Ref. Ares(2018)1694829 - 27/03/2018

ENVRI[plus] DELIVERABLE

D12.2

WHITE PAPER ON GENERAL GUIDELINES, RECOMMENDATIONS, AND BEST PRACTICES ON COMMUNICATION AND DECISION MAKING UNDER UNCERTAINTY FOR ENVIRONMENTAL HAZARDS AND NATURAL DISASTERS

WORK PACKAGE 12
A FRAMEWORK FOR ENVIRONMENTAL LITERACY

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Accepted by: Mairi Best (Theme 4 leader)

Deliverable type: REPORT

Dissemination level: PUBLIC

Deliverable due date: 01.01.2018

Actual Date of Submission: 03.27.2018

ABSTRACT

We present in this deliverable a brief though thorough selection of scientific papers and reports describing / discussing best practices and proposing guidelines for communication and decision making during earthquake and volcanic crises. The range of environmental system crises of interest for the project RIs is certainly broader (encompassing extreme weather (also related to climate change), avalanches, mudslides, coastal erosion, instability of infrastructure due to permafrost thawing, to mention just a few), and some of the project RIs apparently have very limited roles in crisis communication and management to date. Even so, we believe that the present literature review is broadly relevant to different disciplines and can be used as checklist / reference for scientists who, in the future, will face the challenges posed by communicating natural hazards and risks to the general public and the authorities before, during, and after an environmental crisis. The main results of this deliverable are: (a) a selective collection of heterogeneous sources of information into one single document easily accessible to the project RIs and stakeholders; (b) a summary of up-to-date recommendations and guidelines on communication and decision making under uncertainty and; (c) the compilation of a survey to be used as a self-assessment tool of the procedures implemented by each RI with active roles in environmental crisis communication and decision making.

Project internal reviewer(s):

Project internal reviewer(s):	Beneficiary/Institution
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Document history:

Date	Version
15.01.2018	for technical review
23.02.2018	updated version from technical review
28.02.2018	2nd update from technical review
3.13.2018	Accepted by Mairi Best

DOCUMENT AMENDMENT PROCEDURE

Amendments, comments and suggestions should be sent to the authors

PROJECT SUMMARY

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs. ENVRIplus develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

TABLE OF CONTENTS

RECOMMENDATIONS AND BEST PRACTICES ON COMMUNICATION AND DECISION MAKING UNDER UNCERTAINTY FOR ENVIRONMENTAL HAZARDS AND NATURAL DISASTERS.

1 - INTRODUCTION AND MOTIVATION

Natural hazards are naturally occurring. physical phenomena caused either by rapid or slow onset events which can be geophysical, hydrological, climatological, meteorological or biological. All of the above can be relevant for the RIs involved in the ENVRIplus project. Times of heightened natural hazards identify the onset of environmental and earth system (EES) crises that potentially lead to natural disasters.

Within WP12 of ENVRIplus, the informed feedback loop of the Human-Environment System (HES, Scholz, 2011) is a key concept considered in our approach towards assessing the role of environmental RIs in societies. It is, therefore, worthwhile to note at least on the side that the HES feedback loop (*action-impact-learning-decision*) is remarkably similar to the concept of integral risk management (also often referred to as the risk management or disaster (risk) management cycle, e.g., Atkinson et al., 2006) with its elements *response-recovery-prevention/mitigation-preparation*. In consequence, it should be relevant also for environmental RIs to assess their role in the risk management cycle with a view towards the societal feedback mechanisms that are active or can be activated according to the HES framework.

Crisis management typically comprises the following elements / roles / phases: (a) crisis response planning (*i.e.*, emergency simulations and exercises, training of stakeholders' community); (b) crisis forecasting, recognizing and warning; (c) communicating hazards and risks associated with the crisis; (d) decision making; (e) crisis termination (*i.e.*, shifting from emergency to routine operations; rendering an account of what has happened). While some of these roles are typically dealt with at governmental / civil protection level, research institutions can be often required to actively contribute to (a), (b) and (c), and to provide critical input to (d) and (e). Communication and decision making are a crucial part of crisis management. Therefore, it is important to provide the project RIs with a comprehensive though concise overview of the current best practices.

Our approach to compile such overview is mainly based on literature scrutiny, but we also encouraged partner input along with input from experts not involved in the Project. This deliverable contains also a questionnaire that we originally conceived as a survey to collect critical input data from the RIs representatives, but that can and will also serve in the future as a self-assessment tool of the procedures implemented by each RI with active roles in crisis communication and decision making.

RIs in Environmental and Earth System Sciences find themselves in very varied and different contexts regarding crisis communication and decision taking. National level actors often have well established connections to the usually national or sub-national level crisis management and response authorities (including defined tasks and responsibilities). They may also have established practices to engage in communication with media and the general public. This is for example the case for many (national) seismological or volcanological observatories and monitoring centers. In other cases, individual scientists (less often specific RIs as organizations) may receive requests to supply expert information and assessment, by authorities as well as by media. Sometimes, they may communicate actively on their own, using whatever channels they prefer. Multinational or pan-European RIs today often do not have well defined counterparts to provide crisis-relevant information to, owing to the fact that crisis management and response is first and foremost happening on or below the national level. Some notable exceptions exist, e.g., the 'regional' tsunami information centers established under the UNESCO/IOC umbrella (www.ioc-tsunami.org), the volcanic ash advisory centers (VAAC) of the ICAO (www.icao.int or https://gis.icao.int/icaovaac), or the recent pilot project to establish a European rapid information system for meteorological and geophysical disasters responding directly to the EC's Emergency Response Coordination Center ERCC (project website http://aristotle.ingv.it). But in all the above, the institutional partners are not classical *'Research Infrastructures'* (with the emphasis on *research*), at least the partners do not act in that role, but rather in their role as natural hazard monitoring agencies.

Despite the above, we believe that it is highly relevant that European level RIs of the EES sector actively engage with communication of natural hazard information in crisis situations. On one hand, often very close links exist between the European level RIs and their national partners or members, which are directly exposed to crisis communication challenges. On the other hand, it is to be expected that European coordination in crisis response and management will continue to grow. This will force relevant European counterparts to provide scientific expertise. Further, due to a comprehensive and fast access to information, interested media, authorities or citizens may increasingly directly contact RIs to receive a first-hand crisis assessment. This evolution might be accelerated through social media activities of RIs (e.g., twitter accounts), promoting rapid, informal, mutual interactions. While the content of this report is mainly informed by current practices in the seismological community, and in particular by those implemented by earthquake and volcano observatories, we believe that the general recommendations presented in this white paper are broadly applicable throughout the variety of crises of relevance to the Project RIs. We often use directly the words and sentences of other authors as taken from their relevant publications, all cited in the references, especially if the publication is not easily accessible online or the publishing journal requires institutional or private subscriptions. The reason for this choice is that, in our opinion, reformulating well-calibrated sentences that are already published in peer-reviewed journals is neither useful nor appropriate in this context. We note that this deliverable is mainly compiled for those RIs and their members who have not yet extensively considered their role in crisis communication, rather than for "experts" who are already aware of guidelines and recommendations. While the former will profit from a consolidated list of key references and a concise presentation of their relevance and importance as presented in this paper, we certainly acknowledge that once one engages more deeply with this topic, issues soon tend to become seriously complex and specialized, and addressing them adequately is well beyond the scope of this work. The main objective of this white paper is the selective collection of heterogeneous sources of information into one single document easily accessible to the project RIs and stakeholders. PDF copies of most of the publications listed in the references are available to the Project participants at https://polybox.ethz.ch/index.php/s/Kd1LO4YQnHySoEP; the password to access the folder will be delivered upon request.

In the coming sections, we first present some crisis communication principles. This is followed by a key literature compilation on the lessons learned and the experiences gained in earthquake and volcanic crises, focusing on specific topics / aspects that prompted the development and publication of recommendations and guidelines. We then present a summary of the recommendations segregated by crisis management phase and the self-assessment survey delivered to the project RIs.

2 – CRISIS COMMUNICATION PRINCIPLES

Uncertainties are an inherent part of natural hazards, but not what most people are primarily interested in. When a natural catastrophe hits, people focus first on dealing with the crisis and do not have any resources to understand or interpret scientific forecasts (Wein et al., 2016). Also, before an event, probability estimates are only one small piece in people's understanding and assessment of a given hazard. Similarly important are personal traits, experiences, trust or their social environment, to mention a few (Mileti et al., 2004). Successful communication before, during and after a crisis is based on the following principles.

- *Know your goals*

This might be an obvious point, but often it is not clear to everyone engaged in crisis communication, what the specific goals are. At each stage, different goals apply. For example, raising awareness of a natural hazard is an important aspect in preparation for a potential crisis. People only prepare for things they are aware of. However, awareness is just a first step towards behavioral intentions and actual conduct. The challenge compounds not only in making relevant information available but also in presenting it in understandable ways (Peters et al., 2008). For example, to control the trade-off between information completeness and comprehensibility. Having access to more complete information does not necessarily lead to an enhanced understanding or better choices (Peters et al., 2007).

- *Know your audience and its needs*

The needs of the recipients of hazard information are not uniform, nor is their knowledge, their experience, or their capability to process information. Therefore, information material has to be compiled and designed differently for different user groups. Whereas for example professionals are familiar with technical jargon, concerned residents might not understand it. Studies in the field of flood hazard for example show that "return periods expressed as probabilities" (Meyer et al., 2012) or the term "one hundred year flood" (Hagemeier-Klose and Wagner, 2009) are often misunderstood by non-experts. In addition, users also have specific preferences regarding distribution channels. Whereas some are listening to the radio, others prefer social media channels to receive information.

- *Involve your audience*

Effective crisis communication and its preparation should not be a one-way-effort. RIs need to involve their audience before a crisis hits. They should ask what they need or want and test relevant products beforehand (Perry et al., 2016).

- *Be prepared*

In contrast to many stakeholders and the public, institutions dealing with natural hazards know that a crisis might hit. Therefore, they should get ready before an event happens by knowing their goals, audiences and partners in crisis management. Further, they should design key messages, define and establish distribution channels and assign responsibilities for communicating in all stages of a crisis.

- *Stay tuned*

Successful crisis communication is not a one-time effort. Key messages need to be repeated frequently on different channels to maintain and raise awareness (Sheppard et al., 2012). The design of the messages further needs to be evaluated frequently for updates with respect to new scientific findings, consumer habits or distribution channels. During a crisis, it is in addition crucial to monitor ongoing public discussions, allowing an organization to detect upcoming issues and make preparations.

3 – LESSONS LEARNED FROM EARTHQUAKE CRISES

3.1 - RECOMMENDATIONS ON THE IMPLEMENTATION OF OPERATIONAL EARTHQUAKE FORECASTING

According to Marzocchi et al. (2017), earthquake forecasting is "the ultimate challenge for seismologists, because it condenses the scientific knowledge about the earthquake occurrence process, and it is an essential component of any sound risk mitigation planning". Long-term forecasting is usually referred to as Probabilistic Seismic Hazard Analysis (PSHA). The results of PSHA are typically presented as maps of the seismic shaking levels associated with a given probability of exceedance within a given, long time span. Typical examples are maps of peak ground or spectral acceleration with probability of exceedance equal to 0.1 in 50 years, that are used to define the seismic input to design ordinary buildings in the vast majority of earthquake-prone countries. Short-term earthquake forecasting, often referred to as "Operational Earthquake Forecasting", is the ability to forecast earthquakes on time scales as short as days, and is particularly appealing to inform risk mitigation decisions during ongoing seismic crisis (Jordan et al., 2011). Due to its attractiveness and inherent large uncertainties, OEF is one of the most debated topics in applied seismology to date (Zechar et al., 2016). Demonstration systems are steadily developed and improved worldwide. Earth scientists and decision makers have developed guidelines for OEF implementation (Jordan et al., 2011; Field et al., 2016) and dissemination of OEF results.

Particularly relevant within the context of this ENVRIplus deliverable is the work of Jordan et al. (2011), who summarized the activities carried out by the International Commission of Earthquake Forecasting (ICEF) to respond to a request from the Italian Government to assess the scientific knowledge of earthquake predictability and provide guidelines for the implementation of operational earthquake forecasting. The request of the Italian Government was made shortly after the damaging and deadly earthquake occurred in L'Aquila, Central Italy, in 2009. The L'Aquila trial, in which seven Italian officials were charged with involuntary manslaughter, was at least partly a consequence of miscommunications about earthquake risk by the Italian Department of Civil Protection. The ICEF took the opportunity of the L'Aquila case study to address some larger issues that that are generally relevant for scientists involved in hazard management and risk communication (Jordan, 2013). Among the main lessons of L'Aquila was:

> *" [...] the need to separate the role of science advisors, whose job is to provide objective information about natural hazards, from that of civil decision makers, who must weigh the benefits of protective actions against the costs of false alarms and failures-to-predict. [...]*

through the use probabilistic rather than deterministic statements in characterizing short-term changes in seismic hazards."

The ICEF made a series of recommendations on the implementation of OEF systems that are applicable in our opinion to a large range of natural hazards beyond earthquakes. For example, one can easily note the remarkable similarity of these recommendations with the most up-to-date methods and tools for meteorological hazard assessment and communication. Therefore, the reader is invited to read through the following recommendations (taken from Jordan, 2013) substituting words like "seismic" and "earthquake" with adjectives and nouns closer to the domain of his / her RIs.

- ✓ The public should be provided with open sources of information about the short-term probabilities of future earthquakes that are authoritative, scientific, consistent, transparent, and timely.
- ✓ This information should be made available at regular intervals, during periods of normal seismicity as well as during seismic crises. The public must be educated into the scientific conversation through repeated communication of what can be expected. Agencies should not try to deliver new types of information during times of crisis.
- ✓ Public advisories should be based on operationally qualified, regularly updated seismicity forecasting systems that have been rigorously reviewed and updated by experts in the creation, delivery, and utility of earthquake information.
- ✓ The quality of all operational models should be evaluated for reliability and skill by retrospective testing, and they should be under continuous prospective testing against established long-term forecasts and alternative time-dependent models. Alert procedures should be standardized to facilitate decisions at different levels of government and among the public.
- ✓ Earthquake probability thresholds should be established to guide alert levels based on objective analysis of costs and benefits, as well as the less tangible aspects of value of information, such as gains in psychological preparedness and resilience.
- ✓ The principles of effective public communication established by social science research should be applied to the delivery of seismic hazard information, for example, consistency of messaging.

In essence, the ICEF highlighted the importance of crisis communication and promoted the use of transparent, quantitative, scientific methods to inform risk mitigation strategies, as further discussed in the following Sections.

3.2 - A CONSOLIDATED STUDY ON SOCIETAL RESPONSE TO EARTHQUAKE FORECASTS

Mileti and Darlington (1995) used data collected on the general public, health, safety and wellness organisations, and businesses in the San Francisco Bay Area to describe people's reactions to receiving an informational newspaper insert about revised probabilities for an incoming damaging earthquake in the region. Although this work is possibly partly outdated, it includes general recommendations for optimal communication strategies that are worth recalling.

- ✓ The public, local government and business should be informed in appropriate style and language. The information should come from official government sources and scientists and should explain clearly and specifically what the risk and probability are, when and where the crisis is going to happen, what the effects will be, what people should do before, during and after the crisis, and where to get more information.
- ✓ Maps should be user-friendly to enhance public understanding.
- ✓ The order in which information is presented is important. The most important information for the public to get is what people should do, how to do it, encouragement to talk things over with others and instructions on how to get additional information. Science information, although interesting also for the public, should be presented later.
- ✓ Put all information about a given topic in the same place.
- ✓ People who make decisions for organizations and members of the general public need to get the message several times, from different sources and through as many different channels as possible.

Based on those findings and more recent studies in the field of earthquake communication the following recommendations are highlighted (Mileti and Fitzpatrick, 1992; Mileti and Darlington, 1995; Nathe, 2000; Mileti et al., 2004). An important success factor of an effective hazard communication is to explain things in non-technical terms. Another is that the information should be distributed by various credible sources in a consistent manner. Supplementary to media reports, people like to have written documents and easy access to further information they can refer to and discuss with their peers. It is important to include information on what has to be done prior to, during and after an earthquake. In principle, people are more willing to act if they understand what they could do to reduce their risk. In addition, an attractive presentation of the information including visuals is supportive. Finally yet importantly, it is crucial to keep in mind that the public is not uniform (Nathe, 2000). Successful communication measures are tailored to the specific needs of a wide variety of recipients (Mileti et al., 2004). They motivate stakeholders to participate, aim to improve the quality of decisions, and support informed decision taking. Thereby, it is relevant to not focus on accuracy and completeness only, but to consider also the presentation format (Peters 2008).

3.3 - LESSONS LEARNED DURING THE 2011-12 CHRISTCHURCH (NEW ZEALAND) SEISMIC SEQUENCE

Poole (2012) described how a large Public Information Management (PIM) team was formed at the time of the 2011 Christchurch (New Zealand) earthquake crisis. The earthquake caused 185 deaths, thousands of injuries, and the destruction of the central business district of Christchurch, along with widespread damage and destruction to residential and industrial buildings. For the first time in New Zealand, a state of national emergency was declared, and the separate civil defense emergency management responsibilities of national, regional and local government came together to provide a single, unified response to a major emergency. Poole (2012) scrutinised the unfolding events and the PIM team's tactics and made recommendations for the management of public information in future large-scale emergencies. The lessons learned and the recommendations, available at https://ajem.infoservices.com.au/items/AJEM-27-04-04, can be ported to a variety of environmental crises beyond damaging earthquake sequences and they have general transnational validity.

The guidelines of Poole (2012) were recently complemented by the study of Wein et al. (2016) who focused on improving communication with the public during a (seismic) crisis. They also used the Christchurch earthquake sequence to conduct focus groups and interviews about geoscience communications. The results of Wein et al. (2016) indicate that that public consumption of geoscience information changes throughout the sequence and differs with respect to ways of coping. They support the need to accompany earthquake information with advice on protective actions, psychosocial support, and self-care strategies but find it necessary to distinguish between crisis and risk communication regarding the balance of these types of information; initially, people are more focused on the crisis than the science. They concluded that geoscientists can be more effective in planning and preparing to communicate during a seismic crisis if they:

- ✓ appreciate the complexity of psychosocial aspects affecting communication of earthquake information and aftershock forecasts and are trained to communicate with compassion and refer to qualified sources;
- ✓ understand diverse and evolving needs within the public for scientific information and prepare ahead for challenges that reduce attention to aftershock forecasts;
- ✓ understand the benefits of coordinating communication roles and develop relationships with other responding agencies (e.g., health and welfare, emergency management).

3.4 - A PROPOSAL FOR QUANTITATIVE COMMUNICATION OF TIME-VARYING SEISMIC RISK DURING EARTHQUAKE SEQUENCES

Consistent with the guidelines compiled by the ICEF, Van Stiphout et al. (2010) suggested an approach for objective short-term evacuation decisions based on probabilistic risk forecasting combined with cost–benefit analysis. This work was recently updated by Herrmann et al. (2016), who performed a similar exercise based on a synthetic scenario earthquake sequence that simulated the possible repeat of the 1356 Basel seismic crisis, one of the most damaging known to have occurred in central Europe. Herrmann et al. (2016) used an advanced aftershock forecasting model and detailed settlement data to make spatial forecasts and inform decision making at the level of detail of a city district. The method of Herrmann et al. (2016) allows the making of predictive statements about earthquake consequences, specifically quantified in terms of human loss. This evaluation of course requires a quantification schema for human losses (cost of life, etc.), which again may be subject of wide-ranging and controversial discussions, and Hermann et al. (2016) assume that such a quantification schema is available as input to their method. In particular, they chose to estimate the potential losses for a given shaking intensity, following the procedure of QLARM (Trendafiloski and Wyss, 2009). After having set the statistical value of a human life in Switzerland equal to 10 million CHF, and the socioeconomic cost of evacuating a person per day to 1000 CHF, they compared costs of an evacuation with its benefits. Within this framework, an evacuation is preferable if its costs are exceeded by the expected loss, and the benefit is a monetary equivalent for saved human lives. The cost-benefit threshold identified by Hermann et al. (2016) refers to the individual risk through normalization by the population number. Such an economic perspective of risk might be adequate for decision makers but not for an individual, because everyone is treated equally. This is a potential limitation of the approach by Hermann et al. (2016), mainly justified by simplicity considerations. Even so, their final cost–benefit analysis provides objective (within the context of the employed quantification schema) statements that may justify evacuations. To deliver supportive information in a simple form, Herrmann et al. (2016) proposed a color-coded earthquake alarm level, based on the cost–benefit ratio of action to be taken (Figure 1). This color-coded alarm strategy matches some widely-accepted key requirements for scientifically rigorous and effective communication, i.e., it:

- ✓ is easily passed on and widely used in other scientific communities;
- ✓ is a result of a probabilistic approach that accounts for the uncertainties and summarises all available information on hazard and vulnerability;
- ✓ is fully reproducible;
- ✓ can be computed automatically.

While the last point might look like an outlier within the context of crisis communication, it is actually quite critical within the broader domain of crisis response and decision making, where any options available to keep the human workload sustainable should be carefully considered and implemented. This is also consistent with the recommendation of Poole (2012) to "Scale up early and fast, as it is impossible to manage public information successfully in a serious and escalating situation with the resources used in routine events."

Consistent with Woo and Marzocchi (2014), Hermann et al. (2016) found it reasonable to:

> " [...] provide different warnings to the public without imposing any specific mitigation action [...] essentially 'nudging' people to adopt their own mitigation strategy."

The last statement, which seems to contradict some general recommendations of Mileti and Darlington (1995) and other social-science studies, is likely based on the assumption that the recipients of the warnings are already aware of possible mitigation strategies as identified during previous training / education activities, and that "their acceptance of the risk assessment and risk management transpires largely from the trust in the models and in their authors" (Fischoff, 2015). Indeed, according to UNISDR (2006), the following elements have to be in place and maintained to ensure the success of natural hazard early warnings: "knowledge of the risk faced, technical monitoring and warning service, dissemination of meaningful warnings to those at risk, and public awareness and preparedness to act". If any of those elements is not covered or is weak, any early warnings will fail. Based on the UNISDR survey including 122 countries, early warnings most often miss their target because of failures in the distribution of the messages or the recipients lacking knowledge on what to do. In conclusion, being aware of options for action is just as important for efficient mitigation as having adequate event information. Knowing what is happening without knowing what to do is likely as useless as knowing what to do in principle, but not knowing whether one should do something at a given moment.

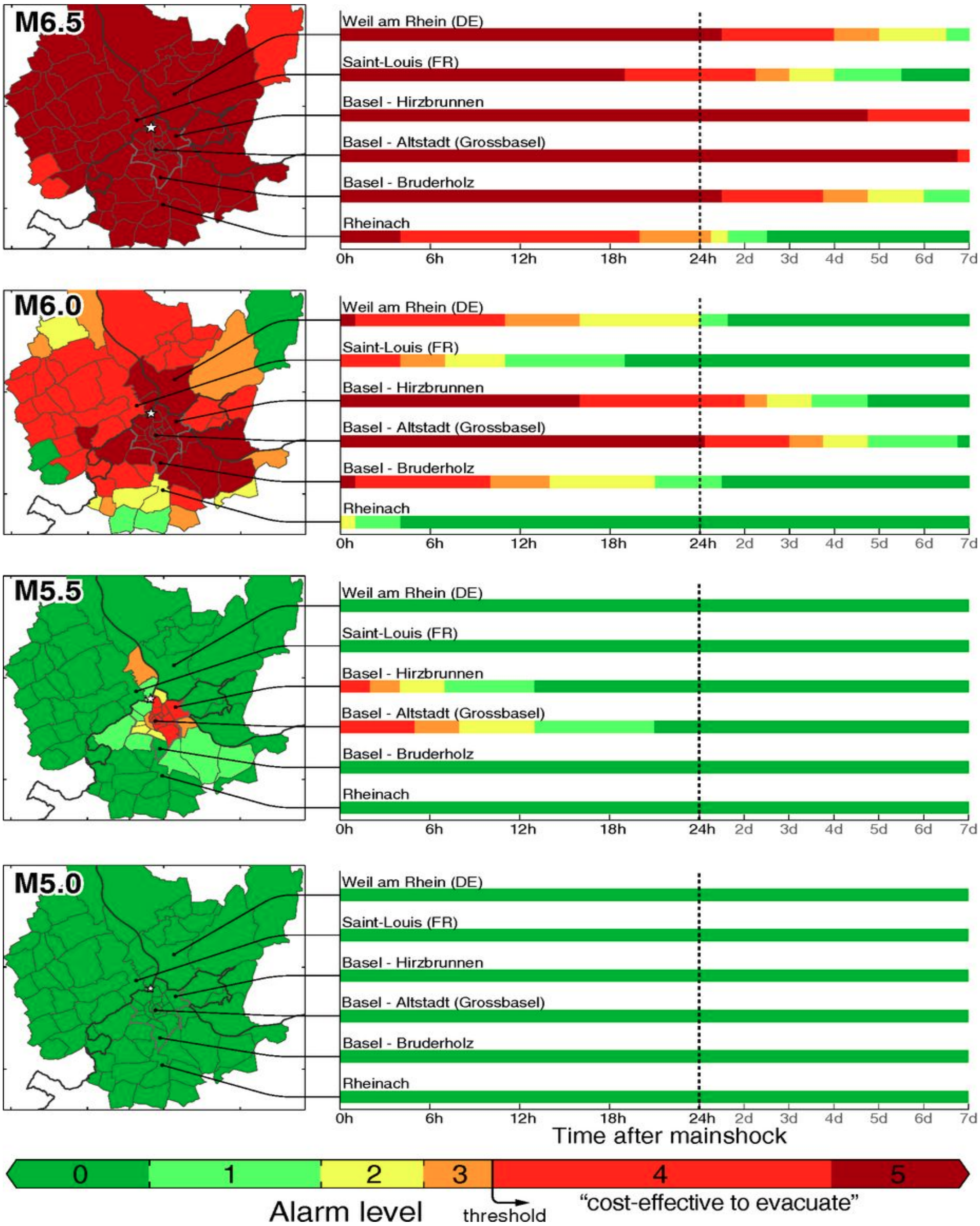

FIGURE 1 - FIGURE 9 OF HERRMANN ET AL. (2016). COLOR-CODED ALARM LEVEL BASED ON EVACUATION COSTS AND BENEFITS PROPOSED BY HERRMANN ET AL. (2016) AND ITS APPLICATION TO EARTHQUAKES OF DIFFERENT MAGNITUDE IN THE BASEL CITY AREA.

3.5 - THE USE OF RISK-COST-BENEFIT ANALYSIS FOR INDUCED SEISMICITY RISK GOVERNANCE

Geo-energy projects worldwide face challenges posed by felt induced earthquakes and the concerns they cause. As a consequence, the topic of induced earthquakes is now a priority on the agenda of many research institutions worldwide, leading to a strong increase in the number of scientific, peer-reviewed publications. A recent example is the work of Trutnevyte and Wiemer

(2017) and the report of Wiemer et al. (2017), which focus on induced seismicity risk governance, i.e., “the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed, and communicated and how management decisions are taken” (IRGC, 2005). Wiemer et al. (2017) emphasise that:

> [...] key elements of this process are a clear separation of roles, the transparency of the process, and the quality of the two-way exchanges and communication. In such situations, it is the role of science and engineering to produce the factual baseline for discussion and decision-making. Ideally, risk-cost-benefit analyses offer a transparent pathway to assemble and integrate relevant evidence to support such complex decision-making processes under deep uncertainties and with knowledge gaps. In a recent review article, Fischhoff (2015) outlined and discussed this kind of approach, based on selected case studies from the past. Ultimately, the acceptance of the risk assessment and risk management transpires largely from the trust in the models and in their authors [...]”

The full report by Wiemer et al. (2017) is available on line at http://seismo.ethz.ch/export/sites/sedsite/research-and-teaching/.galleries/pdf_products_software/Good-Practice-Guide-for-Managing-Induced-Seismicity-in-Deep-Geothermal-Energy-Projects-in-Switzerland_v1.0.pdf

3.6 - LITERATURE REVIEWS AND GUIDELINES COMPILED WITHIN PROJECT REAKT

The recently completed EC-funded project REAKT comprised one work package (namely WP6) devoted to improved decision-making for real-time earthquake risk reduction either through Earthquake Early Warning or Operational Earthquake Forecasting. The WP6 of REAKT compiled literature reviews and guidelines that are highly relevant to the problem at hand. In particular, their deliverables are:

- ✓ D6.1 Critical review of participatory decision making in other fields (Douglas et al., 2012; http://www.reaktproject.eu/deliverables/REAKT-D6.1.pdf)
- ✓ D6.2 Review of social science studies on the behavioral response of population to hazard warning (Woo, 2012; http://www.reaktproject.eu/deliverables/REAKT-D6.2.pdf)
- ✓ D6.3 Guideline to establish quantitative protocols for decision-making in operational forecasting (Woo, 2013; http://www.reaktproject.eu/deliverables/REAKT-D6.3.pdf)
- ✓ D6.4 Guidelines for establishing a decisional framework in life cycle time dependent risk analysis (Woo, 2014; http://www.reaktproject.eu/deliverables/REAKT-D6.4.pdf)
- ✓ D6.5 Guideline for the involvement of citizen in the decision-making process (Woo, 2014b; http://www.reaktproject.eu/deliverables/REAKT-D6.5.pdf)
- ✓ D6.6 Guidelines for decision-making procedures in aftershock environment risk analysis (Woo, 2014c; http://www.reaktproject.eu/deliverables/REAKT-D6.6.pdf)
- ✓ D6.7 Report on the application of communication protocols to REAKT test cases (Le Guenan et al., 2014; http://www.reaktproject.eu/deliverables/REAKT-D6.7.pdf)

which are a valuable source of information for the Project RIs. Note that REAKT D6.2 contains a comprehensive review of “Public Attitudes to Warnings” - comprising though not limited to the seminal works by Dennis Mileti (e.g., Mileti 1999) - that is definitely worth reading for those RIs involved in hazard and risk communication. Since all the above documents are permanently and easily available online, we do not replicate their content here. The reader is referred to the links given above to access the documents.

3.7 - ON THE REDUNDANCY OF INFORMATION

Critical in the context of earthquake hazard and risk communication is the use of a multiplicity of means of information (e.g., Mileti and Darlington, 1995; Poole, 2012) to ensure that messages are redundantly and effectively delivered and received. This applies to communicating with the general public and stakeholders during times of heightened hazards, and with decision makers, stakeholders and the general public during the phase of crisis response planning. Amongst the means of information that an RI can use for crisis communication are: news on institutional websites; press releases; media interviews (e.g., press, television, radio); social media posts (e.g. twitter, Facebook, blogs); smartphone apps, direct communication with stakeholders / decision makers; public lectures / events; written material (e.g., flyers, newspaper inserts). It is important to emphasise that all these lines of communication should already be open before the onset of a crisis, so that all stakeholders know where to look for information when an event happens. For example, the Swiss Seismological Service (SED) uses all the aforementioned tools, with emphasis placed on institutional website news, media posts and smartphone apps. Bossu et al. (2015) used the case study of the 2015 Nepal earthquake sequence to demonstrate the importance of mobile devices and smartphone apps to provide access to earthquake information, with focus on felt and potentially damaging events. Bossu et al. (2015) report that users of the smartphone app “LastQuake” in Nepal, India and Bangladesh identified the rapidity, usefulness and the simplicity of the app as its key strengths, and suggested that it could profit from addition of safety instructions and risk prevention measures. It is interesting to note that this users’ feedback about LastQuake is fully consistent with the classical recommendations of Mileti and Darlington (1995), amongst others.

It certainly is by now unchallenged that the public welcomes (and even is hungry for) any information about an ongoing crisis (whether affected by the crisis or not), and for that information provision internet-based communication like smartphone apps and social media play an increasingly important role. In addition, advanced communication technology and the increase of ‘open access’ to data in near real time is leading to a growing number and variety of publishers of information. If uncoordinated, this can lead to discrepancies. It remains, therefore, important to consider and critically reflect upon the role of scientists / scientific institutions in particular during an ongoing crisis and with respect to the 'authoritativeness' of any communication, and on the responsibilities for any consequences resulting from that communication. Particularly delicate is the case of alarms delivered to unprepared / untrained citizens and stakeholders (no matter whether the alarm is false or correct), as this could trigger panic and a cascade of negative impacts.

3.8 - COMMUNICATION AT THE SWISS SEISMOLOGICAL SERVICE

The Swiss Seismological Service (SED) at ETH Zurich is the federal agency responsible for monitoring earthquakes in Switzerland and its neighboring countries. When an earthquake occurs, the SED informs the public, authorities, and the media about the earthquake location, magnitude, and possible consequences. While in this context the SED acts as a classical 'monitoring agency', the SED is at the same time strongly engaged in research, teaching and outreach, and the scientific staff at SED needs to clearly distinguish whether they are in any specific moment acting as 'research scientists' or as members of a federal monitoring agency. This duality of roles is not uncommon in the environmental and earth system sciences, in particular on the national level, and poses significant challenges in particular for crisis communication. The SED has a dedicated "Communications" group, responsible for media and public relations. The group is also involved in communication and social-science components of large-scale seismological research projects. Michèle Marti, Head of Communications at the SED, answers below to some general questions related to earthquake crisis management and communication in her Institution. After each answer, we highlight the relevant "best practices" contained therein.

✓ Who is responsible for crisis response at the SED?

> We have three experts on duty 24/7: first, a seismologist (trained for interacting with media), who is responsible for immediate crisis response, coordination of all relevant activities, and interactions with authorities and media. Second, a person who takes care of manual earthquake locations. Third, an IT specialist in charge of solving urgent technical problems. In case of a widely felt or damaging earthquake, further people like the director and its deputies, other duty seismologists and communications specialists are ready to take or taking actions.

Roles and responsibilities of the personnel involved are identified in advance; communication strategy, including media liaising, is defined in advance; roster management is considered.

✓ Concerning earthquake communication, what are the biggest challenges your organisation faces?

> Probably the most challenging factor is time. We receive the first media requests immediately after an event. We realized that we can decrease media pressure if we quickly publish a statement on our website, answering frequent questions like, how was the event perceived, when was the last event of such a magnitude or what is the historical seismicity context for the region. With the compilation of such a statement comes the next challenge. The SED usually publishes its news articles in four languages: German, French, Italian and English; translations are required (and not all the seismologists working at SED can speak all above languages), and this is another time-consuming activity.

Communication strategy, including media liaising, is defined in advance; communication is multilingual to reach different communities. An organization can have a series graduated severity templates prepared in advance, with "fill in the blank" elements that everyone on duty is trained how to fill in, particularly given that much of the details will be numeric. However, every event is in a sense unique and communication activities should address eventual particularities.

- ✓ Do you have any guidelines defining your crisis management?

  Yes, we have numerous documents to assist duty seismologists to accomplish their tasks. The main elements are checklists for different event types, ensuring that nothing important is missed and pointing to documents with further information. We recently updated these checklists based on an event evaluation. They are now much shorter and handy than any previous versions. We also try to enhance and simplify the coordination of responsibilities and activities by introducing a “duty chat”.

All procedures are defined in advance; no new type of information is delivered under pressure.

- ✓ How do you coordinate with other authorities in case of a major earthquake?

  The SED coordinates its activities closely with all relevant natural hazard and civil defense institutions in Switzerland. The earthquake announcements of the SED are automatically distributed to all emergency services and additionally broadcasted by the national natural hazards portal (http://www.natural-hazards.ch/home/current-natural-hazards.html) and published on one of the most popular (weather) apps in Switzerland (MeteoSchweiz). Other authorities can reach the SED anytime via a dedicated phone number if they seek for advice or further information. In Switzerland, it is in the responsibility of cantonal or local emergency services to instruct the public on what to do in case of a crisis. The SED can and will only provide recommendations.

Roles of the SED are clarified in advance; relationships amongst responding agencies are developed in advance; communication is multi-channel (including also non-digital dissemination pathways if required) and consistent with latest technologies.

- ✓ Have you ever faced major communication difficulties in a crisis?

  So far, we have not experienced any major difficulties. One reason might be that we were not confronted with a damaging earthquake in the past years. Another, that we are seen as a trustworthy institution in Switzerland. With open and transparent communication, we aim to keep up this status.

SED is identified as an authoritative scientific institution / advisor; the public and the stakeholders are continuously engaged in the scientific conversation.

In addition to earthquake response, the SED is in charge of evaluating the seismic hazard of Switzerland. The latest Swiss hazard model (Wiemer et al., 2016) is presented using maps designed following international best practices in hazard communication. Due to the large availability of the report online (http://www.seismo.ethz.ch/export/sites/sedsite/knowledge/.galleries/pdf_knowledge/SUIhaz2015_final-report_16072016_2.pdf), we do not repeat its content herein. The reader is referred to Section 9.2 of Wiemer et al. (2016) and the references listed therein.

4 - VOLCANIC CRISES

The main difference between earthquake and volcanic crises is that the eruption of a volcano is somewhat more easily anticipated by precursors, including ground shaking, deformation, and gas emissions (https://volcanoes.usgs.gov/vhp/forecast.html). Operating modern monitoring networks in volcanic areas means that eruptions can be reliably forecasted by authoritative institutions with several months to few days of notice. Even so, a volcanic eruption is a dramatic natural phenomenon with a potential to trigger a crisis and heavy impacts on the population and infrastructure.

4.1 - IAVCEI GUIDELINES

The International Association for Volcanology and Chemistry of the Earth's Interior (IAVCEI) represents scientists working on volcanic hazard evaluations and risk mitigation. It promotes and moderates discussions amongst its members on: (i) how to best understand and forecast volcanic activity and the associated hazards, and to contribute to risk evaluations; (ii) the appropriate roles and responsibilities of scientists prior to, during and after crises; (iii) the nature of scientists' relationships with government authorities, populations at risk, and the media; (iv) the manner and extent of involvement of scientists in processes that eventually lead authorities to make decisions, the extent of the liability or vulnerability of scientists to outcomes of these decisions, and the way that scientists' input may be perceived and judged by others; (v) the role of national and local culture and perception of risk in both mitigation policy and communication of hazard and risk; (vi) the effectiveness of descriptions of forecasted volcanic phenomena and associated hazards, and of their related uncertainties; (vii) how to best increase the awareness, preparedness and empowerment of individuals, and society as a whole, in order to reduce the impact of volcanic phenomena on society. In particular, IAVCEI, developed guidelines concerning:

- ✓ the roles and responsibilities of scientists involved in volcanic hazard evaluation, risk mitigation, and crisis response (IAVCEI, 2015);
- ✓ the professional conduct of scientists during volcanic crises (Newhall et al., 1999; Geist and Garcia, 2000; Newhall et al., 2000).

While IAVCEI (2015) - that is also consistent with Jordan et al. (2011) and Jordan (2013) - is definitely more relevant within the context of this Deliverable, we also encourage the readers to follow the discussion triggered by Newhall et al. (1999), that deals with the delicate topic of frictions that could develop within and between groups of experts dealing with a given environmental crisis situation. The guidelines are openly available online at http://www.iavcei.org/iavcei-products/iavcei-guidelines.html . The reader is therefore referred to these online resources and the references therein. Note that the abovementioned guidelines focus on topics which are also dealt with in WP13 of ENVRIplus.

5 - A SURVEY FOR SELF-ASSESSMENT OF RIs' PROCEDURES IN CRISIS COMMUNICATION AND DECISION MAKING

Based on the recommendations and guidelines listed in the previous Sections, we have prepared a questionnaire, which was also delivered by email to the RI representatives of ENVRIplus in December 2017. Where applicable, this survey can be used to assess the current practices implemented by each RI and to compare them with international guidelines and case studies introduced in this Deliverable.

(1) What are the environmental and earth system (EES) crises (e.g., natural disasters) relevant for your research infrastructure (RI)? Recall that a natural disaster is a sudden and terrible event in that usually results in serious damage and many deaths.

Please list

(2) What are /should be the roles of your RI in EES crisis (hereinafter "crisis") management?

Please mark with an X - One or more options can be selected.

> (2a) Crisis response planning (emergency simulations and exercises, training of stakeholder communities)
>
> (2b) Crisis forecasting, detection and warning
>
> (2c) Communicating hazard
>
> (2d) Communicating risk
>
> (2e) Decision making
>
> (2f) Crisis termination (shifting from emergency to routine operations; rendering an account for what has happened)

(3) If your RI has communication roles in crisis management:

> 3a) Do you have a clear communication plan for crises?
>
> Please Yes / No, plus brief explanation
>
> (3b) Who is responsible for crisis communication in your RI?
>
> Please list (e.g., the director, the vice-director)
>
> (3c) Are the responsibilities clear to everyone involved in crisis communication?
>
> Please Yes / No, plus brief explanation
>
> (3d) Do you envisage that during a crisis you may define various specific communication roles (e.g., responsible person for public relations, for website, for communication with authorities, …)?

Please Yes / No, plus brief explanation

(3e) Have those responsible for crisis communication received special training?

Please Yes / No, plus brief explanation

(4) Are you well informed and aware of the possible public and legal consequences that the conduct and actions of your RI during a crisis can have?

Please Yes / No, plus brief explanation

(5) Are the roles and responsibilities of your RI in a crisis situation clearly defined?

Please Yes / No, plus brief explanation

(6) Are the roles and responsibilities of your RI in a crisis situation clearly distinct from those of other authorities?

Please Yes / No, plus brief explanation

(7) Is your RI the authoritative source for some information or communication, or the authoritative actor for some aspects regarding the crisis, and is the authoritativeness of your roles fully acknowledged by the other institutions involved in crisis management?

Please Yes / No, plus brief explanation

(8) If applicable to your RI:

(8a) What are your means of communication in a crisis situation?

Please give percentages (for example, if your RI always uses twitter to inform the general public about ongoing crisis, please check “Social media posts”, 100% twitter). If your RI uses “Social media posts (e.g. twitter, Facebook)” for crisis communication, please specify the channel you are using.

News on institutional websites

Press release

Media interviews (e.g., press, television, radio)

Social media posts (e.g. twitter, Facebook) - Please specify the channel you are using

Smartphone App

Direct communication with stakeholders / decision makers

Public lectures / events

Written material (e.g. flyers, newspaper inserts)

Others, e.g. blogs

(8b) Do your communication means change over time during the evolution of a crisis?

Please Yes / No, plus brief explanation

(8c) Is the material used by your RI for communicating hazard and risk professionally designed to ensure scientific and technical rigorousness, usefulness, clarity, effectiveness, completeness, understandability? How did you reach these goals?

Please Yes / No, plus brief explanation

(8d) Does your RI use a single voice for public statements?

Please Yes / No, plus brief explanation

(8e) If your RI does not use a single voice, does your RI ensure that all public statements are consistent and if so by which means?

Please Yes / No, plus brief explanation

(8f) In your experience, do people trust the information your RI is publishing?

Please Yes / No, plus brief explanation

(9) Are you aware of publications documenting best practices, successful and unsuccessful examples in crisis management and communication?

If yes, please list.

(9a) Do you follow any of such best practices as guidelines for your RI?

Yes / No

(9b) Do you routinely review the literature for updates?

Yes / No

(10) Has your RI developed its own crisis management and hazard / risk communication guidelines? Are they available for sharing?

Please Yes / No, plus brief explanation

(11) Does your RI participate / follow multidisciplinary studies including also the social, cultural, political, economic, and legal perspectives of crisis management and communication?

If yes, please list.

(12) Have you ever measured the impact of your crisis communication or do you have any reference on how it is received?

If yes, please specify.

6 – SUMMARY AND RECOMMENDATIONS

We presented in this deliverable a brief though thorough selection of scientific papers and reports describing / discussing best practices and proposing guidelines for communication and decision making during earthquake and volcanic crises, as summarized in Table 1. While reading though this summary table, the reader is encouraged to note that most recommendations deal with crisis response and communication planning, rather than reacting; key elements of the planning process are: (a) the preparation of an assessment of crisis topics and possible responses before any crisis; (b the preparation of a clear communication plan, including clear roles, before a crisis; (c) testing of said communication plan with minor events to 1) scientifically assess models and 2) figure out what one might want to communicate. The range of environmental system crises of interest for the Project RIs is certainly broader (encompassing, e.g., extreme weather increasingly including related to climate change, avalanches, mudslides, coastal erosion, instability of infrastructure due to permafrost thawing, to mention just a few), and some of the project RIs apparently have had very limited roles in crisis communication and management to date. Even so, we believe that the present literature review is highly portable to different disciplines and can be used as checklist / reference for scientists who, in the future, will face the challenges posed by communicating natural hazards and risks to the general public and the authorities before, during, and after an environmental crisis. The guidelines compiled by seismological and volcanological communities reflect the state of the art developed following very recent, highly debated crises (such as the infamous 2009 L'Aquila, Central Italy, earthquake) and the informed opinion of scientists who are used to communicating hazards and risks to the authorities and the public as part of their daily tasks. In other words, even if every crisis is unique (in terms of precursors, rate of growth, scale, impacts, mitigation actions, etc.), scientists involved in crisis communication and decision making will homogeneously face similar challenges and can profit from the experience of the seismological and volcanological communities as collected in this report. Amongst the cited references, we recommend to all potential recipients of this deliverable to read at least through the works of Jordan (2013), IAVCEI (2015) and Poole (2012), keeping in mind that crises are also opportunities to develop and test emergency procedures. The readers more interested in communication strategies will certainly profit from reading Mileti and Darlington (1995), Wiemer et al. (2016), Bossu et al. (2015) and visiting the multi-hazard cross-disciplinary portals of Switzerland (www.natural-hazards.ch/home/current-natural-hazards.html) and of the United States Geological Survey USGS (https://www2.usgs.gov/natural_hazards/), where simple homogenous color-scales and explanations of hazard levels are applied to a variety of natural hazards in real-time. Those curious about scientifically informed decision making will find a useful recipe in Hermann et al. (2016), Fischhoff (2015) and the deliverables compiled within REAKT WP6. Often overlooked by scientists, partly because not covered by their *curricula studiorum*, adequate communication is crucial in emergency management (Jordan et al., 2011; Poole, 2012). Those in charge of communication during a crisis should be aware that various aspects are influencing how people understand and deal with hazard related information. Such aspects include trust, gender, age, previous experience, political views, and personal values (e.g., Heller et al., 2005; Becker et al., 2013; Perez-Fuentes and Joffe, 2015; Lindell et al., 2009). While probabilistic statements should be used to provide objective scientific information on natural hazards, dealing with statistical information and / or uncertainties is challenging (for experts and non-experts), as investigated by Lamontagne et al. (2016), Hudson-Doyle et al. (2011), Mileti & Darlington (1995), Nathe (2000) amongst others.

Table 1 – Summary of the recommendations organised by crisis management phase.

Crisis Management Phases	Universal recommendations	Specific recommendations	Stakeholders / target audience	Who is involved
Crisis response planning	Mark clearly the distinction between scientific activities that inform civil protection decisions and civil protection decisions and actions themselves. Use principles of effective public communication established by social science (including authoritativeness, scientific validity, clarity, conciseness, consistency, transparency, timeliness, redundancy, matching messages and channels to target audiences). Provide open sources of information about the probabilities of incoming crisis at regular intervals as well as recommendations on what to do. Manage rosters carefully. In a short, sharp event, people can cope with working long hours. In a long-running response, rostering has to be carefully managed.	Inform the decision makers and the public on what the risk and probability are, when and where the crisis is going to happen, what the effects will be, what people should do before, during and after the crisis, and where to get more information. Engage the public into the scientific conversation through repeated communication of what can be expected. Identify scientific advisors. Define communication strategies, including media liaising. Define authoritative roles. Define constructive roles for elected members Coordinate communication roles and develop relationships amongst responding agencies.	Decision makers, general public, stakeholders, media	Scientific advisors, decision makers, general public, stakeholders, media

	Promote / follow the publication and sharing of best practices in hazard studies and crisis management. Train scientific advisors and communicators to; (a) appreciate the complexity of psychosocial aspects affecting crisis communication; (b) communicate with compassion and refer to qualified sources; (c) understand diverse and evolving needs within the public for scientific information and prepare ahead for challenges that reduce attention to forecasts. Promote / initiate / join inter- and multi-disciplinary studies and scientific programs aimed at improving the understanding of the multi-faceted nature of earth systems, their hazards, and crisis management, including the scientific aspects and also the social, cultural, political, economic, and legal perspectives. Scientists should: (i) fulfill their responsibilities in good faith and to the best of their abilities, working to facilitate informed decisions by civil	Standardize alert procedures facilitate decisions at different levels of government and among the public. Identify and rank scientific methods for crisis forecasting and define their periodic revision. Define thresholds in risk-cost-benefit analyses to inform decision making. Consider / implement participatory decision making.		
Crisis forecasting, recognizing and warning		Focus on communication of short-term hazard and risk probabilities Implement media liaising promptly	Decision makers, general public, stakeholders, media	Scientific advisors, decision makers, media
Communicating hazards and risks associated with the crisis		Implement media liaising promptly Avoid delivery of new types of information	Decision makers, general public, stakeholders, media	Scientific advisors, decision makers, stakeholders, media

	protection authorities and at-risk individuals; (ii) safeguard not only their own legal status, but also the status and credibility of their advice which should be independent, neutral, objective, unbiased, and value-free; (iii) be aware and respectful of applicable protocols and procedures, and all relevant legal requirements and cultural issues. Follow crisis communication principles.	Scale up early and fast, as it is impossible to manage public information successfully in a serious and escalating situation with the resources used in routine events. Work with welfare teams to reach those most severely affected; some people will be too traumatized to hear or understand official messages.		
Decision making		Use results of risk-cost-benefit analyses to initiate and justify actions. Work with welfare teams to reach those most severely affected; some people will be too traumatized to hear or understand official messages.	Stakeholders, general public, media	Decision makers, general public, stakeholders, media
Crisis termination			Decision makers, general public, stakeholders, media	Scientific advisors, decision makers, stakeholders, media

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