Chapter 21

Risk assessment case history: the Soufrière Hills Volcano, Montserrat

W.P. Aspinall and G. Wadge

21.1 Introduction

Volcanic hazard and risk at Soufrière Hills Volcano, Montserrat (SHV) has been assessed in a consistent and quantitative way for over 17 years (1997-2014), during highly variable eruptive activity involving andesitic lava dome growth (Wadge & Aspinall, 2014). This activity has placed serious stresses and constraints on the Montserrat population: about 12,000 people lived on this small Caribbean island prior to the start of the eruption in July 1995 and now (2014) this has stabilised at just over 4,000 souls. Over the years following 1995, a series of five very active dome growth episodes produced many pyroclastic flows, explosions and lahars, whose net effect was to destroy the main town, Plymouth, and most infrastructure, forcing people to leave Montserrat or live only in the northern part of the island. In June 1997, nineteen people were killed when a dome collapse pyroclastic flow caught a number of persons inside the exclusion zone.

The risks faced by the people of Montserrat from volcanic activity are the responsibility of the UK government, and hazard and risk assessment work on Montserrat has been carried out by a Scientific Advisory Committee on Montserrat Volcanic Activity (SAC) (and the predecessor Risk Assessment Panel) appointed by them, working in collaboration with the Montserrat Volcano Observatory (MVO). While the administrative basis of the SAC has changed, the quantitative risk assessment methodology for enumerating risk levels (Aspinall et al., 2002, Aspinall & Sparks, 2002), has been kept the same since 1997 to ensure comparability of findings from one assessment to the next. In a protracted eruption crisis, continuity in scientific inputs to decision-making is essential: any major change in concepts, modelling or assumptions could entail large differences in evaluated risk levels and hence engender doubts for officials and confusion in the minds of the public. This series of multiple, repeated quantitative volcanic hazard and risk assessments must be unique in volcanology.

In the case of Montserrat, by 'volcanic risk' we mean the probability that a person will be harmed by some volcanic hazard within some specified timeframe; assessing other risks and losses, such as damage to buildings or infrastructure, have had only a limited consideration in terms of framing scientific advice.

Aspinall, W.P. & Wadge, G. (2015) Risk assessment case history: the Soufrière Hills Volcano, Montserrat. In: S.C. Loughlin, R.S.J. Sparks, S.K. Brown, S.F. Jenkins & C. Vye-Brown (eds) *Global Volcanic Hazards and Risk,* Cambridge: Cambridge University Press.

21.2 Assessment methods and their effectiveness

Comprehensive risk assessments for Montserrat were first undertaken by a Risk Assessment Panel in December 1997, following the fatalities and then a series of violent Vulcanian explosions. Thereafter, whenever activity changed significantly assessments were updated. The SAC came into being in 2003, superseding the risk panel, and further developed risk assessment methods, using the following sources of information in regular meetings, usually every six months:

- MVO data on current activity at the SHV
- knowledge of other dome volcanoes
- computer models of hazardous volcanic processes
- formalised elicitations of probabilities of future hazards scenarios
- probabilistic event trees
- Bayesian belief networks
- census data on population numbers and distribution
- Monte Carlo modelling of risk levels faced by individuals and society.

Knowledge elicitation about hazard scenarios and analysis of judgements by the Classical Model method (Cooke, 1991) have been used to formulate probabilistic forecasts of future hazardous events, typically over the following 12 months. These scenario forecasts have been used in Monte Carlo simulations to quantify risk exposures of individuals and the population as a whole (Aspinall, 2006).

Hazard scenarios allow volcanologists to visualise - and describe to the authorities and the public - the potential occurrence and dangers of future events. Probabilities of occurrence of hazards, with associated confidence limits, are evaluated by judging factors that make such events likely to happen. This evaluation is done by expert elicitation, informed by experience of previous events at the volcano, its current activity state, by model simulations, and by discussion of precedents elsewhere at similar volcanoes. The elicitation process can be stimulating but also burdensome, so generally only a restricted number of scenarios or outlooks are considered (typically 10 to 30). The process may thus be limited to major hazards: i.e. explosion; large dome collapse, or lateral blast, and event probabilities are usually evaluated for each, for one year ahead. However, if a significant event occurs then the conditions under which these probabilities were judged will have changed, so a risk assessment is only valid up to the time of the next 'significant event'. Hazard and risk updating is needed at that point.

The accuracy of SAC hazard forecasts has been tested using the Brier Skill Score. Although this metric has some limitations, it is used in weather forecasting and we have adopted the analysis method for volcanic forecasts. We have tested 110 scenario probabilities against actual outcomes: seventy-five of these can be termed life-critical, and for 83% of these a positive Brier Skill Score was achieved. This shows that, in the overwhelming majority of cases, our experts outperformed an 'uninformed' baseline probabilistic forecast, demonstrating the value of the process in supporting the civil authorities and the people of Montserrat to mitigate risk. As yet, no hazard has happened that was a surprise to the scientists, and none has exceeded our scenario envelopes in terms of size or intensity.

https://doi.org/10.1017/CBO9781316276273.023 Published online by Cambridge University Press

In the main, the SAC risk assessment implementation is distinct from day-to-day observatory operations - where the duty is to provide immediate hazard advice - but it is closely linked with and relies on MVO inputs. While this may seem an unusual separation of responsibilities, we believe it has worked well on Montserrat because the SAC brings to bear a separate, independent pool of expertise and long-term experience. This approach offers a deeper analytical perspective on issues of future hazards, complementing the monitoring competencies of MVO. This said, in future it is intended that MVO staff will take on more of the tasks of quantitative risk assessment.

21.3 Expressing risk to the public

After deriving event scenario probabilities and their uncertainties by elicitation and then quantifying risks and their uncertainties by Monte Carlo modelling, the SAC assessments present the level of risk in several ways:

(i) A Preliminary Statement and the SAC Report generally state whether, overall, risk in the populated part of Montserrat has gone up, down or stayed the same.
(ii) Societal risk is expressed quantitatively as a curve of the probability of exceeding a given total number of fatalities, for different total numbers.
(iii) Individual risk is given as an annualised probability of death (from the volcano) for any person living in a specific area.
(iv) Added occupational risk, due to the volcano, is given for people working under certain conditions in specific areas.

Societal risk is presented as an *F-N* graph (probability of *N* or more potential fatalities in a given time plotted against *N*) and is useful for comparing situations from different periods and for assessing mass casualty scenarios. For instance, in Figure 21.1 the *F-N* curve for May 2003 (red), together with a second curve (green), showed how societal risk could be reduced by extending the evacuated area. For natural disaster risk comparison purposes, rudimentary *F-N* curves for hurricane and earthquake risk on Montserrat are also shown.

https://doi.org/10.1017/CBO9781316276273.023 Published online by Cambridge University Press

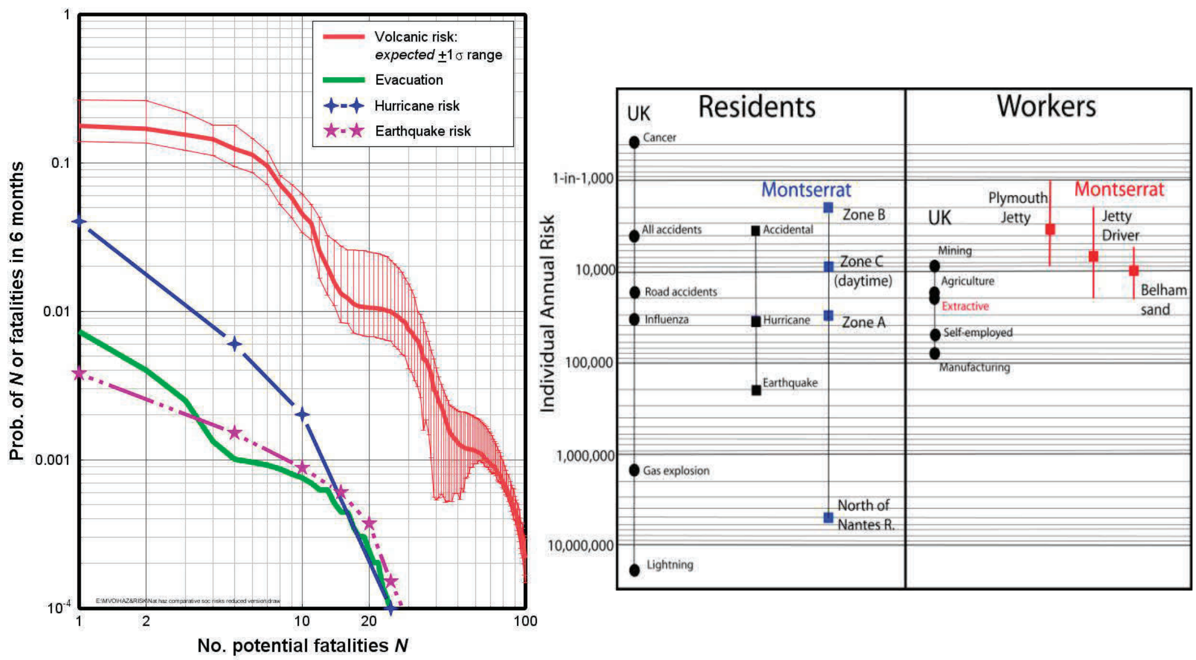

Figure 21.1 Montserrat quantitative risk assessments: (left) societal risk F-N curve for population exposure (red, with uncertainty estimates), and the risk reduction possible if the evacuation area is extended (green), plus background hurricane (blue) and earthquake risks (mauve); (right) summary plot of annualised individual risk exposures for residents and workers (latter plotted in red, with indicative uncertainties on risk estimates). Modified from Figures 24.8 and 24.9 of Wadge & Aspinall (2014).

Uncertainty analysis of the Monte Carlo societal risk modelling furnishes confidence bounds on these alternative volcanic risk *F-N* curves (Figure 21.1), indicating that meaningful risk reductions could be achieved by basic mitigation measures. In contrast with typical linear *F-N* plots for industrial risks, the volcano societal risk curves exhibit marked changes of slope and humps. These arise because an erupting volcano has a variety of ways of doing harm to a population, with differing levels of hazard intensity and spatial extent potentially causing different total magnitudes of casualty numbers, all with different probabilities of occurrence. Such complexity in volcanic *F-N* curve serves to make decision-taking about public safety very much more challenging than in the industrial risks case, especially when the risk findings are convolved with the substantial scientific uncertainties associated with volcano forecasting.

Individual risk can be a more influential measure for expressing exposure in that many people, but not all, base their own responses to threats on their own personal risk level. The SAC has used several measures for individual risk, but mainly we calculate the 'individual risk per annum' (IRPA) metric, expressed in odds form (e.g. a 1-in-1000 chance of being killed in the next year). Graphical comparison of IRPA values on a logarithmic ladder with some relevant published risk levels for everyday hazards and occupations to provide context (Figure 21.1) has proved popular with the authorities on Montserrat. The Zones used to calculate individual risk are defined geographically by the Hazard Level System managed by MVO (www.mvo.ms). The positioning of the zone boundaries has implications not just for risk levels but also evacuation actions and emergency management. There is a rudimentary feedback process, from the SAC

https://doi.org/10.1017/CBO9781316276273.023 Published online by Cambridge University Press

and MVO through the civil authorities, between the level of hazard estimated and the resultant risks ensuing for a given set of boundaries (Wadge et al., 2008).

Subjectively, the general perception of whether the risk has gone up or down is reflected by changes both in calculated societal risk levels and in individual risk estimates. However, criteria for public safety and tolerable levels of volcanic risks are not established in Montserrat (or elsewhere); this vacuum is exacerbated in a crisis by inevitable tensions between individuals' acceptance of elevated risk and society's wish to avoid casualties.

The SAC risk assessments are made public within a few weeks. There are two reports: a Summary Report of about 4-5 pages and a much longer, Full Report, giving all the technical analysis. They are available at www.mvo.ms.

21.4 Government response to risk assessments

How have the authorities used the SAC risk assessments to guide actions in protecting the people of Montserrat? Because volcanic dangers at SHV are dominated by pyroclastic flows and surges, the spatial boundary of the probable extent of any future flow is the overriding concern for risk management. Generally, such actions appear to have been responsive to SAC risk level assessments, but it is difficult to evaluate this in detail (Wadge & Aspinall, 2014). This is partly because the MVO has responsibility for day-to-day guidance and recommends changes in the Hazard Level, the main cue for mitigation measures. Also, there is no formal feedback from the authorities to the SAC in terms of the reasoning about decisions to change zone boundaries. While many such decisions have been taken over the years, few if any can be directly linked to specific SAC advice, but most were consonant with levels of risk assessed by the scientists.

While the aim of the SAC has been to keep the nature and standard of advice consistent from one assessment meeting to the next, changing conditions at the volcano and changing requirements from the authorities inevitably dictated some alteration to the way advice was formulated and presented by the SAC. This said, during recent periods several pyroclastic flows have travelled further towards the populated areas and could have led easily to injuries or deaths had there not been updated official access restrictions in response to the risk assessment advice. Other risk-based decision approaches, such as cost-benefit or probabilistic criteria to inform evacuations have not, thus far, formed part of risk decision-making in Montserrat.

21.5 Summary

Since its inception in 2003, the SAC's principal role in efforts to mitigate danger from the Soufrière Hills volcano has been to consider likely future behaviour patterns of the volcano on the basis of observations, data, modelling and expert knowledge and to communicate our collective scientific understanding of processes driving the evolving eruption and limitations in that understanding. Related advances in probabilistic volcanic hazard and risk assessment methodologies have been achieved, and our appraisals of the volcano's state and the chances of potential impacts on the population by eruptive activity have represented the substantive science input to decision-making by the authorities and the provision of risk information to the public. In the face of scientific uncertainty and other challenges associated with living with an active volcano, risk-informed hazard mitigation measures have ensured there has been no

https://doi.org/10.1017/CBO9781316276273.023 Published online by Cambridge University Press

fatality caused by the volcano during all the long years of eruptive activity and dangerous events since the tragic events of June 1997.

References

Aspinall, W. 2006. Structured elicitation of expert judgement for probabilistic hazard and risk assessment in volcanic eruptions. *In:* Mader, H. M. (ed.)*Statistics in Volcanology.* Geological Society of London.

Aspinall, W., Loughlin, S., Michael, F., Miller, A., Norton, G., Rowley, K., Sparks, R. & Young, S. 2002. The Montserrat Volcano Observatory: its evolution, organization, role and activities. *Geological Society of London Memoirs,* 21, 71-92.

Aspinall, W. P. & Sparks, R. S. J. 2002. Montserrat Volcano Observatory: volcanic risk estimation - evolution of models. MVO Open File Report 02/1.

Cooke, R. M. 1991. *Experts in uncertainty: opinion and subjective probability in science*, Oxford University Press.

Wadge, G. & Aspinall, W. 2014. A review of volcanic hazard and risk assessments at the Soufrière Hills Volcano, Montserrat from 1997 to 2011. *In:* Wadge, G., Robertson, R. & Voight, B. *The Eruption of Soufriere Hills Volcano, Montserrat, from 2000 to 2010: Geological Society Memoirs, Vol. 39.* Geological Society of London.

Wadge, G., Aspinall, W. P. & Barclay, J. 2008. Risk-based policy support for volcanic hazard mitigation. Report commissioned by Foreign and Commonwealth Office.