

Prepared jointly by the U.S. Geological Survey, the University of Utah, and Yellowstone National Park

Cooperating Organizations: Montana Bureau of Mines and Geology, Wyoming State Geological Survey, Idaho Geological Survey, and UNAVCO, Inc.

Protocols for Geologic Hazards Response by the Yellowstone Volcano Observatory



Circular 1351

Cover. Images clockwise from upper left: Schematic organization of an Incident Command incorporating Yellowstone Volcano Observatory.
University of Utah and Yellowstone National Park staff during wintertime equipment deployment.
Example of data routing for monitoring data from Yellowstone Seismic Network.
Logo of Yellowstone Volcano Observatory

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By the Yellowstone Volcano Observatory

Circular 1351

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Protocols for Geologic Hazards Response by the Yellowstone Volcano Observatory

By the Yellowstone Volcano Observatory¹

Executive Summary

The Yellowstone Plateau hosts an active volcanic system, with subterranean magma (molten rock), boiling, pressurized waters, and a variety of active faults with significant earthquake hazard. Within the next few decades, large and moderate earthquakes and hydrothermal explosions are certain to occur. Volcanic eruptions are less likely, but are ultimately inevitable in this active volcanic region. This document summarizes protocols and tools to be used by the Yellowstone Volcano Observatory (YVO) during earthquakes, volcanic eruptions, hydrothermal explosions or any similar geological activity that could lead to a volcanic eruption.

As needed, YVO will be an advisor within the National Incident Management System (NIMS). The YVO Branch within the Operations Section of the Incident Command will consist of three prescribed groups (Monitoring, Information, and Support). The three groups and their subsidiary teams form a scalable system to respond to a variety of scenarios of geological and volcanic unrest. The YVO response will be organized through an event coordination committee, led by the YVO Branch Chief (also known as the Scientist-in-Charge) and consisting of the group supervisors and the existing YVO coordinating scientists. An independent advisory board will work in conjunction with YVO to suggest further avenues for monitoring and research during quiescent periods and will provide scientific oversight to crisis response during unrest.

Formal alerts and information statements will be issued by the U.S. Geological Survey (USGS) in conjunction with YVO partners and through standard telephone and Internet “calldown” lists. External communications will be coordi-

nated by the public information team leader, in association with any Joint Information Center set up through the Incident Command. Internal communications will be handled through a computerized log system that can be used as an archive for public and non-public documents and to provide a forum for discussion by observatory personnel and collaborators.

Within 2 months of publication of this document, provisional group supervisors and team leaders will be assigned. The response plan will be updated every three years by the YVO coordinating scientists and will be available through the YVO and USGS public websites. The calldown list will be updated at least once per year and placed on the internal log system.

1. Introduction and Scope

1a. Purpose of Plan

Yellowstone National Park (fig. 1) is centered on a youthful, active volcanic system in the northern Rocky Mountains in Wyoming, Montana, and Idaho. Over the past 2.1 million years, three immense explosive volcanic eruptions blanketed parts of the North American continent with ash and debris. Each of these eruptions created sizable calderas, basins formed by collapse of the ground after evacuation of subsurface magma reservoirs. The Yellowstone Caldera, which comprises nearly one-third of the land area in the park, formed 0.64 million years ago and was followed by dozens of less explosive but areally significant lava flows, the last of which erupted 70,000 years ago. Basin and Range extension of the western U.S. has created a series of regional faults that are responsible for large and devastating earthquakes in the Yellowstone region along the Teton and Hebgen Lake Faults; most recently a devastating M_s 7.5 earthquake in 1959 killed 28 people. Yellowstone’s famous geothermal waters create fabulous hot springs and geysers but occasionally explode catastrophically to create hydrothermal explosion craters found throughout the park.

In 2001, the U.S. Geological Survey (USGS), Yellowstone National Park (YNP), and the University of Utah (UU) joined to form the Yellowstone Volcano Observatory (YVO). This partnership builds upon a program, dating from

¹This report was prepared jointly by the attendees of the Yellowstone Volcano Observatory planning meeting. Attendees include Jacob B. Lowenstern, John Bellini, Dan Dzurisin, John Eichelberger, Margaret Mangan, Jill McCarthy, Manuel Nathenson, and Willie Scott, of the U.S. Geological Survey; Henry Heasler, Michael Keator, Christine Lehnertz, and Tom Olliff, of Yellowstone National Park; Robert B. Smith, Walter Arabasz, Relu Burlacu, Dave Drobeck, Jamie Farrell, and Michael Thorne, of the University of Utah; Roy Breckenridge, of the Idaho Geological Survey; Edmund Deal, and Michael Stickney, of the Montana Bureau of Mines and Geology; Allory Deiss, and Ron Surdam, of the Wyoming State Geological Survey; and Mike Jackson and Dave Mencin, of UNAVCO. Tina Neal and Cynthia Gardner, U.S. Geological Survey, reviewed this report.

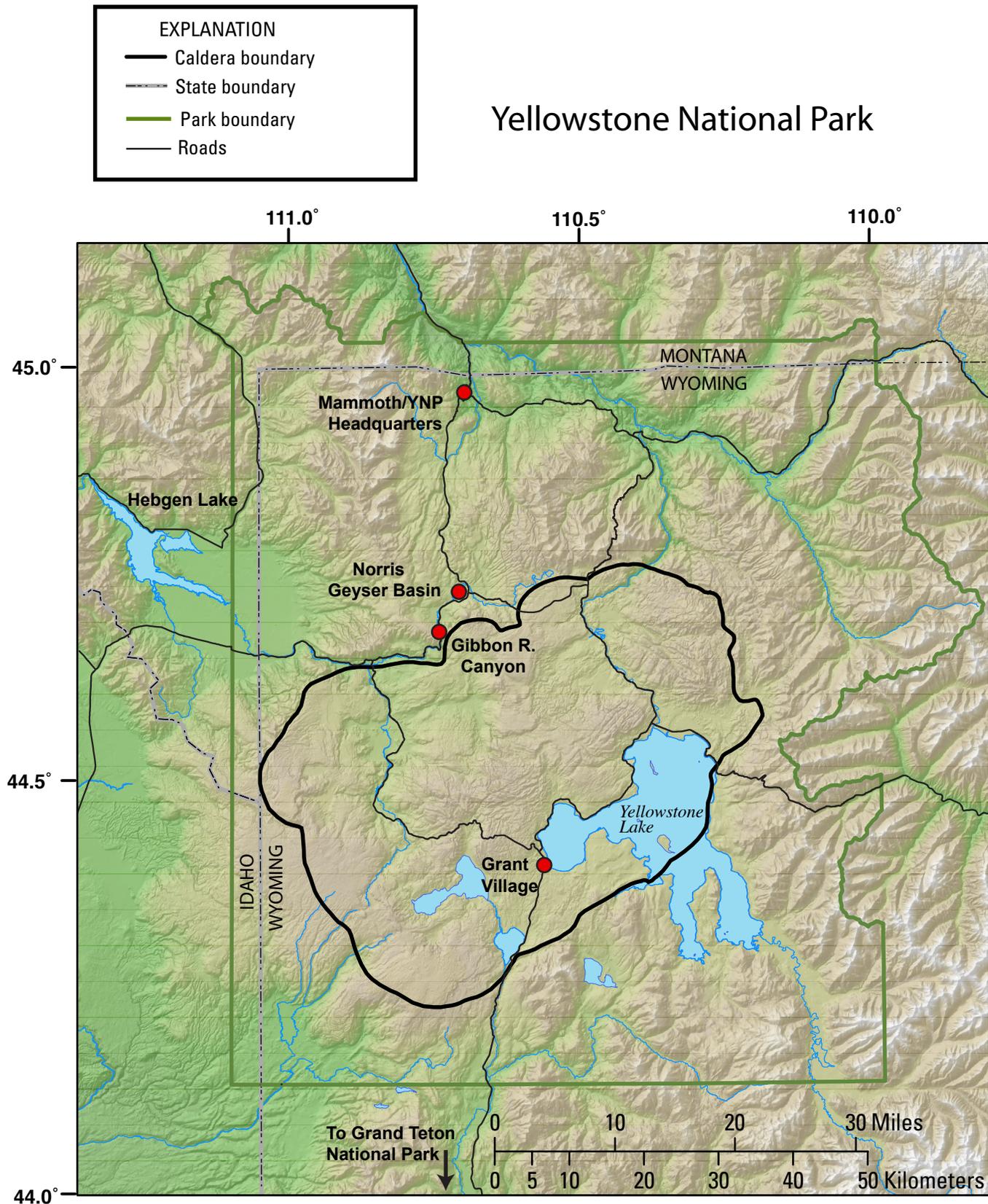


Figure 1. Location map for Yellowstone National Park, including Yellowstone Caldera, roads, state and national park boundaries, and place names mentioned in this document.

the 1970s, of collaborative geologic monitoring and related research at Yellowstone by the USGS and UU. YVO provides professional and critical earth-science expertise, operates modern monitoring facilities, processes and interprets seismic and ground deformation signals, and rapidly assesses the significance of geologic processes that may threaten the infrastructure and visitors to Yellowstone National Park and the public beyond its borders. YVO provides the necessary information and support to respond rapidly to geologic hazards at Yellowstone and can respond to requests for information from park management, emergency responders, the media, and the public.

Emergency-response readiness is a key responsibility of the USGS Volcano Hazards Program (VHP) stemming from a congressional mandate (PL93-288) that the USGS issue “timely warnings” of potential hazards to responsible emergency-management authorities and to the public. Both YVO and its parent, the USGS VHP, must maintain capabilities and protocol for the rapid deployment of staff and equipment during periods of seismic, hydrothermal, or volcanic unrest at YNP. The plan described herein provides a basic framework for emergency response by YVO that will be used during periods of geological unrest at YNP. This initial response plan is intentionally inward-focused, identifying the structures and protocols for use within the incident-command, emergency-response structure utilized by YNP.

1b. Organization of the Yellowstone Volcano Observatory

YVO has three coordinating scientists, who represent their separate organizations and affiliated scientists and staff (fig. 2, see glossary). Though some volcano observatories (for example, the USGS Hawaiian Volcano Observatory) have a facility and permanent staff, YVO can be thought of more as a partnership, without a permanent staff, but instead composed of affiliated staff from the three partners. The most recent Memorandum of Understanding, outlining organizational responsibilities, was signed by USGS, UU, and YNP on January 30, 2008, to remain in effect through 2012. The USGS is legally responsible for providing volcano alerts, and the USGS coordinating scientist for YVO, the Scientist-in-Charge, has ultimate authority over YVO operations. USGS scientists affiliated with YVO undertake research projects in geochemistry, geology, hydrology, and geophysics. Most scientists are organizationally housed within the Volcano Science Center (VSC), which is funded by the VHP and encompasses the staff of the five U.S. volcano observatories. Geophysical monitoring is carried out by the University of Utah Seismograph Stations (UUSS), in conjunction with the University of Utah (UU) Seismology and Active Tectonics Research Group, which provides real-time earthquake locations, undertakes geophysical research, and helps interpret ongoing phenomena such as caldera uplift and subsidence. YNP is the land manager and is responsible for all emergency response to

natural disasters within YNP park boundaries. YNP geology staff focuses primarily on hydrology, geology, and remote sensing, and is administratively located within YNP’s Yellowstone Center for Resources. In addition, many scientists from other universities and organizations undertake hydrothermal, geophysical, and geological research projects that overlap with the YVO mission at the Yellowstone volcano. As much as possible, YVO aids and collaborates with the scientists outside the YVO partnership.

1c. YVO Monitoring Systems

A combination of equipment operated and maintained by many groups inside and outside the YVO partnership is used for real-time monitoring of the Yellowstone volcano. The UUSS maintains seismic stations of the Yellowstone Seismographic Network and locates earthquakes with the data generated by that network. The UUSS operates its regional seismic network as part of the Advanced National Seismic System (ANSS). Within the ANSS framework, earthquakes throughout the U.S. larger than about M3.0 are located by the USGS National Earthquake Information Center (NEIC), which operates on a 24/7 basis, providing backup to the UUSS and other ANSS regional seismic networks. The NEIC operates a small, but modern seismic network in the Teton Range, just south of Yellowstone. The Montana Bureau of Mines and Geology (MBMG) seismic network locates earthquakes in Montana.

Global Positioning System (GPS) receivers are jointly maintained by UU and by UNAVCO, a non-profit corporation funded partly through the National Science Foundation’s Plate Boundary Observatory (PBO) program. Multiple organizations and universities record and process the data from the GPS stations and make the data available to the public through websites (for example, <http://www.unavco.org>, <http://www.uusatrg.utah.edu/>, and the USGS crustal deformation website). PBO also maintains borehole strainmeters, tiltmeters, and seismometers installed in 2007-08 through the National Science Foundation’s Earthscope program. Another Earthscope program, USArray, recently installed several state-of-the-art seismic stations within and around Yellowstone as part of a temporary, mobile research array. By 2010, all USArray seismic stations will be removed except for one (near Grant Village) that will be left in place as an EarthScope legacy station. Finally, real-time stream flow and meteorological data are collected by the USGS Water Science Centers in Montana, Wyoming, and Idaho, through the National Water Information System (NWIS) with partial funding by YNP. Most data streams are available on the internet at (<http://volcanoes.usgs.gov/yvo/activity/monitoring/index.php>). Data stream latency ranges from seconds (seismic) to 1 day (GPS).

During a period of geological unrest, YVO personnel would use these existing data streams and any new data from additional monitoring instrumentation deployed during unrest. Staff from the three partners, UNAVCO, IRIS (the Incorporated Research Institutes for Seismology), and other university

and state cooperators would be available to help respond to the needs of the park, press, and public as described in subsequent sections. USGS personnel would include YVO project scientists, VSC staff not normally assigned to work at Yellowstone, seismologists and analysts from the NEIC, and others from other relevant science centers.

2. Geological Unrest, Alert Levels, and Information Products

YVO responds to a variety of geological events that can signal unrest leading to volcanic eruption. These events

include large earthquakes, earthquake swarms, hydrothermal (steam) explosions, and unusual toxic gas emissions. The nature and frequency of these hazards are discussed in USGS Open-File Report 2007-1071 and in USGS Fact Sheet 2005-3024. With assistance from various partners and collaborators, YVO can also provide rapid response to associated events such as earthquake-induced landslides or floods. Part of any response plan involves organizing and deploying scientific personnel and equipment to investigate current activity and assess possible outcomes and impacts. At the same time, helpful summary information must be provided as soon as possible to land managers, emergency responders, and the public-at-large.

ORGANIZATION OF YVO

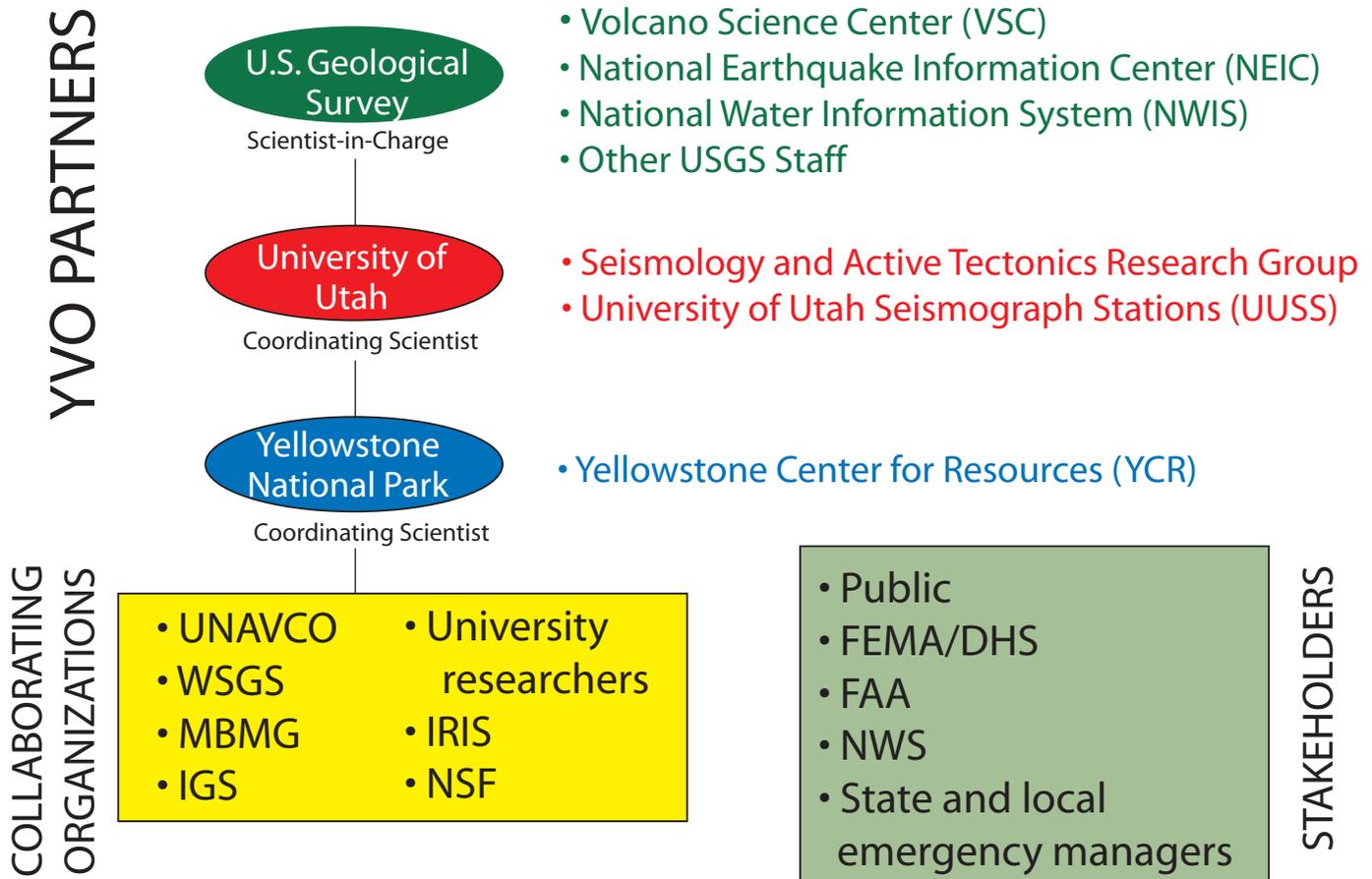


Figure 2. Organization of Yellowstone Volcano Observatory (YVO). The three YVO partners are the U.S. Geological Survey (USGS), University of Utah (UU) and Yellowstone National Park (YNP), each with a Coordinating Scientist. Collaborating organizations include UNAVCO, WSGS (Wyoming State Geological Survey), MBMG (Montana Bureau of Mines and Geology), IGS (Idaho Geological Survey), National Science Foundation, university researchers, and IRIS (Integrated Research Institutes for Seismology). Stakeholders include the general public, FEMA/DHS (Federal Emergency Management Agency of the Department of Homeland Security), the FAA (Federal Aviation Administration), NWS (National Weather Service), and state and local emergency managers.

2a. Notification System for Volcanic Activity

To issue warnings of volcanic unrest and eruptions, YVO utilizes an alert notification system implemented in 2006 by the USGS Volcano Hazards Program (<http://pubs.usgs.gov/fs/2006/3139/>). This alert system consists of two parallel warning schemes designed for two different types of hazards (airborne ash and gas hazards affecting aviation as well as ground-based hazards, see fig. 3). The alerts of airborne hazards to aviation are summarized by four Aviation Color Codes: Green, Yellow, Orange, and Red. The alerts of ground-based hazards use terminology similar to that used by the National Weather Service: Normal, Advisory, Watch, and Warning. Typically, the two four-stage alert levels rise and fall in parallel, yielding Green/Normal, Yellow/Advisory, Orange/Watch, and Red/Warning, though the system is designed to be flexible so that, for example, alert of an ongoing eruption can remain Warning/ORANGE if a volcano poses a significant ground hazard but has no significant plume or ash cloud that could endanger aircraft.

The above Volcano Alert Level and Aviation Color Code System has been used by YVO since 2006, and the status of the Yellowstone Caldera has remained Normal/Green during the entire time. It is important to recognize that large earthquakes, earthquake swarms, or hydrothermal explosions would not necessarily cause a change in alert level unless those events were thought to be part of an ongoing process that could culminate in a volcanic eruption.

2b. Event Response

Such important geological events as large earthquakes or hydrothermal explosions nevertheless would require action by YVO and an event response can be initiated along with an information statement that would summarize the event and its implications (see next section). An event response includes formal actions taken by YVO, outside normal monitoring that is intended to characterize anomalous activity, provide assessments of potential outcomes, and inform the public and partners of information gathered. Details of the structure of an event response and how this fits into the National Incident Management System (NIMS) are given in section 4.

2c. Written Information Products

Currently, YVO releases a monthly summary update through its website. This update summarizes seismic, geodetic (ground motion), and unusual geothermal activity for the previous month. An information statement is a formal public statement outside the usual monthly updates. The monthly summary updates, information statements, and alert levels are all released electronically through the USGS Hazard Activity Notification System (HANS) and are automatically forwarded to a variety of government agencies, to the YVO and VHP websites, and to partners and collaborating agencies. If

volcanic activity or a large hydrothermal explosion became a likely possibility, YVO would release two additional information products to the aviation community and through the VHP website: the Volcanic Activity Notice (VAN) and the Volcanic Observation Notification for Airmen (VONA). Currently, the public and media can subscribe to an realtime syndication service (RSS) feed on the VHP website (<http://volcanoes.usgs.gov/publications/feeds/index.php>). Emergency managers and cooperators may also ask to receive the information products automatically as e-mails or text messages sent at the time of release. To demonstrate the use of an event response and these information products, two plausible scenarios and potential responses by YVO are outlined in Section 7.

3. YVO and the National Incident Management System

In the case of a volcanic eruption, large earthquake, or hydrothermal explosion where lives are at stake, infrastructure threatened, or access needs to be controlled, Yellowstone National Park would activate an Incident Response within the Incident Command System (ICS). The response may be run entirely by park staff or, where desired, as a collaboration of multiple organizations such as nearby counties, states, or federal land management agencies. The response would be structured within the National Incident Management System (NIMS), a program developed by the Federal Emergency Management Agency of the U.S. Department of Homeland Security. As defined at <http://www.fema.gov/emergency/nims>

The National Incident Management System (NIMS) provides a systematic, proactive approach to guide departments and agencies at all levels of government, nongovernmental organizations, and the private sector to work seamlessly to prevent, protect against, respond to, recover from, and mitigate the effects of incidents, regardless of cause, size, location, or complexity, in order to reduce the loss of life and property and harm to the environment. NIMS works hand in hand with the National Response Framework (NRF). NIMS provides the template for the management of incidents, while the NRF provides the structure and mechanisms for national-level policy for incident management

NIMS is based on the premise that utilization of a common incident management framework will give emergency management/response personnel a flexible but standardized system for emergency management and incident response activities. NIMS is flexible because the system components can be utilized to develop plans, processes, procedures, agreements, and roles for all types of incidents; it is applicable to any incident regardless of cause, size, location, or

The USGS Alert-Notification System for Volcanic Activity

Volcano Alert Levels Used by USGS Volcano Observatories

Alert Levels are intended to inform people on the ground about a volcano’s status and are issued in conjunction with the Aviation Color Code. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption and about potential or current hazards and likely outcomes.

Term	Description
NORMAL	Volcano is in typical background, noneruptive state <i>or, after a change from a higher level,</i> volcanic activity has ceased and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level <i>or, after a change from a higher level,</i> volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, OR eruption is underway but poses limited hazards.
WARNING	Hazardous eruption is imminent, underway, or suspected.

Aviation Color Code Used by USGS Volcano Observatories

Color codes, which are in accordance with recommended International Civil Aviation Organization (ICAO) procedures, are intended to inform the aviation sector about a volcano’s status and are issued in conjunction with an Alert Level. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption, especially in regard to ash-plume information and likely outcomes.

Color	Description
GREEN	Volcano is in typical background, noneruptive state <i>or, after a change from a higher level,</i> volcanic activity has ceased and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level <i>or, after a change from a higher level,</i> volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, OR eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].
RED	Eruption is imminent with significant emission of volcanic ash into the atmosphere likely OR eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].

Standard Volcano Icons

Ground-based Volcano Alert Levels

Normal Advisory Watch Warning



Aviation Color Codes

Green Yellow Orange Red



△ Unassigned (Insufficient monitoring to make assessment)

Figure 3. The USGS Volcano Hazards Program system for volcano alert levels. Two parallel scales correspond to ground and aviation hazards. The standard icons (bottom) may be replaced with variations depending on the situation (red/watch, orange/warning).

complexity. Additionally, NIMS provides an organized set of standardized operational structures, which is critical in allowing disparate organizations and agencies to work together in a predictable, coordinated manner.

During events when human and financial resources need coordination, the ICS can provide infrastructure and transportation (for example, temporary headquarters, helicopter access) to aid YVO in its mission to provide timely assessments to the park and the public. The establishment of an ICS allows YVO to fit into a larger organization, ensuring public safety, clear communications, transportation, and other critical needs. A schematic diagram (fig. 4) illustrates how the ICS might be organized and how YVO would fit into the ICS system.

4. The Event Response

4a. Declaring an Event Response

After consultation with the YVO coordinating scientists, the Scientist-in-Charge may declare a formal event response. In doing so, he/she will release an information statement that includes details of the geological or geophysical activity and, if appropriate, a pronouncement that YVO will initiate increased monitoring during the period of unrest. Not all event responses will result in a change in alert level or aviation color code. However, all event responses will trigger release by YVO of daily information statements to keep the public informed until the event response is complete.

4b. Relation of YVO Event Response to Incident Command System

Declaration of an event response does not in any way require Yellowstone National Park to implement an ICS. However, if Yellowstone National Park, or surrounding land managers or communities, decide to implement an incident command, YVO would form a Branch of the ICS and would act as an advisor on geological conditions, potential scenarios for future activity and hazards assessment (fig. 4). It is also possible that the Park could stand up an ICS without YVO declaring an official event response, as there are situations where geological and geophysical activity are unlikely to result in additional hazards (for example, a landslide that blocks road access).

4c. Internal Organization of YVO

In preparation for an event response or participation in an ICS, YVO will utilize an organizational scheme based on

fig. 5; the YVO Branch contains teams and groups that are provisionally assigned prior to the event. In ICS terminology which will be used in subsequent sections of this document, the head of the event response is the YVO Branch Chief (also known as the Scientist-in-Charge). The response will be overseen by three functional groups: monitoring, information, and support. The YVO Branch Chief, in consultation with the coordinating scientists and group supervisors, will determine the assignment of team and group roles. The smallest scale of event response would include a single person in each group. Team members may come from any of the YVO partners or other participating agencies. Individually, each group, the teams that compose those groups, and the overall event coordination committee (the group supervisors plus the coordinating scientists) would convene at regular intervals, typically once per day. If appropriate and logistically feasible, all groups and teams could convene together at a single meeting. Because YVO is a distributed partnership with staff in multiple locations, it is expected that meetings would be primarily by teleconference or video conference. Decision-making by all team members, regardless of institutional affiliation, would follow this organizational structure, with ultimate authority placed upon the YVO Branch Chief.

Upon raising the volcano alert level beyond Normal/Green, the YVO Branch Chief will assign a duty scientist and a deputy scientist. The duty scientist assignment will be filled 24/7 and will be rotated among the coordinating scientists, group supervisors, and team leaders, so that someone is always responsible for evaluating the latest monitoring data. The deputy scientist would be a USGS employee who would assist the YVO Branch Chief on a variety of responsibilities, including communications and calldowns (see Section 4d). During an event response when the volcano alert level remains at Normal/Green, the assignment of staff to both the duty scientist and the deputy scientist positions is at the discretion of the YVO Branch Chief.

Monitoring Group

The monitoring group will consist of up to four teams (seismology, geodesy, geology [including hydrology and geochemistry], and remote sensing). During small events, the supervisor for the monitoring group may be one of the team leaders. Similarly, for event responses of limited scope, the teams may consist solely of the team leader or may be larger. The team leaders will convene regularly, with a frequency chosen by the group supervisor. When the volcano is at an elevated alert level or aviation color code, each team will grow to be composed of multiple team members as shown in figure 5 and described below. In these instances, at least one team member will be located at Yellowstone National Park or its immediate vicinity. Each team will convene at regular intervals (at least once per day)

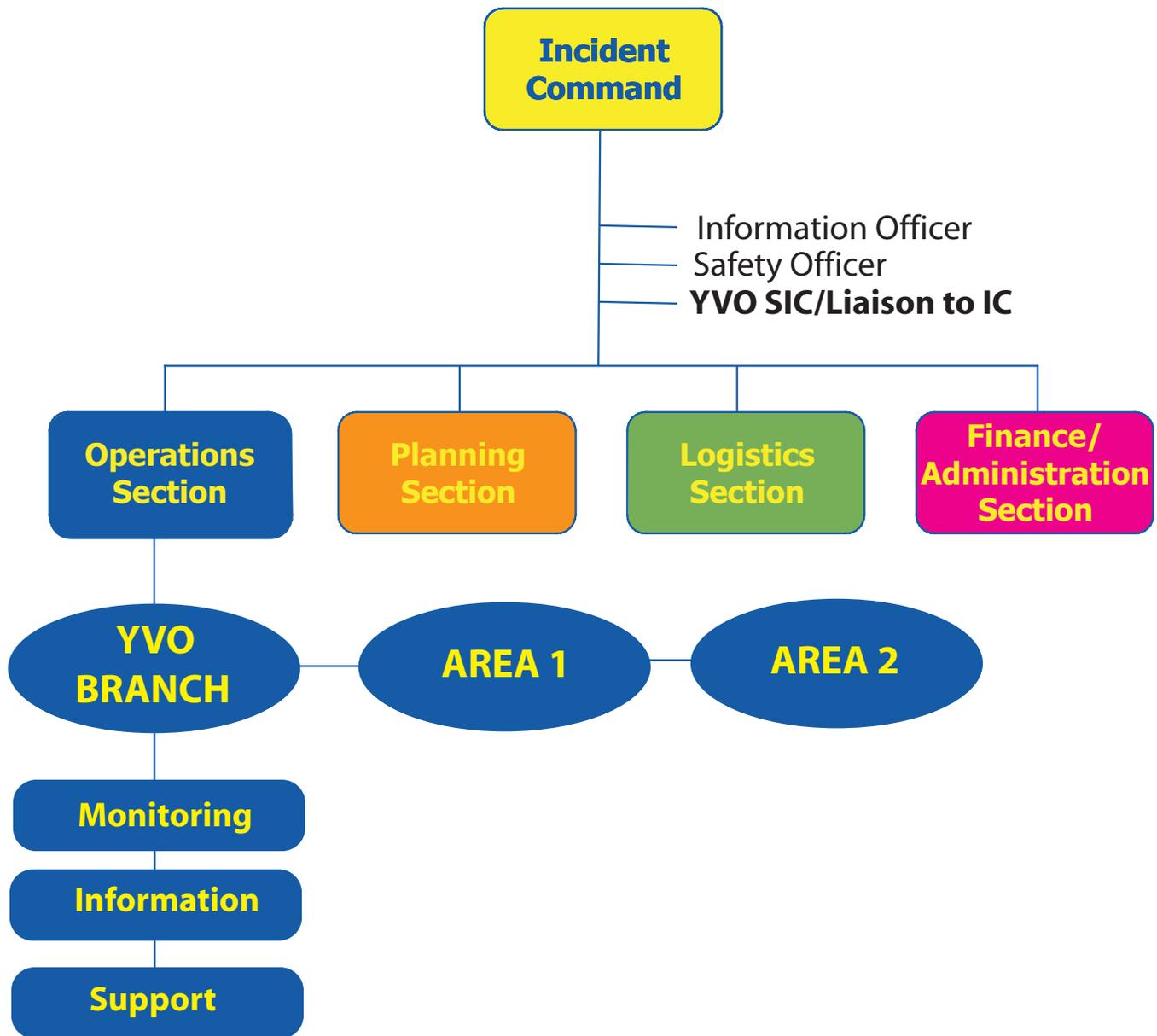


Figure 4. Hypothetical organization of an Incident Command System (ICS) during an event response at the Yellowstone Caldera. The YVO Branch is one part of the Operations Section of the Incident Command. Each section would consist of multiple branches. For example, if a lava flow started a forest fire, then the Operations Section could consist of the YVO Branch and a separate Fire Mitigation Branch. Area 1 and 2 ellipses represent geographic regions that would require separate oversight (for example, a volcanic eruption and downstream flood hazards). The YVO Branch could operate within multiple areas.

YVO Branch Organization (headed by Branch Chief/ Scientist-in-Charge)

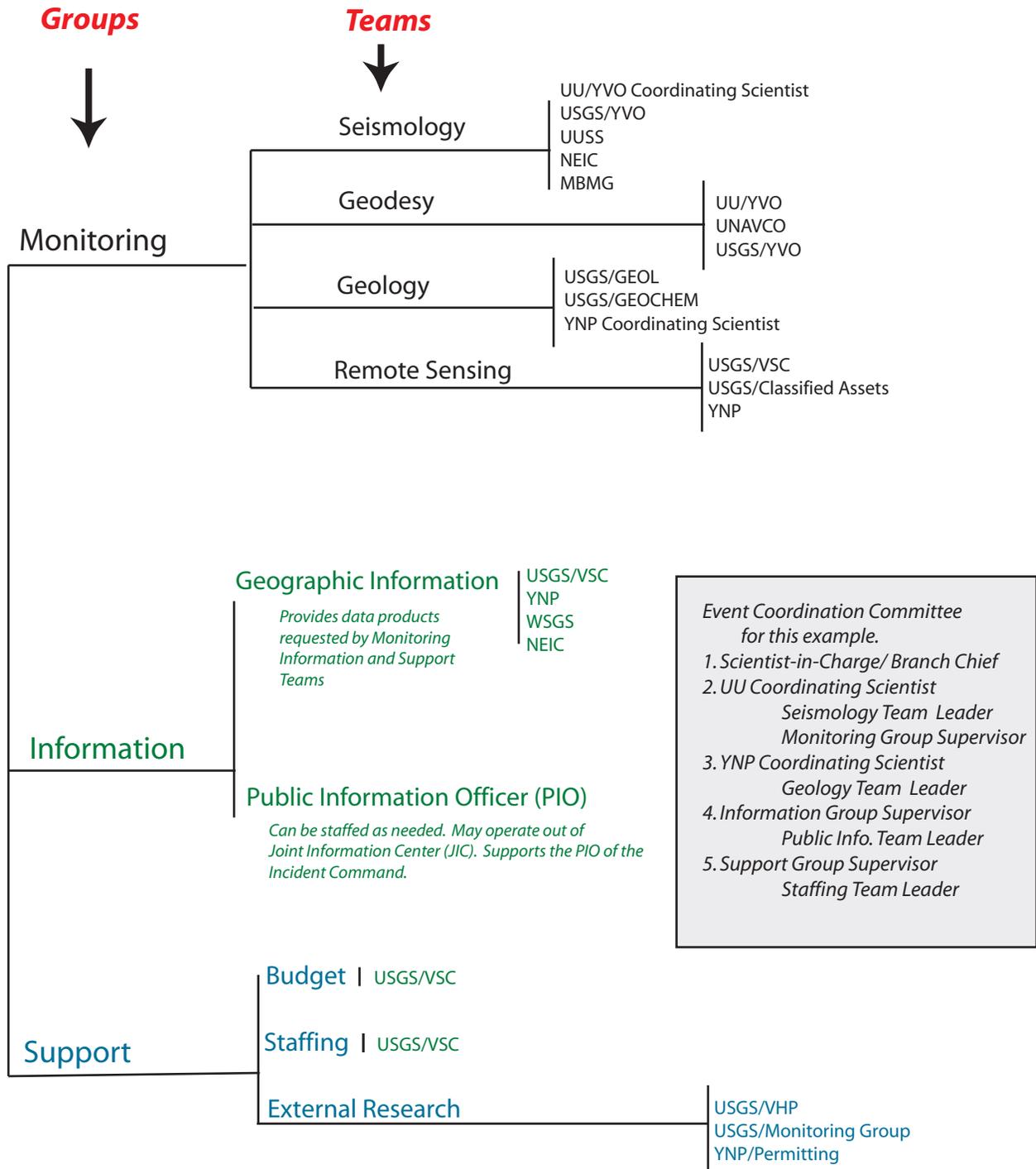


Figure 5. YVO Branch Organization. The YVO Branch consists of three groups divided into various teams. The Event Coordination Committee consists of the group supervisors and the coordinating scientists. In this diagram, the teams are populated with one possible grouping of people, though other options may be preferred at the time of unrest. The roles of groups and teams are explained in the text. Abbreviations and acronyms are listed in the glossary.

to characterize ongoing activity, discuss upcoming plans, and provide a summary statement for their team within the monitoring group.

The following writeup describes an initial set of teams for a scenario where precursory activity that may lead to an eruption has been detected or observed. Based upon experience at other USGS volcano observatories, these teams would need to expand to meet the demand for field personnel during any extended period of unrest (more than a few weeks). As such, the teams outlined below are minimum organizational units for an event response when a Volcano Advisory or Watch has been issued.

The seismology team will consist of the YVO coordinating scientist at UU, one or more individuals from the UUSS, the USGS/YVO, the NEIC, and a local seismic network operator (Montana Bureau of Mines and Geology). One of these individuals will be the team leader. The team will track the locations, magnitudes and depths of earthquakes with time and will analyze waveforms to interpret the source and nature of the earthquake activity. The team will be responsible for deploying any necessary temporary equipment to increase understanding of the unrest. As needed, the USGS would provide equipment and additional help, either through VSC staff located at other volcano observatories or Earthquake Hazards Program staff, including those at the NEIC. These individuals could be deployed to Yellowstone National Park, or to UUSS facilities in Salt Lake City.

The geodesy team will consist of members from UU, UNAVCO, and the USGS/YVO. This team will be responsible for identifying trends in ground deformation that relate to current unrest, using data from continuous GPS stations, borehole strainmeters and tiltmeters, and interferometric synthetic aperture radar (InSAR) observations. The team will be responsible for deploying any needed temporary equipment to increase understanding of the unrest and for developing numerical models of the source(s) of deformation.

The geology team will consist of a geologist from the USGS, a geochemist from the USGS, and a scientist from Yellowstone National Park. This team will be responsible for noting changes in hydrothermal activity, gas discharge, water chemistry, or other geological factors accompanying unrest. The team will be responsible for planning, organizing, and staffing fixed-wing aircraft and helicopter surveillance flights. The team will be responsible for deploying any needed temporary equipment to increase understanding of the unrest.

The remote sensing team will consist of a geologist from Yellowstone National Park, a remote-sensing specialist from the VSC, and a USGS representative with a security clearance and access to classified satellite data that could aid interpretation of geological processes. The team will be responsible for identifying any changes in topography, heat discharge, vegetation, or other surface characteristics that can be tracked from air or space. A representative from this team will coordinate with the geology team to recommend and deploy any instrumentation that will help the remote

sensing team to interpret remotely sensed data. Under some circumstances, the YVO Branch Chief may merge the geology and remote sensing teams under one team leader.

Information Group

The information group will consist of two teams (geographic information and public information) and during small events will be supervised by the team leader of the public information team. The information group supervisor, alternatively known as Public Information Officer (PIO), serves as part of the event coordination committee of the YVO (see fig. 5).

The geographic information team will consist of individuals from Yellowstone National Park, the USGS/VSC, NEIC, and the Wyoming State Geological Survey. This team provides visual and cartographic data products and support as requested by the monitoring, information, and support groups. The team assists the public information team in providing contextual materials for distribution to the media and to the public through the YVO website.

The public information team will be led by an individual from the USGS and may consist of a variety of team members from YVO partners and affiliated agencies. The team consists of specialists with technical familiarity sufficient to conduct outreach and education through the YVO website. The team also serves as a resource of scientific information as part of any joint information center (JIC) set up within the ICS. The team is responsible for summarizing current scientific knowledge as “talking points” and conceiving and producing illustrations for use in communicating geologic concepts and activity to the public. The team leader will be part of the event coordination committee and will serve as YVO’s primary contact with the Incident Command’s Public Information Officer, the latter being a position that is likely to be held by a representative from Yellowstone National Park or a local governmental agency.

Support Group

The support group will consist of three teams (budget, staffing, and external research) and will be led by a support group supervisor. The budget team will be led by an administrative staff member from the Volcano Science Center. In many cases, only a single person will be needed to fulfill this role. The budget team will be responsible for requisitions, budgeting, and coordination with the Volcano Program office (funding through USGS headquarters) to allocate funding beyond that available through normal channels. The budget team leader will also act as a contact with administrative groups at UU and Yellowstone National Park.

The staffing team will consist of a single USGS scientist or staff member who meets with the group supervisors and YVO Branch Chief to identify VSC or other USGS scientists around the country who could fill needed science or support

roles. The individual would also act as a liaison between the event coordination committee and the VSC Director who has line authority over most of the USGS employees working with YVO.

The external research team will consist of three or four people including a team leader from the monitoring group. The team will act as a liaison with scientists from outside YVO, including other governmental and academic institutions. Scientists interested in assisting with the event response or conducting independent or collaborative related research can send communications to the external research team for vetting of research proposals, assistance with logistics, and coordination of sample and data distribution. The team will include scientists from the VSC, academia, and surrounding state agencies who are not intimately involved with the event response and will be impartial coordinators for diverse groups seeking to undertake fieldwork, deploy instrumentation, or acquire data or collect samples as part of the response. The team leader from the monitoring group will coordinate with the rest of the monitoring teams to ensure that the external research complements ongoing monitoring programs and does not negatively interfere with logistics. Ideally, the team would include a member of the YNP research permitting office.

4d. Calldown and Related Communications Lists

Upon declaring an event response or announcing a change in the volcano alert level or aviation color code, YVO will institute a formal calldown whereby staff will place telephone calls and initiate Internet communication protocols to notify colleagues and cooperators of the current situation. Figure 6 displays an example of the calldown scheme. A version of the YVO calldown list will be populated with phone numbers, web and Internet addresses, and placed on the YVO internal log system for retrieval by YVO staff and cooperators. In addition, most of the individuals will also be sent an automatic e-mail or text message to their computer and (or) phone at the time of the information statement and (or) alert-level change and accompanying aviation information products (VAN/VONA). As such, a telephone call may be redundant but allows back-and-forth discussion between YVO staff and key distributors of hazards information. In the current plan, Yellowstone National Park or the IC staff above the YVO will contact state and local government officials. In addition, the YVO Coordinating Scientist from YNP will contact the state geologists so as to provide additional geological context for state officials and governments. The UU will be responsible for contacting regional seismic networks. The YVO Branch Chief or a designee will alert the VHP Coordinator and the VSC Director, who in turn notify USGS area, regional, and national program contacts and the DOI 24/7 office. The VHP Coordinator will also interface with the Hazard Response Executive Committee that oversees USGS responses to hazardous events.

The YVO calldown list will be re-evaluated at least once per year and will be maintained by the YVO public information officer and stored on the internal log system.

4e. Information Releases

As of March 2010, YVO issues a monthly update on the status of the Yellowstone volcano on or around the first of each month. The update synthesizes the monitoring information and expert opinion solicited from YVO cooperators and collaborators. After a notable earthquake, earthquake swarm, hydrothermal explosion or other geological event, the YVO may choose to release an information statement that provides details on the event and possible outcomes. During an event response or an upgrade in alert level, YVO will release daily updates.

Currently, the UUSS policy is to issue a press release after any earthquake greater than magnitude 3.5 within the UUSS reporting area for the Yellowstone region. They typically do the same after the onset of any notable earthquake swarm, especially those that attract public interest or include felt events. YVO then re-issues the press release as an information statement; YVO might include in the information statement additional content as it relates to potential volcanism. Press releases by any of the three YVO partners are normally vetted through the other partners. As discussed above, during a Volcano Advisory or Watch, YVO will release daily updates. Any separate press releases by the USGS, YNP, or UU will be closely coordinated with the public information team (or the Joint Information Center organized through the ICS structure) if there is the potential for related volcanic activity.

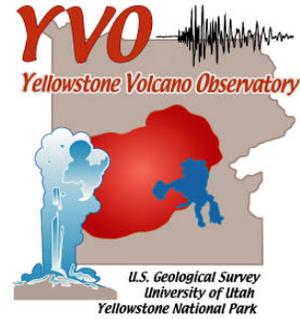
5. Alert Notification Scheme and Decision Criteria

The VHP criterion for a Volcano Advisory includes the following: “Volcano is exhibiting signs of elevated unrest above known background level.” Assessing what constitutes elevated unrest is somewhat subjective and at Yellowstone requires consideration of both the type and level of activity, as well as the historic behavior of the volcanic and hydrothermal system. For example, during an earthquake swarm, activity may be above background levels but is not necessarily precursory to an eruption. This is in contrast to many stratovolcanoes that most commonly experience swarms or ground deformation as a direct result of magma ascent into the upper crust. At Yellowstone, however, earthquake swarms and caldera-wide ground deformation are relatively common events that can reflect regional tectonism, hydrothermal pressurization, or deep magma intrusion that appear to have occurred for thousands of years without ever leading to a volcanic eruption. Similar activity is noted at other large calderas around the world.

The following five guidelines will inform YVO decisionmaking during future episodes of geological activity.

(1) YVO may choose to initiate an event response for an intense earthquake swarm, an episode of rapid ground

YVO Provisional Calldown List



Used when changing volcano alert level or declaring event response



- YVO Scientist-in-Charge calls:
 - Volcano Hazards Program Coordinator → USGS Director or her designee
Associate Director for Geology
DOI 24/7 Watch Office
 - Volcano Science Center Director → Relevant Area Executive(s) in Western Region
Central Region Director
Western Region Director
USGS Office of Communications
 - Group Supervisors (Monitoring, Support, and Information) → Respective Team Leaders
→ Respective Teams

- YVO Deputy Scientist-in-Charge calls: (Alert level change only) → Meteorologic Watch Office, Kansas City
FAA Regional Office, Salt Lake City
Weather Forecast Office, Riverton, WY
Washington VAAC, Washington, DC
FEMA Region VIII contact, Denver

- UU YVO Coordinating Scientist calls:



- UUSS Director → UUSS Associate Director
- UUSS Network Manager → Manager, Montana Seismic Network
Manager, INL Network
- NEIC Director → NEIC 24/7 Watch Office Staff
- UNAVCO Network Manager for PBO

- YNP YVO Coordinating Scientist calls:



- YNP Communications Center → Affected local communities
- Director, Yellowstone Center for Resources → YNP Superintendent
YNP Deputy Superintendent
YNP Chief Ranger
- Wyoming, Montana and Idaho State Geologists → Relevant State Government Offices (Governor, Homeland Security)
NOTE: redundant lines of communication through the ICS would provide information to these offices.

Figure 6. Provisional calldown list for Yellowstone Volcano Observatory. The three Coordinating Scientists and Deputy Scientist-in-Charge call only those to the left of the arrows. Those individuals, in turn, make calls to those in the list to the right. VAAC stands for Volcanic Ash Aviation Center. FAA is Federal Aviation Administration. Other abbreviations and roles are described in the text. Actual calldown list may differ from this example.

displacement, a significant hydrothermal explosion that generates a large crater (tens to hundreds of meters in diameter), or a pronounced increase in heat or gas discharge.

(2) An alert level change from Normal to Volcano Advisory (with accompanying change of aviation color code from Green to Yellow) may be declared when monitoring parameters exceed known thresholds previously observed at Yellowstone. One example could be if an intense earthquake swarm (>500 earthquakes, some with magnitude > 4.5) is accompanied by a rapid change in ground displacement (for example, > 5 cm over 30 days) or a significant hydrothermal explosion. It is unlikely that a Volcano Advisory would be called for a single large earthquake and its sequence of aftershocks unless it had considerable accompanying pre-earthquake ground displacement and (or) hydrothermal explosions. It is possible that lesser activity could trigger announcement of a Volcano Advisory. It is also possible that in some situations YVO would choose not to issue a Volcano Advisory, unless all three criteria (an intense earthquake swarm, rapid ground displacement, and a significant hydrothermal explosion) were met. The Yellowstone hydrothermal system normally releases abundant CO₂ and H₂S, but does not normally release the high-temperature sulfur gas SO₂, therefore, any significant release of SO₂ would merit serious consideration for issuance of a Volcano Advisory.

(3) A change in alert level from Normal/Green to Advisory/Yellow will always trigger a formal event response by YVO.

(4) Changes in alert levels and color codes or declaration of an event response is the responsibility of the YVO Branch Chief, who will normally consult closely with the other coordinating scientists before making any such decision.

(5) Change from a higher alert level and color code (Advisory or Watch) to a lower alert level will be at the discretion of the YVO Branch Chief, in association with the event coordination committee. The criteria for such a decision are likely to vary widely, depending on the nature of the event.

6. Scientific Oversight and Information Sharing

6a. Advisory Panel

To provide guidance during periods of heightened unrest, and independent oversight during other times, the coordinating scientists will assemble an advisory panel of experts. Members will consist of two USGS scientists not affiliated with YVO, as well as three to five volcanologists, geodesists, and seismologists from other government science agencies (for example, NOAA, NASA), universities, and (or) private consultants. The expertise of the advisory panel members will span the various scientific fields relevant to the ongoing unrest and monitoring systems. The advisory panel would be expected to do the following:

(1) Consult with the YVO Branch Chief and group supervisors on a periodic basis (no less than once per week) during an event response to provide an objective perspective on geologic activity.

(2) Serve as additional liaisons to the media for background information (not daily updates and reports of rapidly evolving phenomena), taking pressure off YVO scientists and allowing other knowledgeable sources of information to interact with the public and press during a time of unrest.

(3) Attend YVO science and planning meetings to familiarize themselves with the geological and geophysical characteristics of the Yellowstone volcano and offer their perspective on YVO operations.

6b. Log System

YVO maintains a secured weblog system that provides a forum for discussion of monitoring data. This password-protected system shall be used continually, during periods of quiescence and unrest, and provide a searchable archived system of plots, observations, and discourse related to geological activity at Yellowstone. Such systems have proven critical to information sharing at the Hawaiian, Cascades, and Alaska Volcano Observatories. Log systems ensure that everyone works with the same set of information and that ideas can be shared, discussed, and vetted in an organized manner. The log contains a record of phenomena, ideas, and decisions that can be used by observatory staff to evaluate operational protocols. The log system will not contain any real-time data sources that are not available elsewhere. Its purpose is to enable discussion among YVO partners and collaborators in the aftermath of events.

YVO practice is to make all reliable real-time data available to the public through Internet-based archives (currently seismic, GPS, strain, tilt, and hydrologic data).

7. Scenarios of Unrest and Initiation of Event Response

Below, two scenarios are provided to demonstrate how the YVO response plan might be used as a basis for an Event Response.

7a. Scenario 1: Day 1: During a 6-hour period on a July afternoon, four magnitude 5.0 to 6.0 earthquakes occur near Gibbon River Canyon (hundreds of smaller felt events occur over the next three days). Landslides have blocked the roads in Gibbon River Canyon and between Mammoth and Norris, effectively closing off access to Norris and Mammoth from the southwest.

Coincident with the beginning of the earthquake activity, the Norris strain and tiltmeters show large signals indicating significant local deformation. Though two continuous GPS (set at minute solutions) are deployed nearby, the data are not telemetered.

Day 2: Hydrothermal explosions are detected in the Norris Back Basin, leading to closure of the entire Norris Geyser Basin. The largest resulting crater is 20 meters across; 15 additional hydrothermal explosions are detected with the Norris seismometer and strain/tilt meter.

On Day 1, YNP initiates an ICS to help manage transportation around the affected area, restore infrastructure, and assist park visitors. YVO initiates an event response and is designated as a branch within the operations section of the IC structure. At the same time, a Volcano Advisory and aviation color code YELLOW is declared by the YVO Branch Chief along with a summary of observations and current prospects for future activity. A VAN/VONA is issued by the YVO Branch Chief to alert the aviation industry and a calldown is completed. The event response requires implementation of three teams (~13 people) within the monitoring group (seismology, geodesy, and geology/remote sensing). The information group consists of three individuals (two in the geographic information team) and is supervised by the public information team leader. The support group consists of three individuals, one each for the budget, staffing, and external research teams. The staffing team leader supervises the support group. Team members of the monitoring group plan for deployment of additional equipment to detect local deformation and assist in the identification of seismic sources that could indicate migrating magma. The YVO Branch Chief works with the public information team leader to create information products for use during a press conference set up through the IC on Day 2. A duty scientist position is created and is rotated among the three coordinating scientists for Day 2 and Day 3. A USGS scientist is appointed as Deputy Scientist-in-Charge.

On Day 3, representatives of the YVO advisory panel are contacted by the YVO Branch Chief and a conference call is set up between the advisory panel and the Event Coordination Committee. Assuming that unrest did not increase, this basic organizational structure would be used as a basis for response to the initial unrest and would remain in place for as long as desired by the coordinating scientists and ICS.

7a. Scenario 2: Day 1: Forty ($M > 2.0$) earthquakes are recorded over a 10-hour period on a winter day at Yellowstone Lake. Several of the earthquakes are felt by park staff, but no damage is recorded. No deformation or hydrothermal changes are noted.

Day 2: The swarm continues and residents express concern about their safety. 200 $M > 2.0$ earthquakes are now recorded.

On Day 3, YNP initiates an ICS to help plan possible options for moving staff out of the Yellowstone Lake area to alternative locations in the park. The YVO Branch Chief releases an information statement and begins an event response. The alert level remains at Normal. The monitoring group consists of the two coordinating scientists from UU and YNP. The information group consists of a single person from the USGS. The support group remains unstaffed. The

event coordination committee consists of the three coordinating scientists (including the YVO Branch Chief) plus the information group supervisor. A daily information statement is provided through the YVO website until the swarm ceases. Due to the relatively low level of activity, the event coordination committee decides not to deploy temporary equipment unless geological activity increases. The incident command managers have a daily teleconference to re-assess the situation. No YNP staff are moved from the area and the earthquake swarm eventually ceases after six days and the ICS is demobilized at that time.

8. Summary and Protocols for Updating This Plan

This plan summarizes protocols and tools to be used by the Yellowstone Volcano Observatory during episodes of unusual geological unrest at the Yellowstone Caldera.

- The YVO Branch Chief will call for an event response and if appropriate will enter into an ICS led by Yellowstone National Park or another nearby land management agency. The YVO Branch within the Operations Section of the Incident Command will consist of prescribed groups (Monitoring, Information, and Support) and their associated teams.
- An advisory panel will be created to assist the YVO both during periods of geological unrest and quiescence.
- Information will be provided externally through the USGS Hazard Activity Notification System (HANS), the YVO and USGS VHP websites, and a calldown list. Internal communications will be organized through group and team meetings and through the YVO log system.
- Provisional group and team leaders will be assigned, and the group and team roster will be listed as a document on the YVO log system. In addition, a fully populated calldown list with office, home, and cell phone numbers will be uploaded into the log. These documents will be provided to everyone on the lists. The information group supervisor is responsible for annual updates of the roster and calldown list.
- This plan will be modified no less than every three years to account for changes in staff, organizational structures, and other potential variations in the protocols. The current version of this plan will be loaded on the official USGS publications website for viewing by the general public. Similarly, the calldown list and group and team members list will be kept up-to-date on the secured log system (not public) and will be updated yearly.

For more information

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<http://pubs.usgs.gov/fs/2006/3139/>].

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Yellowstone Volcano Observatory, 2006, Volcano and earthquake monitoring plan for the Yellowstone Volcano Observatory, 2006-2015: U.S. Geological Survey Scientific Investigations Report 2006-5276, 17 p.
<http://pubs.usgs.gov/sir/2006/5276/>

Websites with Monitoring Data

YVO Monitoring Webpage
<http://volcanoes.usgs.gov/yvo/activity/monitoring/index.php>

UUSS Recent Earthquakes at Yellowstone National Park
<http://www.seis.utah.edu/req2webdir/recenteqs/Maps/Yellowstone.html>

UUSS Seismic Waveform Images (Webicorders)
http://quake.utah.edu/helicorder/yell_webi.htm

UU GPS Data
http://www.uusatrg.utah.edu/ts_ysrp.html

PBO GPS Data
<http://pboweb.unavco.org/?pageid=88>

PBO Strain Data
<http://pboweb.unavco.org/?pageid=89>

YVO Hydrologic Monitoring with Links to NWIS
http://volcanoes.usgs.gov/yvo/activity/monitoring/hydro_data.php

To reach YVO
 e-mail: yvowebteam@usgs.gov

Glossary of terminology and acronyms

ANSS Advanced National Seismic System: The USGS-sponsored system for providing uniform information products for seismic activity including, locations, magnitudes, effects on buildings, and so forth. Includes the NEIC, the backbone network of USGS seismic stations, and 15 regional seismic networks operated by partner agencies.

Coordinating scientists The designees of the three YVO partners who coordinate normal operations of the observatory.

Deputy Scientist-in-Charge During large event responses, a deputy scientist-in-charge will be assigned to assist with communications, calldowns, and other responsibilities. Normally, this position will not be created unless the alert level has been raised above Normal/Green.

Duty scientist Rotating position among the coordinating scientists and monitoring group and team leaders. The duty scientist is responsible for continuous (24/7) evaluation of monitoring data and communication of important findings to the observatory staff and leadership. The duty scientist position will be utilized whenever the volcano is at an alert level above Normal/Green.

Event Coordination Committee Consists of group supervisors plus the coordinating scientists. Led by the YVO Scientist-in-Charge (YVO Branch Chief).

Event Response An official action taken by the Observatory to react to an increase in geological activity.

FAA Federal Aviation Administration

FEMA/DHS Federal Emergency Management Agency of the Department of Homeland Security. Yellowstone sits within FEMA Region VIII, which is headquartered in Denver.

GPS Global Positioning System: A satellite-based system for location and navigation. It is used in geoscience (and by YVO) to monitor displacement of benchmarks and other monuments as a means of tracking tectonic and volcanic deformation.

HANS Hazards Activity Notification System: A computer interface used by USGS volcano observatories for issuing volcano alerts, information statements, and other advisories.

ICS Incident Command System: A set of personnel, policies, procedures, facilities, and equipment, integrated into a common organizational structure designed to improve emergency response operations of all types and complexities.

IGS Idaho Geological Survey

INL Network The seismic network of the Idaho National Laboratory.

IRIS Integrated Research Institutes for Seismology

JIC Joint Information Center

MBMG Montana Bureau of Mines and Geology

MOU Memorandum of Understanding

NASA National Aeronautics and Space Administration

NEIC National Earthquake Information: Center Denver-based group within USGS responsible for overall monitoring of earthquakes in U.S. Maintains a 24/7 Watch Office and a “backbone” network of seismic stations that complements regional networks such as UUSS.

NIMS National Incident Management System

NOAA National Oceanic and Atmospheric Administration

NSF National Science Foundation

NWIS National Water Information System

NWS National Weather Service

PBO Plate Boundary Observatory: One of the components of Earthscope, a research facility to explore the structure and evolution of the North American Continent. Earthscope is funded by the National Science Foundation. PBO focuses primarily on ground deformation as measured by GPS and strain and tilt meters.

PIO Public Information Officer

Scientist-in-Charge The coordinating scientist from the USGS, who has ultimate authority over Observatory operations. In ICS terminology, the Scientist-in-Charge is called the YVO Branch Chief.

UNAVCO Non-profit company that, in part, assists NSF with installation and operation of PBO instrumentation.

USGS U.S. Geological Survey

UU University of Utah

UUSS University of Utah Seismograph Stations: A research, educational and public-service entity that serves as an ANSS regional network and serves populations in Utah, eastern Idaho, and western Wyoming. UUSS is responsible for location of earthquakes at Yellowstone as part of the Memorandum of Understanding for the Yellowstone Volcano Observatory.

University of Utah Seismology and Active Tectonics Research Group Researchers, faculty and students focused on interpreting and modeling the Yellowstone region seismic and ground deformation data acquired by the University of Utah and others. Research projects include the Yellowstone hotspot, seismicity, magmatism, heatflow, and ground deformation.

VAAC Volcanic Ash Aviation Center

VAN Volcanic Activity Notice

VHP Volcano Hazards Program: USGS program that funds the USGS Volcano Observatories and the Volcano Science Center that administers most USGS employees involved in volcano-related projects.

VONA Volcanic Observation Notification for Airmen

VSC Volcano Science Center: The organizational unit within which most USGS volcano scientists reside. Staff are located primarily at the Alaska, Cascades, and Hawaiian Volcano Observatories, and in Menlo Park, California. Led by the VSC Director.

WSGS Wyoming State Geological Survey

YCR Yellowstone Center for Resources

YNP Yellowstone National Park

YVO Yellowstone Volcano Observatory

YVO Advisory Board A group of scientists and technical experts external to the YVO who will act as advisors during and in between periods of unrest at the Yellowstone Caldera.

YVO Branch The organizational unit occupied by YVO within the Operations Section of the ICS; led by the YVO Branch Chief (Scientist-in-Charge).

18 Protocols for Geologic Hazards Response by the Yellowstone Volcano Observatory

YVO collaborating organizations Informal cooperators such as UNAVCO, the Wyoming State Geological Survey, Montana Bureau of Mines and Geology, Idaho Geological Survey, Integrated Research Institutes of Seismology, and the National Science Foundation/Earthscope. Some of these organizations have a Memorandum of Understanding (MOU) and a cooperating agreement with one or more YVO partner.

YVO partners Signatories to the YVO Memorandum of Understanding (MOU), most recently signed in 2008 by the U.S. Geological Survey, Yellowstone National Park, and the University of Utah.

