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ScienceDirect
Journal of Volcanology and Geothermal Research 172 (2008) 308 – 314
Journal of volcanology and geothermal research
www.elsevier.com/locate/jvolgeores

Research paper

Communicating eruption and hazard forecasts on Vesuvius, Southern Italy

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Received 24 January 2007; accepted 11 December 2007
Available online 15 January 2008

Abstract

Emergency response plans have been formalised for only one third of the 32 volcanoes that have erupted in the past 500 years in Europe and its dependent territories. As local and tourist populations increase around the remaining 67%, so also the need for an appropriate emergency plan becomes more urgent. A cornerstone of such a plan is to ensure that local decision makers are aware of the volcanic hazards that may be faced by their communities. Hence, instead of applying existing plans from another volcano, it is pertinent first to evaluate the impact that these plans have had on local decision makers. This paper reports results from a preliminary evaluation of interviews with decision makers at Vesuvius, in Southern Italy, for which an emergency response plan has been available since 1995. The volcano last erupted in 1944, so that none of the monitoring scientists or civil authorities have direct experience of responding to Vesuvius in eruption. The results of the surveys suggest that, although the civil authorities on the volcano are aware that Vesuvius poses a hazard, their understanding of how to respond during an emergency is incomplete. They also indicate opportunities for increasing such understanding during future revisions of the emergency plan, provided they are done before a crisis arises.

Keywords: volcanic crisis; communication; Vesuvius

1. Introduction

For eruption and hazard forecasts to be useful, they must be communicated effectively to the groups responsible for responding to a volcanic emergency. Since the mid-1970s alone, most of the casualties from eruptions have been the result of poor communication and consequent delays in initiating mitigating procedures [e.g., Newhall and Punongbayan, 1995; Peterson, 1995; Tilling, 1995; Voight, 1995]. Two key problems have been (1) inexperience among non-scientific decision makers about volcanic processes and, hence, a misperception of the issues involved, and (2) inexperience among monitoring scientists on how to prevent such misperceptions from taking hold.

The potential for poor communication is especially high at volcanoes that have not erupted for several generations, because it is likely that most of the decision makers, including monitoring scientists, will not have been involved in a volcanic emergency; neither will they have a direct memory of eruptions at their local volcano. This situation is prevalent at European volcanoes (including those on territories across the world that are politically united with, or dependent on, European countries), few of which have had threatening eruptions for generations. Thus, of the 32 European volcanoes that have erupted in the last 500 years, less than one third have erupted within the past 30 years (notionally one generation), and almost half have not erupted for more than 60 years (using data from Simkin and Siebert, 1994, updated with records from the Smithsonian Institution, 2006).

A further consequence of long repose intervals is that specific plans for emergencies have still to be formalised at about two-thirds of European active volcanoes. The absence of such plans is remarkable and, in Europe, cannot reasonably be attributed to a lack of money or expertise. It is self-evident that, to optimize strategies for mitigating a volcanic crisis, a response plan should be available before an emergency begins; otherwise contradictory advice (based on differences of opinion among academics that are often emphasised by the media, at the expense of reporting on where opinions agree) can worsen a crisis and cause public confusion and antagonism against decision

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doi:10.1016/j.jvolgeores.2007.12.027

makers. During the past 30 years, such confusion has occurred several times at European volcanoes, from the 1976 crisis at La Soufrière on Guadeloupe (Tazieff, 1977; Kilburn, 1978; Fiske, 1984) to the 2004 emergency on Tenerife, which has not had an eruption since 1909 (Carracedo et al., 2006; Garcia et al., 2006).

A pressing need therefore exists to develop appropriate response plans for most European volcanoes (Chester et al., 2002). However, rather than simply adapting a plan designed for another volcano, it is pertinent first to evaluate the impact of existing plans on local decision makers. As a contribution to such an evaluation, this paper reports the initial evaluation of interviews with decision makers at Vesuvius, in Southern Italy, selected because (1) an integrated emergency response plan has been available since 1995 (Italian Civil Protection, 1995; Chester et al., 2002) and (2) since at least the 1980s, sustained programmes have been conducted to raise awareness among all age groups, driven primarily by the Vesuvius Observatory (Giuseppe Luongo, pers. comm.; Rosella Nave, pers. comm.) and Vesuvius National Park (Adriana Nave, pers. comm.). Accordingly, a good awareness of volcanic hazard might be anticipated among the local decision makers. The survey results suggest that decision makers are indeed aware of the potential hazards. However, they also indicate that the level of understanding may be much lower than first appears. As a result, local scientists may have been lulled into a false sense of security in their success in communicating fundamental ideas about volcanic hazard to the non-scientific decision makers.

2. Volcanic risk at Vesuvius and the original emergency response plan

Vesuvius is one of the most famous volcanoes in the world and supports a population of some 600,000 people. It has undergone several changes in style of activity during its evolution (e.g. Arno et al., 1987; De Vivo et al., 1993): from 35,000 to 25,000 years BP, it was essentially an effusive volcano, much like the modern Mt Etna; from 25,000 BP to AD 472, activity was dominated by seven plinian eruptions, between repose intervals of millennia (including the well-known AD 79 eruption that destroyed Pompeii and Herculaneum); and since the Middle Ages, it has again been largely effusive, with near-persistent activity and occasional subplinian eruptions occurring from 1631 to 1944. Since 1944, the volcano has been in repose and uncertainty remains as to the style of a future eruption (Marzocchi et al., 2004).

Interviews with local decision makers were conducted in 2002 and 2003, when the available Vesuvius Emergency Plan was the original version completed in 1995 (and which had been distributed to the local authorities on the volcano; Italian Civil Protection, 1995). A public summary of the current plan is available on the website of Italy's Department of Civil Protection at www.protezionecivile.it (following the links to "Rischio Vulcanico", and then to "Vesuvio"). The original plan considered the response to a worst-case scenario, taken to be a subplinian eruption on the scale of that of 1631 and based on the reconstruction of Rosi et al. (1993), which recognised ash fall and pyroclastic flows as the primary volcanic hazards. The 1631 eruption appears to have been preceded by about 2 weeks of ground uplift at the volcano's summit and about 1 week of felt local seismicity (Rosi et al., 1993, Bertagnini et al., 2006). The precursory unrest led to the spontaneous evacuation of some 40,000 people but, even so, the eruption claimed about 4000 victims. By analogy with these events, the emergency plan assumed that it would be possible to initiate evacuation of the volcano at least 2 weeks ahead of an eruption. This time interval is significant because of its potential influence on the view of local decision makers on scientists' ability to forecast volcanic eruptions.

To design the response to a subplinian eruption, the emergency plan divided Vesuvius and the surrounding region into three hazard zones, according to their exposure to pyroclastic flows and to heavy ash fall (Fig. 1):

1. Red Zone, with the potential to be affected by pyroclastic flows and ash fall.
2. Yellow Zone, beyond the range of pyroclastic flows, but with the potential to be affected by significant ash fall.
3. Green Zone, beyond the limits of significant ash fall.

Having defined the three hazard zones, the plan established an eight-level scheme for responding to different stages of an emergency, from initial unrest to post-eruption conditions. These stages, summarized in Table 1, were each associated with a specific response from the civil authorities. From the viewpoint of local decision makers, the key point here is that they were expected to follow an established procedure, without account being taken of possible local necessities requiring a deviation from the idealised response.

3. Perception of volcanic emergencies: methodology

To investigate levels of risk perception and confidence in emergency communication at Vesuvius, surveys were conducted in 2002 and 2003 among local decision makers and scientists. The surveys were based on direct interviews and questionnaires designed to evaluate how the threat from Vesuvius is perceived (in a general sense, without specifying formal definitions for words such as 'vulnerability' and 'risk').

Fifty written answers were obtained as follows:

1. 21 questionnaires from local decision makers (hereafter referred to as "The Authorities"), including the mayors of 12 of the 18 administrative districts on Vesuvius (in the so-called "Red Zone"; Fig. 1 and Table 1), as well as representatives from the regional, provincial and local Civil Protection, Red Cross, fire brigade and police.
2. 29 questionnaires from local scientists, mostly from the Vesuvius Observatory, which is the organisation officially responsible for monitoring Vesuvius (and which has since been integrated into the INGV, Italy's National Institute for Geophysics and Volcanology) and the Department of Geophysics and Volcanology of the University of Naples ("Federico II"). The sample represents about 50% of scientists in Naples who would potentially be involved in evaluating conditions on Vesuvius once evidence of unrest became apparent.

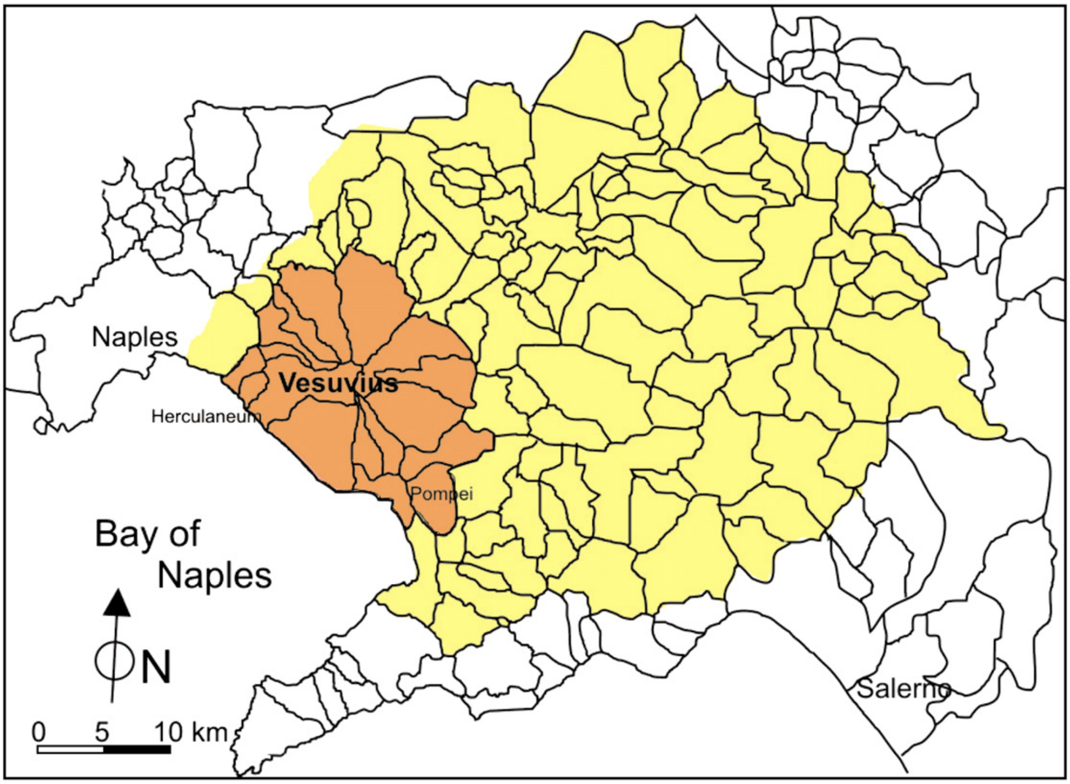

Fig. 1. The emergency evacuation zones for Vesuvius and surrounding area, as defined by the original Vesuvius Evacuation Plan. The Red Zone (*dark grey*) includes all administrative districts on the volcano itself. The Red Zone is potentially vulnerable to pyroclastic flows and will be the first to be evacuated (Risk Level 4, Table 1); it has a populatuion of about 600,000 people. The Yellow Zone (*light grey*) covers administrative districts in which evacuation might be initiated if ash fall becomes too heavy (Risk Level 6, Table 1). The Green Zone (*white*) shows the area within and beyond which the impact of ash fall is expected to be insignificant. The current, revised plan also includes a "Blue Zone", highlighting areas threatened by inundation and lahars. This zone lies along the northern edge of the red zone.

The questionnaires were completed anonymously and usually collected on the day of completion, to reduce the opportunity for consultation among interviewees (although, about 10% of the total was returned up to a week later).

The questionnaire distributed among the Scientists is given in the Appendix; for this paper, the accompanying questionnaire for the Authorities is virtually identical (both questionnaires were presented in Italian). The questionnaires were designed to evaluate how scientists and decision makers perceived the threat from Vesuvius and the current strategy for issuing eruption forecasts. Questions were grouped into four sections: questions 1–3 were designed to establish the interviewee's background

Table 1
Alert levels from the Vesuvius Emergency Response Plan. The Red and Yellow Zones are shown in Fig. 1

Risk level	Alert	Behaviour of volcano	Emergency response
0	**No alert**	Daily behaviour typical for repose during previous 20 years. All monitoring signals at background levels.	No action required.
1	**1st-level warning**	Values from one monitoring signal exceed background level.	Change in signal made public as factual statement.
2	**2nd-level warning**	Values from one monitoring signal continue to increase above background level. The sustained increase suggests possible reawakening of volcano.	Permanent monitoring networks supported with additional instruments. Emergency teams put on alert.
3	**Initial alarm**	Values from more than one monitoring signal are maintained above background levels. The combined increase suggests the volcano is entering the preparatory phases before eruption.	The Government declares a State of Emergency. Emergency teams are mobilised.
4	**Full alarm**	Values from several monitoring signals continue to increase. Their acceleration *might* still be reversible.	Evacuation of communities from volcano (the "Red Zone").
5	**Eruption imminent**	Acceleration in values from monitoring signals irreversable. Eruption is imminent.	Evacuation of all personnel from volcano.
6	**Eruption in progress**	Eruption in progress.	Evacuation as necessary to avoid heavy tephra fall in the Yellow Zone, beyond the volcano.
7	**End of eruption**	The eruption has ceased. Hazards may still exist from landslides, mud flows and gas emission.	The State of Emergency is rescinded. Populations may return to safe zones.

knowledge of Vesuvius; questions 4–6 addressed knowledge of volcanic emergencies and the Vesuvius Emergency Response Plan; questions 7–9 considered the readiness of peers (scientists or decision makers) for an emergency; and questions 10–21 focused on the type of information that should be communicated during an emergency and the most appropriate means of communication.

Answers to the questionnaires were supplemented by the results from informal direct interviews with 18 of the 21 Authorities, conducted after they had completed the written questionnaire. The face-to-face interviews naturally allowed for more flexibility in the answers provided and enabled interviewees to express a spontaneous personal opinion. As shown below, the spontaneous comments revealed a lack of understanding not apparent from the answers to the formal questionnaires.

4. Perception of volcanic emergencies: written results

The principal answers are summarized in Tables 2 and 3. Encouragingly, all interviewees were aware of the importance of volcanic hazard to their community and that an emergency plan existed for an eruption of Vesuvius, although one in three of the monitoring scientists considered that the plan did not allow for the full range of potential eruptions (Point 4, Table 2). In detail, however, the answers to the questionnaires revealed divergent and unrealistic opinions that, innocuous in normal circumstances, have the potential to exacerbate conditions during an emergency.

4.1. Eruption forecasts and times for an emergency response

Sixty percent of the Authorities believe that the style and size of an eruption can be forecast, while more than half believe that eruptions can be forecasted weeks in advance, with an error margin of days. At the same time, 40% of the authorities and 45% of monitoring scientists believed that weeks might be required to organise an evacuation.

Table 2
Vesuvius results: monitoring scientists (29 results)

1. Scientific knowledge of Vesuvius
21% consider that the behaviour of Vesuvius is extremely well understood, 50% believe it is well understood and 27% believe that is adequately understood.
2. Confidence of warning systems.
57% expect to receive the first signals of an impending eruption months in advance.
3. Confidence in emergency response strategies
45% consider that the authorities may require up to weeks to organise an evacuation.
63% believe that the civil authorities expect information about an impending eruption months in advance.
4. Confidence in the 1995 emergency plan for Vesuvius
All interviewees were aware of the emergency plan for Vesuvius.
13% consider the emergency plan to be acceptable, 48% consider it to be adequate (i.e., possibly not considering all eruptive eventualities of importance to hazard mitigation), and 34% consider it to be unrealistic (i.e., definitely not considering all eruptive eventualities of importance to hazard mitigation).
5. Scientific responsibility for forecasting eruptions
94% expect that the civil authorities understand the meaning and consequences of eruption forecasts.

Table 3
Vesuvius results: local decision makers, or "Authorities" (21 results)

1. Awareness of the Vesuvius emergency plan.
All interviewees were aware of the emergency plan for Vesuvius.
84% were aware that volcanic activity is the natural hazard that could cause the largest damage in the area.
90% knew the official communication sequence for volcanic emergencies.
90% knew personally a volcanologist working in the Neapolitan area.
2. Self-evaluation of understanding volcanoes and Vesuvius in particular.
75% believe they well understand scientific ideas and terminology.
25% believe they have an average knowledge on volcanoes, 45% believe they have a good knowledge and 10% an excellent knowledge.
75% believe that they would have no difficulties understanding scientists.
70% believe that the public is unprepared (50% think that the public knows little about volcanoes and 20% think that the public know nothing at all).
3. Perception of warning time available.
55% believe that scientists can forecast an eruption weeks in advance, with a margin of error of days.
40% considered that an evacuation may require up to weeks.
4. Preferred mode of receiving emergency information
48% consider an eruption forecast to be the most important data that scientists can provide; 19% believe that advice on response actions is the most important; 24% believe that both types of information is vital.
All believe it is important to transmit emergency information in several different ways. 40% consider it vitally important to transmit information in a written form. Only 5% believe that forecasts should be provided in statistical form (e.g. "There is an X% probability of an eruption occurring in Y days.")
For long-term strategies for disseminating emergency information, 40% believe schools to be the most important places, while 35% favour centres with public access. None thought that the media are relevant to a long-term information campaign.
During an emergency, 30% believe that information should be distributed via the media, while 25% preferred pamphlets delivered directly to houses and business premises.

At present, neither forecasting capability is realistic (Kilburn, 2003; Sparks 2003; Marzocchi et al., 2004). It is possible that the forecasting time perceived by the authorities was conditioned by the belief that a similar time would be required for an evacuation. Another interpretation is that the emergency plan itself had influenced opinions. Thus, by describing only the response to a 1631-style subplinian eruption, the impression may have been given that such an event was guaranteed. In addition, the reconstruction of the 1631 eruption declared that macroscopic precursors (ground deformation and seismicity evident without instruments) were apparent 1–2 weeks before the eruption, and this may have given the impression that similar or longer warning times are today feasible with the aid of modern instruments. A condition not cited in the plan was that some time is required to understand that precursors may indeed be leading towards eruption, in which case the notional warning time is shorter than the interval at which potential precursors are first registered.

4.2. Authorities' understanding of Vesuvius

Eighty percent of the authorities believed that they had at least an average understanding of volcanic behaviour and 75%

considered that they would not have difficulties in understanding scientific ideas and terminology. In contrast, they were less confident in the ability of the general public, with 70% believing that the public has little or no knowledge of volcanoes. Possibly, the authorities feel more confident in their own ability because of direct contact with monitoring scientists. Indeed, 94% of the scientists considered that the authorities understand the meaning and consequences of eruption forecasts, although only 48% believed that the authorities had at least an adequate knowledge of volcanic behaviour. However, all interviewees might be overestimating the authorities' real understanding of volcanoes. As will be shown later, once the questionnaires had been completed, informal conversation with the authorities suggested a level of awareness much lower than that apparent from the written answers.

4.3. Scientists' understanding of Vesuvius

Scientists agreed that, the general behaviour of Vesuvius is established, although the perception of the level of understanding among their own community ranges from adequate to exceptional (Table 2). The differences may reflect academic discussions about details of Vesuvius' behaviour and so may not necessarily be relevant to the response to a volcanic emergency. However, as indicated above for Guadeloupe and Tenerife, academic differences can be transformed by the media into major controversies, and so adversely affect the trust of vulnerable populations in the scientific community. The results therefore indicate that more discussion is required among the scientists monitoring Vesuvius, in order to agree on the capabilities for understanding the behaviour of the volcano and the meaning of expected precursory signals.

4.4. Communications during an emergency

During an emergency, 72% of the authorities considered an eruption forecast to be the most important data that scientists can provide, while 43% also believe that guidelines on response actions is equally or more important. By themselves, neither result is surprising. Of greater importance is that just 5% of the authorities were confident to receive forecasts in only statistical form (e.g. "There is an X% probability of an eruption occurring in Y days"), as opposed to a deterministic statement, such as "an eruption is expected between date A and date B". Combined with the request for advice on a suitable response, the preference for deterministic statements might indicate a reluctance to take responsibility for interpreting inherently uncertain information during a crisis (and the potential for a wrong decision). If correct, the additional fact that 40% of the authorities consider it vitally important to transmit information in written form may reflect a bureaucratic desire to respond only to legally-binding documents.

5. Perception of volcanic hazards: anecdotal evidence

Answers to the questionnaires indicated that 75% of the civil authorities consider that they understood scientific ideas and terminology, a view broadly supported by the scientific community (Tables 2 and 3). Yet, informal conversation with the Authorities showed that their knowledge was more superficial than appeared from the written answers.

An illuminating example concerns understanding the nature of pyroclastic flows, which are one of the two principal volcanic hazards (together with ash fall) described in the emergency plan (Italian Civil Protection, 1995); also significant is the fact that lava flows are not discussed in the plan. When talking of pyroclastic flows, the Authorities correctly used appropriate terminology and evidently understood that such flows are a major hazard. Extended conversation, however, frequently revealed confusion with the behaviour of lava flows. For instance, although the advance rate of lava flows was correctly identified at kilometres per hour or less, the speeds of pyroclastic flows were considered to be similar or, at most, tens of kilometres an hour, a factor of ten smaller than reality. Such a misunderstanding might appear unimportant while Vesuvius is in repose. However, Vesuvius is a small volcano (about 5 km in radius) and so underestimating the speed of a pyroclastic flow also increases the maximum perceived response time from its actual value of minutes to about an hour or more.

Confusion among types of flow may seem surprising, given that Vesuvius is famous for the pyroclastic flows that overwhelmed Pompeii and Herculaneum in 79 AD (Sigurdsson et al., 1982). It is less surprising when considering the recent behaviour of the volcano. Since 1631, eruptions at Vesuvius have been dominated by effusions of lava. Today, many communities hold an annual festival commemorating the destruction—or miraculous escape—of parts of their towns by lava flows, including Torre Del Greco, Torre Annunziata, San Sebastiano, Massa, San Gregorio and Portici (Adriana Nave, pers. comm.). The action of lava flows thus forms part of the cultural fabric of the communities, so affecting the perception of volcanic hazard among local officials. In addition, knowledge of the advance rates of flows may not have appeared essential to the Authorities, on the assumption that the volcano ideally would have been evacuated before an eruption had begun.

The key point here is that, at the modest level of contact between the Authorities and monitoring scientists when no emergency exists, the impression may be given that the hazard message from scientists has been effectively communicated to other decision makers. A similar impression emerges from the written answers to the questionnaires. Nevertheless, informal discussion suggests that the communication of ideas may have been only partly effective. Any such lack of effectiveness must be checked and remedied before a crisis arises, because it has the potential to result in severe misunderstanding during an emergency, when all participants would be operating under unusually high levels of stress.

6. Conclusions and recommendations

Preliminary analysis of the information from written answers to questionnaires and from informal interviews has highlighted four potential problems that could arise during a volcanic emergency on Vesuvius. These problems could readily be addressed during revisions of the emergency response plan and before a crisis arises.

First, it is becoming increasingly popular to issue emergency forecasts in terms of probabilities (e.g., Newhall and Hoblitt, 2002; Marzocchi et al., 2004). The Authorities, however, preferred to receive unambiguous statements of future events. Possible resolutions to these conflicting objectives include: (1) linking probabilities of eruption to appropriate responses by the authorities, so that eruption probabilities could be re-expressed in terms of a required response; and (2) expressing forecasts in terms of time windows within which an eruption is expected, the size of the windows being adjusted as new data are acquired—thus returning to a method being applied at least two decades ago (Swanson et al., 1983).

Second, the Authorities prefer official crisis information in written form, possibly reflecting a bureaucratic instinct to respond only to legally-binding documents. However, efficient written communication cannot be guaranteed during an emergency. Ideally, therefore, contingencies should be prepared to allow verbal communications from designated officials also to be legally-binding.

Third, the original emergency plan may have influenced perceptions of a future crisis by focussing on a single eruption scenario. In particular, it appears that the Authorities typically take for granted (1) that the next eruption on Vesuvius will be subplinian, and (2) that it will be possible to forecast this eruption weeks ahead of time. Both assumptions need to be modified. Introducing alternative eruption scenarios (from effusive to plinian events) might raise awareness of the uncertainties of eruption forecasts and the importance of a flexible response to emergencies (an issue recently discussed by Marzocchi et al., 2004).

Finally, the Authorities and scientists are both confident that communications will run smoothly during an emergency. Such confidence may arise from a false premise. While some Authorities may have theoretical knowledge of volcanoes, few have any practical experience of eruptions. They may thus unwittingly overestimate their true understanding of volcanic processes, only to realise their shortcomings during an emergency. Scientists must therefore ensure that their messages are being properly understood *before* an emergency develops.

Acknowledgements

The help of numerous colleagues was essential to distributing and completing the questionnaires and we appreciate the open response from the Vesuvius Observatory, University of Naples, the regional and local Civil Protection, the mayors of Vesuvius' administrative districts, and the Red Cross and fire service. Particular thanks are due to Claire Collins, Ernesto Calcara and Francesco Santoianni. In addition, Adriana and Rosella Nave both provided insights into the cultural interpretations of the data. Funding was provided by the EU Project Volcalert (EVG1-CT-2001-00047), about which additional information is available at www.benfieldhrc.org/volcanoes/project_pages.htm.

Appendix

Questionnaire for scientists. The questionnaire was prepared in the native language of interviewees.

1. How well-known is the behaviour of Vesuvius? (Rate from 0 to 10, 0 being completely unknown).
2. Is Vesuvius active or dormant?
3. With the equipment available, how long in advance would you expect to receive the first signals that a volcanic eruption might occur?
4. Do you have any practical experience in volcanic emergencies?

Yes? How much overall? (months/years).

No? Do you have any practical experience in any type of major emergency?

5. Do you have specific emergency plans for volcanic eruptions?

Have you, or your group, participated in the development of these plans?

How realistic are the plans?

6. Do you think scientists should be involved in the management of a volcanic emergencies?
7. Please rate from 0 to 10 how much do you think the authorities in your area know about volcanoes in general (0 = nothing).
8. How long in advance do you think the authorities expect to receive information about a possible volcanic eruption?
9. How long do you think it will take the authorities to take action after receiving information concerning an impending volcanic eruption?
10. Would you or your group be involved (even in monitoring roles) in a volcanic emergency in your area?
11. What information would you produce? (Please rate by importance 1 being the most important. Leave blank if not relevant).

Advice on what actions to take. Forecast of activity. Organisation of the crisis. All the previous. Other (specify).

12. In which form do you expect the data to be transmitted? (Please rate by importance, 1 being the most important. Leave blank if not relevant or not contemplated).

Numerical (time to an eruption). Statistical (probability of an eruption).

Written. Spoken. All the previous. Other (specify).

13. Who would transmit the information? (Please rate by importance, 1 being the most important. Leave blank if not relevant).

Anybody on duty. The head/director of the group. A designated spokesperson. An external advisor. Other (specify).

14. To whom would you transmit your information?
15. Do you think the people receiving the information would understand the meaning and consequences of the information you produce?
16. Do you expect that the authorities would face any difficulty in understanding scientific information?
17. Please rate from 0 to 10 how much do you think the public knows about Vesuvius (0 = nothing).

18. How long before an eruption occurs do you think the population expect background information on volcanic eruptions?

19. How long do you think it would take people to react if they thought that a volcanic eruption might affect them in a few years time?

20. Where do you think public information about volcanic eruptions should be available from? (Please rank in order of importance: 0 = not important; 10 = essential.)

On the TV. On the radio. In newspapers. At schools. In public centres (town halls, hospitals, etc.). All the previous. Other (specify).

21. In which format do you think information should be released during an emergency? (Please rank in order of importance: 0 = not important; 10 = essential.)

As a press release. As a report. As a book. As a pamphlet. As posters. All the previous.

Other (specify).

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