEWS this number would increase 5 to 10 times. The bulk of the data is from the real-time geophysical networks and from a variety of satellite-based sensors. In addition to the real-time data is a skyrocketing amount of video and digital photography. At the present time, the amount of data is swamping the existing IT infrastructure.

The NVEWS model recognizes the need for greater computational power at each observatory data center and broadband connections for rapid data transmission between them. To address this, NVEWS would establish the necessary online data servers where the data are collected. Rather than fight the natural flow of information to an observatory from its networks, each observatory data center would maintain several servers capable of holding 10's of terabytes of data and the ability to add more. NVEWS would establish standard technologies for these servers to acquire, store, and serve data to scientists. Standard interfaces and databases will enable developers to produce tools that can be used at all observatories. This degree of inter-operability will permit the efficient operation of a 24X7 Volcano Watch Office (see below).

For long-term data archiving, NVEWS would take advantage of the several existing centers that have been set up by the various scientific communities for specific data where staff are dedicated to tracking data storage in a systematic manner. For example, GPS data can be archived through UNAVCO, seismic data at one of several data centers (e.g., IRIS or UC-Berkeley), and satellite data at the USGS Eros Data Center among other groups. However, there is no existing institution that is set up to archive all of the diverse kinds of data that the NVEWS will produce. Such a volcano data archive (a National Volcano Data Center) could be established within one of the CUSVO member institutions to provide a single portal to volcanic data rather than requiring researchers to go the different archives to assemble the data set they need. The volcano-data archive may still draw on data stored at the other discipline-specific archive centers, but it will simplify retrieval and integration of those data with other data sets.

24X7 National Volcano Watch Office
NVEWS proposes to institute a National 24X7 Volcano Watch Office to improve alerting capabilities and provide authoritative information on U.S. volcanic activity and greater situational awareness of volcanic activity globally. A Volcano Watch Office does not supersede or replace existing observatories but instead complements them by providing a true 24X7 capability, replacing the system of alarms, pagers, answering services, assigned checks of data from home during nonbusiness hours, etc. currently used by the observatories. The Watch Office cannot be detached from the observatories as a stand-alone entity. It is to be an arm of each observatory in order to insure that significant changes in volcanic activity are detected quickly and appropriate action taken. However, the Volcano Watch Office can take advantage of the enhanced inter-operability of observatories possible under NVEWS by sharing watch duties among all the observatories in a distributed fashion. Watch Office staff also should be able to contribute to other tasks related to expansion of monitoring networks and development of IT systems. The National Volcano Watch Office would complement the National Earthquake Information Center (NEIC), NOAA's Pacific and Alaska Tsunami Warning Centers, and pertinent DoD operations.

Figure 6A. Proposed model for data and information flow through an observatory under NVEWS. Data collected locally and from non-observatory collaborators flow into the observatory data servers. NVEWS staff, both inside and outside the observatory, accesses the data using common tools and protocols.

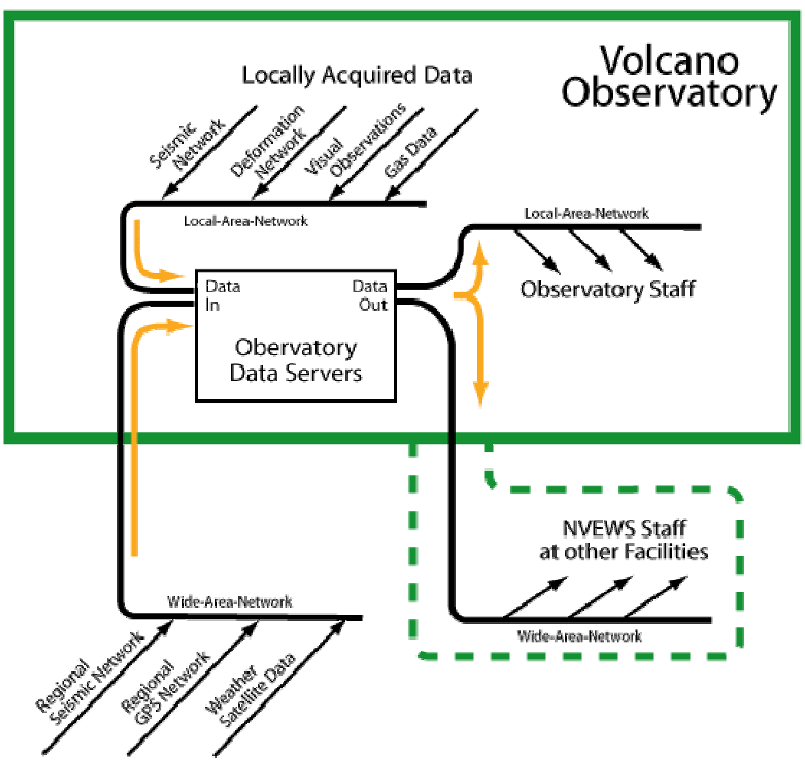
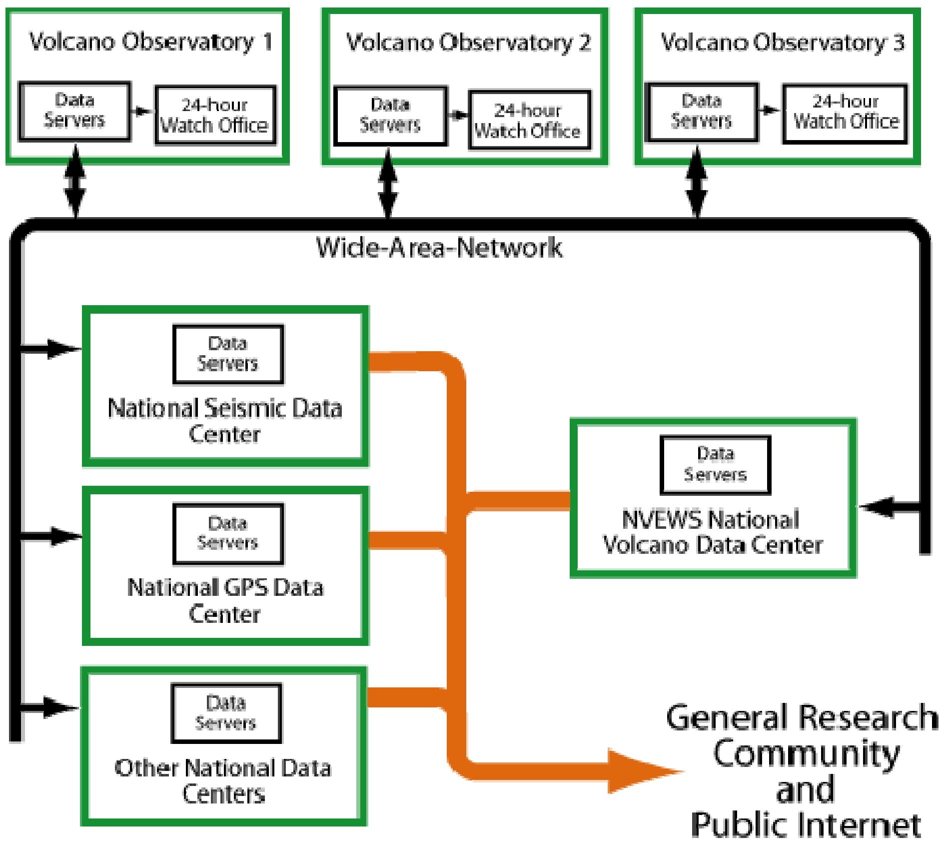


Figure 6B. Proposed model of NVEWS data and information flow to data centers and general research community. Individual volcano observatories and the Volcano Watch Office maintain data holdings at their facilities for their own use. Copies of the data are sent to national centers where they are archived and available for public use. For data with no suitable national center, NVEWS proposes to establish a National Volcano Data Center (NVDC) to hold and distribute these data. Additionally, the NVDC would provide portals to all data, whether on NVDC servers or elsewhere, for users interested in acquiring integerated data sets specific to volcanology.



NVEWS Coordination Mechanisms

We propose that an NVEWS coordinating committee be established under CUSVO to develop a full implementation plan. Coordination with NSF-funded projects will take place primarily through EarthScope committees, in particular the Science and Education Committee, Facilities Executive Committee, EarthScope/PBO Standing Committee, and PBO Magmatic Systems Site Selection Committee. Some CUSVO members already serve on or advise these committees, and a PBO representative is a member of CUSVO.

Regional seismic networks that are operated to track earthquake hazards also provide data about volcano seismicity in some areas, and vice versa. Accordingly, NVEWS will coordinate development of its seismic networks with the Advanced National Seismic System (ANSS). The administration of ANSS is along regional lines – Alaska, Hawaii, Washington/Oregon, California, and Yellowstone – that can mesh sensibly with the volcano-observatory structure of NVEWS.

NVEWS also will rely on ongoing activities that use Synthetic Aperture Radar (SAR) interferometry to monitor deformation at volcanoes. USGS scientists have access to data from European Space Agency SAR satellites and, in collaboration with NASA and with the Alaska Satellite Facility at the University of Alaska, have access to SAR data from the Canadian Radarsat satellite. Access to future Japanese SAR data will also be coordinated through the Alaska Satellite Facility.

Major interagency coordination is necessary to issue real-time hazard warnings about volcanic-ash clouds to the aviation sector. Much of that coordination is done through the NOAA's Office of the Federal Coordinator for Meteorology (OFCM), specifically the Volcanic Ash Working Group which has representation from the USGS, NOAA, FAA, NASA, DOD, and Smithsonian Institution. NVEWS will continue to use that venue for coordination of its relevant activities.

Role of Research in NVEWS

Research on volcanic processes is integral to volcano-monitoring activities and is conducted by the USGS, as well as by the academic community. Observations from monitoring networks are used to formulate and test models of volcanic behavior so that unrest can be interpreted more definitively and forecasts improved. Monitoring without research into the driving physico-chemical processes becomes mechanistic pattern recognition, an inadequate approach to phenomena as complex as volcanoes. Research and experience in the 25 years since the 1980 eruption of Mount St. Helens has brought volcanology to a point where, with adequate monitoring systems in place, the timing of volcanic eruptions can be forecast with some confidence hours to days in advance. The next first-order scientific goal for volcanology is to be able to accurately forecast the style and magnitude of eruptions. NVEWS will help achieve this goal by creating a much richer body of observations and data on volcanic activity and eliminating barriers that impede the use of monitoring data for innovative and multi-disciplinary scientific research.

External Grants Program

To augment its knowledge base, NVEWS proposes a competitive, peer-reviewed program to award research grants to entities in academia and the private sector for investigations *coordinated with and complementary to NVEWS activities*. This initiative would more directly incorporate the Nation's volcanological expertise in academia. NSF does not have a program devoted specifically to volcanology, nor are the practical aspects of monitoring and volcano-hazard assessment the main focus of NSF-funded projects. The USGS Volcano Hazards Program could administer such a grants program. We propose that 10-15% of new funding for NVEWS be devoted to an external grants program.

Next Steps for NVEWS

As a next step, the USGS Volcano Hazards Program will convene workshops to review and refine the implementation framework proposed here. A workshop will be held with the full CUSVO membership and other scientific stakeholders to establish data and operational policies and launch topical working groups. At another workshop, a broader group including representatives from other Federal agencies (such as the National Oceanic and Atmospheric Administration, Federal Aviation Administration, National Park Service, Department of Homeland Security, and National Science Foundation), State and County emergency management agencies, and business and private organizations, will be consulted about their specific information requirements.

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APPENDIX 1

C U S V O
CONSORTIUM OF U.S. VOLCANO OBSERVATORIES
Alaska, Cascades, Hawaii, Long Valley, Yellowstone

CHARTER
23 January 2002

CUSVO is established to strengthen interaction and communication among Federal, state, and academic representatives of the five U.S. volcano observatories supported by the USGS Volcano Hazards Program – the Alaska Volcano Observatory (AVO), the Cascades Volcano Observatory (CVO), the Hawaiian Volcano Observatory (HVO), the Long Valley Observatory (LVO), and the Yellowstone Volcano Observatory (YVO). The purpose of the consortium is to enhance scientific and technical coordination on operational and research matters that are of broad mutual concern among the observatories, with the goal of generating consensus, where appropriate, for common operating procedures and uniform data standards and products. The consortium will meet periodically as a group to discuss specific pertinent matters and also may convene scientific workshops on specialized topics, prepare technical white papers and planning documents, undertake educational outreach to promote understanding of observatory activities, and interact with other groups involved with volcano monitoring and related research.

CUSVO is a voluntary scientific working group. It is not administered as a bureaucratic unit of any single institution or entity. The objectives and undertakings of CUSVO are aligned with the Federal monitoring, research, and mitigation mission of the USGS Volcano Hazards Program, which provides the primary funding and overall scientific direction for observatory activities. Recommendations, decisions, and policies espoused by the consortium will be based on inclusive, open discussion and solid consensus among its members.

Membership in CUSVO is *ex-officio* and consists of the: USGS Volcano Hazards Team Chief Scientist, USGS Volcano Hazards Program Coordinator, USGS Scientist-in-Charge of AVO, Coordinating Scientist of AVO at the University of Alaska Fairbanks Geophysical Institute, AVO state representative at the Alaska Division of Geological and Geophysical Surveys, USGS Scientist-in-Charge of CVO, Director of the Pacific Northwest Seismic Network at the University of Washington, USGS Scientist-in-Charge of HVO, Director of the Center for the Study of Active Volcanoes at the University of Hawaii, USGS Scientist-in-Charge of LVO, USGS Scientist-in-Charge of YVO, Coordinating Scientist of YVO at the University of Utah, Coordinating Scientist of YVO at Yellowstone National Park, USGS Chief of the Volcano Disaster Assistance Program for the VHP, seismic-network manager for the USGS Earthquake Hazards Program, and an executive secretary who can be from any participating agency or institution. Members may be added or removed to reflect changes in the scientific offices of the participating groups. There is no standing chairperson of CUSVO; each meeting is to be chaired by a member(s) appropriate for the topic of the meeting and agreeable to the majority of other members.

LIST OF PARTICIPANTS IN MEETINGS TO FORMULATE NVEWS

Meetings were held on:

25-26 Feb. 2004, Cascades Volcano Observatory, Vancouver WA
13-14 May 2004, Cascades Volcano Observatory, Vancouver WA
10 Aug. 2004, Cascades Volcano Observatory, Vancouver WA
11 Dec. 2004, American Geophysical Union Annaul Meeting, San Francisco CA

Attendees, in alphabetical order:

David Applegate, USGS
Steven Brantley, USGS
Peter Cervelli, USGS
Daniel Dzurisin, USGS
John Eichelberger, University of Alaska Fairbanks
Elliot Endo, USGS
William Evans, USGS
John Ewert, USGS
Marianne Guffanti, USGS (meetings chair)
Christopher Harpel, USGS
Rosalind Helz, USGS
David Hill, USGS
Shaul Hurwitz, USGS
Michael Jackson, UNAVCO
Michael Lisowski, USGS
Jacob Lowenstern, USGS
Steven Malone, University of Washington
Kenneth McGee, USGS
C. Dan Miller, USGS
Seth Moran, USGS
Thomas Murray, USGS
Manuel Nathenson, USGS
Christopher Nye, Alaska Division of Geological and Geophysical Surveys
John Power, USGS
David Oppenheimer, USGS
James Quick, USGS
David Schmidt, University of Oregon
Robert Smith, University of Utah
Donald Swanson, USGS
Donald Thomas, Universtiy of Hawaii
Jeffrey Wynn, USGS

APPENDIX 2

EXPLANATION OF HAZARD AND EXPOSURE FACTORS FOR NVEWS THREAT ASSESSMENT

Hazard factors

The hazards-ranking schema relies heavily on the Smithsonian's Global Volcanism Program (GVP) volcano reference file as the principal source of the volcano coordinate, volcano type, eruption frequency, and eruption magnitude data. Other references used as general information sources are Wood and Kienle (1990), and Miller and others (1998) supplemented as necessary with other maps, reports or journal articles. There are a number of "not determined" (nd) entries, particularly for the unrest fields for Alaskan volcanoes. These uncertainties reflect the state of monitoring capabilities at this writing.

Volcano Type (0,1): The GVP classification of volcano type is used to help score other factors. *Type 0* volcanoes are cinder cones, basaltic volcanic fields, shields, tuff rings, and fissure vents. *Type 1* volcanoes are the generally more explosive stratovolcanoes, lava domes, complex volcanoes, maars, or calderas. The score given for volcano type is the most basic breakout of less dangerous (Type 0) versus more dangerous (Type 1). The *Type* assigned in the GVP system does not always accurately reflect the behavior of the volcanic system. For instance, both Newberry and Medicine Lake are listed as shield volcanoes, but both have produced moderate-sized explosive silicic eruptions. In cases where the assigned type does not accurately reflect known behavior, the volcano was scored as appropriate. Volcanoes modified were Yanuska, Okmok, Nunivak Island, Ingakslugwat Hills, St. Micheal, and Wrangell, Alaska; Newberry and Medicine Lake, Oregon; Clear Lake and Mono Lake, California; Black Rock Desert, Utah; and Kilauea, Hawaii; which received a score of 1. Mt. Jefferson, Oregon, a stratovolcano whose only Holocene activity has come from basaltic flank vents, received a score of 0.

Maximum VEI (scored 0-3 in this scheme): The Volcano Explosivity Index (VEI), defined by Newhall and Self (1982), is a simple 0-8 index of increasing eruptive explosivity, each interval representing an increase of approximately a factor of 10. Owing to uncertainties in assigning VEI estimates to prehistoric or early historic eruptions, and the gradational transition from one VEI level to the next, this system codes VEI designations into 4 scoring categories based mainly on the GVP catalog listings. VEI ≤ 2 receive a 0 because they tend to be short lived and/or not particularly dangerous except in areas close to the vent. VEI 2 is also the GVP's default designation for historical explosive eruptions for which there are no additional descriptive information (Simkin and Siebert, 1994) and as such includes many smaller magnitude eruptions as well. Larger eruptions are more reliably reported historically and usually leave clear evidence of their prehistoric occurrence in the geologic record, giving us greater confidence that the larger eruptions are more accurately captured. VEI 3-4 receive a 1, VEI 5-6 receive a score of 2, and VEI 7-8 receive a score of 3. If no eruption magnitudes are reported in the literature, *Volcano type* is used to assign a default score of 0 (for Type 0 volcanoes) or 1 (for Type 1 volcanoes). In the United States, the score of 3 is limited to the few large Pleistocene-age silicic caldera systems—Long Valley, Yellowstone, and Valles—none of which have had Holocene-age magmatic eruptions. In these cases, the score of 3 is based on the estimated volume of the ignimbrite rather than a formal VEI designation.

Explosive Activity and Major Explosive Activity (0-1): These two factors are meant to emphasize particularly active, explosive systems, and de-emphasize systems that may have had major explosive activity at some point in the Holocene, but have changed their eruptive style or have quieted down since (e.g., Crater Lake, Oregon).

Eruption Recurrence (0,1): This factor is meant to capture the average time between eruptions, irrespective of explosivity. Eruption recurrence intervals are often bimodal, with clusters of frequent eruptions separated by longer times of quiet (Nathenson, 2001). Because only a limited number of volcanoes have had extensive radiometric dating of eruption products, we employ only 4 broad groupings of recurrence intervals. Although volcanoes with longer eruption recurrence intervals tend to produce more powerful eruptions, this behavior is accounted for in the Explosive activity codes. Large Pleistocene-age silicic caldera systems receive a score of 1 for this factor only if they have demonstrable seismic, deformation *and* fumarolic unrest. The Eruption Recurrence code factor recognizes large basaltic systems like Kilauea and Mauna Loa for non-explosive but frequently occurring hazards.

Holocene Pyroclastic Flows (0,1): Pyroclastic flows are one of the most destructive and lethal of volcano hazards. If a system has generated pyroclastic flows in past eruptions, it is deemed capable of producing them again.

Holocene Lahar (0,1): This factor is meant to account for large lahars (volcanic debris flows), that traveled beyond the immediate eruption site, beyond the volcanic edifice, and reached now-populated, or potentially-populated areas. As with pyroclastic flows, if a system has generated lahars in past eruptions, it is deemed capable of producing them again.

Holocene Lava Flows (0,1): This factor flags volcanoes that have produced a lava flow that traveled to populated or potentially populated areas, i.e. some distance beyond the immediate vicinity of the vent.

Holocene Tsunami (0,1): Volcanogenic tsunamis can be generated by several causes. If a tsunami was generated by a sector collapse, and collapses are no longer a factor, then a score of 0 is given. Otherwise, if the tsunami was caused by factors such as explosions through water, dome collapse, or pyroclastic flows, then more may be deemed possible, and a score of 1 is given.

Hydrothermal Explosion Potential (0,1): This factor is meant to capture those systems that have evidence of significant Holocene phreatic explosive activity, and/or those systems whose thermal features are extensive enough to pose a potential for explosive activity.

Sector Collapse Potential (0,1): This factor is probably the most ambiguous in its application. It is limited to stratovolcanoes, and large oceanic shield volcanoes (Kilauea and Mauna Loa, Hawaii). In general if the volcano has more than about 1000 m relief, has active fumaroles, or has large altered areas and/or has a permanent snow and ice cover, and appears steep sided, it was scored positively. If a volcano has a history of sector collapses and has rebuilt its edifice it also received a score of 1. For instance, Mount Shasta got a score, but Mount St. Helens did not. The Alaska Volcano Observatory considers all Aleutian stratovolcanoes that form the bulk of islands or are near the coastlines of islands to have significant collapse potential and these were scored accordingly. This factor can be more rigorously evaluated on a case by case basis if detailed geological and topographical data are available, such as was done for Mount Rainier (Reid and others, 2001).

Primary Lahar Source (0,1): Not all volcanoes have been mapped well enough to determine whether or not lahars are part of their history, so this factor considers the key ingredient, water in the form of lakes, rivers and ice on the volcanic edifice. Approximately 10^6 m^3 is the threshold water volume to filter out volcanoes with small lakes and marginal permanent snow cover.

Historical unrest factors

Unrest is taken to mean abnormal geophysical activity since the last eruption. The unrest factors apply if the unrest occurred since the last eruption and is ongoing or occurs in fits and starts. Fumarolic activity and the presence of magmatic gas isotopes in cold springs or vents provide the most persistent signal of unrest or latent magmatic activity. Fumarolic or hot spring activity is easily observed and these phenomena have been widely catalogued through time providing greater confidence that this form of unrest is accurately captured in this study. Seismic and deformation unrest nearly always require instrumental detection, and thus, the number of volcanoes scoring positively for this factor is small because the sample time frame is short. Globally, there are exceptions where long historical records include reports of persistent felt seismicity near volcanoes in the Mediterranean, Latin America, and Asia, and where deformation that can be tracked by evidence left by apparent changes in sea level on natural and man-made features, but these are rare. Owing to the short time (approximately 30 years) over which we have instrumental observations in the U.S., seismic and deformation unrest at numerous volcanoes is scored as ‘not determined’ (nd).

Seismic Unrest (0,1): The criterion for scoring this factor is any seismic activity within about 20 km of a volcano. Some volcanoes are larger than 40 km in diameter so some flexibility in the distance is necessary. The only type of seismicity excluded from this code comprises tectonic earthquakes that occur on regional faults not directly related to the volcanic system.

Deformation Unrest (0,1): This factor is meant to capture those systems that are deforming in response to magma intrusion or that exhibit gross changes in the existing hydrothermal system. Not included are those systems that are only subsiding (e.g., Medicine Lake). Most of the examples of deformation come from either USGS leveling campaigns or InSar surveys, and more systems are likely to be found actively deforming as InSAR data become more extensive and more instruments are deployed globally. Lu and others (2003, and references therein) was the principal source of information for Alaskan volcanoes.

Fumarolic or Other Magmatic Degassing (0,1): Any fumaroles or thermal features associated with a volcanic system result in a score. Cold degassing of magmatic gases is also included as a positive factor (e.g. carbon dioxide at Long Valley, sulfur/chloride anomalies at South Sister).

Exposure factors rationale

Population potentially at risk on the ground can now be easily estimated through the use of the LandScan population database (Ewert and Harpel, 2004). Infrastructure potentially at risk was coded using map data at various scales (e.g., Federal lands at 1:2M, http://nationalatlas.gov/atlasftp.html), and Heiken and others (1995) for power generation/transmission. A volcano's proximity to airports was determined using a U.S. Department of Transportation Master Coordinate Table for airports (http://www.transtats.bts.gov). Regional aviation risk is based primarily on passenger counts and does not take into account the significant amount of freight traffic flying the North Pacific or other air routes. Much more work needs to be done to better quantify the number of planes and passengers traversing volcanic regions and the aviation numbers reported here are minimums. Exposure to tephra fall hazards beyond the immediate vicinity of the volcano are not considered here though more people are adversely affected by airfall tephra than any other volcanic phenomena. Where tephra falls beyond the immediate vicinity of the volcanic edifice is determined by the vicissitudes of wind velocity and direction, and estimating the numbers of persons that would be potentially affected by this phenomena is beyond the scope of this study.

VPI_{30} (0 to x): This code is the $\log_{10}$ of the population within 30 km radius circle of a volcano. The LandScan 2002 database (http://www.ornl.gov/sci/gist/landscan/) produced by the Oak Ridge National Laboratory is used in conjunction with coordinate data from the GVP reference file to calculate the number of people within 30 km. The 30 km distance was chosen for several reasons: 1) population distributions near volcanoes vary greatly with latitude and 30 km appears to catch proximal population in all regions, 2) data in Newhall and Hoblitt (2002) show that for VEI 4-5 (for many systems the likely worst case) eruptions, a pyroclastic flow has a small but significant (approximately 5 percent) chance of exceeding 30 km distance from the vent, 3) data from Newhall and Hoblitt (2002) also indicate an that the probability of tephra accumulations exceeding 10 cm at 30 km downwind are about 10 percent for a VEI 3 eruption, and about 80% for VEI $\geq$4. Pyroclastic flows are a lethal hazard, and accumulation of several centimeters of tephra has adverse effects on surface transportation, electric power distribution, surface water supplies, etc. A 10 cm accumulation volcanic ash, particularly if it is wet, is the threshold beyond which structural damage to buildings begins. Thus, this index estimates how many persons on the ground may be subject to serious (life-threatening) effects.

Yellowstone and other volcanoes with decidedly seasonal populations did not score appropriately with this metric. For instance, the Landscan data base indicates that there are no people within 30 km of the coordinate given for Yellowstone (not far from Old Faithful), yet visitation to the park is close to 3 million people per year, most of it in the summer months. Similar situations exist for most other National Park and National Monument volcanoes. Where annual visitor statistics are available, those numbers were divided by 365 to produce a nominal average population whose activities would potentially be affected by volcanic activity and the $\log_{10}$ of this number was added to the LandScan-derived number and the result entered as the VPI_{30}. Visitor statistics were available for National Parks and Monuments administered by the National Park Service. This procedure was also followed for the town of Mammoth Lakes which lies within 30 km of three volcanoes and has a transient recreational population that is double the permanent population in both winter and summer. Visitor statistics for popular volcano-recreation sites on U.S. Forest Service land (e.g., Mount Hood, Newberry Volcano, Mount Shasta, etc.) were not readily available for this study.

In volcanic fields which consist of numerous vents dispersed over large areas, the VPI_{30} estimate is taken from the single GVP coordinate for the field, which approximates the geometric center of the entire field (Simkin and Siebert, 1994).

Log_{10} of Approximate Population Downstream or Downslope, outside the 30 km VPI circle (0-x): This factor is used only with volcanoes that have a primary lahar hazard (e.g., Cascade or Alaskan stratovolcanoes) or significant lava flow hazard (e.g., Mauna Loa) that extends farther than 30 km from vent areas. Where digital volcano hazards maps exist as Geographic Information System (GIS) layers, the flowage hazard zones outside the 30 km VPI circle were overlain on the LandScan 2002 to estimate this factor. These calculations were made for Kilauea, Mauna Loa, Mauna Kea, Hualalai, Mount Baker, Glacier Peak, Mount Rainer, Mount St. Helens, Mount Adams, Mount Hood, South Sister, Crater Lake, and Newberry Volcano. Estimates were made for Mount Shasta and Lassen Peak by USGS volcanologists familiar with the hazards and geography of these areas (Michael A. Clynne, oral communication, 2004). This methodology has not yet been applied to Alaskan volcanoes, though given the generally sparse population in the volcanic regions of Alaska, this factor will probably not change the overall threat rankings significantly.

Historical Fatalities (0,1): If there were fatalities at a volcano in the past and a permanent, population is still present, chances are good that fatalities may happen again.

Historical Evacuations (0,1): If there were evacuations at a volcano in the past and a permanent, population is still present, chances are good that evacuations may be imposed again.

Local aviation exposure (0-2): Local threats to aviation by volcanoes are principally to airports. We reviewed a database on effects of volcanic activity on airports (Guffanti and others, 2003) and found that 75 percent of airports adversely affected by volcanic activity were all within 300 km of the erupting volcano, while those affected solely by basaltic-type eruptions were generally within 50 km. To quantify airport exposure the following scoring criteria are used: If any type volcano is within 50 km of a jet-service airport it gets a score of 1; if a Type 1 volcano (generally explosive potential) is within 300 km of a jet-service airport it gets a score of 1; if a Type 1 volcano is within 300 km of a major international airport it gets a score of 2; if none of these criteria are met the volcano gets a score of 0. Jet service airports used were: Adak, Cold Bay, Sitka, Petersburg/Wrangel, Ketchikan, Sun Valley, Idaho Falls, Jackson Hole, Reno, Mammoth, Albuquerque, Klamath Falls, Medford, Bend-Redmond, Salt Lake City, Phoenix, Sacramento, and Aspen. All *Type 1* volcanoes in the conterminous U.S. are within 300 km of a jet service airport. Major international airports used were: Anchorage, Fairbanks, Seattle/Tacoma, Portland, San Francisco-Oakland, Las Vegas, Honolulu, Kona, and Saipan.

Regional Aviation exposure = log_{10} of daily passenger count (0-x): This is one of the more difficult exposure factors to quantify. Information on how many jet aircraft and passengers traverse a volcanic area in a given time period are not easily available. As a starting point, we used the airport statistics available from the US D.O.T. (2001) for the principal airports located in or near volcanic areas (Anchorage, Fairbanks, Seattle-Tacoma, Portland, Sacramento, San Francisco, Honolulu, Hilo, Kona, Maui, Guam, and Saipan). These statistics give the number of enplaned (departing) passengers per year. Checking statistics in individual port annual reports generally confirms the DOT statistics and indicates that the approximate numbers of departing *and* arriving passengers can be obtained by multiplying the enplaned passengers by two. Air cargo flights are not included in this factor, though for the North Pacific routes these are an important part of the aviation exposure.

Passengers per day for US volcanic regions were estimated in the following manner: For the Washington and Oregon Cascades, the daily number of passengers reported for Seattle-Tacoma and Portland airports were added. For the California Cascades and Long Valley area the daily number of passengers at Sacramento and San Francisco/Oakland were added. For Hawaii the daily number of passengers from Honolulu, Kona, Hilo, and Maui were added. The intermountain portion of the conterminous U.S., Alaska and the Mariana Islands are a little more of a challenge to quantify owing to the greater proportion of overflight traffic in these regions. In the intermountain west, four volcanoes, Yellowstone, Dotsero, Valles, and Sunset Crater have potential regional aviation exposure, but there are few major airports in the region to provide passenger statistics. A factor of 5 was given to these four volcanoes, slightly less than for the volcanoes in the Pacific states, but in keeping with the overall high level of air traffic in the conterminous U.S. For the Marianas, an estimate of about 25,000 flights per year (about 67 per day) for a narrowly drawn box around the Northern Mariana Islands (including Guam) was received from Air Services Australia in 2003 (Christopher Bruce, written communication 2003). Airport statistics for Saipan and Guam indicate about 2.5 M passengers go to and from the Marianas each year (~6800 per day), but there are many flights each day between northern and southern Asia/Australia that transit the downwind area to the west which are not accounted for by the airport statistics or the Air Services Australia data. A conservative estimate of another 3200 passengers/per day was made to account for these giving the round number of 10,000 passengers/day potentially affected by eruptions in the Mariana Islands. Similarly for Alaska, the airport statistics for Anchorage and Fairbanks show about 11,100 passengers/day, but the data do not account for non-stop transits of the region. Miller and Casadevall (2000) estimate 200 flights and 20,000 passengers/day on the North Pacific air routes and their figure is used.

In all cases the $\log_{10}$ of the daily passenger counts was used as the regional aviation risk code. For the different regions, this code varies between 4 in the Mariana Islands and 5.15 in the California Cascades and Long Valley region. The regional code is applied only to *Type 1* volcanoes and those T*ype 0* volcanoes that have a history of producing explosive eruptions. The numbers are minimums, but the relative scores appear appropriate relative to one another.

Power Infrastructure (0,1): Power generation, transmission, or distribution within 30 km or within flowage hazard zone (e.g., power generation/transmission for electricity, oil, or gas), or a generation facility in the area typically downwind of the volcano get a score of 1 for this factor. Heiken and others (1995) are the main data source for this factor. Small distribution lines to a few cabins were not counted as “infrastructure”, but distribution lines within a town or city downwind were.

Transportation Infrastructure (0,1): Port facilities, rail lines, and major roads are included, and for this study state highways and interstate highways were considered major roads. In addition, as civil aviation is a critical mode of transportation in Alaska, Type 1 volcanoes near heavily used air traffic corridors received a point. Alaskan volcanoes that received this score were Mount Spurr, Mount Redoubt, and Augustine Volcano.

Major Development or Sensitive Area (0,1): This factor is meant to cover economically and symbolically important places, things, and activities. If a volcano is within a developed national park, it got a point. A volcano in a national park may also threaten developed areas outside park boundaries. Other examples that were counted as positives for this factor are ski areas on Cascade volcanoes and the fish packing plant at Akutan in the Aleutians.

Volcanic Island (0,1): Experience with eruptions on small populated islands over the past 100 years demonstrates the particular difficulty in mitigating volcano hazards in such situations. A volcano making up a significant portion of an island poses higher risk because islands are difficult to evacuate. This factor is only applied to islands with a permanent population.

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Hazard and exposure factors used in threat assessment of U.S. volcanoes for the National Volcano Early Warning System. See appendix text for discussion and explanation of abbreviations.	
Hazards Factors	**Score**
Volcano type If volcano type is cinder cone, basaltic field, small shield, or fissure vents: Score = 0 If volcano type is stratocone, lava domes, complex volcano, maar or caldera: Score = 1	
Maximum Volcano Explosivity Index (VEI) If maximum known VEI ≤ 2: Score = 0 If maximum known VEI = 3 or 4: Score = 1 If maximum known VEI = 5 or 6: Score = 2 If maximum known VEI ≥ 7: Score = *3* If no maximum VEI is listed by GVP and if volcano type = 0: Score = 0 If no maximum VEI is listed by GVP but volcano type = 1: Score = 1 If no known Holocene eruptions and the volcano is *not* a silicic caldera system: Score = 0	
Explosive activity If explosive activity (VEI ≥ 3) within the last 500 years: Score = 1	
Major explosive activity If major explosive activity (VEI ≥ 4) within last 5000 years: Score = 1	
Eruption recurrence If eruption interval is 1-99 years: Score = 4 If eruption interval is 100 – 1,000 years: Score = 3 If eruption interval is 1,000 to several thousand years: Score =2 If eruption interval is 5,000-10,000 years, or if no Holocene eruptions but it is a large-volume restless silicic system that has erupted in the last 100,000 years: Score = 1 If no known Holocene eruption: Score = 0	
Holocene pyroclastic flows? If yes: Score = 1	
Holocene lava flows? If Holocene lava flows have traveled beyond the immediate eruption site or flanks and reached populated areas: Score =1	
Holocene lahars? If Holocene lahars have traveled beyond the flanks and reached populated areas: Score =1	
Holocene tsunami(s)? Has it produced a tsunami within the Holocene? If yes: Score = 1	
Hydrothermal explosion potential? If the volcano has had Holocene phreatic explosive activity, and/or the volcano has thermal features that are extensive enough to pose a potential for explosive activity: Score =1	
Sector collapse potential? If the volcano has produced a sector collapse in Quaternary-Holocene time *and* has re-built its edifice, *or*, has high relief, steep flanks and demonstrated or inferred alteration: Score = 1	
Primary lahar source? If volcano has a source of permanent water/ice on edifice, water volume > 10^6 m^3: Score = 1	

Cont'd.

Historical Unrest Factors	
Observed seismic unrest Since the last eruption, in the absence of eruptive activity, within 20 km of the volcanic edifice? If yes: Score = 1	
Observed ground deformation Since the last eruption, in the absence of eruptive activity, inflation or other evidence of magma injection? If yes: Score = 1	
Observed fumarolic or magmatic degassing Since the last eruption, in the absence of eruptive activity, either heat source or magmatic gases? If yes: Score = 1	
Total of Hazard Factors	
Exposure Factors	
Log_{10} of Volcano Population Index (VPI) at 30 km Calculated with LandScan population database. Visitor statistics for volcanoes in National Parks and other destination recreation areas are added to the VPI factor where available.	
Log_{10} of approximate population downstream or downslope Population outside the 30 km VPI circle included within the extent of Holocene flow deposits or reasonable inundation modeling. This factor to be used only with volcanoes that have a primary lahar hazard (e.g. Cascade stratovolcanoes) or significant lava flow hazard (e.g. Mauna Loa).	
Historical fatalities? If yes, and a permanent population is still present: Score = 1	
Historical evacuations? If yes, and a permanent population is still present: Score = 1	
Local aviation exposure If any type volcano is within 50 km of a jet-service airport, score = 1; if a *Type 1* volcano is within 300 km of a jet-service airport, score = 1; if a *Type 1* volcano is within 300 km of a major international airport, score = 2; if none of these criteria are met, score = 0.	
Regional aviation exposure This score is based on the log_{10} of approximate daily passenger traffic in each region. At present, in the U.S., this score ranges from 4 to 5.15. The regional risk code is applied only to *type 1* volcanoes and those *type 0* volcanoes that have produced explosive eruptions.	
Power infrastructure Is there power infrastructure (e.g., power generation/transmission/distribution for electricity, oil, or gas) within flowage hazard zones, or in an area frequently downwind of the volcano and close enough to considered at some risk? If yes, score =1	
Transportation infrastructure Is there transportation infrastructure (e.g. port facilities, rail lines, major roads) within flowage hazard zones, or in an area frequently downwind of the volcano and close enough to considered at some risk? If yes, score = 1	
Major development or sensitive areas Are there major developments or sensitive areas threatened (e.g., National Park facilities, flood control projects, government facilities, developed tourist/recreation facilities, manufacturing or other significant economic activity)? If yes, score =1	
Volcano is a significant part of a populated island Holocene volcanic deposits cover >25% of land mass. If yes, score = 1	
Total of Exposure Factors	
Sum of all hazard factors x Sum of all exposure factors = Relative Threat Ranking	

APPENDIX 3

Scoring of NVEWS Hazard Factors at U.S. Volcanoes.

See Appendix 2 for explanation of factors.

NUMBER	NAME	LATITUDE	LONGITUDE	TYPE CODE	MAXIMUM VEI CODE	VEI≥3 IN LAST 500 YRS?	VEI≥4 IN LAST 5000 YRS?	ERUPTION RECURRENCE CODE	HOLOCENE PFS?	HOLOCENE LAHARS?	HOLOCENE LAVA FLOWS?	HOLOCENE TSUNAMI?	HYDROTHERMAL EXPLOSION POTENTIAL?	SECTOR COLLAPSE POTENTIAL?	PRIMARY LAHAR POTENTIAL?	SEISMIC SOURCE?	GROUND DEFORMATION?	FUMAROLIC,OTHER EGASSING?	**HAZARD SCORE**
1101-01-	Buldir	52.35	175.91	1	1	0	0	0	0	0	0	0	0	1	0	nd	nd	0	3
1101-02-	Kiska	52.10	177.60	1	1	1	1	4	0	0	0	0	0	1	1	nd	nd	1	11
1101-03-	Segula	52.02	178.14	1	1	0	0	1	0	0	0	0	0	1	0	nd	nd	0	4
1101-04-	Davidof	51.97	178.33	1	1	0	0	0	0	0	0	0	0	0	0	nd	nd	0	2
1101-05-	Little Sitkin	51.95	178.54	1	1	0	0	4	1	0	0	0	0	1	0	nd	nd	1	9
1101-06-	Semisopoch-noi	51.93	179.58	1	2	0	1	4	1	0	0	0	0	1	0	nd	nd	1	11
1101-07-	Gareloi	51.79	-178.79	1	1	1	1	4	1	0	0	0	0	1	1	1	nd	1	13
1101-08-	Tanaga	51.89	-178.15	1	1	0	0	3	0	0	0	0	0	1	1	1	nd	1	9
1101-09-	Takawangha	51.87	-178.01	1	1	0	0	0	0	0	0	0	0	1	1	nd	nd	0	4
1101-10-	Bobrof	51.91	-177.44	1	1	0	0	0	0	0	0	0	0	1	0	nd	nd	0	3
1101-11-	Kanaga	51.92	-177.17	1	1	1	1	4	1	0	0	0	0	1	1	1	nd	1	13
1101-111	Moffett	51.94	-176.75	1	1	0	0	0	0	0	0	0	0	1	1	0	nd	1	5
1101-112	Adagdak	51.99	-176.59	1	1	0	0	0	0	0	0	0	0	1	1	0	nd	1	5
1101-12-	Great Sitkin	52.08	-176.13	1	1	1	1	4	1	0	0	0	0	1	1	1	nd	1	13
1101-13-	Kasatochi	52.18	-175.51	1	1	0	0	3	0	0	0	0	0	1	0	nd	nd	0	6
1101-14-	Koniuji	52.22	-175.13	1	1	0	0	0	0	0	0	0	0	1	0	nd	nd	0	3
1101-15-	Sergief	52.03	-174.93	1	1	0	0	0	0	0	0	0	0	1	0	nd	nd	0	3
1101-16-	Atka (Korovin)	52.38	-174.15	1	1	1	0	4	0	0	0	0	0	1	1	nd	nd	1	10
1101-18-	Seguam	52.32	-172.51	1	2	1	1	4	1	0	0	0	0	0	0	nd	1	1	12
1101-19-	Amukta	52.50	-171.25	1	1	1	0	4	0	0	0	0	0	1	0	0	0	0	8
1101-20-	Chagulak	52.58	-171.13	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	3
1101-21-	Yunaska	52.64	-170.63	1	1	1	1	3	0	0	0	0	0	0	0	nd	nd	0	7
1101-22-	Herbert	52.74	-170.11	1	1	0	0	0	0	0	0	0	0	1	0	nd	nd	0	3
1101-23-	Carlisle	52.89	-170.05	1	1	0	0	3	0	0	0	0	0	1	1	nd	nd	0	7
1101-24-	Cleveland	52.83	-169.94	1	1	1	0	4	0	0	0	0	0	1	1	nd	nd	1	10
1101-25-	Uliaga	53.07	-169.77	1	1	0	0	0	0	0	0	0	0	1	0	nd	nd	0	3
1101-26-	Kagamil	52.97	-169.72	1	1	0	0	2	0	0	0	0	0	1	0	nd	nd	1	6
1101-27-	Vsevidof	53.13	-168.69	1	1	1	1	4	0	0	0	0	0	1	1	nd	nd	0	10
1101-28-	Recheschnoi	53.16	-168.54	1	1	0	1	2	0	0	0	0	0	1	1	nd	nd	1	8
1101-29-	Okmok	53.43	-168.13	1	2	1	1	4	1	1	0	1	0	0	1	1	1	1	16
1101-30-	Bogoslof	53.93	-168.03	1	1	1	0	4	0	0	0	0	0	0	0	nd	nd	1	8
1101-31-	Makushin	53.89	-166.92	1	2	1	1	4	1	1	0	0	0	1	1	1	1	1	16
1101-311	Table Top-Wide Bay	53.97	-166.68	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2

1101-32-	Akutan	54.13	-165.99	1	2	1	1	4	1	1	0	0	0	1	1	1	1	1	16
1101-34-	Westdahl	54.52	-164.65	1	2	1	1	4	1	0	0	0	0	0	1	1	1	1	14
1101-35-	Fisher	54.65	-164.43	1	2	1	1	2	1	0	0	0	0	0	0	0	nd	1	9
1101-36-	Shishaldin	54.76	-163.97	1	2	1	0	4	1	1	0	0	0	1	1	1	nd	1	14
1101-37-	Isanotski	54.77	-163.72	1	1	0	0	0	0	0	0	0	0	1	1	0	nd	0	4
1101-38-	Roundtop	54.80	-163.59	1	1	0	0	1	1	1	0	0	0	1	1	nd	nd	1	8
1101-39-	Amak	55.42	-163.15	1	1	0	0	2	0	0	0	0	0	1	0	nd	nd	0	5
1102-01-	Frosty	55.08	-162.81	1	1	0	0	1	1	1	0	0	0	1	1	nd	nd	0	7
1102-011	Dutton	55.17	-162.27	1	1	0	0	1	1	1	0	0	0	1	1	1	nd	1	9
1102-02-	Emmons Lake	55.34	-162.08	1	2	0	0	1	1	0	0	0	0	0	0	0	nd	1	6
1102-03-	Pavlof	55.42	-161.89	1	1	1	0	4	1	1	0	0	0	1	1	1	nd	1	13
1102-04-	Pavlof Sister	55.45	-161.84	1	1	0	1	2	0	1	0	0	0	1	1	nd	nd	1	9
1102-05-	Dana	55.64	-161.21	1	2	0	1	2	1	0	0	0	0	0	0	nd	nd	1	8
1102-051	Stepovak	55.93	-160.00	1	1	0	0	1	0	1	0	0	0	1	1	nd	nd	0	6
1102-06-	Kupreanof	56.01	-159.80	1	1	0	0	2	0	1	0	0	0	1	1	nd	nd	1	8
1102-07-	Veniaminof	56.17	-159.38	1	2	1	1	4	1	1	0	0	0	0	1	1	nd	1	14
1102-08-	Black Peak	56.55	-158.79	1	2	0	1	2	1	0	0	0	0	0	0	0	nd	0	7
1102-09-	Aniakchak	56.88	-158.17	1	2	1	1	3	1	1	0	1	0	0	0	1	nd	1	13
1102-10-	Yantarni	57.02	-157.19	1	2	0	1	2	1	0	0	0	0	1	1	nd	nd	0	9
1102-11-	Chiginagak	57.14	-156.99	1	1	0	1	2	1	1	0	0	0	1	1	nd	nd	1	10
1102-12-	Kialagvik	57.20	-156.75	1	1	0	0	1	1	0	0	0	0	0	1	nd	nd	0	5
1102-13-	Ugashik-Peulik	57.75	-156.37	1	2	1	1	3	1	1	0	0	0	1	1	nd	1	1	14
1102-131	Ukinrek Maars	57.83	-156.51	1	1	1	0	2	1	0	0	0	0	0	0	1	0	1	8
1102-132	Unnamed	57.87	-155.42	1	1	0	0	0	0	0	0	0	0	0	0	0	nd	0	2
1102-14-	Martin	58.17	-155.36	1	1	0	1	2	1	0	0	0	0	1	1	1	0	1	10
1102-15-	Mageik	58.20	-155.25	1	1	0	1	2	1	0	0	0	0	1	1	1	0	1	10
1102-16-	Trident	58.24	-155.10	1	1	1	1	2	1	0	0	0	0	1	1	1	1	1	12
1102-17-	Katmai	58.28	-154.96	1	1	1	1	2	1	1	0	0	0	1	1	1	0	1	12
1102-18-	Novarupta	58.27	-155.16	1	2	1	1	2	1	0	0	0	0	0	0	1	0	1	10
1102-19-	Griggs	58.35	-155.09	1	1	0	1	2	1	1	0	0	0	1	1	0	0	1	10
1102-20-	Snowy Mtn	58.34	-154.68	1	1	0	0	1	1	0	0	0	0	1	1	1	0	1	8
1102-21-	Denison	58.42	-154.45	1	1	0	0	1	0	0	0	0	0	1	1	nd	nd	0	5
1102-22-	Steller	58.43	-154.40	1	1	0	0	1	0	0	0	0	0	1	1	nd	nd	0	5
1102-23-	Kukak	58.45	-154.36	1	1	0	0	1	0	0	0	0	0	1	1	nd	nd	1	6
1102-25-	Kaguyak	58.61	-154.03	1	2	0	1	2	1	?	0	0	0	0	1	nd	nd	1	9
1102-26-	Fourpeaked	58.77	-153.67	1	1	0	0	0	0	0	0	0	0	1	1	nd	nd	0	4
1102-27-	Douglas	58.86	-153.54	1	1	0	0	2	0	0	0	0	0	1	1	nd	nd	1	7
1103-01-	Augustine	59.36	-153.43	1	1	1	1	4	1	1	0	1	0	1	0	1	nd	1	14
1103-02-	Iliamna	60.03	-153.09	1	1	1	1	2	1	1	0	0	0	1	1	1	nd	1	12
1103-03-	Redoubt	60.49	-152.74	1	1	1	1	4	1	1	0	0	0	1	1	1	0	1	14
1103-04-	Spurr	61.30	-152.25	1	1	1	1	4	1	1	0	0	0	1	1	1	nd	1	14
1103-05-	Hayes	61.64	-152.41	1	2	0	1	2	1	1	0	0	0	0	1	0	nd	0	9
1104-01-	St. Paul Is.	57.18	-170.30	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1104-02-	Nunivak Is.	60.02	-166.33	1	1	0	0	1	0	0	0	0	0	0	0	nd	nd	0	3
1104-03-	Ingakslugwat Hills	61.43	-164.47	1	1	0	0	1	0	0	0	0	0	0	0	nd	nd	0	3
1104-04-	St. Michael	63.45	-162.12	1	1	0	0	1	0	0	0	0	0	0	0	nd	nd	0	3
1104-05-	Kookooligit Mtns	63.60	-170.43	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1104-06-	Imuruk Lake	65.60	-163.92	0	0	0	0	2	0	0	0	0	0	0	0	nd	nd	0	2
1105-001	Buzzard Creek	64.07	-148.42	1	1	0	0	1	0	0	0	0	0	0	0	nd	nd	0	3
1105-01-	Sanford	62.22	-144.13	1	1	0	0	0	0	0	0	0	0	1	1	nd	nd	0	4

1105-02-	Wrangell	62.00	-144.02	1	2	0	1	3	1	0	0	0	0	1	1	1	nd	1	12
1105-021	Gordon	62.13	-143.08	0	0	0	0	0	0	0	0	0	0	1	1	nd	nd	0	2
1105-03-	Churchill	61.38	-141.75	1	2	0	1	2	1	1	0	0	0	1	1	nd	nd	0	10
1105-04-	Edgecumbe	57.05	-135.75	1	2	0	0	2	0	1	0	0	0	0	0	nd	nd	0	6
1105-05-	Duncan Canal	56.50	-133.10	0	0	0	0	1	0	1	0	0	0	0	0	nd	nd	0	2
1105-06-	Tlevak Strait-Suemez Is.	55.25	-133.30	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1105-07-	Behm Canal-Rudyerd Bay	55.32	-131.05	0	0	0	0	0	0	0	0	0	0	0	0	nd	nd	0	0
1201-01=	Baker	48.78	-121.81	1	1	0	0	1	1	1	0	0	1	1	1	0	0	1	9
1201-02-	Glacier Peak	48.11	-121.11	1	1	0	1	3	1	1	0	0	0	1	1	0	0	1	11
1201-03-	Rainier	46.87	-121.76	1	1	0	1	3	1	1	0	0	1	1	1	1	0	1	13
1201-04-	Adams	46.21	-121.49	1	0	0	0	2	0	1	0	0	0	1	1	0	0	1	7
1201-05-	St. Helens	46.20	-122.18	1	2	1	1	4	1	1	0	0	0	0	1	1	1	1	15
1201-06-	West Crater	45.88	-122.08	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	2
1201-07-	Indian Heaven	45.93	-121.82	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
1202-01-	Hood	45.37	-121.69	1	1	0	0	3	1	1	0	0	1	1	1	1	0	1	12
1202-02-	Jefferson	44.69	-121.80	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1202-03-	Blue Lake Crater	44.42	-121.77	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
1202-04-	Sand Mtn Field	44.38	-121.93	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1202-05-	Washington	44.33	-121.84	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1202-06-	Belknap	44.29	-121.84	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
1202-07-	N. Sister Field	44.17	-121.77	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0	4
1202-08-	South Sister	44.10	-121.77	1	1	0	1	2	1	1	0	0	0	1	1	1	1	1	12
1202-09-	Bachelor	43.98	-121.69	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3
1202-10-	Davis Lake	43.57	-121.82	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1202-11-	Newberry	43.72	-121.23	1	1	0	1	2	1	1	1	0	0	0	0	0	0	1	9
1202-12-	Devils Garden	43.51	-120.86	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1202-13-	Lava Mountain	43.47	-120.75	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1202-14-	Four Craters Lava Field	43.36	-120.67	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1202-15-	Cinnamon Butte	43.24	-122.11	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1202-16-	Crater Lake	42.93	-122.12	1	3	0	0	2	1	1	0	0	0	0	1	nd	nd	1	10
1202-17-	Diamond Craters	43.10	-118.75	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1202-19-	Jordan Craters	43.15	-117.47	0	0	0	0	1	0	0	1	0	0	0	0	nd	nd	0	2
1202-20-	Jackies Butte	42.61	-117.59	0	0	0	0	1	0	0	0	0	0	0	0	nd	nd	0	1
1203-01-	Shasta	41.42	-122.20	1	1	1	1	3	1	1	0	0	0	1	1	1	0	1	13
1203-02-	Medicine Lake	41.58	-121.57	1	1	0	0	2	0	0	1	0	0	0	0	1	0	1	7
1203-03-	Brushy Butte	41.18	-121.44	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-04-	Big Cave	40.96	-121.37	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-05-	Twin Buttes	40.78	-121.60	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-06-	Tumble Buttes	40.68	-121.55	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-08-	Lassen	40.49	-121.51	1	1	1	0	3	1	1	0	0	1	1	1	1	0	1	13
1203-09-	Eagle Lake Field	40.63	-120.83	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-10-	Clear Lake	38.97	-122.77	1	1	0	0	1	0	0	0	0	1	0	0	1	0	1	6
1203-11-	Mono Lake Volc Field	38.00	-119.03	1	1	0	0	2	0	0	0	0	0	0	0	0	0	1	5
1203-12-	Mono Craters	37.88	-119.00	1	1	0	1	2	1	1	0	0	0	0	0	0	0	1	8
1203-13-	Inyo Craters	37.69	-119.02	1	1	0	1	2	1	1	0	0	0	0	0	0	0	1	8
1203-14-	Long Valley	37.70	-118.87	1	3	0	0	1	0	0	0	0	1	0	0	1	1	1	9

1203-15-	Red Cones	37.58	-119.05	0	0	0	0	1	0	0	0	0	1	0	0	1	1	1	5
1203-16-	Ubehebe Craters	37.02	-117.45	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	4
1203-17-	Golden Trout Creek	36.36	-118.32	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-18-	Coso Volc Field	36.03	-117.82	1	1	0	0	1	0	0	0	0	0	0	0	1	0	1	5
1203-19-	Lavic Lake	34.75	-116.63	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1203-20-	Amboy	34.55	-115.78	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
1204-01-	Shoshone Lava Field	43.18	-114.35	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
1204-02-	Craters of the Moon	43.42	-113.50	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	3
1204-03-	Wapi Lava Field	42.88	-113.22	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
1204-04-	Hell's Half Acre	43.50	-112.45	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
1205-01-	Yellowstone	44.43	-110.67	1	3	0	0	1	0	0	0	0	1	0	0	1	1	1	9
1206-01-	Steamboat Springs	39.38	-119.72	1	1	0	0	0	0	0	0	0	1	0	0	0	0	1	4
1207-01-	Santa Clara	37.26	-113.63	0	0	0	0	1	0	0	0	0	0	0	0	nd	0	0	1
1207-03-	Bald Knoll	37.33	-112.41	0	0	0	0	1	0	0	0	0	0	0	0	nd	0	0	1
1207-04-	Markagunt Plateau	37.58	-112.67	0	0	0	0	1	0	0	0	0	0	0	0	nd	0	0	1
1207-05-	Black Rock Desert	38.97	-112.50	1	1	0	0	1	0	0	0	0	0	0	0	nd	0	0	3
1208-01-	Dotsero	39.65	-107.03	1	1	0	0	1	0	1	0	0	0	0	0	nd	0	0	4
1209-01-	Uinkaret Field	36.38	-113.13	0	0	0	0	1	0	0	0	0	0	0	0	nd	0	0	1
1209-02-	Sunset Crater	35.37	-111.50	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	3
1210-01-	Carrizozo	33.78	-105.93	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
1210-02-	Zuni-Bandera	34.80	-108.00	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
1210-03-	Valles Caldera	35.87	-106.57	1	3	0	0	0	0	0	0	0	0	0	0	0	0	1	5
1302-01-	Kilauea	19.43	-155.29	1	1	1	1	4	1	0	1	1	1	1	0	1	1	1	16
1302-02=	Mauna Loa	19.48	-155.61	0	0	0	0	4	0	1	1	1	0	1	0	1	1	1	11
1302-03-	Mauna Kea	19.82	-155.47	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	3
1302-04-	Hualalai	19.69	-155.87	1	0	0	0	3	0	0	1	0	0	0	0	1	0	0	6
1302-06-	Haleakala	20.71	-156.25	0	0	0	0	3	0	0	1	0	0	0	0	0	0	1	5
0804-14=	Farallon de Pajaros	20.53	144.90	1	0	0	0	4	0	0	0	0	0	1	0	1	0	1	8
0804-141	Ahyi	20.42	145.03	0	0	0	0	3	0	0	0	0	0	1	0	nd	0	0	4
0804-142	Supply Reef	20.13	145.10	0	0	0	0	3	0	0	0	0	0	1	0	nd	0	0	4
0804-143	Maug Islands	20.02	145.22	1	1	0	0	1	0	0	0	0	0	0	0	nd	nd	1	4
0804-15=	Asuncion	19.67	145.40	1	1	0	0	3	0	0	0	0	0	1	0	1	nd	1	8
0804-16=	Agrigan	18.77	145.67	1	1	1	1	3	1	0	0	0	0	1	0	1	0	1	11
0804-17=	Pagan	18.13	145.80	1	1	1	1	4	1	1	0	0	0	1	0	1	?	1	13
0804-18=	Alamagan	17.60	145.83	1	1	0	0	3	1	0	0	0	0	1	0	1	0	1	9
0804-19=	Guguan	17.32	145.85	1	1	0	0	3	0	0	0	0	0	1	0	1	0	1	8
0804-191	Sarigan	16.71	145.78	1	1	0	0	2	0	0	0	0	0	1	0	1	0	0	6
0804-20=	Anatahan	16.35	145.67	1	1	0	0	2	1	0	0	0	0	1	0	1	1	1	9
0804-201	Ruby	15.62	145.57	0	0	0	0	4	0	0	0	0	0	1	0	1	nd	0	6
0804-21=	Esmeralda Bank	15.00	145.25	0	0	0	0	4	0	0	0	0	0	1	0	1	nd	0	6

Scoring of NVEWS Exposure Factors at U.S. Volcanoes.

See Appendix 2 for explanation of factors.

NUMBER	NAME	LATITUDE	LONGITUDE	LOG VPI30	LOG APPX. DOWNSTREAM/SLOPE POPULATION	HISTORICAL FATALITIES?	HISTORICAL EVACUATIONS?	LOCAL AVIATION EXPOSURE?	REGIONAL AVIATION EXPOSURE?	POWER INFRASTRUCTURE?	TRANSPORTATION INFRASTRUCTURE?	MAJOR DEVELOPMENT OR SENSITIVE AREA?	>25% OF A POPULATED ISLAND?	Exposure Score
1101-01-	Buldir	52.35	175.91	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-02-	Kiska	52.10	177.60	0.00	0.00	0	0	0	4.3	0	0	1	0	5.3
1101-03-	Segula	52.02	178.14	0.00	0.00	0	0	0	4.3	0	0	1	0	5.3
1101-04-	Davidof	51.97	178.33	0.00	0.00	0	0	0	4.3	0	0	1	0	5.3
1101-05-	Little Sitkin	51.95	178.54	0.00	0.00	0	0	0	4.3	0	0	1	0	5.3
1101-06-	Semisopochnoi	51.93	179.58	0.00	0.00	0	0	1	4.3	0	0	1	0	6.3
1101-07-	Gareloi	51.79	-178.79	0.00	0.00	0	0	1	4.3	0	0	1	0	6.3
1101-08-	Tanaga	51.89	-178.15	0.00	0.00	0	0	1	4.3	0	0	1	0	6.3
1101-09-	Takawangha	51.87	-178.01	0.00	0.00	0	0	1	4.3	0	0	1	0	6.3
1101-10-	Bobrof	51.91	-177.44	1.66	0.00	0	0	1	4.3	0	0	1	0	8.0
1101-11-	Kanaga	51.92	-177.17	1.58	0.00	0	0	1	4.3	0	0	1	0	7.9
1101-111	Moffett	51.94	-176.75	1.38	0.00	0	0	1	4.3	0	0	1	0	7.7
1101-112	Adagdak	51.99	-176.59	1.36	0.00	0	0	1	4.3	0	0	1	0	7.7
1101-12-	Great Sitkin	52.08	-176.13	0.60	0.00	0	0	1	4.3	0	0	1	0	6.9
1101-13-	Kasatochi	52.18	-175.51	0.00	0.00	0	0	1	4.3	0	0	0	0	5.3
1101-14-	Koniuji	52.22	-175.13	0.00	0.00	0	0	1	4.3	0	0	0	0	5.3
1101-15-	Sergief	52.03	-174.93	0.00	0.00	0	0	1	4.3	0	0	0	0	5.3
1101-16-	Atka (Korovin)	52.38	-174.15	0.85	0.00	0	0	1	4.3	0	0	0	1	7.1
1101-18-	Seguam	52.32	-172.51	0.00	0.00	0	0	1	4.3	0	0	0	0	5.3
1101-19-	Amukta	52.50	-171.25	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-20-	Chagulak	52.58	-171.13	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-21-	Yunaska	52.64	-170.63	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-22-	Herbert	52.74	-170.11	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-23-	Carlisle	52.89	-170.05	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-24-	Cleveland	52.83	-169.94	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-25-	Uliaga	53.07	-169.77	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-26-	Kagamil	52.97	-169.72	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-27-	Vsevidof	53.13	-168.69	1.26	0.00	0	0	0	4.3	0	0	0	0	5.6
1101-28-	Recheschnoi	53.16	-168.54	1.57	0.00	0	0	0	4.3	0	0	0	0	5.9
1101-29-	Okmok	53.43	-168.13	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-30-	Bogoslof	53.93	-168.03	0.00	0.00	0	0	0	4.3	0	0	0	0	4.3
1101-31-	Makushin	53.89	-166.92	3.19	0.00	0	0	0	4.3	0	1	1	0	9.5
1101-311	Table Top-Wide Bay	53.97	-166.68	3.02	0.00	0	0	1	0	0	0	0	0	4.0
1101-32-	Akutan	54.13	-165.99	1.46	0.00	0	0	1	4.3	0	0	1	1	8.8
1101-34-	Westdahl	54.52	-164.65	0.00	0.00	0	0	1	4.3	0	0	0	0	5.3
1101-35-	Fisher	54.65	-164.43	0.00	0.00	0	0	1	4.3	0	0	0	0	5.3

1101-36-	Shishaldin	54.76	-163.97	2.15	0.00	0	0	1	4.3	0	0	0	0	7.4
1101-37-	Isanotski	54.77	-163.72	1.88	0.00	0	0	1	4.3	0	0	0	0	7.2
1101-38-	Roundtop	54.80	-163.59	1.95	0.00	0	0	1	4.3	0	0	0	0	7.3
1101-39-	Amak	55.42	-163.15	1.38	0.00	0	0	1	4.3	0	0	0	0	6.7
1102-01-	Frosty	55.08	-162.81	2.12	0.00	0	0	1	4.3	0	0	0	0	7.4
1102-011	Dutton	55.17	-162.27	1.97	0.00	0	0	1	4.3	0	0	1	0	8.3
1102-02-	Emmons Lake	55.34	-162.08	1.83	0.00	0	0	1	4.3	0	0	0	0	7.1
1102-03-	Pavlof	55.42	-161.89	1.99	0.00	0	0	1	4.3	0	0	0	0	7.3
1102-04-	Pavlof Sister	55.45	-161.84	2.06	0.00	0	0	1	4.3	0	0	0	0	7.4
1102-05-	Dana	55.64	-161.21	2.10	0.00	0	0	1	4.3	0	0	0	0	7.4
1102-051	Stepovak	55.93	-160.00	1.26	0.00	0	0	1	0	0	0	0	0	2.3
1102-06-	Kupreanof	56.01	-159.80	1.54	0.00	0	0	1	4.3	0	0	0	0	6.8
1102-07-	Veniaminof	56.17	-159.38	1.51	0.00	0	1	1	4.3	0	0	0	0	7.8
1102-08-	Black Peak	56.55	-158.79	1.18	0.00	0	0	1	4.3	0	0	0	0	6.5
1102-09-	Aniakchak	56.88	-158.17	1.45	0.00	0	0	1	4.3	0	0	0	0	6.7
1102-10-	Yantarni	57.02	-157.19	0.48	0.00	0	0	1	4.3	0	0	0	0	5.8
1102-11-	Chiginagak	57.14	-156.99	1.00	0.00	0	0	1	4.3	0	0	0	0	6.3
1102-12-	Kialagvik	57.20	-156.75	1.46	0.00	0	0	1	4.3	0	0	0	0	6.8
1102-13-	Ugashik-Peulik	57.75	-156.37	1.34	0.00	0	0	1	4.3	0	0	0	0	6.6
1102-131	Ukinrek Maars	57.83	-156.51	1.18	0.00	0	0	1	4.3	0	0	0	0	6.5
1102-132	Unnamed	57.87	-155.42	0.60	0.00	0	0	1	4.3	0	0	0	0	5.9
1102-14-	Martin	58.17	-155.36	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-15-	Mageik	58.20	-155.25	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-16-	Trident	58.24	-155.10	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-17-	Katmai	58.28	-154.96	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-18-	Novarupta	58.27	-155.16	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-19-	Griggs	58.35	-155.09	2.20	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-20-	Snowy Mountain	58.34	-154.68	2.20	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-21-	Denison	58.42	-154.45	2.20	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-22-	Steller	58.43	-154.40	2.20	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-23-	Kukak	58.45	-154.36	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-25-	Kaguyak	58.61	-154.03	2.21	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-26-	Fourpeaked	58.77	-153.67	2.22	0.00	0	0	1	4.3	0	0	0	0	7.5
1102-27-	Douglas	58.86	-153.54	2.22	0.00	0	0	1	4.3	0	0	0	0	7.5
1103-01-	Augustine	59.36	-153.43	0.48	0.00	0	0	2	4.3	0	1	1	0	8.8
1103-02-	Iliamna	60.03	-153.09	1.54	0.00	0	0	2	4.3	0	0	1	0	8.8
1103-03-	Redoubt	60.49	-152.74	1.42	0.00	0	1	2	4.3	1	1	1	0	11.7
1103-04-	Spurr	61.30	-152.25	0.00	0.00	0	0	2	4.3	1	1	1	0	9.3
1103-05-	Hayes	61.64	-152.41	0.00	0.00	0	0	2	4.3	1	0	1	0	8.3
1104-01-	St. Paul Island	57.18	-170.30	1.89	0.00	0	0	0	0	0	0	0	1	2.9
1104-02-	Nunivak Island	60.02	-166.33	1.63	0.00	0	0	0	4.3	0	0	0	0	5.9
1104-03-	Ingakslugwat Hills	61.43	-164.47	1.65	0.00	0	0	0	4.3	0	0	0	0	6.0
1104-04-	St. Michael	63.45	-162.12	2.41	0.00	0	0	1	4.3	0	0	0	0	7.7
1104-05-	Kookooligit Mountains	63.60	-170.43	2.12	0.00	0	0	0	0	0	0	0	0	2.1
1104-06-	Imuruk Lake	65.60	-163.92	1.36	0.00	0	0	0	0	0	0	0	0	1.4
1105-001	Buzzard Creek	64.07	-148.42	1.30	0.00	0	0	1	0	0	0	0	0	2.3
1105-01-	Sanford	62.22	-144.13	2.00	0.00	0	0	1	4.3	0	0	1	0	8.3
1105-02-	Wrangell	62.00	-144.02	2.00	0.00	0	0	1	4.3	0	0	1	0	8.3
1105-021	Gordon	62.13	-143.08	2.00	0.00	0	0	0	0	0	0	0	0	2.0
1105-03-	Churchill	61.38	-141.75	2.00	0.00	0	0	1	4.3	0	0	1	0	8.3
1105-04-	Edgecumbe	57.05	-135.75	3.56	0.00	0	0	1	4.3	0	0	0	0	8.9
1105-05-	Duncan Canal	56.50	-133.10	2.54	0.00	0	0	1	0	0	0	0	0	3.5

1105-06-	Tlevak Strait-Suemez Is.	55.25	-133.30	2.85	0.00	0	0	0	0	0	0	0	0	2.8
1105-07-	Behm Canal-Rudyerd Bay	55.32	-131.05	0.00	0.00	0	0	1	0	0	0	0	0	1.0
1201-01=	Baker	48.78	-121.81	3.65	4.69	0	0	2	5.04	1	1	0	0	17.4
1201-02-	Glacier Peak	48.11	-121.11	2.42	4.66	0	0	2	5.04	0	0	0	0	14.1
1201-03-	Rainier	46.87	-121.76	3.69	5.07	0	0	2	5.04	1	1	1	0	18.8
1201-04-	Adams	46.21	-121.49	2.93	4.13	0	0	2	5.04	1	1	0	0	16.1
1201-05-	St. Helens	46.20	-122.18	2.84	3.93	1	1	2	5.04	0	1	1	0	17.8
1201-06-	West Crater	45.88	-122.08	3.95	0.00	0	0	1	0	0	0	0	0	5.0
1201-07-	Indian Heaven	45.93	-121.82	3.69	0.00	0	0	0	0	1	1	0	0	5.7
1202-01-	Hood	45.37	-121.69	3.75	3.98	0	0	2	5.04	1	1	1	0	17.8
1202-02-	Jefferson	44.69	-121.80	3.03	0.00	0	0	0	0	0	0	0	0	3.0
1202-03-	Blue Lake Crater	44.42	-121.77	3.48	0.00	0	0	2	5.04	0	0	0	0	10.5
1202-04-	Sand Mountain Field	44.38	-121.93	3.18	0.00	0	0	0	0	0	0	0	0	3.2
1202-05-	Washington	44.33	-121.84	3.43	0.00	0	0	0	0	0	0	0	0	3.4
1202-06-	Belknap	44.29	-121.84	3.42	0.00	0	0	0	0	0	1	0	0	4.4
1202-07-	North Sister Field	44.17	-121.77	3.50	2.00	0	0	2	5.04	0	1	0	0	13.5
1202-08-	South Sister	44.10	-121.77	3.32	3.83	0	0	2	5.04	1	0	1	0	16.2
1202-09-	Bachelor	43.98	-121.69	4.06	2.00	0	0	2	5.04	0	0	1	0	14.1
1202-10-	Davis Lake	43.57	-121.82	3.67	0.00	0	0	0	0	0	0	0	0	3.7
1202-11-	Newberry Volcano	43.72	-121.23	4.01	0.00	0	0	2	5.04	1	1	1	0	14.0
1202-12-	Devils Garden	43.51	-120.86	2.52	0.00	0	0	0	0	0	0	0	0	2.5
1202-13-	Lava Mountain	43.47	-120.75	2.65	0.00	0	0	0	0	0	0	0	0	2.7
1202-14-	Four Craters Lava Field	43.36	-120.67	2.74	0.00	0	0	0	0	0	0	0	0	2.7
1202-15-	Cinnamon Butte	43.24	-122.11	2.96	0.00	0	0	0	0	0	0	0	0	3.0
1202-16-	Crater Lake	42.93	-122.12	3.36	3.70	0	0	2	5.04	1	0	1	0	16.1
1202-17-	Diamond Craters	43.10	-118.75	2.18	0.00	0	0	0	0	0	0	0	0	2.2
1202-19-	Jordan Craters	43.15	-117.47	2.22	0.00	0	0	0	0	0	0	0	0	2.2
1202-20-	Jackies Butte	42.61	-117.59	2.18	0.00	0	0	0	0	0	0	0	0	2.2
1203-01-	Shasta	41.42	-122.20	4.03	3.00	0	0	1	5.15	1	1	1	0	16.2
1203-02-	Medicine Lake	41.58	-121.57	2.99	2.00	0	0	1	5.15	1	0	1	0	13.1
1203-03-	Brushy Butte	41.18	-121.44	3.54	0.00	0	0	0	0	0	0	0	0	3.5
1203-04-	Big Cave	40.96	-121.37	3.79	0.00	0	0	0	0	0	0	0	0	3.8
1203-05-	Twin Buttes	40.78	-121.60	3.71	0.00	0	0	0	0	0	0	0	0	3.7
1203-06-	Tumble Buttes	40.68	-121.55	3.67	0.00	0	0	0	0	0	0	0	0	3.7
1203-08-	Lassen Volc Center	40.49	-121.51	3.46	3.70	0	0	1	5.15	0	0	1	0	14.3
1203-09-	Eagle Lake Field	40.63	-120.83	3.83	0.00	0	0	0	0	0	0	0	0	3.8
1203-10-	Clear Lake	38.97	-122.77	4.64	0.00	0	0	2	5.15	1	1	1	0	14.8
1203-11-	Mono Lake Volc Field	38.00	-119.03	2.87	0.00	0	0	2	5.15	0	1	0	0	11.0
1203-12-	Mono Craters	37.88	-119.00	4.09	0.00	0	0	2	5.15	0	1	0	0	12.2
1203-13-	Inyo Craters	37.69	-119.02	4.11	0.00	0	0	2	5.15	0	1	1	0	13.3
1203-14-	Long Valley	37.70	-118.87	4.11	0.00	0	0	2	5.15	1	1	1	0	14.3
1203-15-	Red Cones	37.58	-119.05	4.10	0.00	1	0	1	0	0	0	1	0	7.1
1203-16-	Ubehebe Craters	37.02	-117.45	3.47	0.00	0	0	2	5.15	0	0	1	0	11.6
1203-17-	Golden Trout Creek	36.36	-118.32	2.18	0.00	0	0	0	0	0	0	0	0	2.2
1203-18-	Coso Volc Field	36.03	-117.82	2.43	0.00	0	0	2	5.15	1	0	0	0	10.6
1203-19-	Lavic Lake	34.75	-116.63	3.61	0.00	0	0	0	0	0	0	0	0	3.6
1203-20-	Amboy	34.55	-115.78	3.36	0.00	0	0	0	0	0	0	0	0	3.4
1204-01-	Shoshone Lava Field	43.18	-114.35	3.82	0.00	0	0	1	0	0	0	0	0	4.8
1204-02-	Craters of the Moon	43.42	-113.50	3.09	0.00	0	0	0	0	0	0	1	0	4.1
1204-03-	Wapi Lava Field	42.88	-113.22	3.01	0.00	0	0	0	0	0	0	1	0	4.0
1204-04-	Hell's Half Acre	43.50	-112.45	3.80	0.00	0	0	1	0	0	1	1	0	6.8
1205-01-	Yellowstone	44.43	-110.67	3.91	0.00	0	0	1	5	0	1	1	0	11.9

1206-01-	Steamboat Springs	39.38	-119.72	5.41	0.00	0	0	2	5.15	1	1	1	0	15.6
1207-01-	Santa Clara	37.26	-113.63	4.69	0.00	0	0	0	0	0	0	0	0	4.7
1207-03-	Bald Knoll	37.33	-112.41	2.98	0.00	0	0	0	0	0	0	0	0	3.0
1207-04-	Markagunt Plateau	37.58	-112.67	2.79	0.00	0	0	2	5	0	0	0	0	9.8
1207-05-	Black Rock Desert	38.97	-112.50	3.53	0.00	0	0	2	5	0	0	0	0	10.5
1208-01-	Dotsero	39.65	-107.03	4.29	0.00	0	0	1	5	0	1	0	0	11.3
1209-01-	Uinkaret Field	36.38	-113.13	1.95	0.00	0	0	0	0	0	0	1	0	3.0
1209-02-	Sunset Crater	35.37	-111.50	4.65	0.00	0	0	0	5	1	0	0	0	10.7
1210-01-	Carrizozo	33.78	-105.93	2.82	0.00	0	0	0	0	0	0	0	0	2.8
1210-02-	Zuni-Bandera	34.80	-108.00	2.79	0.00	0	0	0	0	0	0	0	0	2.8
1210-03-	Valles Caldera	35.87	-106.57	3.97	0.00	0	0	1	5	0	0	1	0	11.0
1302-01-	Kilauea	19.43	-155.29	4.09	4.29	1	1	2	4.87	1	1	1	0	20.3
1302-02=	Mauna Loa	19.48	-155.61	3.68	4.75	1	1	1	0	1	1	1	1	15.4
1302-03-	Mauna Kea	19.82	-155.47	3.86	4.20	0	0	1	0	0	1	1	0	11.1
1302-04-	Hualalai	19.69	-155.87	4.51	0.00	0	1	2	4.87	1	1	1	0	15.4
1302-06-	Haleakala	20.71	-156.25	4.83	0.00	0	0	1	0	0	1	1	1	8.8
0804-14=	Farallon de Pajaros	20.53	144.90	0.00	0.00	0	0	0	4	0	0	0	0	4.0
0804-141	Ahyi	20.42	145.03	0.00	0.00	0	0	0	0	0	0	0	0	0.0
0804-142	Supply Reef	20.13	145.10	0.00	0.00	0	0	0	0	0	0	0	0	0.0
0804-143	Maug Islands	20.02	145.22	0.00	0.00	0	0	0	4	0	0	0	0	4.0
0804-15=	Asuncion	19.67	145.40	0.00	0.00	0	0	0	4	0	0	0	0	4.0
0804-16=	Agrigan	18.77	145.67	1.00	0.00	0	1	0	4	0	0	0	1	7.0
0804-17=	Pagan	18.13	145.80	1.00	0.00	0	1	0	4	0	0	0	1	7.0
0804-18=	Alamagan	17.60	145.83	1.00	0.00	0	0	2	4	0	0	0	1	8.0
0804-19=	Guguan	17.32	145.85	0.00	0.00	0	0	2	4	0	0	0	0	6.0
0804-191	Sarigan	16.71	145.78	1.00	0.00	0	0	2	4	0	0	0	1	8.0
0804-20=	Anatahan	16.35	145.67	1.00	0.00	0	1	2	4	0	0	0	1	9.0
0804-201	Ruby	15.62	145.57	0.00	0.00	0	0	0	0	0	1	0	0	1.0
0804-21=	Esmeralda Bank	15.00	145.25	0.00	0.00	0	0	0	0	0	1	0	0	1.0

APPENDIX 4

GUIDELINES FOR RATING THE LEVEL OF MONITORING AT U.S. VOLCANOES.

These guidelines are used to characterize both current and future (desired) monitoring levels. For each volcano, the main monitoring methods (seismic, deformation, gas, hydrologic, remote-sensing) are rated on a scale of 0-4. Then an overall rating is given, also using a 0-4 scale. Seismic pertains to real-time stations. Remote sensing pertains to airborne, satellite, and/or ground based instruments that are independent of airborne gas measurements and satellite-based InSAR. The seismic rating strongly influences the overall rating; for any volcano, the overall rating cannot be higher than its seismic rating. For each volcano, six numbers are assigned (see Appendix 5): a number for the level of each of the five monitoring techniques (seismic, deformation, gas, hydrologic, and remote-sensing) and a number for the overall level of monitoring.

LEVEL 0: No ground-based monitoring

No real-time data from ground-based sensors are available. Eruption confirmation (up to hours after the fact) is provided only by remote-sensing data or from people observing the event.

LEVEL 1: Minimal monitoring

Monitoring provides the ability to detect that an eruption is occurring or that gross changes are occurring/have occurred near a volcano. Data are not collected systematically or at very long intervals (e.g., >5 years).

Seismic –Volcano lies within a regional network; no near-field stations are in place but at least one station is within 50 km of the volcano. (Example: Crater Lake). Or, a single near-field station is present, but no regional network exists. (Example, Sarigan).

Deformation – Geodetic benchmarks and baseline measurements exist for detection of deformation via repeated surveys at multiple-year intervals. (Example: Shasta). Or, coherent InSAR interferogram(s) exist(s).

Gas – Airborne or campaign gas measurements are done rarely as an infrequent reconnaissance check for anomalous degassing.

Hydrologic - Inventory exists of temperature and major chemistry of fumaroles, thermal, and slightly thermal springs and wells. Where lahar potential exists, study of past lahars and debris flows has been conducted, including as appropriate, estimation of extent of hydrothermal alteration and estimates of slope stability.

Remote sensing - Baseline inventory exists of Landsat-class (15-30 m resolution) satellite images. Routine scans for eruption clouds are conducted by meteorological agencies.

LEVEL 2: Limited monitoring for change detection

Monitoring provides the ability to detect and track activity frequently enough in near-real time to recognize that something anomalous is occurring.

Seismic – Volcano lies within a regional network and 1-2 near-field (within ~10 km of volcano) stations are in place. (Examples: Hood, Lassen).

Deformation - Geodetic network exists, with baseline established by two or more surveys. InSAR observations are possible on a summer-to-summer basis. At least three continuous stations (GPS or tiltmeters are operating in the vicinity of the volcano. The combination of techniques enables tracking of geodetic unrest in space and time at a minimal level. (Example: Three Sisters).

Gas – Repeated airborne or campaign gas measurements have been conducted to establish a baseline of carbon dioxide emission rate (or other gas as appropriate to the volcano) for identification of significant changes in degassing.

Hydrologic - Comprehensive temperature, chemical, and isotopic database exists on gases and waters, with scheduled re-sampling of selected features. Scheduled measurements are taken of stream discharge, sediment transport, if appropriate, along with annual max-min estimates of snow and ice cover. Water levels in wells that respond to strain events are recorded.

Remote sensing - Regular processing and review of near-real-time meteorological satellite images (AVHRR, GOES), and/or review of non-real-time research satellite images (e.g., MODIS) is done by an observatory. Baseline inventory exists of air photos and/or satellite images with high spatial resolution (1 m).

LEVEL 3: Basic real-time monitoring

Monitoring provides the ability detect and track pre-eruptive and eruptive changes in real-time, with a basic understanding of what is occurring.

Seismic – Volcano network includes 3-4 near-field stations and a total of at least six within 20 km of vent. The volcano may or may not be within regional network. Network may or may not have a single three-component instrument. (Examples: Rainier, Redoubt)

Deformation - Geodetic network exists, and surveys are routinely repeated. At least six continuous stations (GPS and/or tiltmeters) are operating in the vicinity of the volcano. This enables tracking of geodetic unrest in space and time and source modeling at a basic level. LIDAR-derived images are available for active features. (Example: St. Helens).

Gas – Airborne or campaign measurements of gas emissions are done frequently (annually to monthly, as appropriate), with support of 1-2 telemetered continuous monitoring installations. Less frequent plume measurements are supplemented by ground-based instruments.

Hydrologic - Level-2 coverage is available along with continuous-sensing probes deployed in features of primary interest, including water wells. LIDAR-derived DEMs are available for lahar-runout modeling.

Remote sensing – Level 2 capability plus routine use of multi-channel thermal-infrared data from an ASTER-class satellite. Airborne thermal and/or SAR overflights, are conducted as indicated by other monitoring data. Where practicable, remote video camera is in operation.

LEVEL 4: Well-monitored

Monitoring provides the ability to track detailed changes in real-time and to develop, test, and apply models of ongoing and expected activity.

Seismic – 12-20 stations are in place within 20 km of vent; including several near-field sites. Network includes numerous three-component instruments and a mix of other instrument types, including several digital broadband stations, acoustic sensors, and accelerometers. Borehole instruments are used where practicable. (Examples: Long Valley, Kilauea)

Deformation - Geodetic surveys are routine, and sufficient continuous stations (GPS, tiltmeters, and/or dilatometers) are installed to track closely geodetic unrest in space and time and do detailed source modeling to help distinguish among alternative mechanisms. (Examples: Long Valley, Kilauea)

Gas – Airborne or campaign gas measurements done frequently. A continuous monitoring array of several stations and other types of gas measurements (including DOAS) is deployed as appropriate for the volcano to enable quick identification of key geochemical changes.

Hydrologic - Level-3 coverage is available along with real-time monitoring of hill-slope soil moisture, stream discharge, etc. as appropriate. AFM systems are installed, where warranted, and supported by models predicting lahar size and area of impact.

Remote sensing – Level 3 coverage is available along with other data from all pertinent satellite sensors (e.g., daily multi-channel, high-resolution thermal-infrared images and frequent, high resolution, multi-channel visible images). Where practical, continuous ground-based thermal imaging and Doppler radar coverage is available for ash detection and eruption-rate estimates.

APPENDIX 5

RATINGS OF CURRENT MONITORING CAPABILITIES AT U.S. VOLCANOES.

See Appendix 4 for criteria of rating levels 0-4.

Vnum	Volcano Name	Current Seismic Rating	Current Deform-ation Rating.	Current Gas Rating	Current Hydro-Logic rating	Current Remote-Sensing	Current Overall Monitoring Rating
1101-01-	Buldir	0	0	0	0	2	0
1101-02-	Kiska	0	1	0	0	2	0
1101-03-	Segula	0	0	0	0	2	0
1101-04-	Davidof	0	0	0	0	2	0
1101-05-	Little Sitkin	0	0	0	0	2	0
1101-06-	Semisopochnoi	0	0	0	0	2	0
1101-07-	Gareloi	3	0	0	0	2	3
1101-08-	Tanaga	3	0	0	0	2	3
1101-09-	Takawangha	3	0	0	0	2	3
1101-10-	Bobrof	2	0	0	0	2	2
1101-11-	Kanaga	3	1	0	0	2	3
1101-111	Moffett	2	0	0	0	2	2
1101-112	Adagdak	2	0	0	0	2	2
1101-12-	Great Sitkin	3	1	0	0	2	3
1101-13-	Kasatochi	0	0	0	0	2	0
1101-14-	Koniuji	0	0	0	0	2	0
1101-15-	Sergief	0	0	0	0	2	0
1101-16-	Atka (Korovin)	3	1	0	0	2	3
1101-18-	Seguam	0	1	0	0	2	0
1101-19-	Amukta	0	0	0	0	2	0
1101-20-	Chagulak	0	0	0	0	2	0
1101-21-	Yunaska	0	0	0	0	2	0
1101-22-	Herbert	0	0	0	0	2	0
1101-23-	Carlisle	0	0	0	0	2	0
1101-24-	Cleveland	0	0	0	0	2	0
1101-25-	Uliaga	0	0	0	0	2	0
1101-26-	Kagamil	0	0	0	0	2	0
1101-27-	Vsevidof	0	0	0	0	2	0
1101-28-	Recheschnoi	0	0	0	0	2	0
1101-29-	Okmok	3	3	0	0	2	3
1101-30-	Bogoslof	0	0	0	0	2	0
1101-31-	Makushin	3	1	0	0	2	3
1101-311	Table Top-Wide Bay	0	0	0	0	2	0
1101-32-	Akutan	3	3	0	0	2	3
1101-34-	Westdahl	3	1	0	0	2	3
1101-35-	Fisher	3	0	0	0	2	3
1101-36-	Shishaldin	3	1	0	0	2	3
1101-37-	Isanotski	3	0	0	0	2	3
1101-38-	Roundtop	1	0	0	0	2	1

1101-39-	Amak	0	0	0	0	2	0
1102-01-	Frosty	2	0	0	0	2	2
1102-011	Dutton	2	0	0	0	2	2
1102-02-	Emmons Lake	2	0	0	0	2	2
1102-03-	Pavlof	3	1	0	0	2	3
1102-04-	Pavlof Sister	3	1	0	0	2	3
1102-05-	Dana	1	0	0	0	2	1
1102-051	Stepovak	0	0	0	0	2	0
1102-06-	Kupreanof	1	0	0	0	2	1
1102-07-	Veniaminof	3	1	1	0	2	3
1102-08-	Black Peak	1	0	0	0	2	1
1102-09-	Aniakchak	3	1	0	0	2	3
1102-10-	Yantarni	0	0	0	0	2	0
1102-11-	Chiginagak	1	0	0	0	2	1
1102-12-	Kialagvik	0	0	0	0	2	0
1102-13-	Ugashik-Peulik	3	1	1	0	2	3
1102-131	Ukinrek Maars	3	0	1	0	2	3
1102-132	Unnamed	0	0	0	0	2	0
1102-14-	Martin	3	0	2	0	2	3
1102-15-	Mageik	3	0	2	0	2	3
1102-16-	Trident	3	1	0	0	2	3
1102-17-	Katmai	3	1	0	0	2	3
1102-18-	Novarupta	3	1	0	0	2	3
1102-19-	Griggs	3	0	1	0	2	3
1102-20-	Snowy Mountain	3	0	0	0	2	3
1102-21-	Denison	2	0	0	0	2	2
1102-22-	Steller	2	0	0	0	2	2
1102-23-	Kukak	2	0	0	0	2	2
1102-25-	Kaguyak	2	0	0	0	2	2
1102-26-	Fourpeaked	2	0	0	0	2	2
1102-27-	Douglas	1	0	1	0	2	1
1103-01-	Augustine	3	3	2	0	2	3
1103-02-	Iliamna	3	0	2	0	2	3
1103-03-	Redoubt	3	1	2	0	2	3
1103-04-	Spurr	3	2	2	0	2	3
1103-05-	Hayes	1	0	0	0	2	1
1104-01-	St. Paul Island	1	0	0	0	2	1
1104-02-	Nunivak Island	0	0	0	0	2	0
1104-03-	Ingakslugwat Hills	0	0	0	0	2	0
1104-04-	St. Michael	0	0	0	0	2	0
1104-05-	Kookooligit Mountains	0	0	0	0	2	0
1104-06-	Imuruk Lake	1	0	0	0	2	1
1105-001	Buzzard Creek	1	0	0	0	2	1
1105-01-	Sanford	1	0	0	0	2	1
1105-02-	Wrangell	2	1	0	0	2	2
1105-021	Gordon	0	0	0	0	2	0
1105-03-	Churchill	1	0	0	0	2	1

1105-04-	Edgecumbe	1	0	0	0	2	1
1105-05-	Duncan Canal	0	0	0	0	2	0
1105-06-	Tlevak Strait-Suemez Is.	1	0	0	0	2	1
1105-07-	Behm Canal-Rudyerd Bay	0	0	0	0	2	0
1201-01=	Baker	2	1	2	1	1	2
1201-02-	Glacier Peak	1	0	0	1	1	1
1201-03-	Rainier	3	1	1	1	1	2
1201-04-	Adams	2	1	1	0	1	2
1201-05-	St. Helens	4	3	3	3	3	4
1201-06-	West Crater	1	0	0	0	1	1
1201-07-	Indian Heaven	1	0	0	0	1	1
1202-01-	Hood	2	2	1	2	1	2
1202-02-	Jefferson	2	0	1	1	1	1
1202-03-	Blue Lake Crater	1	0	0	0	1	1
1202-04-	Sand Mountain Field	1	0	0	1	1	1
1202-05-	Washington	1	0	0	0	1	1
1202-06-	Belknap	1	0	0	1	1	1
1202-07-	North Sister Field	2	1	0	1	1	1
1202-08-	South Sister	2	2	1	2	2	2
1202-09-	Bachelor	2	1	0	1	1	2
1202-10-	Davis Lake	1	0	0	0	1	1
1202-11-	Newberry Volcano	2	2	1	1	1	2
1202-12-	Devils Garden	1	0	0	0	1	1
1202-13-	Lava Mountain	1	0	0	0	1	1
1202-14-	Four Craters Lava Field	1	0	0	0	1	1
1202-15-	Cinnamon Butte	1	0	0	0	1	1
1202-16-	Crater Lake	1	1	0	1	0	1
1202-17-	Diamond Craters	1	0	0	0	1	1
1202-19-	Jordan Craters	0	0	0	0	1	0
1202-20-	Jackies Butte	0	0	0	0	1	0
1203-01-	Shasta	2	1	1	1	1	2
1203-02-	Medicine Lake	2	1	1	1	1	2
1203-03-	Brushy Butte	2	0	0	0	1	1
1203-04-	Big Cave	1	0	0	0	1	1
1203-05-	Twin Buttes	2	0	0	0	1	1
1203-06-	Tumble Buttes	1	0	0	0	1	1
1203-08-	Lassen Volc Center	3	1	1	2	1	2
1203-09-	Eagle Lake Field	1	0	0	0	1	1
1203-10-	Clear Lake	2	0	0	1	1	1
1203-11-	Mono Lake Volc Field	1	1	1	1	1	1
1203-12-	Mono Craters	1	1	1	1	1	1
1203-13-	Inyo Craters	2	2	1	1	1	2
1203-14-	Long Valley	4	4	3	3	2	4
1203-15-	Red Cones	3	3	3	2	2	3
1203-16-	Ubehebe Craters	2	0	0	0	1	1
1203-17-	Golden Trout Creek	1	0	0	0	1	1
1203-18-	Coso Volc Field	2	1	0	1	1	2

1203-19-	Lavic Lake	1	1	0	0	1	1
1203-20-	Amboy	0	1	0	0	1	0
1204-01-	Shoshone Lava Field	1	0	0	0	1	1
1204-02-	Craters of the Moon	2	1	0	0	1	2
1204-03-	Wapi Lava Field	1	1	0	0	1	1
1204-04-	Hell's Half Acre	2	0	0	0	1	1
1205-01-	Yellowstone	3	3	2	2	1	3
1206-01-	Steamboat Springs	2	0	0	2	1	2
1207-01-	Santa Clara	1	0	0	0	1	1
1207-03-	Bald Knoll	1	0	0	0	1	1
1207-04-	Markagunt Plateau	1	0	0	0	1	1
1207-05-	Black Rock Desert	1	0	0	0	1	1
1208-01-	Dotsero	0	0	0	0	1	0
1209-01-	Uinkaret Field	1	0	0	0	1	1
1209-02-	Sunset Crater	2	0	0	0	1	2
1210-01-	Carrizozo	0	0	0	0	1	0
1210-02-	Zuni-Bandera	0	0	0	0	1	0
1210-03-	Valles Caldera	2	0	0	1	1	2
1302-01-	Kilauea	4	4	4	2	3	4
1302-02=	Mauna Loa	3	3	2	1	2	3
1302-03-	Mauna Kea	2	1	0	1	1	2
1302-04-	Hualalai	2	1	0	1	1	2
1302-06-	Haleakala	2	1	0	1	1	2
0804-14=	Farallon de Pajaros	0	0	0	0	1	0
0804-141	Ahyi	0	0	0	0	1	0
0804-142	Supply Reef	0	0	0	0	1	0
0804-143	Maug Islands	0	0	0	0	1	0
0804-15=	Asuncion	0	0	0	0	1	0
0804-16=	Agrigan	0	0	0	0	1	0
0804-17=	Pagan	0	0	0	0	1	0
0804-18=	Alamagan	0	0	0	0	1	0
0804-19=	Guguan	0	0	0	0	1	0
0804-191	Sarigan	1	0	0	0	1	1
0804-20=	Anatahan	2	0	0	0	1	2
0804-201	Ruby	1	0	0	0	1	1
0804-21=	Esmeralda Bank	1	0	0	0	1	1