COMMUNICATING GEOGRAPHICAL RISKS IN CRISIS MANAGEMENT: THE NEED FOR RESEARCH

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Abstract

In any crisis, there is a great deal of uncertainty, often geographical uncertainty or, more precisely, spatio-temporal uncertainty. Examples include the spread of contamination from an industrial accident, drifting volcanic ash, and the path of a hurricane. Estimating spatio-temporal probabilities is usually a difficult task, but that is not our primary concern. Rather, we ask how analysts can communicate spatio-temporal uncertainty to those handling the crisis. We comment on the somewhat limited literature on the representation of spatial uncertainty on maps. We note that many cognitive issues arise and that the potential for confusion is high. We note that in the early stages of handling a crisis the uncertainties involved may be deep, i.e. difficult or impossible to quantify in the time available. In such circumstance, we suggest the idea of presenting multiple scenarios.

Keywords: crisis response; geographical risk; risk communication; scenario-focused thinking; spatio-temporal uncertainty.

1 INTRODUCTION

Crisis management is fraught with uncertainties, many of which relate to geographical issues: uncertain volumes of contamination from an industrial accident or ash from a volcano may be dispersed by wind and washed out by rain. The uncertain path of a hurricane can put communities at risk. Disease spread can provide interesting issues when transport networks and complex food chains spread the infection across great distances between ‘nodes’ from which it can spread out as a contagion. Although it is hard to develop spatio-temporal models to assess such risks and provide crisis managers with predictions to guide their response, that is not our focus. Rather we are concerned with how analysts should convey their assessments to crisis managers. Communicating spatial risks is a surprisingly under-researched topic. Many cognitive issues arise and the potential for confusion is high. The representation of geographical uncertainty is an active research front and there is a lack of guidance on good practice. We provide some suggestions on improving such communication; but our primary aim is to stimulate further research. Recently we have completed a project on *Presenting Uncertain Information in Radiological Emergencies* (1) and that together with our long experience of emergency planning for such events may bias our comments to that context. Also much of our experience is UK centric. Nonetheless, we believe that our remarks have much wider relevance.

In the next section, we consider the crisis management context, noting the importance of addressing geographical uncertainty in many cases. In Section 3 we summarise some relevant issues in risk communication, a well-researched topic in relation to public communication, but far less so in relation to communication between analysts and crisis managers. We describe some current practices and indicate our concerns in relation to the presentation of geographical uncertainty. The urgency of the early hours of a crisis means that many uncertainties are deep, i.e. difficult to quantify with any confidence. In Section 4 we discuss how deep uncertainty may affect geographical risks and suggest ways of presenting limited information on these through the means of several scenarios. We close with a general discussion and suggestions on avenues for future research.

2 THE CRISIS MANAGEMENT CONTEXT

2.1 Introduction

Crises and emergencies take many forms: natural disasters, industrial accidents, epidemics, financial crashes, terrorism, and so on. Most involve considerable uncertainty and most of those involve some aspect of geographical risk. Our focus is on major accidents and disasters, typically at regional, national or international levels, in which teams of analysts with many different areas of expertise are quickly assembled to provide advice and guidance to those managing the response. We avoid discussion of terrorist or similar deliberate incidents, in which, e.g., the location of the perpetrators may be unknown (2).

2.2 Radiation accidents

Chernobyl and Fukushima hang heavy in our memories of industrial disasters, and their costs are still accumulating, though their health hazards may not be as great as first feared (3, 4). Typically accidental releases of radiation at nuclear plants have three broad phases: threat, immediate response and long term recovery. Early decisions are driven primarily by the imperative to reduce exposure to radiation. In the later phases, however, issues of reducing stress, socio-economic consequences, agricultural and environmental impacts are likely to become much more important [5]. Our concern is with decisions on off-site countermeasures to protect the public from the contamination. Geographical uncertainty is central to many of the decisions that are needed: most obviously, what are the likely levels of exposure to radiation to the public living in different areas and during what periods will they be most at risk? Such uncertainties arise from many causes, particularly in relation to the strength, composition, profile and duration of the release, i.e. the *source term*, and to the vagaries of the weather which will transport the cloud. The source term is notoriously difficult to forecast and – fortunately! – we have little empirical information from past accidents to help. Moreover, meteorological uncertainty and source term uncertainty interact in complex ways and need to be considered in combination.

2.3 Volcanic ash clouds

Volcanic ash is a major hazard to air travel. Fine ash clouds can cause engine damage and cut-outs. The 2010 Eyjafjallajökull eruption in Iceland grounded most European flights for more than a week and is estimated to have cost the airline industry some €3.3billion, aside from the wider disruption it caused. Thus when a volcano erupts or threatens to erupt, there is an urgent need to bound the areas that may be a risk to the safety of aircraft. The only really effective countermeasure is to avoid ash clouds or perhaps limit the total flying time in such clouds before engine maintenance is undertaken. Further complications arise because the limited range of aircraft prohibits long diversions. The decisions on whether to fly and what route to follow are made by each pilot following his or her airline's guidelines; with government agencies and air traffic controllers largely only advising. Geographical uncertainty is again key in the decision-making, and like the radiation accident context, it is driven by factors relating to the strength, composition, profile and duration of the eruption and the meteorology; but there is an added complication in that 3-dimensional information is needed; it may be possible to fly over or, perhaps, under the cloud.

2.4 Food safety

Food safety can have many geographical dimensions due, e.g., to complex global food chains. Europe is home to a complex network of food producers, processors, packagers and outlets. A pizza from a supermarket may have been made in another country from ingredients sourced from several others. So when a food safety issue arises, tracking down the source can be very difficult. The 2011 outbreak of E-coli poisoning in Germany claimed over 50 lives and led to diplomatic incidents arising from false accusations about Spanish cucumbers, before the true source of contaminated sprouts from Saxony was identified. Geographic uncertainty here is very different to that relating to atmospheric dispersion. Transport links can move contaminated food vast distances, leading to local spread around nodes in a supply network with links extending hundreds or thousands of kilometres. Many decision-makers are involved in handling food safety crises, including national and international regulators, supermarkets and producers, and the public (via change in dietary habits).

2.5 Commonalities and Differences

There are common features in these examples: the need to predict the location, the spread and duration of risks. Uncertainty is high at the outset of a crisis. Initially not only is there little data, but also expertise may be lacking, either because it takes time to bring people together or because the experts are focused on dealing with some localised aspect. There are differences, however. The decision-makers vary between the contexts: in a radiation incident, emergency managers are the dominant decision-makers. For volcanic ash, each pilot has the ultimate authority, though they may be offered very strong guidance by their company. The authorities and agencies largely only have advisory roles. In the case of food safety, decision-making is widely distributed with the public ultimately deciding what they will eat. This means that information on geographical and other uncertainties needs to be presented to different types of decision-makers, with varying levels of experience, training and knowledge to be expected in different groups.

There are also differences in the imperatives driving decision-making. In the case of radiation accidents and food safety decisions relate to reducing risks from events that have or are happening. In the case of volcanic ash, once any planes in the immediate vicinity of the eruption have landed, decision-making relates to making further flights, i.e. decisions which could actively put the passengers at risk.

3 COMMUNICATING SPATIAL UNCERTAINTY AND RISK

3.1 Introduction

There is an enormous body of research on risk perception and communication, and this has led to much guidance on how to advise stakeholders sensitively and effectively [see, e.g., 6, 7-10]. However, most guidance focuses on communication to the public, not decision-makers. The perception of risk and uncertainty by the unfocused public and the focused crisis manager are similar but not identical. Moreover, very little research concerns perception and communication of geographical uncertainty. MacEachren, Robinson[11] surveyed what little was known a decade ago, including understanding methods for capturing uncertainty and the different components, their interrelationships and influence on decisions, where visualisation aids may help, the methods and tools available and their usefulness. There have been few advances since[1].

Risk, *uncertainty* and *probability* are used almost interchangeably in everyday language. There are many definitions, often contradictory, stemming from different philosophical perspectives [see, e.g., 12, 13-15]. When uncertainty is sufficiently well understood to be modelled quantitatively, we shall assume that this is done probabilistically. We shall use the term *deep uncertainty* to refer to circumstances in which some uncertainties are so great that it is impossible to agree on probabilities for these. *Risk* will be taken to reflect both the uncertainty of an event and its impact.

3.2 Risk and Decision Behaviour

Montibeller and Winterfeldt[16] recently summarised research into risk perception and behaviour, particularly as it affects risk and decision analysis. Kahneman[17] discusses two types of

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1 MacEachren (2014) Private communication.

thinking: System 1 and System 2. The former, often referred to as 'intuition' or 'gut reaction', involves superficial analysis and interpretation of the relevant information based on much simpler forms of thinking on the fringes or outside of consciousness. The latter is characterised by conscious analytical thought and detailed evaluation of a broad range of information. Formal risk and decision analyses are examples of System 2 Thinking that have been validated against both theory and experience [(18-20)]. The methodologies of risk and decision analyses are designed to avoid the pitfalls that may arise from System 1 Thinking and guide those involved to a shared understanding of the uncertainties and possible impacts.

Amongst the many 'shortcomings' of System 1 Thinking, two are particularly relevant to our discussion:

- the *Plausibility Effect* in which people substitute plausibility for probability [(]see, e.g., [21)];
- the *Framing* of statements, in which positively framed descriptions of potential outcomes of actions cause people to become more risk averse and negatively framed ones, risk prone [(]see, e.g., [22)].

3.3 Communicating Risks to Decision-makers

Mishra et al. (2011, 2013, 2015) are among the few to have considered the general information needs of decision-makers in crises. Deitrick and Wentz [(26)] reflect on the different needs of scientists and decision-makers in working with geographical uncertainty, recognising that scientists are interested more in the uncertainties arising from their data, while decision-makers are more interested in the uncertainties about what their actions may achieve. One question is whether it is better to use qualitative or quantitative expressions of uncertainty. Many studies suggest that qualitative expressions can be understood in a variety of ways [(27, 28)]. There are many warnings that the interpretation of uncertainty expressions can be so varied that their use risks significant misunderstandings. The *Intergovernmental Panel on Climate Change* (IPCC) has made considerable efforts over several years to use a formalised system, a *probability lexicon*, to express uncertainties qualitatively. However, ongoing criticism suggests that they may not have been unambiguously successful [(29-31)].

Deep uncertainty relates to uncertainties for which experts cannot agree on quantitative probabilities. In crisis management deep uncertainty usually arises from lack of knowledge and time. Several authors have considered how qualitative and quantitative forms of analysis may be combined to address deep uncertainties, in particular, the use of multiple scenarios to conduct several parallel quantitative analyses [(32-35)]. Some have noted the potential of this approach to structure analyses for nuclear crisis management [(36-39)]. However, these references have tended to use more quantitative and probabilistic methods that are not yet computationally feasible in the first few hours of a crisis. Also, it may be difficult to muster the expert judgements needed to initialise them quickly. For the present, more qualitative explorations of scenarios in the tradition of scenario planning may offer the way forward [(35, 40, 41)]. We discuss this further in Section 4.

3.4 Communicating Geographical Risk and Uncertainty

Discussions of uncertainty and probability modelling usually focus on uncertainty about events, unknown quantities or, perhaps, propositions. Adding a spatial dimension to the things about which we are uncertain introduces several conceptual, technical and psychological complexities. Uncertainty about a single point is not so hard, but uncertainty about a line, boundary or region inevitably brings in issues of probabilistic dependence: properties of points spatially close together are usually correlated. Understanding and modelling spatial probabilistic dependence is hard. With the addition of a time dimension relating to the evolution or movement of an entity, the problem becomes even more complex. Notwithstanding this difficulty, statisticians have developed many approaches to modelling and analysing spatio-temporal processes [(see, e.g., 42)]. Atmospheric or hydrological dispersion models are examples of spatio-temporal stochastic processes of specific natural processes [(43)]. However, there has been remarkably little work and less progress on how to communicate the results of such analyses to non-technical decision-makers and others [(see, e.g., 1 for an extensive survey)]. Since the MacEachren, Robinson[(11)] review, little progress has been made. Jurin, Roush[(44)], Gregory, Failing[(45)] Tomaszewski[(46)] are essentially silent, though representing uncertainty on maps would seem important to their topics. Although the concept video[2] produced for the US Department of Homeland Security show some interesting suggestions for exploring the

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2 http://precisioninformation.org/.

implications of different weather scenarios, both it and the accompanying report contain little on the communication of geographical uncertainty [47].

There are many reasons why the communication of geographical uncertainty is particularly challenging. Conceptually, defining spatio-temporal events in unambiguous terms is not trivial. Although they may be defined with mathematical precision, non-technical decision-makers are likely to miss or misunderstand nuances, particularly in the urgent circumstances of crisis management [1]. Geographical uncertainty inevitably means that the points and areas of interest and uncertainties about them will be located on maps, introducing psychological and cultural issues. Cartography and its conventions are long established. Maps are expected to be precise (see, e.g., [48]) and do not show uncertainty in their everyday forms. Any communication of uncertainty is left to an accompanying commentary – and the vagaries of qualitative uncertainty expressions. A guiding principles of developing clear statistical figures is to focus on at most 3 or 4 'messages' [49, 50]. Maps, however, show many hundreds of details; overlaying any representation of uncertainty risks confusion with extraneous geographical details. But which details are extraneous in the handling of some crisis *a priori*: a village name, the location of the regional hospital, the course of a stream?

Wu, Lindell[51] considered the presentation of the uncertain paths of hurricanes. They found "mixed evidence for people's ability to comprehend probabilistic information about hurricanes." Generally local officials understood the uncertainty inherent in a hurricane's path, but their judgement of the uncertainty were affected by its intensity, the higher the strength the more likely they thought they would be struck.

There have been some previous suggestions for displaying uncertainty relating to paths and strengths of plumes in the context of a radiation accident [39, 52, 53]. These suggestions provided an *action focus* within the plots, indicating the uncertainty of thresholds above which countermeasures should be implemented: *cf*. Deitrick and Wentz[26] suggestion that decision-making requires attention primarily to what one can or should do. Haywood[39] suggested the plotting of multiple plumes generated by sampling from the probability distributions of the source term and the weather predictions, to show the alternative outcomes from different assumptions in source term strength, release duration and weather evolution.

We have discussed uncertainty in atmospheric events; similar issues arise in hydrological dispersion based upon, e.g., ocean currents. Much more difficult are situations in which transport or similar networks are involved. Diseases may spread locally through contact with infected individuals and then ‘jump’ great distances in a matter of hours. How such uncertainties are represented on maps is far from clear.

4 PRESENTING GEOGRAPHICAL UNCERTAINTY IN CRISIS MANAGEMENT

How is geographical uncertainty represented in crisis management currently? From our perspective: hardly at all – although this does not mean that such uncertainty is unrecognised and ignored. Uncertainty is handled through discussion between experts, looking at available data and drawing on experience, with little or no quantification. Models are used to produce single predictions. Sometimes discussion is supported by agreed prior guidance, such as[3] ‘expect errors in the modelling to be up to 1 or 2 orders of magnitude.’ However, such guidance is not always present and in our experience somewhat optimistic in that experts overestimate the accuracy of their models and predictions. Simply using qualitative descriptions of uncertainty, without regularly used and agreed terminology, provides poor communication, even in expert communities. With inexpert participants, the approach is highly questionable.

Crisis managers often ask: ‘How bad might things get?’ To answer this a reasonable worst case (RWC) is used. RWC is common in emergency planning to ensure sufficient resilience is built into a system without being excessive. The concept has been taken over from emergency planning into emergency response without apparent recognition that these contexts are significantly different. The former relates to possible disasters; the latter to something which has definitely happened. Although in emergency response care is usually taken not to focus

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[3] For example advice given in 2011 by the International Volcanic Ash Task Force (IVATF): http://www.icao.int/safety/meteorology/ivatf/Meeting%20MetaData/IVATF.2.WP.011.2.en.pdf

on an absolute worst case, which might be ridiculously pessimistic, we are aware of occasions when a single RWC has dominated the discussion [1]. The use of RWC was central to the UK's handling of the Swine Flu Pandemic and may have delayed an appreciation that the flu was less virulent than feared [54]. It is far from clear that emergency response should focus on a single RWC. Winkler[55] emphasises the importance of a balanced view of uncertainty in his reflections on the response to Winter Storm Juno. Moreover, many different negative impacts may result from the emergency and some impacts may not be apparent in a single RWC, leading to crisis managers failing to recognise and prepare for some outcomes.

An approach to reducing a tight focus on a single RWC uses scenario analysis, presenting crisis managers with several potential scenarios. We explored this idea in the context of radiation accidents [1]. The most basic forms of scenario analysis develop a series of maybe 4 or 5 scenarios that are 'interesting' in some sense and may be used as backdrops for strategic conversations: e.g.,

- reasonable best and worst cases of some form – useful for bounding possibilities;
- a likely case – useful for maintaining a balanced perspective;
- an assumption that a particular event happens or does not – useful if a key event is unpredictable and shrouded in deep uncertainty.

Since there may be no single RWC which illustrates all potential negative impacts, we might include two or three RWCs. Note that only a handful of scenarios are developed. In crisis management, there is no time to do more. There is also the issue of cognitive capacity in that decision-makers often cannot absorb and balance out the implications of many scenarios [56]. The presentation of each scenario would include maps or sequences of maps showing the evolution of events under the assumptions implicit in its definition: see Figure 1. Our initial experiments relating to the handling of radiation accidents have certainly taken this form [1]. It is important to realise that the scenarios are neither mutually exclusive nor span/partition the future, so assigning probabilities to them is meaningless. The key idea in presenting several scenarios is to stretch the crisis managers' thinking and make them consider a wide range of possibilities. It is important, of course, to guard against framing and plausibility biases. This might be done by a continual process of challenge to justify their thinking implicitly [18].

5 CONCLUDING REMARKS

There is a need for more appropriate ways of presenting geographical uncertainty in crises. We recognise that technological and computational advances are only just making it possible to provide crisis managers with quantitative assessments of spatio-temporal uncertainty; but now assessments are available, there is a need to acknowledge, discuss and address such uncertainty more explicitly than in present procedures. How do we communicate the uncertainty so that sound deliberation can take place? Our review of the research literature and current practices suggests that the answer to this question is far from clear and that it needs much more attention.

One way around the problems of too tight a focus on a single RWC may be to build on the ideas of scenario analysis (40, 41) and present the crisis managers with several potential scenarios. The key idea in presenting several scenarios is to stretch the crisis managers thinking and make them consider a wide range of possibilities. We have begun to explore this idea practically in the context of radiation accidents, presenting several scenarios through sequences of maps showing the evolution of events under different assumptions (1); and this work is continuing in a newly funded project (http://resy5.iket.kit.edu/CONFIDENCE/). It is important, of course, to guard against framing and plausibility biases. This might be done by a continual process of challenge to justify their thinking (18).

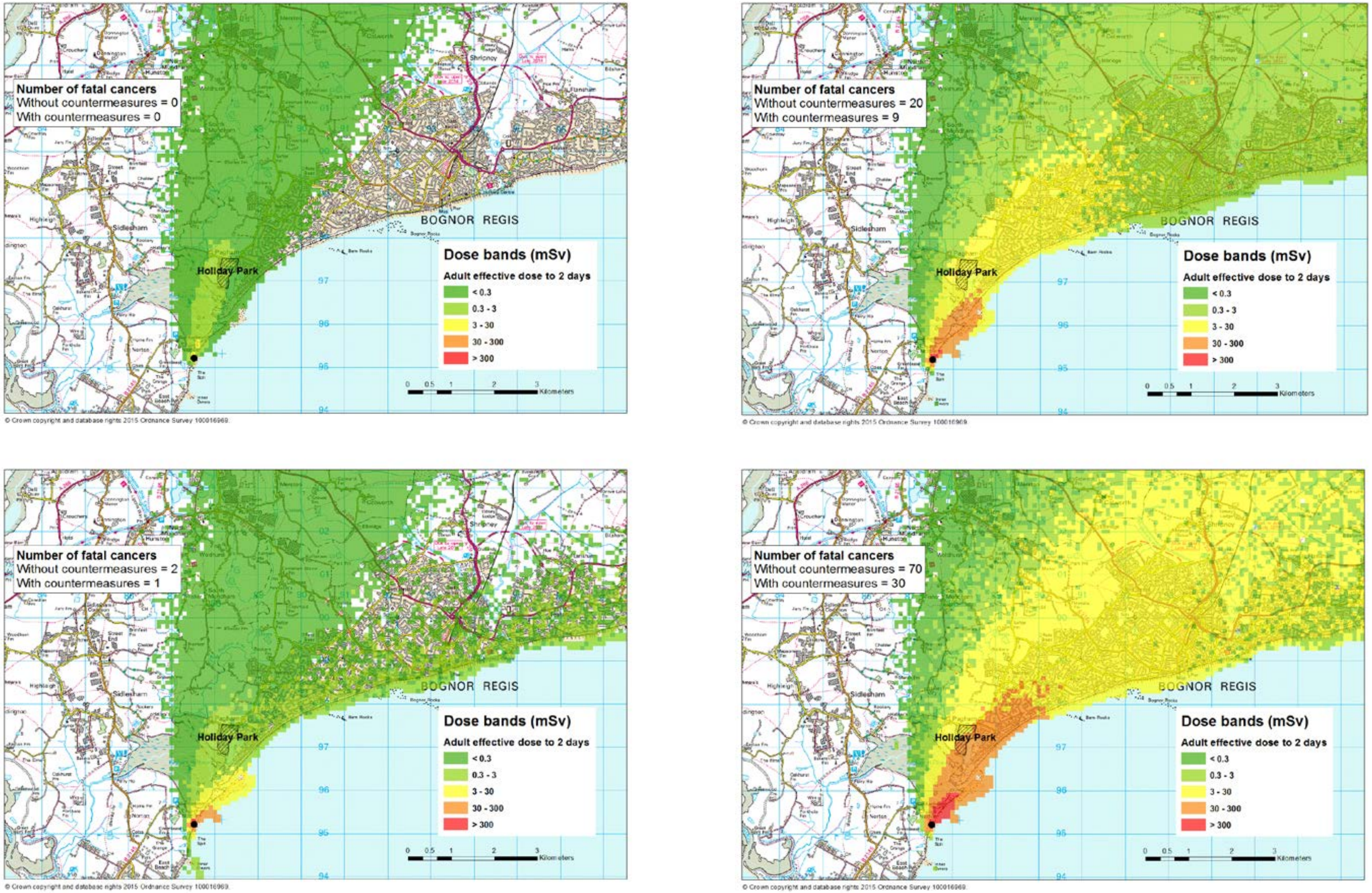

Figure 1: Four scenarios used in a workshop to explore alternatives to a single RWC.

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