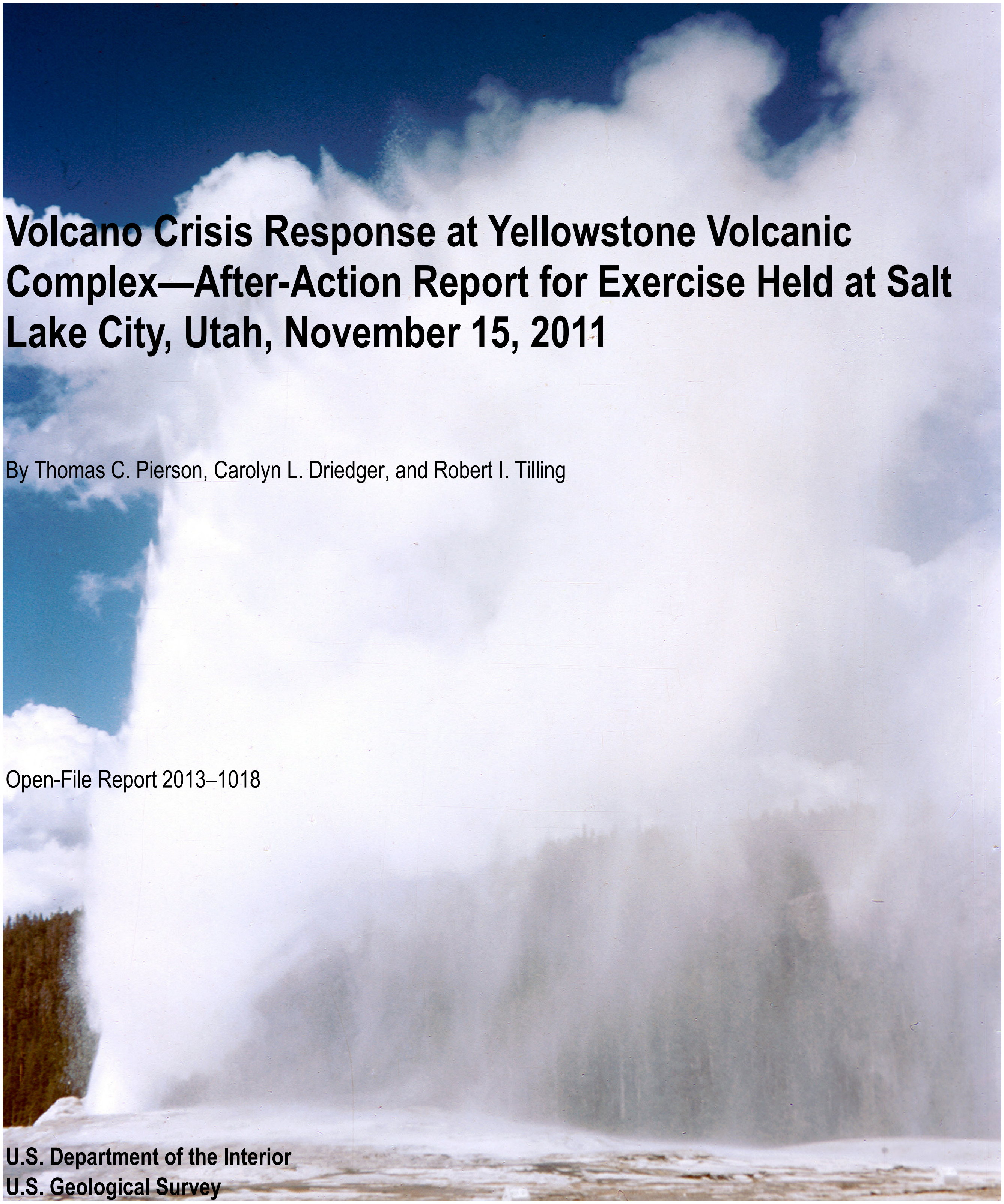
USGS
science for a changing world



Volcano Crisis Response at Yellowstone Volcanic Complex—After-Action Report for Exercise Held at Salt Lake City, Utah, November 15, 2011

By Thomas C. Pierson, Carolyn L. Driedger, and Robert I. Tilling

Open-File Report 2013–1018

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

U.S. Geological Survey, Reston, Virginia: 2013

Suggested citation:
Pierson, T.C., Driedger, C.L., and Tilling, R.I., 2013, Volcano crisis response at Yellowstone volcanic complex—after-action report for exercise held at Salt Lake City, Utah, November 15, 2011: U.S. Geological Survey Open-File Report 2013–1018, 31 p.

COVER
Old Faithful Geyser in the Upper Geyser Basin, Yellowstone National Park. USGS photo by Warren B. Hamilton.

Contents

Figures

Volcano Crisis Response at Yellowstone Volcanic Complex—After-Action Report for Exercise Held at Salt Lake City, Utah, November 15, 2011

By Thomas C. Pierson, Carolyn L. Driedger, and Robert I. Tilling

Executive Summary

A functional tabletop exercise was run on November 14–15, 2011 in Salt Lake City, Utah, to test crisis response capabilities, communication protocols, and decision-making by the staff of the multi-agency Yellowstone Volcano Observatory (YVO) as they reacted to a hypothetical exercise scenario of accelerating volcanic unrest at the Yellowstone caldera. The exercise simulated a rapid build-up of seismic activity, ground deformation, and hot-spring water-chemistry and temperature anomalies that culminated in a small- to moderate-size phreatomagmatic eruption within Yellowstone National Park. The YVO scientific team's responses to the unfolding events in the scenario and to simulated requests for information by stakeholders and the media were assessed by (a) the exercise organizers; (b) several non-YVO scientists, who observed and queried participants, and took notes throughout the exercise; and (c) the participants themselves, who kept logs of their actions during the exercise and later participated in a group debriefing session and filled out detailed questionnaires. These evaluations were tabulated, interpreted, and summarized for this report, and on the basis of this information, recommendations have been made.

Overall, the YVO teams performed their jobs very well. The exercise revealed that YVO scientists were able to successfully provide critical hazards information, issue information statements, and appropriately raise alert levels during a fast-moving crisis. Based on the exercise, it is recommended that several measures be taken to increase YVO effectiveness during a crisis:

1. Improve role clarification within and between YVO science teams.
2. Improve communications tools and protocols for data-sharing and consensus-building among YVO scientists, who are geographically and administratively dispersed among various institutions across the United States.
3. Familiarize YVO staff with Incident Command System (ICS) procedures and protocols, and provide more in-depth training to appropriate staff members, as needed.
4. Train all science team members in the use of all analytical and computational tools available to them, in order to maximize effectiveness of teams in tracking and interpreting possible accelerating unrest at Yellowstone.

Desirable pre-crisis preparations include: (a) updating a catalog of existing map and information products (and identifying additional products) that would be helpful during a crisis; (b) creating "to do" lists of early-crisis tasks for each scientific team; (c) coordinating radio frequencies among partner agencies; and (d) brief training on and promotion of the internal YVO Web log as a repository for

scientific observations, data, photographs, and other material to be shared among YVO scientific teams during a crisis.

This exercise was designed as an opportunity to practice response to a fast-developing volcano crisis and to test for organizational and procedural weaknesses that could emerge during a real crisis. This report is based upon the observations of the exercise organizers during the one-day exercise and upon written evaluations by the participants. It does not attempt to evaluate any other aspect of YVO or the scientific expertise of any of the highly competent YVO staff. Participants unanimously found the exercise to be helpful for improving their response capabilities, and it is our hope that the report will be a starting point for internal discussions that will make YVO even better-prepared for some future volcano crisis.

Acknowledgements

The authors wish to acknowledge the contributions to development of the exercise scenario made by USGS scientists Seth Moran, Mike Poland, Dave Hill, and Peter Kelly.

Part 1: Exercise Overview

Exercise Name.—Volcano Crisis Response at Yellowstone Volcanic Complex by Staff of the Yellowstone Volcano Observatory

Location.—University Guest House and Conference Center (Commander's House), University of Utah campus, Salt Lake City, Utah

Scenario.—A hypothetical, rapid (8-day), build-up of seismic activity, ground deformation, and other precursory activity leading to an explosive phreatomagmatic eruption from an underwater vent in West Thumb bay of Yellowstone Lake

Type of Exercise.—Functional tabletop

Focus.—To test crisis-response capabilities, communication protocols, and decision-making by the staff of the multi-agency Yellowstone Volcano Observatory (YVO), as they reacted to a hypothetical exercise scenario of accelerating volcanic unrest at the Yellowstone caldera

Exercise Date.—November 15, 2011

Number of Participants (Role Players).—33

Participating Organizations.—

- U.S. Geological Survey (USGS)
- USGS Volcano Science Center (VSC)
- National Earthquake Information Center (NEIC)
- University of Utah Seismic Stations (UUSS)
- Yellowstone National Park (YNP)
- University of Wyoming (UW)

- Wyoming State Geological Survey (WSGS)
- University Navstar Consortium (UNAVCO)

Funding Source.—USGS VSC

Federal Sponsoring Agency.—USGS

Exercise Organizers.—Carolyn Driedger and Thomas Pierson (USGS VSC)

Exercise Observers.—Robert Tilling (USGS VSC, emeritus), John Ewert (Scientist-in-Charge, USGS VSC, Cascades Volcano Observatory)

Exercise Overview.—The exercise consisted of a scenario involving rapidly developing unrest at Yellowstone, as indicated by increasing seismic activity, ground deformation, hydrothermal temperature anomalies and small explosions, changes in water chemistry, and changes in volcanic gas emissions. In virtual time, the exercise ran over 8 days, with data and information on the unrest delivered to the exercise participants in four stages. After each stage, participants had about 15 minutes to evaluate and record their actions during the just-completed stage. In real time, the exercise ran from 8:30 a.m. to about 2 p.m., with no breaks (to simulate the reality of a fast-developing crisis). The events were presented to participants by (1) PowerPoint projections of time-sequential maps showing locations of phenomena; (2) handouts on paper sheets given to the leader of each team, which informed them of the latest information and data for the developing crisis; and (3) handouts containing urgent requests for information, interviews, and meetings ("injects") from critical stakeholders, politicians, and the media.

Exercise Evaluation.—Immediately following the end of the exercise, participants took a short break and some time to jot down their thoughts and observations. Then a group debriefing session (a "hot wash") was held, which lasted about 90 minutes. The purpose was to collect the unfiltered first thoughts, reactions, and impressions on the exercise. Participants were also given a detailed questionnaire that they were requested to fill out and return to the exercise organizers within a week of completing the exercise. In addition the exercise organizers, several independent observers roamed about the exercise area, listening to conversations and asking questions, in order to make independent third-party evaluations of task accomplishment during the exercise.

Part 2: Exercise Goals and Objectives

1. Test YVO teams for organizational and procedural effectiveness under the pressure of a fast-developing hypothetical crisis.
2. Provide YVO scientific staff with a realistic sense of (a) individual and team responsibilities during a rapid-onset volcanic crisis, and (b) the intense time pressures and stress levels imposed by a cascade of legitimate demands for information from many sources.
3. Provide a safe environment to identify and practice individual and team tasks during a volcanic crisis, and identify targets for improvement in YVO training, protocols, and procedures.
4. Provide opportunity for practicing communication, consensus-building, and decision-making within teams and between teams and YVO management, given the broad range of scientific disciplines, the different home agencies and institutions, and the geographically separated duty stations of scientific team members and YVO management.

5. Provide an opportunity for YVO staff members to meet face-to-face, to interact, and to build trust.

Part 3: Exercise Events Synopsis

Venue and Exercise Logistics

The exercise was held at the University Guest House and Conference Center at the University of Utah in Salt Lake City. This venue, a former Army base, provided both hotel accommodations and space for the exercise in the nearby Commander's House.

Exercise participants (appendix 1) gathered at the venue at 8 a.m. The exercise started at about 8:30 a.m. and finished at about 4 p.m. The exercise was run in four stages—critical time intervals during the hypothetical volcanic unrest (exercise time): day 1 of the crisis, day 3, day 6, and day 8. Each of these days was compressed into about one hour, and the exercise ran without any formal breaks (to simulate a real crisis), until about 2 p.m. The group debriefing session ("hot wash") lasted until 4 p.m.

Scenario

The exercise scenario (appendix 2) portrayed the rapid build-up of unrest (seismicity, deformation, heat flux, release of volcanic gases, and small hydrothermal explosions) beneath or nearWest Thumb, a bay of Yellowstone Lake, not far from where an actual limited seismic build-up occurred in 2008–2009. This area is near a popular visitor attraction (West Thumb Geyser Basin) and a visitor center (Grant Village)—examples of a number of destinations within Yellowstone National Park where people are frequently in close proximity to hydrothermal features (fig. 1). The scenario included two moderately large earthquakes, a significant hydrothermal explosion in the geyser basin, and a phreatomagmatic (partially steam-driven) explosive eruption from a vent beneath the lake. The explosion triggered a pyroclastic surge (a blast of hot gas and volcanic ash) and a small tsunami.

Figure 1. Visitors to Yellowstone National Park watch the show at Old Faithful geyser. USGS photo by Daniel Dzurisin.

Conducting the Exercise

The exercise began with the presentation of background events and information on hypothetical day 1 of the exercise, defined as July 21, 2012:

- Weather has been good; many visitors in Yellowstone National Park.

- Over the past year there had been a slight increase in overall background seismicity, and in the previous few weeks it had increased a bit more.
- Park rangers had reported a slight increase in the level and vigor of steaming from pools in West Thumb Geyser Basin.
- An InSAR (interferometric synthetic aperture radar) image had been obtained (and a mock-up hypothetical image was presented to participants), showing recent broad uplift on the northwest shore of Yellowstone Lake.
- A "random" complication was introduced to simulate one of the realities of a volcano crisis occurring without much warning: Bob Smith (recently retired lead seismologist at UUSS and the seismology team leader) was said to be on a field trip overseas and could not be reached during day 1 (forcing back-up staff to take over).

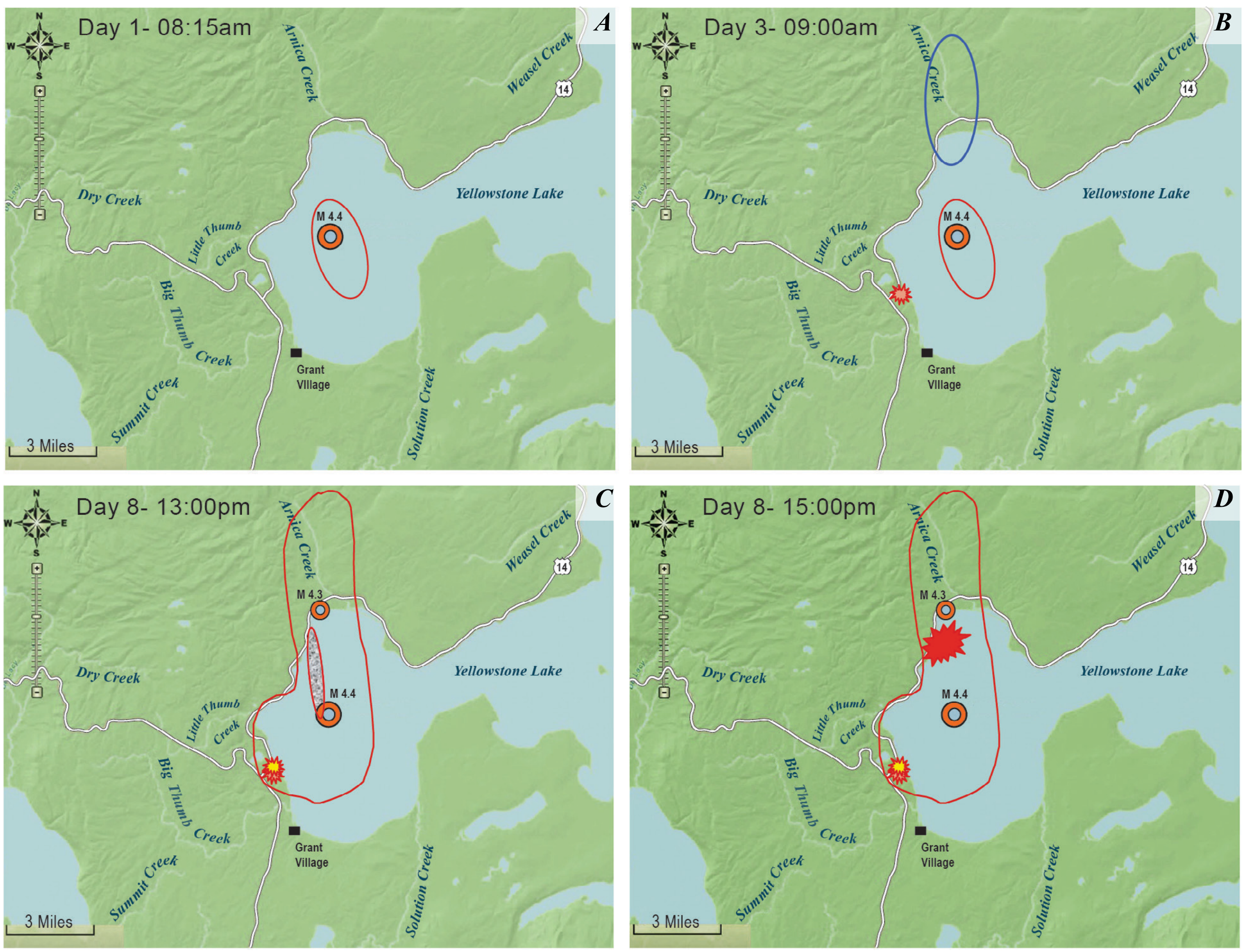


Figure 2. Scenario maps of West Thumb area of Yellowstone Lake for different stages of the exercise. *A*, The morning of day 1 after an earthquake swarm has been located (red oval) and a significantly larger earthquake has just occurred, with epicenter shown as bull's-eye. *B*, The morning of day 3 after a new earthquake swarm (blue oval) has started farther north and a hydrothermal explosion (burst icon) has just occurred at the West Thumb Geyser Basin. *C*, Midday on day 8 following an *M*4.3 earthquake earlier that morning, another hydrothermal explosion at the geyser basin, and an intensification of shallow earthquakes in a narrow zone extending north and south between the earthquake epicenters (thin filled oval). *D*, The climax of the exercise at mid-afternoon on day 8—a phreatomagmatic eruption from an under-water vent (large burst icon), which was accompanied by a high-velocity base surge and small tsunami that caused damage and casualties.

Essential information was presented at the beginning of each stage with (1) PowerPoint slides showing maps of the West Thumb area and the locations of events happening during that stage (fig. 2), and (2) one sheet of paper, handed to each team leader, which listed the events having just happened in the preceding days or hours. During each stage, additional sheets of paper with new developments and data were handed to the team leaders. In addition, more information was available from the exercise leaders if teams requested it.

Whenever new information was delivered, team leaders communicated developments to their teams, and team leaders initiated discussions on (a) necessary team tasks, (b) implications of the new developments, (c) what additional data or tests they would try to obtain and from whom, and (d) what information/conclusions their team needed to pass on and to whom. Each team member was asked to keep a log of all the hypothetical activities that they would carry out in a real situation. Abundant "injects" (for example, requests for media interviews or briefings with concerned public officials) were distributed to each team leader as each stage progressed, for them to decide how to respond. Teams were expected to communicate with each other to share data, opinions, and conclusions. The goal of the exercise leaders was to keep new information coming in quickly, in order to simulate the "drinking from a firehose" pace of a real, fast-developing crisis.

Evaluation of Exercise Effectiveness/Usefulness

Exercise effectiveness/usefulness was evaluated initially in the post-exercise group debriefing, in questionnaires participants filled out for the end of each stage, and in a final evaluation that participants filled out and returned to the organizers in the weeks following the exercise. Eighteen final evaluations (out of 33 participants) were returned.

Part 4: Analysis of Task Performance by Teams and Individuals

Leadership and Task Assignment

Discussion

During progression toward a real crisis at Yellowstone volcano, YVO's role would be to *rapidly and accurately provide scientific information about escalating volcanic activity and potential hazards*—initially to stake-holders and the public, prior to an Incident Command (IC) being established, and subsequently to the IC following establishment of an Incident Command System (ICS) by Yellowstone National Park (YNP). There could well be unrest scenarios (more gradual than the one portrayed in the exercise) when YVO would be operating for some time without an ICS in place. During the exercise some questions arose among team members about how their jobs or responsibilities might be affected or changed once an IC is established.

The roles of YVO and its teams under an ICS are outlined in USGS Circular 1351 (Yellowstone Volcano Observatory, 2010). As presently outlined in Circular 1351, YVO would become the "YVO Branch" under the Operations Section of the ICS, and the YVO Scientist-in-Charge (SIC) would become the YVO Branch Chief and head an Event Coordination Committee within YVO for the purpose of reaching consensus among YVO scientists about conditions and hazards of the volcano. The SIC acts as an official liaison to the IC, and as such the SIC would communicate directly to the Incident Commander about (a) changes in alert level; (b) information about geological conditions, hazards, and possible future scenarios; and (c) operational and logistical needs of YVO scientists.

It is likely that YVO scientists and staff in the Monitoring and Support Groups would not be directly affected by the presence of an overlying ICS management structure, and team members would report to the YVO Branch Chief (SIC) during a crisis just as they would at other times. However, coordination between the YVO Public Information Team (through the team leader) and the IC Information Officer will be important for the effective release of information to the public and the media about the crisis. During the exercise, issues about information release generated the most confusion with regard to the authority of IC.

Aside from ICS questions, participant evaluations revealed that there were some questions among teams about what roles individual team members would have during a crisis. These comments came primarily from team members not affiliated with the USGS, UUSS, or YNP. Because other organizational levels of the USGS (for example, Volcano Science Center Director, Regional Executives, Office of Communication) typically become involved during volcano crises (for emergency funding, logistics, data acquisition, getting out press releases, and so on), questions arose about how their potential activities would be guided or constrained under an established ICS.

Figure 3. Deputy Scientist-in-Charge Peter Cervelli, left, and Scientist-in-Charge Jake Lowenstern, right, evaluating new information during the exercise.

Recommendations

1. URGENT: Assign and clarify the roles of all YVO scientific staff (a) during non-crisis periods or early in a crisis (prior to IC activation), and (b) during a volcanic crisis (under IC). The SIC should provide each team with a list of task responsibilities for both before and after a volcano crisis starts at Yellowstone (see appendix 3 as an example with suggested format). Each team leader should provide the SIC with a list of needs that would help them accomplish their tasks (for example, training, software, equipment, and so on).
2. URGENT: Identify YVO personnel who will have additional responsibilities within an ICS management structure, and identify those responsibilities. Develop a list of the changes in any roles or responsibilities of YVO team leaders, the SIC, and deputy scientist-in-charge (DSIC) for when volcanic activity escalates to the point where an IC is established. For YVO personnel who would perhaps assume new roles under the IC, provide sufficient training to ensure that they understand their roles.
3. Ensure that other USGS offices and entities know their roles during a Yellowstone crisis. Include in future exercises USGS (and other agency) staff outside of YVO who would support YVO during a crisis in gathering and analyzing scientific data.
4. Ensure that YVO has received guidelines from the USGS Director concerning emergency acquisition of necessary resources for scientific data collection and analysis during a crisis

response. This might best be developed on a VSC-wide level, making guidelines clear to SICs at all volcano observatories.

Availability of Information/Data for Task Accomplishment

Discussion

Scenario participants were not required to actually acquire data or information for this exercise (it was given to them by the exercise leaders), but some communication among and between teams about the provided information was required. In a real crisis, significant time would be needed for discussion and deliberation among and between teams, in order to reach consensus on the likely course (and possible outcomes) of the build-up of volcanic unrest. Because of the rate at which new information was presented to the participants, there was not much time to carry out these discussions and deliberations. This was partly by design, in order to give participants a sense of how fast new information can come at them in a real crisis, but it would have been possible to provide more time for discussion/deliberation to reach consensus in at least one of the scenario stages.

During this exercise, participants from each geographic location were seated at particular tables (for example, there was a Menlo Park table, a UUSS table, and so on). Rather than actually communicate by cell phone and email as they would during a real crisis, participants got up and walked to other tables to talk to people with whom they would otherwise communicate remotely. A number of post-exercise evaluation comments suggested that it would be more realistic to physically separate these working groups, in order to force the use of emails and phone calls in team interactions. This undoubtedly would be more time consuming, but it would definitely highlight the challenges of long-distance collaboration and data sharing.

During a real crisis, ready access to baseline high-resolution topographic, geologic, and monitoring data can be extremely helpful. A large amount of such data already exists for the Yellowstone caldera. Although this issue was not directly addressed during the exercise, it is important that relevant imagery and data be easily available and that team members know how to retrieve it.

Figure 4. Team members at a "geographic location" discuss response options during the exercise.

Recommendations

Develop catalogs of existing relevant data sets and common archiving procedures for newly acquired datasets; efficient data management of seismic, geodetic, gas, water geochemistry, and geospatial data will be very important during a volcanic crisis. In coordination with YNP, develop database catalogs for information that would be needed quickly during a crisis (for example, geographic information systems (GIS) digital bases, overlays, and metadata, geologic maps, remote-sensing images, background levels of unrest indicators, such as seismic energy release rates, "normal" rates on inflation/deflation, aqueous and gas geochemistry and fluxes), and if possible ensure that these databases are easily accessible and that newly acquired data will be stored in these same databases.

Adequacy of Training for Task Accomplishment and Crisis Management

USGS scientists work regularly with restless or erupting volcanoes, so although UUSS, UNAVCO, and state agency scientists clearly have good depth and breadth of knowledge about typical background geophysical behavior of Yellowstone, questions arose during the exercise about whether team members who have not previously worked on volcano crises would be fully familiar with the kinds of activity that are common at reawakening volcanoes, and if they would be comfortable in scenarios that are outside their personal experience with Yellowstone. Many team members had not participated in volcano-crisis situations previously, and some had questions about their roles during accelerating volcanic unrest or about how they would communicate, share, and analyze data during a crisis response. In evaluations, a number of participants reported that the exercise provided at least a clearer sense of this.

From the crisis management point of view, however, no teams except those with NPS staff appeared to know what their roles and responsibilities would be under an ICS crisis-management framework. Unfamiliarity with ICS procedures and protocols could, in some cases, lead to inefficiency, unnecessary time delays, communication breakdown, release of unapproved and possibly contradictory information to the media and public officials, and perhaps unintended insubordination within the ICS chain of command. However, as noted above, the need for ICS knowledge by YVO personnel is variable.

Recommendations

1. URGENT: Provide ICS training/exercises for selected personnel to equip them to function effectively and efficiently within ICS during a crisis. Provide training to personnel who will serve in multi-agency ICS functions, and who have a need to know the roles they will play in an ICS framework. Identification of team members needing further training (and at what levels) should be done by the SIC. One option would be to develop and implement an integrated emergency management course (IEMC) through the Federal Emergency Management Agency (FEMA) that addresses activity at Yellowstone. Such courses are often three days long and involve all personnel who will hold roles in the ICS framework. Days 1 and 2 are devoted to presentations by scientists and specialists in the ICS framework about the multiple aspects of response and recovery. The third day is reserved for an exercise and discussion. Funding for these courses is available from the Department of Homeland Security. VSC staff also could participate in IEMCs offered by local emergency management partners focused on other natural hazards. YNP staff who participated in the exercise suggested the following Internet-based FEMA courses about the ICS framework as another training option:
   - FEMA courses IS-100, IS-200, 700, and IS-800
   - FEMA courses IS-300 and IS-400 for anyone serving as a public information officer (PIO) or YVO team leader
   - Either the National Wildfire Coordinating Group (NWCG) S203 or FEMA G290 courses for PIOs, and familiarity with either a FEMA PIO task book or the NWCG PIOF task book to become incident-qualified PIOs.
2. Provide training about monitoring techniques and tools for assessing restless volcanoes. This would be especially valuable for YVO scientific staff not experienced with monitoring signals and trends typical of volcanoes transitioning from dormancy to eruptions. Such training would also be a useful refresher course for those who have had some experience. The USGS Volcano Hazards Program (VHP) should consider sponsoring a workshop for staff of all its volcano observatories

(including both USGS and partner-agency personnel), to be taught by Hawaii Volcano Observatory (HVO), Alaska Volcano Observatory (AVO), and Volcano Disaster Assistance Program (VDAP) experts, in order to share best practices regarding monitoring and analytical tools for seismic, geodetic, gas/water geochemistry, and remote sensing monitoring teams.

Adequacy of Staffing and Resources for Crisis Management

Discussion

YVO currently consists of a Monitoring Group, an Information Group, and a Support Group, and at the time of the exercise YVO had a staff of 28, including one vacancy (appendix 1). These staff members are all highly trained and capable individuals, with considerable experience in their respective fields of expertise. Some have had first-hand experience in dealing with volcanic unrest and crisis responses; others have not. The latter reported that the exercise was very helpful in giving them a sense of what a real crisis would be like.

The Monitoring Group (14 total staff) comprises a seismology team (five people, in four different geographic locations), a geodesy team (three people in three different locations), a geology team (three people in three different locations), and a remote sensing team (three people in three different locations). The Information Group (six total staff) consists of a GIS team (four people in four different locations), and a public information team (two people in two locations). The Support Group (six total staff) consists of an administrative support team (two people in two different locations, with focuses on budget and staffing), and an external research support team (three people and a vacancy, in three different geographic locations). Eleven separate geographic locations in Alaska, Washington, California, Virginia, Colorado, Idaho, Montana, and Wyoming make up the duty stations of these 28 YVO staff members. Every team has a designated leader, and the whole operation is overseen by the YVO SIC and DSIC, who are based in Menlo Park, California. Most, but not all, team members were able to attend this exercise.

The need for a protocol for acquiring back-up personnel for key team positions during a crisis was not explicitly addressed in the exercise, although stage 1 was designed so that a key team leader was not available to lead the discussion about stage 1 events, and the rest of the team members had to react to that fact. But the question remains as to how YVO would address the problem of missing staff members during a real crisis. Does a list of qualified substitutes exist? Do people on such a list know that they are on it and would have to drop everything at a moment's notice to assist YVO during a crisis? Are existing YVO staff members sufficiently cross-trained that they could seamlessly step into someone else's role if they had to do so? During a crisis it may also be necessary to obtain help and expertise from nonYVO scientists in other fields (for example, stream gage readers, ash-cloud transport modelers, specialists in fine atmospheric dust, risk-assessment experts, and others).

The emergency acquisition and deployment of additional physical resources (monitoring instrumentation, field radios, and chartered aircraft, for example), as well as needed additional personnel, can be critical during a crisis. Some of these needs would be handled by the logistics section of the ICS, but others might not. USGS Circular 1351 (2010) does not specify how and by what authority the SIC can requisition additional resources to deal with a crisis.

Figure 5. Exercise observers interacting with participants at one of the tables.

Recommendations

1. URGENT: Compile a list of qualified potential back-up personnel from YVO member agencies and from other agencies and academic institutions, who could be mobilized during a crisis if needed. Identify personnel capable of filling in for critical YVO team members who might be missing during a crisis due to health issues, accidents, family crises, travel status, or other potential conflicts. Notify all persons on that list, so that they could be prepared to drop their normal work and family duties in order to help alleviate any YVO staffing shortage during a crisis.
2. Cross training of team members. See recommendations in previous section concerning cross-training of scientific staff.

Inter- and Intrateam Communication and Interaction—Challenges of Geographic Dispersal of YVO Teams

Discussion

The geographic dispersal of team members is extreme. This scattering of staff all over the United States may not be an issue during times of quiescence at the volcano, but during a volcanic crisis, severe challenges in effective communication, data sharing, data analysis, consensus building, and decision-making are very likely to be encountered among team members and between team leaders and the YVO SIC.

During the exercise, some team members simulated relocation to a central hub near Yellowstone by moving from their duty-station tables to a central table. A scientific hub at which scientists could gather (essentially a forward volcano observatory) may or may not be the same location as the Incident Command Center. Team members probably work more efficiently in their own duty stations where computer data bases, computer files on desktop hard drives, and hard-copy reference materials are readily at hand, but having key team members in a common location could greatly facilitate team interaction.

Intergroup and intragroup communication during the exercise appeared to be good for some teams and not so good for others. During the exercise, some "isolated" team members appeared unengaged for long periods, not being brought into participation by their team leaders. Exercise participants noted that a central place was needed for data posting/transfer, indicating that they were unaware of the existence of the YVO internal Web log.

Communication from team leaders to the SIC was hard to assess during this exercise, in part because the exercise did not allow enough time for realistic simulated communication and deliberation, and comments in some evaluations suggested that there was insufficient communication with YVO leadership.

Discussion during and after the exercise raised the question of whether field radios owned by team members from different agencies and institutions had the capability of communicating on the same frequencies, and also whether all the contingency locations for YVO's forward observatory during a crisis would have the necessary radio communication capabilities and high-speed internet connections.

Recommendations

1. URGENT: Ensure that (1) a robust communication plan exists for a crisis, and (2) all necessary communications hardware, software, linkages, and hookups are in place or could be rapidly acquired and installed. During a crisis critical communication links and protocols would be established and managed by the ICS, but advance planning with YNP could ensure that YVO's communication needs would be met. Robust telephone and broadband Internet infrastructure would be needed to link (a) team members in distant locations with the forward volcano observatory and (b) the forward observatory to IC, assuming that they are not colocated. (Note that cell phone networks could be seriously compromised during a crisis.) Ensure that any firewall issues are addressed within current and planned Internet-access configurations.
2. URGENT: Coordinate radio capabilities. Ensure that all YVO voice-communication radios are preprogrammed or easily programmable to NPS emergency frequencies.
3. Encourage non-crisis communication among YVO scientists. Because scientists cannot easily meet with other members of their teams due to geographic isolation, we suggest periodic activities that help team members get to know each other better and to build trust within teams:
4. Regular updating and sharing of contact information.
5. Regular information sharing through web-hosted talks or discussions, and special theme sessions at scientific meetings.
6. Field trips to YNP for YVO team members in order to meet key YNP staff with whom they would interact during a real volcanic crisis, to become familiar with YNP infrastructure and key geographic locations, and to get to know one another better.
7. Improve coordination within and between YVO member agencies and institutions for data archiving, sharing, and analysis. Convene a committee of database and volcano-monitoring experts to address optimal procedures for data archiving and retrieval, data sharing, data analysis, and systems modeling during a crisis.
8. Encourage use of YVO Web log. Ensure that all YVO staff are familiar with the Web log—what it is for and how to use it.
9. Plan for relocation of personnel to a forward volcano observatory during a crisis. Relocation of personnel from outlying duty stations should be strategically organized and planned ahead of time by the SIC and not left to chance. Team members should know ahead of time whether they should relocate during a crisis, under what conditions relocation is advised, and to where. The SIC should discuss with YNP where forward observatories might be located. Blanket travel authorizations for affected team members should allow this to occur quickly.

Interactions with the Media, Public Officials, and Other Agencies

Discussion

A large number of "injects" were delivered to participants during the exercise. These were requests for interviews or for information from a variety of local to international news organizations and from public officials. Participants were asked to think about how they would respond and who would be delegated to meet these urgent requests. Time did not allow the simulation of media interviews, although they had been planned. During the exercise, these media requests were generally passed on to the Public Information team (two individuals). During a real crisis at Yellowstone, it is absolutely certain that there will be a huge onslaught of media clambering for information and interviews, which undoubtedly will swamp these two individuals. Others with media training will have to be brought in to assist. Even the onset of the small dome-building eruption at Mount St. Helens in 2004 required four full-time USGS interviewees for about a week. Although "anyone" can give an interview for a TV station, scientists untrained in dealing with the media tend to use a lot of big words that lay people can't understand. Feedback from news organizations during the St. Helens media frenzy emphasized that individuals with some media training who have the ability to put scientific concepts into everyday language are much more effective in getting information out to the public.

One potential problem during a crisis is the release of "mixed messages"—conflicting information from multiple sources. The exercise showed that this could easily be a problem at Yellowstone, because the USGS, NPS, and UUSS (and probably also the affected state organizations) are used to acting independently with regard to giving interviews, developing messages, and releasing public information statements for the media. While the IC has authority over the issuance of official press releases, the USGS has the authority to independently issue information statements and make changes to hazard alert levels during a crisis. Coordination and control of outgoing messages to the media apparently has not been practiced in the past, and this could create huge problems during a real crisis.

Figure 6. The Information Group dealing with "injects" during the exercise.

Recommendations

1. URGENT: Develop a YVO Media Response Plan in discussion with YVO partner agencies and institutions. The plan would clarify the circumstances under which authority for information release should be transferred from YVO to the IC. It also should address media-response training (for those who need it) for selected scientific staff from USGS, NPS, UUSS, and State agencies who will be acting as media spokespersons. Furthermore, the plan should clarify the difference between (1) releasing and explaining scientific information during a volcanic crisis, and (2) explaining to the public how the crisis is being managed. The first is the responsibility of YVO; the second is the responsibility of the NPS (and the IC). Protocols for the development of talking points and other mechanisms for consistent messaging among participating agencies should be established. A list of staff (with backups) who are qualified to release information to the public and the media should be prepared.
2. Encourage a culture among YVO institutions and agencies of coordinating the content of messages and information statements about Yellowstone volcano during non-crisis times, and periodically

practice coordinated information releases. During a crisis, the ability to stay "on message" may well depend on the thoughtful collaboration developed between participating agencies during non-crisis information releases.

Part 5: Analysis of Mission Outcome—Was the Crisis Handled Effectively?

Interaction with Emergency Management

Discussion

The limited scope of this exercise was to develop and improve interaction and coordination among the YVO scientific staff. Transfer of scientific information to IC was not practiced in the exercise. However, it is vitally important that YVO staff know what types of information will be required by emergency managers and other stakeholders during a crisis. It is also vitally important that the SIC engage all emergency managers that could be affected by a volcanic crisis at Yellowstone (not just YNP management), and this engagement needs to start before a crisis is imminent. It is important that all emergency managers having responsibilities during Yellowstone volcanic activity be included on YVO's call-down lists.

Recommendations

1. Conduct outreach about Yellowstone volcano hazards with non-YNP emergency managers in surrounding states. Start now by meeting with emergency managers in nearby local communities to explain (a) hazard and risk implications potential volcanic activity at Yellowstone, (b) the types of information that YVO would be able to provide during a crisis, and (c) potential impacts to their jurisdictions. Meeting regularly with these managers can build trust and facilitate communication during a real crisis. At the Cascades Volcano Observatory, this has been accomplished by establishing work groups that meet periodically.
2. Involve emergency managers in other exercises. Work with YNP and other agencies to develop future exercises that will provide practice for interaction, coordination, and cooperation between YVO scientists and local, state, and federal emergency managers.
3. Develop a protocol for regularly updating all call-down lists. The SIC should check with YNP and UUSS to see what duplication exists in emergency call-down lists. Lists should be coordinated and duplication should be eliminated. Such lists should be updated at least annually.

Establishment of Incident Command

Discussion

During the exercise some team members were aware that an Incident Command System would have been activated by YNP management early in the crisis being simulated. Although the tasks of YVO scientists would probably not be affected by the ICS, release of information about their work could be. As addressed earlier, additional familiarity with ICS protocols would enhance response coordination during a crisis. It should be recognized that NPS employees who are part of YVO could potentially be asked to take on major ICS responsibilities, which would leave a personnel gap within the YVO structure.

Recommendations

1. URGENT: Clarify crisis roles of YNP staff under the ICS who are also team members of YVO. Will they remain working as YVO team members, or will they be pulled out by YNP management for other duties as part of the NPS Incident Management Team?
2. For planning purposes, identify which YVO team members could have additional duties imposed by the IC and the degree to which those additional duties could affect their regular YVO duties during a crisis. For example, members of the YVO Information Group might be asked to provide maps and imagery for the Incident Commander, and would be unavailable to fulfill image procurement requests from the Monitoring Group.

Issuance of Information Statements and Changes in Alert Levels

Discussion

During the exercise the SIC and some YVO team members had a clear vision for when information statements were needed. Some draft information statements were prepared, although there was not sufficient time during the exercise to fully discuss the unfolding events and reach consensus about what should go into these information statements.

The exercise was designed to portray a rather smooth build-up in precursory activity, at least initially, without the clearly defined trigger events noted in Circular 1351 (2010) for changing alert levels. Although no specified trigger events were given for this exercise, YVO staff seemed to have a good sense of when alert levels needed to be changed. Again, because of time constraints, it was not possible to fully simulate the process of issuing alert-level changes. From past experience with volcano crises, information statements and changes in alert levels guarantee a flurry of media attention, and in a real crisis, YVO will need to be ready to handle it.

Recommendations

1. URGENT: Identify staff members from YVO member agencies and institutions who are trained and would be available to help with YVO's media response during a real crisis. See discussion and recommendations in part 4, sections called "Adequacy of Training for Task Accomplishment and Crisis Management," "Adequacy of Staffing and Resources for Crisis Management," and "Interactions with the Media, Public Officials, and Other Agencies."
2. All YVO staff should become familiar with the national standards for volcano alert levels.

Part 6: Review of the Exercise

Discussion

Overall, exercise participants did an admirable job responding to the simulated volcano crisis at Yellowstone under intense time pressure, and they evaluated the exercise very positively (appendix 4). A number of people noted that there simply was not enough time to digest all the information and interact with other team members. The exercise was highly condensed, and organizers provided only minimal time for team interaction, in order to simulate the feel of a real crisis. However, more time for interactions would have allowed participants better opportunity to practice reaching consensus about new data, making decisions, and communicating findings to the SIC.

Long-distance communication between team members, which is a reality of YVO, was not adequately tested. Having different geographic centers represented by different nearby tables (where communication between tables was easy) did not realistically portray the kinds of barriers to communication that would have to be overcome during a crisis. Another omission due to the highly compressed schedule was the lack of opportunity for participants to practice writing information statements.

Several logistical issues could be improved for future exercises. Participants were not given nametags, and perhaps most egregiously, coffee was not provided—a major oversight!

Recommendations

1. Allow time for simulated conference calls. Ensure that time is allotted for at least one conference call that would allow teams to reach consensus and make a recommendation to the SIC about the most likely course of the simulated unrest.
2. Simulate the physical separation of team and group members more realistically. Simulate challenges of long-distance collaboration by putting staff from different geographic centers in different rooms or buildings, so that they could not talk with each other except by phone or email. If this is done, maps will have to be provided to participants in hard copy, not simply projected on a single screen.
3. Help participants keep track of virtual time during the exercise. Use more effective visual cues to indicate "exercise time," and make it clear to participants when exercise time or actual real time is being referred to as the exercise progresses.
4. Practice effective communication to facilitate management decisions. In future exercises, make time to practice communication between team members who have important data to share with the YVO SIC and DSIC, who must be able to distill and evaluate these various information streams to make important decisions and recommendations.
5. Practice writing information products. Provide time for key personnel to write and issue effective information statements, news releases, and changes in volcano alert levels, and other official notifications, such as Volcanic Activity Notices (VANs) and Volcano Observatory Notices for Aviation (VONAs).
6. Increase duration of exercise: A number of participants thought it would be useful to increase duration of the exercise, which would allow greater realism and depth of involvement by participants.
7. Provide nametags and coffee.

Part 7: Conclusions

Successes

The Yellowstone Volcano Observatory is a well-organized institution staffed by highly talented scientists from a number of Federal and state agencies and institutions. Its mandate is to provide scientific information, judgments, and forecasts to emergency managers, the media, and the public about any developing unrest at Yellowstone that could potentially lead to hazardous volcanic processes and eruptive activity. The exercise demonstrated that the YVO leadership and scientific teams could handle the exercise scenario well; they are prepared and capable of dealing with future volcanic activity at Yellowstone. But as is true for any organization, there is some room for improvement.

Participants reported that this exercise was very useful because it helped them identify and refine roles and responsibilities, practice those roles, and identify where further preparation was needed. The most successful outcomes of the exercise, according to participant feedback, were: (1) participants gained a sense of the immediacy, urgency, and interdependencies associated with a volcanic crisis; (2) participants became acquainted with one another—many met face-to-face for the first time; and (3) participants learned about the variety of tasks they would have to perform and also about challenges inherent with a crisis atmosphere that can impede accomplishment of tasks. Most participants reported that they would welcome future opportunities to participate in exercises of this type. Many also felt that other volcano observatories could benefit from similar exercises.

Key Challenges and Recommendations

Currently some key challenges are faced by YVO that affect its potential effectiveness during a real, fast-developing volcanic crisis at Yellowstone. Areas judged to be in need of further development or improvement include:

1. Uncertainty about the specific roles to be played by the different YVO partner agencies—the U.S. Geological Survey (USGS), the National Park Service (NPS), and the University of Utah (UU)—during a real crisis. Clarity is needed for their respective roles in releasing information, coordinating with each other, and reaching consensus about the likely course of future activity.
2. Communication challenges posed by the wide geographic dispersal of YVO team members. Team members working together will require adequate means for effective communication, data-sharing, and consensus-building during a future crisis.
3. Need for improved knowledge of Incident Command System (ICS) procedures and protocols by some team members who would be involved during a crisis.
4. Need for training of all science team members in the use of all analytical and computational tools available to them, in order to maximize effectiveness of the teams in tracking and interpreting possible accelerating unrest at Yellowstone.

Specific recommendations are made in this report to address these and other challenges being faced by YVO. Recommendations fall into several broad categories:

1. Negotiating with partner agencies and establishing clear operational protocols for information and data sharing, data analysis, field communications and procedures, and decision-making during a crisis.
2. Updating and organizing existing databases for information that would need to be rapidly accessed during a crisis, and setting up easily accessible new databases for storing future monitoring data.
3. Clarifying and preassigning tasks for scientific teams before a crisis occurs.
4. Further training and cross-training staff.
5. Providing regular opportunities for team communication and interaction before a crisis occurs, including practice in sharing information through the YVO Web log.
6. Planning in greater depth for the extraordinary demands of a crisis in areas such as staffing, media response, monitoring capability and continuity.

This exercise was designed to allow YVO scientists to practice handling a crisis and to test for organizational and procedural weak spots that could emerge during a fast-developing crisis. Participants unanimously found the exercise to be helpful for improving their response capabilities.

Reference

Yellowstone Volcano Observatory, 2010, Protocols for geologic hazards response by the Yellowstone Volcano Observatory: U.S. Geological Survey Circular 1351, 18 p. (Available at http://pubs.usgs.gov/circ/1351/.)

Appendix 1. Exercise Participants

Abbreviations:
SIC—Scientist-in-Charge
DSIC—Deputy Scientist-in-Charge
UNAVCO (University Navstar Consortium)
UU—University of Utah
YNP—Yellowstone National Park
USGS—US Geological Survey
UW—University of Wyoming
INL—Idaho National Labs
CVO—Cascades Volcano Observatory
MBMG—Montana Bureau of Mines and Geology

<u>YVO Team Members</u>

YVO Leadership
- SIC: Jake Lowenstern, USGS
- DSIC: Peter Cervelli, USGS

Seismology Team
- Bob Smith, UU
- David Shelly, USGS
- Relu Burlacu, UU
- Harley Benz, USGS NEIC

Geodesy Team
- Dan Dzurisin, USGS
- Jamie Farrell, UU
- Christine Puskas, UNAVCO

Geology Team
- Bill Evans, USGS

Remote Sensing Team
- Rick Wessels, USGS
- Bill Burton, USGS

Geographic Information Team
- Joel Robinson, USGS
- Richard Dart, USGS NEIC
- David Lucke, WSGS

Public Information Team
- Wendy Stovall, USGS
- Al Nash, YNP

External Research Team
- Shaul Hurwitz, USGS
- Chuck Meertens, UNAVCO
- Christie Hendrix, YNP

<u>Others attending who are not part of YVO but who might be involved in a volcano crisis response at Yellowstone:</u>

Seth Carpenter, INL
Dave Hallac, YNP
Dan Reinhart, YNP
Chuck Wicks, USGS
Dave Mencin, UNAVCO
Ken Sims, UW
John Ewert, USGS (Scientist-in-Charge at CVO)
John Eichelberger, USGS (Program Coordinator, Volcano Hazards Program)
Warren Day, USGS (Acting Associate Regional Geologist – Southwest)
Fred Massin, UU

<u>Exercise Leaders:</u>

Tom Pierson, USGS
Carolyn Driedger, USGS
Bob Tilling, USGS

<u>On YVO teams but not attending:</u>

Hank Heasler, YNP
Cheryl Jaworowski, YNP
Mike Stickney, MBMG
Lisa Morgan, USGS
Barbara Reed, USGS

Appendix 2. Yellowstone Exercise Scenario

Note: This scenario represents one possible course of future activity; real future activity at Yellowstone could be quite different. Exercise time given in 24-hour format. Key information is given in bold-face font.

Scenario information given initially according to scenario time line	Additional information given if requested by players
SUNDAY, JULY 22 (day 1)—0800 • Weather: sunny and warm • **An EQ swarm started at about 1800 MDT yesterday; locations are under West Thumb of Yellowstone Lake.** • Initially all M <2 until a M 3.3 occurred at midnight. • Event rate increases from 2–3 per hour at start to 5–6 per hour by 10 p.m., 15–20 per hour following the M 3.3; rate declines to 5–6 per hour by 0600 this morning. • By 0800 ~120 earthquakes have triggered the UU system. • Epicenters of located quakes contained within oval (on map); focal depths are poorly defined but none appear to be deeper than 8 km.	• STRAIN METERS: There is a "strain signal" on Lake and West Thumb strain meters (run by UNAVCO) that starts about the time of the earthquake swarm starts. The West Thumb signal could be hard to interpret because the boiling hydrothermal system would add signal noise. The Lake instrument would be more suggestive. • InSAR: No InSAR data is available during this crisis for two reasons: 1) one of the satellite systems failed in May, so no recent image obtained from that system, and 2) the other satellite system will pass over Yellowstone and acquire an image on July 31. • GPS stations now seem to be moving away from West Thumb, if recent deformation data has been analyzed.
SUNDAY, JULY 22 (day 1)—0815 • **At 0810 M 4.4 EQ occurred with a preliminary depth of 3 km; epicenter in middle of West Thumb, ~6.5 km NNE of Grant Village.** • *The earthquake is broadly felt across the Park, particularly in Grant Village where tourists rapidly congregate at the Grant Village Lodge and Gift Store in search of information and wondering if the earthquake is going to lead to an eruption.* • The mainshock is followed by a vigorous aftershock sequence centered on the mainshock, with rates of 1–2 events/minute for the first two hours following the mainshock, then 15–20 per hour for the next two hours; depths range from 0 to 10 km.	EARTHQUAKE DETAIL: • Epicenter of M 4.4 is over the southern edge of the tomographically imaged crustal magma body (lat 44.43N long 110.56W) • A UU analyst reports that first motions from the mainshock give a normal focal mechanism with nodal planes oriented NNW-SSE. • As UU analysts progressively locate EQs (10–20 per hour), depths become more clearly concentrated at depths of 4–8 km. • A UU researcher reports that relocations of the M 4.4 in a 3-D velocity model push the depth from 3 km down to 8 km (in real time this might be available within 10–15 min of mainshock).
SUNDAY, JULY 22 (day 1)—1130 • **Just now reports are starting to come in of a**	• *Park staff urgently requesting expert opinion of USGS staff as to*

geyser eruption/explosion that occurred about 5 minutes ago from Black Pool in West Thumb Geyser Basin. • Low-amplitude tremor occurring irregularly for periods up to tens of minutes. • 911 cell phone calls from tourists at West Thumb Geyser Basin report blast of hot water, black mud, and rocks up to small boulder size thrown several hundred feet from vent. • The explosion apparently damaged several sections of the adjacent boardwalk, and several tourists are injured; number and extent of injuries unknown. • Aftershocks continuing at rate of 15–20 per hour; depths range from 0–10 km. • *A crowd of several hundred tourists are now gathered outside the Grant Village Lodge seeking information; some are getting panicky.*	*whether another explosion can be expected and how safe the area is. INJECT* HYDROTHERMAL EXPLOSION HISTORY: • Several different geysers have erupted periodically here over the years, and some hot pools have experience heating cycles. • Instances of increased bubbling and H_2S smell from the lake were reported in 2002. • There are two hydrothermal explosion craters in West Thumb: The Duck Lake Hydrothermal Explosion Crater (located 0.6 km NW of West Thumb Geyser Basin), a post-glacial 700 x 500 m, 20 m crater, and The Evil Twin Hydrothermal Explosion Crater - sublacustrine (~40 m below lake surface), recognized in 2007, 500 m diameter, 12 to 20 m deep. Fluids were sampled with an ROV and were 72 °C, with a pH of 6.6. DEFORMATION: • None of the GPS stations recorded any coseismic displacements. • Strain at Lake and West Thumb fairly constant in rate and sense of strain.
SUNDAY, JULY 22 (day 1)—1300 • **Reports continue to come some West Thumb Geyser Basin pools have turned milky and discolored following the eruption.** • *The first photos and videos of the explosion are appearing on CNN courtesy of several iReporters, and hundreds of calls are coming in to the NPS switchboard. UU and USGS staff are also receiving many calls from the media seeking information.* • Aftershock sequence continues but at a reduced rate—events are occurring every 3–5 minutes, the largest aftershock so far has been a M 3.5. Several aftershocks have been felt by tourists gathered in Grant Village, increasing anxiety levels and causing some to begin self-evacuating.	• EARTHQUAKE DETAIL: UU analysts report that reviewed locations of the larger aftershocks have depths of 4–8 km and align along a well-defined N-S trend extending to the middle of West Thumb. A moment tensor analysis shows that the mainshock is 50 percent shear-faulting and 50 percent isotropic. • MEDIA INJECTS
TUESDAY, JULY 24 (day 3)—0900 • Weather: sunny and warm • **Abyss Pool and Black Pool are reported to be**	• INJECT—large number of media inquiries at this point • WATER CHEMISTRY

bubbling (boiling?) vigorously. Abyss Pool has also become more turbid than normal. Water levels in Perforated Pool and Blue Funnel Spring seem to be lower than normal. • **Scattered EQs at the north end of West Thumb are now clustering into a new swarm.** • Periods of low-amplitude tremor occurring again. • Events occurring at rate of 2–3 per hour in new swarm; most less than M 2.0 but a few up to M 2.5; focal depths 0–6 km. • First swarm continues but rate decreased to about 3–4 per hour. • Park staff report increased steaming in northern part of West Thumb Geyser Basin.	HISTORY: West Thumb Geyser Basin is a water-dominated neutral to alkaline hydrothermal system with subaerial and sublacustrine vents. Visitors can walk around the area on a boardwalk. • pH is slightly lower than normal in several West Thumb pools. EARTHQUAKE DETAIL • UU researchers report that relocations of swarm 1 events in a 3-D model appear to be showing a shallowing of maximum depths with time, as well as a migration to the north.
TUESDAY, JULY 24 (day 3)—1300 • Park staff report smell of rotten eggs being stronger in West Thumb area than before. • GPS data being analyzed; possible uplift at LKWY but amounts still within noise; LKWY does appear to have moved several mm to west, however. Displacements at other GPS stations appear to be within normal scatter. • Event rate for second swarm increases to 5-6/hour, max magnitude M 3.0 (felt in Grant Village and Lake areas). • Both swarm epicenter patterns have increased in area (see map). • Several water samples collected from West Thumb area for analysis. • Field measurements show Black Pool has a pH of 7, temperature of 83 °C, and specific conductance of 2240 µS/cm.	• BACKGROUND WATER CHEMISTRY: As of 2002, three other pools in West Thumb (Lakeshore Geyser, an unnamed pool, and Seismograph Pool) had pH from 7.3–7.9, Temps from 76 to 92 °C, and specific conductance from 1770 – 1920 µS/cm using field instruments. • MOCK PRESS CONFERENCE—Tell SIC that the Park Superintendent has called for a press conference at 1400 and that USGS needs to be there to answer questions. Hold this press conference in Sun Room in 15 minutes from when this notice is given.
FRIDAY, JULY 27 (day 6)—0900 • Weather: partly cloudy; light to moderate gusty winds • **Bubbling observed from the lake surface in a few locations near northern shoreline of West Thumb; very strong odor of rotten eggs detected by people downwind and relatively close to bubbling water.** • **Blue Funnel and Perforated pools have drained, vigorous surging from Abyss and Black pools.**	• Pool changes suggest the local water table level is being drawn down, and might indicate increased risk of a small hydrothermal explosion. These pools have drained when Abyss and Black are active). • The largest hydrothermal explosion crater known on earth is Mary Bay in Yellowstone Lake (~12–15 ka,~2.8 km diameter, 55–105 m

<table>
<tr>
<td>

Field testing shows Black Pool now has pH=6.6, temp=85 °C, spec cond.=2020 µS/cm. Abyss Pool is 88 °C, pH=7.0, spec. cond=1900 µS/cm.
Water samples sent to lab for further analysis.
Event rate in swarm 1 started increasing again two days ago (July 25), peaking at 5–10 per hour before declining to 5–6 per hour early this morning. Epicenters are more spread out.
Events in second swarm continued to increase, are presently occurring at 5–10 per hour. Most are M <2.5.
Total number of M >3 events between the two swarms is 15, all widely felt in eastern part of Park.
Small earthquakes started showing up on YLT and B44 webicorders starting 0400. No locations possible.
ASTER image acquired last night detects elevated ground temperatures around and north (along shoreline) of West Thumb Geyser Basin.
Uplift at HVWY and LKWY GPS stations at ~2 mm/day, and about 1 mm/day at OFW2 and P709; GPS stations moving away from West Thumb at rates up to 2 mm/day.

</td>
<td>
deep)

Observations should suggest that magma is present at fairly shallow depth.
Things are getting slightly acidic, which is strange for this area. They’re also slightly hotter than usual.
People are getting jumpy—blizzard of inquiries from public and media and Park staff should be hitting YVO staff now.
H17A (a broadband station near Grant Village) shows primarily low-frequency noise on webicorder; if hi-pass filters are applied, then the small events on YLT & B44 are also visible on H17A.
If they have people visually checking webicorders, then inject that a small LP (long-period EQ) was observed on YLT, B44, and H17A at 0615, and another one was seen at 0850. Not locatable, too small to trigger network.
STRAINMETERS: Strain signal has grown significantly. The strainmeters at Yellowstone also have a capability of indicating direction, so we can say that the strain is consistent with a source of inflation beneath the western part of West Thumb. The participants might ask for information about the magnitude of the signal, and I think on that we should just say "look, this is an exercise. It's a decent-sized signal, well above background, and clearly anomalous. Whatever that means to you."

</td>
</tr>
<tr>
<td>
FRIDAY, JULY 27 (day 6)—1300

YLT- and B44-only earthquakes have gotten large enough for poorly constrained locations to show events occurring west of the July 22 M 4.4 mainshock epicenter and closer to the NW shoreline of West Thumb, depths are somewhat unreliable (due to close-by stations) and range from 0-2 km.

</td>
<td>

If they’ve deployed one or two temporary seismometers with telemetry, then YLT-and B44-only earthquake depths are confirmed to be shallow and epicenters confirmed to be offshore but near the western shore of West Thumb.
If they get people checking

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

<table>
<tr>
<td>

• **LP event just triggered the network, location poor due to emergent arrivals but is in general vicinity of swarm 1 & M 4.4 epicenter. Amplitude magnitude equivalent to M 1.0, well-recorded at stations up to 50 km away.**

• Tremor has been picked up again; going for longer periods than before.

</td>
<td>

webicorders, then give info that small LPs first started occurring at 0615.
• The fact that the M 1.0 event can be seen 50 km away should have them realizing that the LP is deep-ish.
• If they propose doing moment tensor inversion, tell them it is too poorly recorded.
• If they propose doing particle-motion plots, tell them that indications are the depth is 10-12 km.

DO A MOCK TV INTERVIEW WITH OBSERVERS PLAYING ROLES OF CAMERAMAN AND INTERVIEWER – is it going to lead to an eruption??????

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

SUNDAY, JULY 29 (day 8)—0900
• Weather: cloudy/stormy, with localized thunderheads building.

• Water analysis from Tuesday is reported. These reveal some change compared to last sample acquired in 2006 (get results from “data center”).

• No gas flight possible due to bad weather.

• Seismicity began picking up yesterday afternoon in all 3 swarms, epicenters are more widely distributed, and the three EQ swarms have merged more or less into one; focal depths becoming shallower—averaging ~ 3-4 km. Tremor is continuing with somewhat longer durations.

• LP events have been triggering network at rate of 1 every 3-4 hours, largest have magnitudes of M ~2 and are well-recorded showing up across entire Yellowstone network, including stations outside the Park.

• **A M4.3 EQ just occurred at 0852, with preliminary epicenter location along the shoreline in the northwestern part of West Thumb, with preliminary depth of 0.5 km.**

• Uplift rates still highest at HVWY and LKWY appear to have increased over the past two days to perhaps 4 mm/day. Uplift is also clear at stations as far away as Old Faithful and totals several mm over the past 8 days.

</td>
<td>

If they have people checking webicorders, give info that small LP events are occurring every 30-60 minutes now.

WATER ANALYSIS RESULTS:
<table>
<tr><td></td><td>9/18/2006</td><td>7/24/2012</td></tr>
<tr><td>T (°C)</td><td>76</td><td>83</td></tr>
<tr><td>pH (field)</td><td>7.87</td><td>7.04</td></tr>
<tr><td>pH (lab)</td><td>8.78</td><td>7.72</td></tr>
<tr><td>Sp. cond. (µS) (field)</td><td>1920</td><td>2240</td></tr>
<tr><td>Sp. cond. (µS) (lab)</td><td>1999</td><td>2380</td></tr>
<tr><td>Ca</td><td>0.514</td><td>1.753</td></tr>
<tr><td>Mg</td><td>0.017</td><td>0.127</td></tr>
<tr><td>Sr</td><td>0.005</td><td>0.028</td></tr>
<tr><td>Ba</td><td>0.004</td><td>0.019</td></tr>
<tr><td>Na</td><td>443</td><td>463</td></tr>
<tr><td>K</td><td>19.2</td><td>47.0</td></tr>
<tr><td>Li</td><td>3.26</td><td>4.00</td></tr>
<tr><td>SiO_2</td><td>256</td><td>348</td></tr>
<tr><td>alkalinity (HCO_3)</td><td>554</td><td>443</td></tr>
<tr><td>Cl</td><td>307</td><td>428</td></tr>
<tr><td>F</td><td>28.7</td><td>29.7</td></tr>
<tr><td>SO_4</td><td>45.3</td><td>123</td></tr>
<tr><td>B</td><td>3.75</td><td>8.64</td></tr>
<tr><td>Br</td><td>1</td><td>1</td></tr>
<tr><td>Fe(T)</td><td>0.004</td><td>0.047</td></tr>
<tr><td>H_2S</td><td>0.005</td><td>0.052</td></tr>
<tr><td>Mn</td><td>0.001</td><td>0.054</td></tr>
<tr><td>NO_3</td><td>0.2</td><td>0.2</td></tr>
<tr><td>NO_2</td><td>0.0362</td><td>0.0290</td></tr>
</table>

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

SUNDAY, JULY 29 (day 8)—1300
• Weather deteriorating. Afternoon thunderheads building.

• **Another hydrothermal explosion occurred**

</td>
<td>

• If weather is bad, they can’t get a gas flight. One thing that may come out of this is that they are unprepared to make gas measurements quickly. The

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

<table>
<tr><td>

around noon from the West Thumb Paint Pots, slightly smaller event than on July 22 but with ejection of water, mud, and ballistics.

- **An intensification of shallow M1 to M2 earthquakes has started in a narrow zone extending N and S from the M 4.3 epicenter (see map).**
- Park staff on Grand Loop Road report noticeable discoloration of water in West Thumb extending south from NW shoreline of West Thumb.

</td><td>

Volcano Emissions Project at CVO has monitoring equipment that could be express shipped to them, but they may not know that.

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

SUNDAY, JULY 29 (day 8)—1500

- **Seismologists report very large amplitude signal at 1455.**
- About a minute later a very shaken park ranger who was on patrol on Grand Loop Road radios that her vehicle was hit by a high-velocity blast of muddy water and rock fragments that pushed her vehicle into a ditch and shattered window glass facing the lake. She reports that the blast was followed by a 3- to 4-ft-high wave of water that picked up her vehicle and moved it about 50 feet away from the shore until it grounded on a patch of high ground.
- Park staff (and gathered news reporters) at Park HQ (Mammoth Hot Springs) report hearing a loud "thunder clap" (sonic boom?) and seeing a rising black cloud from near West Thumb; thunderstorm activity has some wondering if this is only weather-related.

</td><td>

- **A VEI 2–3 phreatomagmatic eruption has just occurred from an under-water vent near epicenter location of this morning's M 4.3; explosion is accompanied by a high-velocity base surge that causes casualties and damage within a radius of ~4 km and a tsunami that locally reaches 1.5 m in height.**
- QUESTION: What can YVO staff do to determine whether it was another (bigger) hydrothermal explosion or an eruption involving magma?

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

SUNDAY, JULY 29 (day 8)—1515

- **The FAA has received pilot reports of a dark cloud (ash cloud?) rising to 20,000 feet and is calling for confirmation of an eruption; cloud is drifting SE according to pilots.**

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

Appendix 3: Roles and Responsibilities of YVO Staff Positions

Position *(Suggested format with one position described; table to be filled in by YVO SIC)*	**During Non-Crisis Periods or Early in a Crisis (ICS Not Activated)**	**During a Volcano Crisis (under ICS)**
SIC		
DSIC		
Seismology Team Leader	• Update team contact info semi-annually • Ensure that team members have the latest analytical tools/software • Periodically review crisis procedures with team members • Others?	• Relocate to forward volcano observatory or IC Center • Review incoming real-time data • Assign tasks to team members • Communicate regularly with team members • Get task assignments from SIC • Response to media queries as assigned by PIO • Others?
Other Seismology Team Members		
Geodesy Team Leader		
Other Geodesy Team Members		
Geology Team Leader		
Other Geology Team Members		
Remote Sensing Team Leader		
Other Remote Sensing Team Members		
GIS Team Leader		
Other GIS Team Members		
Public Information Team Leader		
Other Public Information Team Members		
Admin Support Team Leader		
Other Admin Team Members		
External Research Support Team Leader		
Other External Research Support Team Members		

Appendix 4: Post-Exercise Evaluations by Participants

(All submitted answers interpreted and summarized by organizers)

Yellowstone Exercise—Final Evaluation

Questions regarding individual roles:

- *Were you clear on your assignments/duties during the exercise? (YES/NO; Comments?)*

  Mostly yes, but comments included:

  1. How, when, and with whom (up the chain) communication should happen was not clear.
  2. My role in contributing to interpretation of data was not clear.
  3. The scope of my role (as I envisioned it) expanded during the exercise.
  4. While clear on my subject area, I was not clear on what specific tasks and duties I would have during a crisis (and the intensity of the exercise prevented asking about this).
  5. There was confusion about assignments/duties, because it was not clear whether ICS had been enacted and an IMT set up.
  6. Procedures regarding PIO spelled out in Circ. 1351 conflict with established ICS procedures.
  7. UU team members didn't know and hadn't communicated much with USGS counterparts.
  8. Time constraints prevented some duties/assignments from getting done.

- *Did you (would you) have the data/information necessary for completion of your task(s)? (YES/NO; Comments?)*

  Mostly yes, but comments included:

  1. Better access to real-time GPS, tiltmeter, and strainmeter data fro PBO/UNAVCO is needed.
  2. Better access to high-res images held by NPS?
  3. New real-time or near real-time data sets would need to be transferred via email or FTP; are mechanisms in place to do this?
  4. Teams didn't always pass data and interpretations up the chain to group leaders for evaluation.
  5. One group is under the impression that data will be interpreted separately by their agencies--IT NEEDS TO BE MADE CLEAR WHO INTERPRETS DATA, HOW INTERPRETATIONS ARE COORDINATED, AND WHO TALKS TO PRESS ABOUT INTERPRETATIONS.

- *Could you work at your duty station or did you need to physically relocate? (YES/NO; Comments?)*

  Most dealing with data interpretation felt it would be better to stay at normal duty station where data interpretation is routinely done, BUT instruments may need to be installed in field, so who would do that? For some, being wherever there was a robust internet connection would be fine. IC would need to be where there was capability of printing paper maps for emergency managers and media. THOUGHT NEEDS TO GO INTO WHERE INCIDENT COMMAND WOULD BE SET UP (SEVERAL ALTERNATE LOCATIONS?) IN ORDER TO ENSURE THAT ALL NECESSARY CAPABILITIES/CONNECTIONS WOULD BE MET.

- *Do you actually have the resources/knowledge/training that would be needed to do your task(s) in a REAL crisis? (YES/NO; Comments?)*

  [Note that the Univerity of Wyoming has a plane, owned and operated by Atmospheric Sciences Department, which is configured and optimized for aerial monitoring. No one seemed aware of this resource during the exercise.] In answer to question, mostly YES, but comments included:

  1. Probably not enough people trained for dealing with the media when the major media storm hits.
  2. Question about funding for an event response.
  3. Not enough training in the following (for a university participant):
     - Crisis management procedures
     - Knowledge of the crisis response hierarchy
     - YVO protocols
  4. Would non-NPS folks have access to NPS radios or frequencies for crisis communication?
  5. UUSS participant feels they need additional capabilities to do real-time LP/tremor identification and location.
  6. ICS training needed (USGS participant).

- *Are communication lines/processes with colleagues adequate within YVO for task accomplishment and decision-making? (YES/NO; Comments?)*

  Not always; it seems that clear crisis communication protocols need to be spelled out more clearly, particularly with regards to:

  1. NPS radios and/or frequencies for adjustable radios need to be made available to all YVO staff in or near Yellowstone.
  2. Practice in use of YVO log would be good.
  3. Advanced System Center in Reston normally has offset/limited hours (as do other centers with important data portals); need protocol for making critical data portals available 24/7.
  4. Questions about who is doing what in terms of seismic data analysis; is there unnecessary duplication of effort? Are there gaps? How do we make collaborative decisions?
  5. Important for YVO organizational chart (with current names and contact info) to be kept updated and distributed to teams.
  6. Updated version of USGS Circular 1351 needs to clarify the processes for issuing press releases, information statements, and other documents to the media both before and after ICS is implemented. How do partner agencies agree on what goes into press releases? Who within IC structure would actually approve press releases?
  7. Regular meetings/conference calls between members of the different teams would be very helpful.
  8. Adequate communication between team members in various remote locations will be a challenge. Should specific protocols be established and put in updated Circ 1351?
  9. A HUGE POTENTIAL ISSUE: The USGS and IC responsibilities for coordinating and issuing information to the public needs to be clearly spelled out! Would USGS need to get permission from IC to release a statement? This could have huge implications in life-threatening situations (for example, a lot of ash in the air suddenly).

- *Are you clear on who should get your task output (and in what format)? (YES/NO; Comments?)*

  Yes and no, mostly yes. Non-NPS team members are probably unclear about their responsibilities under ICS. Specific recommendations of NPS participant:

  1. Every YVO member needs to take, at a minimum, the following FEMA courses: IS-100, IS-200, IS-700, IS-800.
  2. Anyone serving as a PIO or YVO Team Leader should also complete ICS-300 and ICS-400.
  3. PIOs should also at least take either the NWCG S203 or FEMA G290 courses and complete either a FEMA PIO task book or the NWCG PIOF task book to become an incident-qualified PIO.

- *Can your task output be adequately delivered/explained/discussed/acted upon with present YVO protocols? (YES/NO; Comments?)*

  Generally yes. Comments included:

  1. An integration of the YVO protocols with UUSS planning is needed.
  2. NPS participant views separate PIO under YVO branch in organizational chart as a potential problem, since PIO is directly under IC; any YVO information people should be directly under PIO (NPS) at IC. CLARIFICATION WITH NPS ON THIS NEEDED?
  3. NPS participant: Other components of the YVO Branch need to be connected to their appropriate areas in the ICS structure:
     - Monitoring , geographic information, and perhaps external research should fall under the Planning Section.
     - YVO Budget should fall under Finance/Admin Section.
     - YVO Staffing should fall under Logistics Section.

- *TWO things I will do or change to be better prepared for an actual crisis at Yellowstone are:*

  In addition to generalized resolutions to get more familiar with protocols, data sources, methods for accessing databases, emergency contacts, and so on, the following specific needs were mentioned:

  1. Get YNP radio frequencies programmed into voice-communication radios owned by other groups/teams.
  2. Make sure critical contact information is loaded into cell phones and other portable electronic devices (not just sitting in a file in their desktop computer) or carried as hardcopy in our briefcases, in case a volcanic event happens when team members are not in their offices.
  3. Get better access to PBO (Plate Boundary Observatory) geodetic data streams.
  4. Make sure lines of communication between team members are well established, including phone and email. Make sure team members are communicating with each other prior to unrest (many of these folks have never talked to each other).
  5. Identify lists of back-up people with critical expertise, in case YVO in-house capabilities are exceeded.
  6. Make/update contact list of people/agencies who supply commercial data/imagery that would be needed on a short turn-around.
  7. Integrate YVO protocols into the UUSS plan.

8. Prepare GIS maps and templates ahead of time that could be used in a crisis; this would be for maps at multiple scales (YNP, four-state region, western U.S., whole U.S.). Tag maps with important place names.
9. There has to be contingency testing and better interoperability exercises. It was not clear how well VHP is connected via critical real-time data to UUSS and/or NEIC.
10. Is VHP Web infrastructure prepared for the volume of Web activity that would be engendered during a crisis at Yellowstone?
11. There is probably not enough planning to date for robust dissemination of public information. What are the relative roles of the UUSS YVO Web site versus the VHP YVO Web site versus NEIC Web site? How will UUSS, NPS, and USGS press releases be coordinated and how will messages be unified?
12. Make sure cell phone numbers are on emergency-contact and data-access contact lists.
13. Need to learn about ICS.

Questions regarding the effectiveness of my team:

- *How would you rate the level of cooperation/coordination that you experienced with team members? (Poor/Fair/Average/Good/Excellent?) How could it be improved?*

  Generally good to excellent, but better communication with team leaders is desired.

  Seismology team integration is unclear.

  One team leader felt he/she didn't delegate very well to the team.

- *What do you need to do as a team to better facilitate intra- and interteam communication?*

  Verify/update team members' contact information and best contact mode 24/7.

  Need better interoperability between USGS and UUSS.

  We need to get more used to posting on YVO Web log.

  YVO protocol needs to spell out more clearly the respective roles of USGS, UUSS, and NPS during a crisis.

  Run some sort of tabletop exercise annually.

- *If one or more members of your team is/are unavailable during a crisis, do you have a plan in place for filling the gaps?*

  Yes and no. Specific names generally not given to answer the question ("yeah, there's plenty of expertise back at AVO").

Questions regarding the exercise itself:

- *Was this exercise useful/beneficial? How? Please describe.*

  Yes, unanimous. (One team member learned he/she was on the wrong team.)

- *Please give us your thoughts on how the exercise, in general, could be improved.*

1. More time for inter- and intrateam communication (many suggested this).
2. Exercise should be longer.
3. Have PIOs from all partner agencies present for exercise.
4. Have fewer stages and more time to communicate (for example, learn how to reach consensus in big “conference calls”).
5. Include tiltmeter data.
6. Give teams real data to puzzle over (especially material that is ambiguous). Require teams to actually accomplish data transfer to the exercise site.
7. Find a way to test people’s back-up roles (roles for which they are cross-trained but which they don’t get to practice).
8. Have a designated Incident Commander in the exercise. Run exercise in part with ICS in place.
9. Have enough scenario handouts for everybody (not just one per table).
10. Non-USGS folks need to understand how the YVO Web log works.
11. Make it a 2-day exercise (several suggested this).
12. Give a tutorial on the YVO protocols and a talk about a real volcano crisis response with 20/20 hindsight (by those who participated).
13. A tabletop exercise should be run annually.
14. Isolate teams in separate rooms and force them to communicate by cell phone or email, maybe in separate buildings.
15. Send out actual VANs, VONAs.
16. Send scenario updates to participants via email instead of slips of paper.
17. Provide name badges for participants and coffee during the exercise.

- *Specifically, in what ways could this exercise have been more helpful in testing your readiness to respond to a real volcanic crisis at Yellowstone?*

1. Could U.S. military entities such as AFWA (Air Force Weather Agency), NORAD (North American Aerospace Defense Command), and CENTCOM (U.S. Central Command) be included in exercise—at least in role-playing how we would interact with them. They have many assets downwind and could provide additional observations on ash cloud movement.
2. Provide more real graphical data that needed interpretation (like the interferogram).
3. Include opportunity for team leaders to have to assign tasks and to prioritize jobs among their team members.
4. More (broader) participation from NPS.
5. Include a real member of the media in the exercise to add realism about expected needs/demands of the media.