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Social science perspectives on natural hazards risk and uncertainty

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15.1 Introduction

Many of the most pressing challenges for uncertainty analysis in the context of natural hazards relate to the human dimensions of risk. Earthquakes, volcanoes, landslides and many other hazards are themselves, *sensu stricto*, simply events in the natural world. How they come to be classed as hazardous, however, is a consequence of social factors which translate their happening as events for collective experience. Designating these event hazards as risks is a further conceptual step that invokes temporal awareness of hazards from past experience. Risks, and the uncertainties around their prediction, thus emerge from complex spatial and temporal interrelationships of natural and social worlds. Understanding the complexities of these interrelationships between natural and social domains is vital, because the analyses of risks, the processes of designing and managing responses to them and the nature and scope of their uncertainties are part and parcel of how risk *itself* comes to be constituted as a societal 'matter of concern' (Latour, 2004a).

Risks are usually understood as threats to people. Increasingly they are even seen as opportunities to be exploited. Natural hazards become risky as a function of how they are considered problematic within the systems or 'assemblages' (see Çalişkan and Callon, 2010) of which people are a part. A volcano on earth is hazardous, and presents risks in numerous ways in many human situations, such as air travel or nearby habitation, and so on. In contrast, a volcano on Saturn's moon, Titan, is not a hazard, *unless* it becomes incorporated into a socially interested assemblage and presents a threat to a social activity, for instance, interfering with the function of a space probe. Potential risks and uncertainties presented by such interactions between humans and the natural environment are, therefore, products of how hazards are incorporated into social systems. It is widely accepted within contemporary social science that the way that modern societies negotiate and conceive risk is a function of how risk is itself a manufactured product of specific industrial, technological and scientific capacities (Beck, 1992, 1999). Risks become manifest for us in new ways precisely through the capacities afforded to us by our ever-changing social behaviours and capabilities. Risks, then, are labile functions of changing social descriptions and values. As a result, social research is of central importance to the framing and understanding of

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contemporary risk and uncertainty. However, mainstream risk research has primarily concentrated on environmental and technical dimensions of risk, as the subject matter of this book attests.

In this chapter, we explore the emerging rationale for a more comprehensive engagement with social science expertise and techniques, in assessing risks associated with a wide range of socio-environmental or socio-technical hazards (e.g. Macnaghten *et al*., 2005; Klinke and Renn, 2006; Demeritt, 2008; LWEC, 2008). Key features of this engagement are the opening up of both interdisciplinary and societal dialogues, and a more experimental, self-conscious and provisional approach to identifying responses, recognising that multiply optimised solutions may not exist. The recently created international programme for Integrated Research on Disaster Risk (ICSU-IRDR) is a prime example:

> The Programme Plan breaks new ground in that it calls for multiple starting points: natural sciences; socio-economic sciences; engineering sciences; health sciences; and the policy-making/decision-making arena. There is need for full interaction and involvement of these groups, with each being clear what it needs from the other groups. It is also necessary to work across the interfaces, with continual re-examination as the Programme proceeds. The overall goal of contributing to a reduction in the impacts of hazards on humanity would require some relatively non-traditional research approaches.
> *(ICSU, 2008: 8)*

As we will see, this kind of new engagement across disciplines and the channelling of academic research into policy and society present radical new challenges for the research process. Key among these is the need to integrate a greater range of expert evidence into the suite of risk calculation and response strategies. In this chapter we refer to innovative integrative studies that exemplify how varieties of traditional and non-traditional expertise (in the physical science, social scientific and non-academic communities) shape the production of new knowledges about environmental risks.

To close, we will focus briefly on the capacities for academics to be proactive in shaping society's responses, amidst demands for greater involvement by scientists in hazards policy (HM Government, 2011; Royal Society, 2006). If social scientific and non-traditional learning can be better incorporated in the interdisciplinary research design and analysis of knowledge about natural hazards, then scientific actors will also be better prepared for the demands of political application and social action.

15.1.1 Setting the scope

Insight from social science can and, we argue, *should* – because it already does, even if it is not always explicitly acknowledged – add to our understanding of natural hazards risks and uncertainties. Although a great deal of research into risk and uncertainty has been mobilised in the social sciences (for example, Beck, 1992; Callon *et al*., 2009; Douglas, 1992; Douglas and Wildavsky, 1982; Giddens, 1999; Luhman, 1993; Taylor-Gooby and Zinn, 2006), arguably the crossover of insights to the parallel community in the natural and physical sciences is still wanting. Technocratic models of scientific knowledge production, risk assessment and risk communication prevail in the everyday assumptions and practices of publics, scientists, policy-makers and the media (Hulme, 2009: 102–104; Millstone, 2009; Shrader-Frechette, 2010). This is despite many long arguments about the value complexities of scientific knowledge production and the co-determinate interfaces of science and policy (see, among many examples, Etkin and Ho, 2007; Funtowicz and Ravetz, 1993; Jasanoff, 1990; Shrader-Frechette, 1991; Turnpenny *et al*., 2011; National Research Council, 1996). While our main focus in this chapter is on the qualitative and theoretical approaches that integrate social, technical and environmental systems, as will become clear, this also implies a thorough-going critique of technocratic forms of knowledge production, including those in the social scientific arena. Technocratic models assume that objective and value-free knowledge produced by technically literate experts is both necessary and sufficient for policy decision-making. Related 'top-down' knowledge formation processes like so-called 'decisionist' models (see Hulme, 2009: 100–102; Millstone, 2009: 625; Weber, 1946) similarly privilege the role of experts in defining the terms and frames for what counts as risk-relevant knowledge. Despite surface appearances of doing otherwise, such efforts often unwittingly reproduce technocratic biases by emphasising the role of social science expertise in the communication of scientific knowledge to those affected by hazards (see, for instance, Pidgeon and Fischhoff, 2011). We argue, like Hulme (2009) and others, for a more 'co-productive' model of knowledge formation which seeks, in open forms of democratic and public dialogue with scientists and advisors, the means to embed risk-relevant values, rationalities, world-views and knowledges of those affected by hazards in the production of what counts as scientific knowledge. We even go further to suggest, by way of offering some limited examples, that how risk and hazards are understood, rationalised and communicated is a function of extremely complex human and non-human assemblages of interest. Indeed, the agencies at play in decision forecasting are distributed products of these socio-technical assemblages, and include humans, their material environments, their resonant politics, particular techniques and resultant world-views. In order to effectively understand, mitigate and possibly intervene in hazardous environments we need to take account holistically of these 'knowledge ecologies' which, at a minimum, demand that risk-relevant knowledge is co-produced from its heterogeneous contexts (Farrell, 2011). Furthermore, where once strict academic boundaries governed the non-human and human (and hence the social), increasingly such lines are becoming blurred, expanding the remit of social exploration (see Escobar, 2008; Latour, 2004b). New developments in the sciences of life and environment compel physical scientists to direct attention to the human dimensions of the issues that interest them. They also demand that social scientists themselves reconfigure their own assumptions, politics and starting points, and begin to see the social as a product of hybrid collectives beyond simply human action. We argue that such 'socio-natural' evidence and experience (to use the term of Whatmore, 2002) can provide constitutive grounds for important operational insights that help us in framing and responding to risk and uncertainty in natural hazards research.

The recognition of socio-natural co-implication and imbrication builds from previous social scientific treatments of risk. The sociologist Ulrich Beck, in his influential books *Risk*

Society (1992) and *World Risk Society* (1999), argued that, for modern social and political subjects, the risks that arise from scientific and industrial modernity constitute a new means of social change. He emphasised how contemporary social shifts away from loyalty and trust in institutions and traditional social structures, and towards science and technology and liberalised economic structures, shaped the emergence of risk as a key facet of contemporary life. As a result, risk becomes a function of greater individualism, and indeed, risk is the product of social and technical modernity itself. Risks, defined as the products of modern industrial societies and their future-oriented perspectives and capabilities, are for Beck and others (such as Giddens, 1999) key features of how modern societies understand and organise themselves. The risks that concern us today, that in Beck's words, ask us to move 'beyond a modernity of classical industrial design' (1992: 10) are what Beck calls 'manufactured uncertainties' (Beck, 1999: 19–48). They are the product of things like greater predictive capacities, increased industrialisation (pollution, stress), increased knowledge about disease and risky behaviours (smoking, over-eating for instance), and the capacity of technology and social action, to some extent at least, to create means – if within always uncertain parameters – to assess and address these newfound risks (e.g. with climate modelling, improved geological sensing, flood course prediction, storm tracking, identification of disease and its spread). The social scientific focus since Beck's work, then, has been on analysing how such social changes impact upon individual and collective strategies or abilities to deal with what are labelled risks and uncertainties (for example, Ericson *et al*., 2000; O'Malley, 2004; Rose, 2006). People living in what have since come to be termed 'risk societies' find their options are re-configured within complex, often market-led, structures and forces, and, as a result, they are increasingly left to manage their own safety and risk exposures. However, at the same time, the discourse of science – which is seen to objectively describe the so-called 'natural' conditions of hazard, risk and its avoidance – has become the key means by which risk is thinkable, and as such sets the context for risk and its various politics (Giddens, 1999). The critical social sciences, then, have focused largely on the politicisation of risk as a function of living in scientifically and economically mediated risk societies.

In what follows, our approach is not to survey the extensive social scientific literature on risk societies. We would not be able to do justice to that body of work in the available space, and, we suspect, we would be misaddressing the communities of interest targeted in this book. Instead, we describe some existing and emerging areas of research at the interfaces between society and the natural environment, where a social understanding of risk and uncertainty is being applied. The disciplinary divide in academia between science and social science has meant that this is still a comparatively small area, and further methodological developments are needed. We aim to flag areas where researchers can bridge the divide and attend to calls for greater and more productive collaborations around hazard risks and uncertainties. We highlight three domains where social dimensions are already recognised as important factors of uncertainty in natural hazard risk assessment and management (discussed more fully in Section 15.3).

The first and most fundamental of these domains is in the framing of the problem itself. The social sciences can shed important light on how the knowledge that pertains to hazards and risks is framed, produced and implemented (see Collins and Evans, 2002). To date, risk assessments have largely looked at the social and environmental components separately, so we need to revisit how risk and uncertainty are typically constructed and addressed. While we expect that the quantitative, applied models of complex systems that often frame approaches to natural hazards risks and uncertainties will continue to play a vital role in risk management, constraining the attempt to capture social perceptions and responses to risks simply through quantitative modelling jeopardises the capacity to understand how risks and uncertainties emerge from and are shaped by social and natural interactions (see Odoni and Lane, 2010; Pilkey and Pilkey-Jarvis, 2007; Smil, 2003). Our capacity to respond effectively to natural hazards may thus be blunted by an over-reliance on quantification. To see risk as a product of whole-system relations requires an understanding not just of the natural hazard, but also of the interactions between environmental and human systems (Figure 15.1). As we know, what is considered an acceptable or unacceptable risk (and thus, a rational or irrational response) shifts with geographical, cultural, economic and political context. Uncertainty, too, is a function of time and social expectation, translated and acted upon by the societies and cultures through which it is modulated and becomes meaningful. Thus, knowledge of the social and institutional systems operating in the context of natural hazards is required, just as an understanding of the environmental and technological drivers and constraints of human choices that lead to risk exposure is also necessary. Understanding and invoking the non-quantifiable aspects of risk and uncertainty lends a rich and necessary picture to the resonance and application of natural hazards decisions.

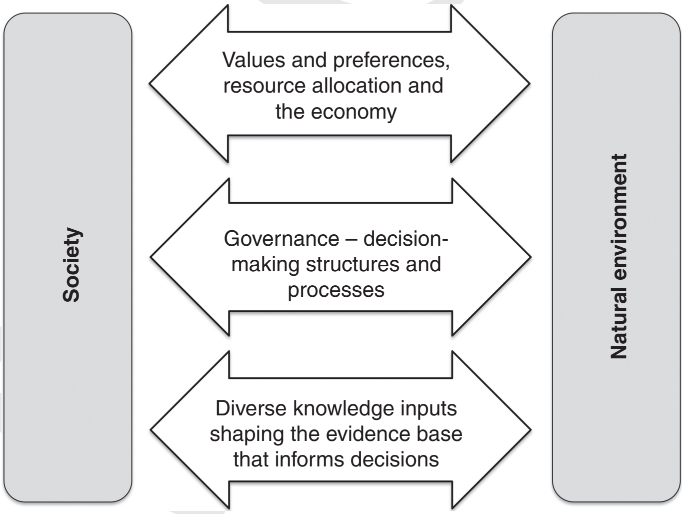

Figure 15.1 Socially mediated interactions between human society and its natural environment.

A fuller characterisation of risks and uncertainties from a coupled socio-environmental perspective necessarily involves a much wider range of epistemic inputs into the assessment process than we often currently see. In addition to the customary inputs from economics and political science, new research fields, approaches and dialogues within longer-established disciplines are shaping the framing of risk and uncertainty. For instance, within sociology, growing attention is being given to these issues in the fields of science and technology studies and actor network theory, and in geography, 'hybrid geographies' are emerging, which draw on both of these new sociological fields. Relevant research in psychology includes prospect theory and plasticity; from philosophy comes game theory and assemblage theory. Input to environmental risk also comes from ethics and law (specifically, socio-legal studies). Bringing this multidisciplinary knowledge together has become an important aspect of assessing risks and addressing social responses to natural hazards. Significantly, there are widespread moves towards the engagement of communities of interest in defining the risk problem and agreeing how they prefer to manage the uncertainties, rather than merely in accepting the proposed solutions. Their experience and knowledge makes them 'contributory experts' (Collins and Evans, 2007), whose voices are no less important than those of the scientists bringing specialist technical expertise.

This takes us to the second domain where a social science perspective plays a vital role. Like many other contemporary environmental issues, the societal risks linked to natural hazards are particularly complex problems to understand, represent and communicate. Uncertainty features prominently in the comprehensibility of environmental risks and their communication to the people who will be affected. Better interdisciplinary engagement can often help in shaping how scientific knowledge and understanding is communicated, received and acted upon in non-scientific contexts – for example, in public understanding or policy application (see Callon, 1999). Ensuring the effectiveness of science communication in the context of environmental risks is a well-documented challenge (e.g. Brulle, 2010; Heath *et al.*, 2007; MacDonell *et al.*, 2002; Sterman, 2011). However, while social research can shed useful light on how best to communicate scientific uncertainty, for us what is significant is that it can also bring social and cultural perspectives to natural hazards science via methodological processes that emphasise the 'co-production of scientific knowledge' through 'knowledge theoretic' approaches (see Lane *et al.*, 2011; Odoni and Lane, 2010). The scientific and methodological implications for people's access to, and constructions of, knowledge, and thus how risks can be understood, translated across different contexts and managed, mark one of the primary contributions of social research for natural hazards risk and uncertainty science.

Our third and final domain is less commonly appreciated. While social scientific perspectives on scientific knowledge production are increasingly shaping how physical or 'hard scientific' knowledge is produced (see, e.g. Odoni and Lane, 2010), they can also shape what 'the social' itself comes to mean within changing contexts. Like the scientific, so the social also changes and adapts through time and space. The rich and nuanced understanding that social research can bring is an important component in responding to natural hazards along the whole chronology of hazard identification, avoidance, mitigation, adaptation and post-event recovery. In this regard, we focus in this chapter on the social learning and actions at the collective and community levels; and on the systems of relations that shape how the social is constituted and involved in the production of scientific knowledge about hazard risks. There is already a considerable body of research into individuals' perceptions of risk, and psychological reasons for making choices (for example, see Kahneman *et al*., 1982; Kahneman and Tversky, 2000; Fox and Tversky, 1995; Tversky and Kahneman, 1991). This is not reviewed in depth here, but is covered in detail in Chapter 16. Instead, we will address how understanding motivations and values influences the collective productions of, and responses to, risk and uncertainty, and how these are deployed in natural hazard risk management. Even when an understanding of the problem is 'complete', social choices – as matters of concern – regarding what to do in response to the problem are often difficult. Issues of collective understanding, choice and human agency bring a different analytical register to uncertainty, the latter of which is coming increasingly to the fore as the predictive power of the scientific dimensions of risk assessment grows.

15.1.2 The social in the science

This chapter seeks a precarious balance. On the one hand we emphasise how social scientific perspectives on hazard risks – as arising primarily from events that impact people – can contribute to effective scientific production, communication and implementation strategies. The social sciences, of course, do have a crucial role to play in the dissemination and mediation of knowledge between and across interested parties and domains. But, critically, on the other hand, social science is not a 'bolt-on' whereby so-called objective scientific truth is disseminated to affected audiences with the help of socially literate intermediaries, although it is too often regarded, unfortunately, in this way by many implicit and explicit technocratic approaches (see, for instance, Pidgeon and Fischhoff, 2011). Critical social analyses need to be woven into the fabric of research design from the outset. Contemporary social analysis, since at least the 1970s and what is known as 'the cultural turn' (Bonnell *et al*., 1999), has been engaged in analysing how scientific discourses and practices are themselves part of the entire constitution of our physical and risk environments. As we illustrated above, many risks are *only* risks because they are products of modern social and scientific practices (see Beck, 1999). In addition, through its development of new forms of evidence and predictive capacity, scientific practice and knowledge-making is constantly producing new parameters of what risk means, and thus moulding the ever-changing landscapes of uncertainty. As a result, how evidence is constructed is a product of the various communities and interests in which it is applied and made meaningful. Van Asselt and Rotmans (2002: 77) broadly summarise the consequence of this often vexing and polarising philosophical fact with two interrelated claims: 'Science is not a purely objective, value-free activity of discovery: science is a creative process in which social and individual values interfere with observation, analysis and interpretation', and 'Knowledge is not equivalent with truth and certainty.'

We suggest that in order to better integrate natural hazards research to efficacious social outcomes, understanding how evidence and its applications are always already products of particular interested communities can go a long way to addressing scientific issues of risk and its translation, reception and application.

But, interdisciplinary alliances are not consequence-free. Balancing social and scientific demands requires significant work on *both* sides of the knowledge-production process. Social science and physical science are almost always changed, sometimes quite radically, by becoming co-implicated with one another. By bringing social scientific research, insights, and methods into natural and physical hazards research, the physical sciences must open themselves to experimental processes with new scientific actors and radical modes of knowledge production. To illustrate this requirement and its benefits, we refer in this chapter to a recent UK research project on natural hazards risk, which exemplifies just such transformative work. Understanding Environmental Knowledge Controversies (UEKC) aimed to integrate specialist physical science, social science and non-science actors within evidence generation, analytic and response processes in order to develop new approaches to flood risk forecasting and communication. UEKC produced scientific and social scientific knowledge, integrated models and policy-relevant findings from various social engagements in the co-production of environmental science. The project, for us, stands as a landmark in integrated scientific analysis, and an exemplar of the radical changes to natural science and hazard processes, and vice versa, that social analyses can and do bring. As the UEKC project attests, both natural science and social science are changed by their fundamental re-engagement with one another.

In writing this chapter, we started out by entreating the physical science community to be more sensitive and receptive to the insights that the social sciences provide. Crucially, however, as also evidenced by the UEKC project, the social sciences must *also* become much more attuned to, and literate with, the significant cutting-edge developments in the physical and natural sciences. Sociology, politics, human geography and some branches of the humanities are often far too parochial and unrigorous in their approach to contemporary developments within the natural sciences. Significant time and work is urgently required by many qualitative social researchers to understand the rigours and subtleties of scientific knowledge production. Critical social scientists are often far too quick to dismiss scientific approaches as positivist, reductive and simplistic. Such reactionary judgements are, today, quite often wrong and certainly not mutually beneficial. So while physical science must open itself to the indubitable fact that science is a social, historical, political and cultural product, so too must social researchers also educate themselves in the thorough delicacies of formal and physical research. Both will benefit as a result.

15.2 The knowledge challenge

15.2.1 Integrating knowledge

Quantitative approaches are essential components in the characterisation of risks. Much research has focused on quantifying and modelling the physical and material (including economic) elements of natural hazards, as outlined in the other chapters of this book. There has also been substantial progress towards predictive approaches in many areas, often combining real-time earth observation from monitoring or satellite imaging with computer models. Yearley (1999) has explored this trend from a sociological perspective, proposing that much more consultation and participation are needed at the stage of model development, especially for models that are applied to public policy.

Yet this is more than just an issue of public understanding of science. The multiple uncertainties that pertain to human vulnerabilities to natural hazards – which include social, ethical and political elements – mean that quantitative approaches are incomplete and internally fraught in so far as they can represent and intervene effectively in the world. The main approaches for quantitative integration draw on methods for representation and assessment already described in the previous chapters, and are therefore only summarised briefly here. Key sources of uncertainty relate to: the quality or quantity of input data; the selection or definition of model parameters; different model structures and resolvability; the representation of functional relations; and the degree of model 'completeness' or abstraction from reality. We also know that quantitative models are themselves fundamentally limited. As Oreskes (2003: 13) writes, 'Models can never fully specify the systems that they describe, and therefore their predictions are always subject to uncertainties that we cannot fully specify.' But although numerical models never can provide deterministic predictions, this does not preclude adaptive responses to perceived risk. For instance, Dessai *et al*. (2009) argue that the fundamental limits to prediction should not obviate risk-attentive decision-making. Quite the opposite – they argue that 'decision-making is less likely to be constrained by epistemological limits and therefore *more likely to succeed* than an approach focused on optimal decision-making predicated on predictive accuracy' (Dessai *et al*. 2009: 64; emphasis added).

Improving information can inform policy decisions about risk, but the availability of information or data is not *in itself* the basis for reaching or justifying those decisions, as the increasing complexity of numerical models would sometimes lead us to believe. Therefore, how this information is packaged and applied as data is significant. We move below to describe how the importance of qualitative information emerges through an awareness of the limitations of quantitative data.

15.2.2 Qualifying quantification

Data issues abound in quantitative social research, as in the physical sciences. Economic data are available from diverse sources on trade, industrial production, household consumption, government expenditure and so on. Typically, social data are obtained from population and household surveys (such as the annual US Survey of Income and Program Participation[1] and the UK General Household Survey[2]). Demographic and economic data, and the use of spatial analysis methods, help elucidate questions such as a population's exposure to the hazard, or a nation's dependence on sectors affected by the hazard. As in most

[1] www.census.gov. [2] www.statistics.gov.uk.

data-dependent situations, uncertainty is associated with the challenges of scaling and resolution; the non-synchroneity of different datasets; the representativeness or otherwise of population sampling; and the necessary splitting or aggregation of datasets in order to obtain usable spatial or temporal coverage. There is a huge body of literature on social data handling and statistics, outlining refinements that are designed to reduce the uncertainty in the application of the data. For example, Davern *et al*. (2006) outline approaches for constructing synthetic variables from publicly available datasets so that estimates can be made of the standard errors of the original surveys, an important factor for the use and reuse of social data. Zintzaras *et al*. (1997) describe methods for deriving individual estimates from household-level data, addressing another instance where the available data do not provide the desired information.

With regard to modelling, there has been a steady evolution from essentially actuarial approaches for estimating risk, which apply algorithms based on observed relationships between the hazard incidence and the societal impact (usually measured in money terms), to simulation modelling and probabilistic approaches that address the dynamics and the multiple causal factors in the human dimensions of risk. These models are generally termed 'integrated assessment models' (Table 15.1). Often they consist of linked physical or environmental and economics modules. Such models are widely used for regional and global climate impacts assessment, and have also been applied to socio-environmental

Table 15.1 *Tools in use in interdisciplinary risk and uncertainty research*

Approach and technique	Context and examples of application
Qualitative or semi-quantitative approaches to uncertainty identification:	
Uncertainty tables help in the systematic elicitation and evaluation of uncertainties, often presented as a preliminary step before 'better' quantification is undertaken.	European Food Safety Authority (2006); UK Food & Environment Research Agency (Hart *et al*., 2010)
Multi-criteria analysis for decision support, based on multi-attribute utility theory or other forms of ranking and optimisation.	Industrial disasters (Levy and Gopalakrishnan, 2009); sustainability of water systems (Ashley *et al*., 2005); climate risk (Brown and Corbera, 2003); air quality problems (Phillips and Stock 2003)
Decision-mapping, where the goal is not to zero in on 'the answer' but to display (and discuss) the breadth of views on alternative actions.	Nanotechnology, genetically modified crops (Stirling and Mayer, 2001)
Combined approaches or multi-stage procedures (qualitative-quantitative synthesis):	
Integrated assessments – most are fully quantitative, such as impacts models or quantitative risk assessment consisting of hazards models coupled to econometric models.	Flood risk (e.g. the RASP model used in the UK Foresight Future Flooding project, Evans *et al*., 2004); global climate impacts (Costanza *et al*., 2007)

Table 15.1 (*cont.*)

Approach and technique	Context and examples of application
Mediated modelling: computational model development in ongoing dialogue between the modellers and stakeholders	Ecosystem services assessments, catchment management (Antunes *et al*., 2006; Prell *et al*., 2007)
Some forms of Bayesian synthesis	Many health contexts (Roberts *et al*., 2002; Voils *et al*., 2009)
Other participatory deliberative techniques for assessing risk and associated uncertainty:	
Expert elicitation using a range of formal methods (such as Delphi methods, multi-criteria analysis, quantitative risk assessments, and others from the list above) to take account of 'expert uncertainty'	Geohazards, nuclear installations (Aspinall, 2010); climate impacts (Titus and Narayanan, 1996; Lenton *et al*., 2008)
Narrative approaches: horizon-scanning, 'imagineering' (narrative approaches combined with education/training plans), foresight exercises – usually engage expert stakeholders. These methods are not intended as formally predictive, unless as enablers for a particular decision pathway	Former DTI's Foresight programme, European Science Foundation's Forward Looks. International Institute for Sustainable Development; GECAFS food security scenarios
Community participation methods: citizens' juries and consensus conferences, community visioning exercises, backcasting – these techniques are often used for obtaining community co-development and acceptance of risk responses and action plans. Experts/scientists can be involved to varying extents.	Many examples at all scales, such as the World Bank's study by Solo *et al*. (2003)

Note: in this chapter we mention several of these approaches but do not expound on them nor critique them. This table is included as an information resource, showing some of the integrative tools that are in use that link the social and physical/natural sciences in risk management.

problems such as pollution (e.g. Hordijk, 1991; Gabbert, 2006) and coastal zone management (e.g. Mokrech *et al*., 2009). Van Asselt and Rotmans (2002) have reviewed these models, with particular attention to the management of uncertainties associated with them. The paradox with these models is that the approximations and simplifications needed to make a manageable, usable description of the real world mean that uncertainty arising in and from the model does not have a direct relation to true uncertainty in the real world.

The result is a tension evident in the literature: quantitative approaches demand quantification of uncertainty, even when quantification is impossible. The existence of indeterminacy, non-linearity and other features of complex socio-natural systems is one area where quantification is constrained. Van der Sluijs (1996) and Batty and Torrens (2005) discuss the limitations of integrated modelling and the lack of practically usable methodologies for handling discontinuities and discrete random events or surprises. Quite often, the socially relevant issues of culture, values, choice and so on are explicitly highlighted in discussions about the uncertainty associated with integrated assessment (see also Eisenack *et al*., 2005; Reichert and Borsuk, 2005 for discussions about dealing with complex socio-environmental system uncertainty in decision-making). Nevertheless, usually the proposed uncertainty management solutions are rigidly structural and assume a deterministic system: 'more consistent interpretations of uncertain parameters and inputs' and 'alternative model structures and equations' (van Asselt and Rotmans, 2002). Van der Sluijs (1996: 49) suggests that once the issues of inputs, parameters, and equations are dealt with, attention should turn to 'model completeness', where model intercomparisons and competition between modelling groups would provide the impetus for reducing the remaining uncertainty arising from model incompleteness. Yet a little earlier in the same article, he expresses his misgivings about adding more and more to models:

> The solution of unknowns cannot simply be 'let's put every single detail that we know in the computer and let's hope that something shows up'. In our view, what is needed for scientific progress is to ask the right questions, not to produce an endless stream of 'what-if answers'. In that sense computers are useless, because they cannot ask questions, they only produce answers.
>
> *(van der Sluijs, 1996: 39)*

In short, quantifications and model representations are necessarily reductive, simplified forms of evidential understanding. Even if these are not inherently inimical to societal application, they are at least made more complicated by social considerations. To understand socio-environmental risk and uncertainty, social considerations must be understood both to contextualise and frame any quantitative application.

Indeed, uncertainties expose the fundamental limits of quantitative models. How quantitative models are parameterised and applied is only ever subjective (Oreskes and Belitz, 2001). Once developed in and for one site, it is often the case that models cannot travel to other contexts (Konikow and Bredehoeft, 1992). And, given that models are necessarily simplified representations, problems with the boundary conditions around prediction are often easily exacerbated and magnified the larger or more complex the model gets (Pilkey and Pilkey-Jarvis, 2007). As Oreskes explains,

> the more we strive for realism by incorporating as many as possible of the different processes and parameters that we believe to be operating in the system, the more difficult it is for us to know if our tests of the model are meaningful. A complex model may be more realistic, yet it is ironic that as we add more factors to a model, the certainty of its predictions may decrease even as our intuitive faith in the model increases.
>
> *(Oreskes 2003: 13)*

In the next section we address how *any* description, whether quantitative or qualitative, social or physical, necessarily appeals to simplified representations of the systems described, explained and predicted. Such limitation is not a failure of description or analysis as such, but it does demand – as recent social science has been at pains to explore – that knowledge production needs to become much more attuned to its own constitution and application. Doing so, and doing it well, involves subjecting the work to a continuous and always exploratory and self-reflexive process, but it produces knowledges and meanings that are much more democratically aware, transparent and responsive to their various publics.

15.2.3 Systems, models, stories

Many consider that human society, conceived as a purposive system that reacts to the knowledge it is given in pursuit of its goals – or indeed as a *purposeful* system that intentionally defines and adapts its goals (Ackoff and Emery, 1972) – cannot be considered adequately from a purely quantitative, mechanistic point of view. Concepts like community life, behaviour and the mind cannot be consistently or meaningfully quantified. However, we would argue that with the exception of carefully controlled experimental arrangements, the same holds for all systems – social, physical or hybrid. The reason lies in what 'systems' are. Any designation of a system, whether physical or social, is a designation of an observable relationship among components; it is meaningful to refer to their relations as a system, but this systematicity is an epistemic, and thus social, construct. We simplify by attributing information from the complexity of the environment to the components. As Niklas Luhmann's 'general systems theory' (1995) argues, social systems *qua* systems are inherently less complex than their environments; the virtue of a system is that it is less complex than its environment – such is the difference between representations (i.e. models, theories, etc.) and reality itself. In other words, systems are products of self-consciously selected pieces of information from within an environment. Researchers must acknowledge that a system's selection is the result of contingent propositions; the system could have been selected differently – and its behaviour would be seen to be different. After all, what information to include, and what to ignore, constitutes much of any calculation regarding natural hazard risk, and is the basis for any decision about parameterisation. Such contingency entails its own internal risk, but reducing the representation of the system further so as to fit applied quantitative constraints exacerbates this contingency, and often prevents the complexities of the environment from being explained in the system's representation. This can happen for practical reasons (e.g. calculability, resolution, etc.) or even ideological constraints, as was the case with the application of flawed financial models leading to the financial crisis of 2008 and beyond (see, for example, Best, 2010; Crotty, 2009; Haldane and May, 2011; McDowell, 2011).

Some recent social analyses go further than this, contesting any teleologically purposeful system, basing their arguments for social emergence in complexity, nonlinearity and volatile systems immanence. These argue that purely quantitative or purely qualitative means fail to capture adequately how patterns of organisation successively transform the manifold elements of the systems themselves, especially when these effects are as diffuse and nebulous as the role of perception in affect, emotional contexts, political interest, tacit coercion, and so on (Coole and Frost, 2010: 14). Thus we must accept that any explanation of social processes is only and always already partial, and can never be otherwise. This is not to say, however, that what is said cannot be meaningful or useful, but the awareness of this partiality means that careful description through multiple modalities is required to make meaningful explanation and possible intervention in social systems.

In short, systems are representational simplifications; quantified systems (sometimes in the form of numerical or computational models) are further simplifications still. While many such quantitative representations are absolutely vital to understanding natural hazards processes, attempting to argue that they are the most effective means of addressing, communicating and equivocating hazards risk assessment is a gross error. The challenge from social science to natural science lies in blending different forms of evidence and methods of representation and analysis such that complexity and heterogeneity can be preserved as much as possible in any description of a system and its interactions. Much of what has been termed, not uncontroversially, the 'post-normal science' paradigm has attempted to define just such ways and means of incorporating 'social robustness' into the quality of scientific knowledge production (Petersen *et al*., 2011: 368; see also Turnpenny *et al*., 2011). Indeed, as Stefan Hartmann (1999) argued, empirical adequacy and logical consistency are not the only criteria for the acceptance of a model or even an explanation about a system. The numbers that models generate need stories by which they can be justified as valuable (a kind of 'dequantification'; see also Rademaker, 1982; Randall and Wielicki, 1997). These stories guide and constrain the construction of models and explanatory systems by prescribing what should be accounted for, what should and should not be taken into account, what the relevancies are for understanding a phenomenon and its relationships among its various systemic aspects. The heterogeneities demanded by multivalent explanations (physical and social, say) of systems reveal that such stories constitute the normative frameworks by which phenomena are modelled and come to be seen to have explanatory value (Peschard, 2007: 166).

The importance of examining physical elements in close conjunction with the valuable stories told via the social lenses is increasingly identified as a major research and management priority in many risk assessment contexts. Examples from food and nanotechnology risks bear this out. First, in the context of food risks, the Royal Society/FSA (2005: 6, 7) argue that 'social scientists on risk assessment committees could help identify behavioural assumptions that need to be taken into account in the assessment process', and 'a range of social science techniques exist to support public engagement'. The report also notes that the risk assessment committees involved in the study were not well aware of social science methods that could aid in improving inclusiveness, equity and engagement. Similarly, in the context of new technologies, particularly nanotechnology, Macnaghten *et al*. (2005: 270) outlines a rationale and process for building in social science insights into societal, technical, scientific and political deliberations, based not on 'critical' engagement, but on 'constructive, collaborative interactions'. Klinke and Renn (2002, 2006) posit that a new form of risk analysis is needed for all systemic risks, namely those 'at the crossroads between natural events (partially altered and amplified by human action such as the emission of greenhouse gases), economic, social and technological developments and policy driven actions' (Klink and Renn, 2006: p. 2). They argue that systemic socio-environmental or socio-technical risks cannot be reduced to the classic risk components of hazard and probability. This new approach needs a broadened evaluation of risk that gives attention to issues of inequity, injustice, social conflict and so on. They also emphasise the importance of deliberation as a means of coping with uncertainty, complexity and ambiguity, which is a theme explored more fully below.

Zinn (2010) calls for narrative and biographical approaches to be better integrated into risk assessment, and reviews work on individual identity and experience in technological and environmental risks. He argues that this field of research potentially helps in understanding the differences in people's perceptions and responses to risk. Such work does not promise to lead automatically to better environmental risk decision-making, but highlights that 'decisions are not just a matter of weighing up present day options or values, but rather are deeply rooted in complex identity structures and social contexts, which evolve over time' (p. 6).

Integration like this – of words and numbers, both of which are used as signifiers of ideas or concepts – is a non-trivial challenge. It entails broad-scale discursive translation across theoretical, empirical and methodological domains (Table 15.1 summarises some of the interdisciplinary and integrative tools currently in development and use). Yet it is at the juxtaposition of these often-contentious translations that both misunderstandings and opportunities for transformative understanding can occur. Progressive and domain-shaping research depends on facilitating the dynamic interchange at these difficult, shifting and productive boundaries. Liverman and Roman Cuesta's (2008) simple appeal for 'a certain level of tolerance and mutual understanding' in such interdisciplinary interaction certainly needs to be borne in mind, but as we will see later on, quite radical forms of knowledge-theoretic description can emerge to change what counts as scientific explanation, evidence and social accountability (Odoni and Lane, 2010; Whatmore, 2009).

In Section 15.3 we address these insights with some attention to how social science might add to the description and explanation of natural hazards risks. Before that, we briefly turn to social conceptions of uncertainty.

15.2.4 Conceptualising uncertainty

The terminology for categories of uncertainty is – rather unhelpfully – often used in slightly different ways in the social sciences than in the physical sciences, partly reflecting the greater contingency and complexity of social phenomena. Here, we outline the three main forms of uncertainty (epistemic, aleatory and ontological) and some of their conceptual resonance within social science.

Epistemic, or systematic, uncertainty arises from a lack of knowledge, due to processes that are unknown or inadequately understood, or the poor characterisation of variability. In principle (indeed, by definition), obtaining more information about the system in question reduces epistemic uncertainty. But in the socio-natural systems of concern to us, epistemic uncertainty itself can never be eliminated, following the two arguments outlined above: first, knowledge is a processual and dynamic social product and not a fixed quantity; and, second, fundamental philosophical problems of perspectival framing and induction preclude determinist or apodictic certainty from descriptive and predictive accounts. Indeed, a central concern in many critical social science approaches today lies not with providing certainty and indubitability about complex and open social processes, but with analysing the work that specific processes do in the world, their staging and their effect. Providing certain foundations for social knowledge has long been deemed impossible. The role of epistemology now is not to provide such foundations, but to analyse how knowledge is produced and enacted. From these post-foundationalist approaches, all knowledge is thus considered to be inherently uncertain – but that does not mean that it is not rational, valuable or necessary. It simply means that we commit ourselves to the everyday messy tasks of analysing its work, application, politics and possibilities, and so see our epistemic task in less hubristic lights than perhaps we once did.

Aleatory or stochastic uncertainty is related to the inherent variability of systems, including their nonlinearity, randomness and contingency. Here, in principle, obtaining more data on the system may assist in constraining or characterising its stochastic or probabilistic elements, but it will not reduce this uncertainty. In the physical sciences, this improved characterisation of variability has emerged as a priority for environmental modelling and prediction (e.g. for climate, extreme weather events and other natural hazards). For the social sciences, the interest lies less in prediction *per se* than in how prediction is mobilised as a strategy for shaping human action and politics. The interest lies in how probabilities are communicated, understood and enacted within the various social and political contexts in terms of which they are deemed valuable or effective. Indeed, recent work on the rise of probabilistic decision-making, strategic forecasting and contingency planning, especially within deregulated market structures and the demise of the welfare state, have produced trenchant critiques of the new forms of governmental strategies that have come to dominate so much of social life (see, for instance, Beck, 1992; Dillon, 2010).

Ontological uncertainty is a term often taken as synonymous with aleatory uncertainty, especially in economics (as described by Dequech, 2004), but it holds slightly different resonance in other areas of social research, where uncertainty is not framed with the same conceptions of probability. Ontological uncertainty relates to what the nature of the real world is, not to knowledge about the real world. In social research, different ontological characterisations of reality can be employed (the issues are clearly summarised by Blaikie, 1991). For most natural and physical scientists, the nature of the real (natural and physical) world is the object of knowledge inquiry, and its reality is obviously not questioned in the normal positivist empirical work that makes up 'the scientific method'. In contrast, much social research needs to recognise the subjectivity of social reality. Whether the observer 'stands outside' the social system of interest –universally deemed an impossibility by contemporary social science – or is a participant within it, understanding the (real) nature of the social involves interpretive or deliberative processes. Some social realities are socially constructed (institutions, for instance), and they are not immutable. In such instances, it makes little sense to think of 'the inherent variability' of the system.

Several people have proposed classifications or taxonomies of uncertainty for social and socio-environmental systems (e.g. van der Sluijs, 1996; van Asselt and Rotmans, 2002; Regan *et al*., 2002; Meijer *et al*., 2006; Maier *et al*., 2008; Lo and Mueller, 2010). Broadly, they all group the 'kinds' of uncertainty into two strands – epistemic and aleatory – that are coherent with use in the bio-physical sciences. Morgan and Henrion (1990) and Rowe (1994), in their typologies of uncertainty, identify human choice dimensions as important, but in addressing how to deal with these issues in their articles they still propose more refined analysis and data acquisition, bringing these dimensions within the epistemic strand.

However, a consideration of human and social dimensions spotlights conceptual and operational challenges in both strands of uncertainty. Human choice interferes with randomness, making characterisation of the variability problematic. It also has implications for the knowability of future social processes. This was a pet issue for Popper (2002), both on logical and moral grounds:

> No scientific predictor – whether a human scientist or a calculating machine – can possibly predict, by scientific methods, its own future results. Attempts to do so can attain their result only after the event. […] This means that no society can predict, scientifically, its own future states of knowledge.
>
> *(p. xiii)*

> But is it not possible to control the human factor by science – the opposite of whim? No doubt, biology and psychology can solve, or soon will be able to solve, the 'problem of transforming man'. Yet those who attempt to do this are bound to destroy the objectivity of science, and so science itself, since these are both based upon free competition of thought. Holistic control, which must lead to the equalization not of human rights but of human minds, would mean the end of progress.
>
> *(p. 147)*

Dequech (2004), in his critique of the socio-economic literature on uncertainty, argues that, for these reasons and others, the epistemic and ontological aspects of the conceptualisation of uncertainty are 'strongly entwined'. Because of human capacity to think, know and act, knowledge about the world can change the nature of the world, as, in fact, the material world agentially changes the nature, potential and capacities for human thought and politics (Bennett, 2010). Socio-environmental systems are complex systems, and human choice and agency are important factors in creating the complexity in the real world, while, crucially also being created by it. The implication of this entwinement of knowledge about the world and the actual agential nature of the material world is that obtaining more analytical information about the issue will not reduce, characterise or constrain uncertainty in domains of human choice and agency. Figure 15.2 shows an attempt to reinstate the different 'flavour' of uncertainty relating to the human world of choice and agency back into the characterisation of socio-environmental uncertainty.

It is apparent that this idea is hard to grasp. Several scholars, including very eminent thinkers, have written about the 'cascade' or 'explosion' of uncertainty, particularly in the context of the assessment of societal risks from climate impacts (Wilby and Dessai, 2010; Pilkey and Pilkey-Jarvis, 2007; Mearns *et al*., 2001; Moss and Schneider, 2000; Jones, 2000; Henderson-Sellers, 1993). Uncertainty in the decision-making process is represented

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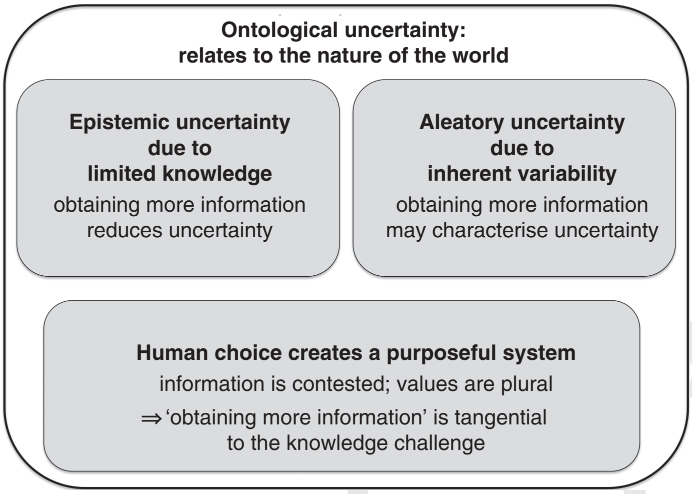

Figure 15.2 Uncertainty in socio-environmental systems.

(Figure 15.3) as expanding pyramids – implying a decision-tree analysis – or growing error bars – implying a numerical error aggregation approach. As an example of the latter, Jones (2000) states that 'ranges are multiplied to encompass a comprehensive range of future possibilities'. Wilby and Dessai (2010) take a decision-tree approach, saying 'information is cascaded from one step to the next, with the number of permutations of emission scenario, climate model, downscaling method, and so on, proliferating at each stage'. Many of these articles conclude that the escalation of these uncertainties hampers any sensible response. For example, Wilby and Dessai state 'the range (or envelope) of uncertainty expands at each step of the process to the extent that potential impacts and their implied adaptation responses span such a wide range as to be practically unhelpful'.

There are many conceptual problems with this approach. Not all of the 'uncertainty steps' in the cascade are multiplicative in nature, nor do all possible permutations of analysis and intervention take place. However, *human choices* can manifestly reduce or even remove uncertainty in some senses and contexts, and they are often given little recognition or attention. Co-productive approaches can often mitigate and translate risks and hazards in ways that address the resonance of uncertainties and their publics. It must also be noted, however, as is evidenced with the recent financial and banking crises between 2008 and the present, human choices can increase and exacerbate uncertainties, often in deeply irrational and sometimes catastrophic ways (Kahneman, 2011). Furthermore, the different kinds of uncertainty are mixed up in these representations, so there are also operational problems with the cascade idea. By bundling epistemic, aleatory and human-agency uncertainties together as these authors do, activities to assess and manage the uncertainty cannot be focused where they are needed. In particular, the uncertainty associated with human choices cannot be dealt with by routines or rational analysis – it requires critical reflexivity and

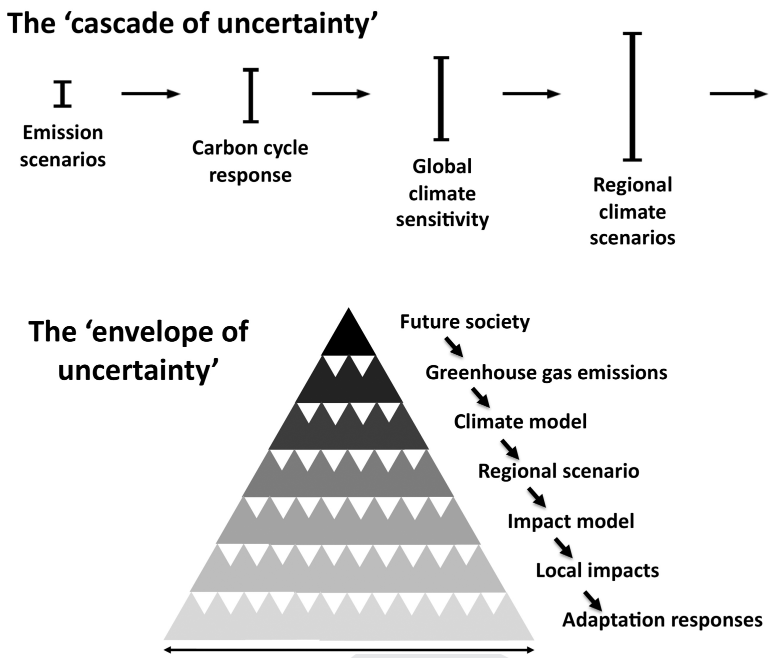

Figure 15.3 Some representations of socio-environmental uncertainty from the literature. Note that the 'cascades' treat very different kinds of uncertainty (arising from models, empirical observations, human choices) as if they were commensurate, quantitative/quantifiable, and unidirectional, although choices can reduce as well as expand uncertainty.

dialogue. A purposeful system (Checkland, 1999: 316–317) – which is what human systems are – cannot be treated as if it were deterministic (the domain covered by epistemic uncertainty), or even contingent (the domain of aleatory uncertainty). Later sections of this chapter review how such systems may be dealt with more fully.

Why might we care about these semantics? Setting appropriate margins for the stochastic uncertainty relating to the deterministic components of the risk problem, and adding information about epistemic knowledge limitations are both vital but non-trivial components of the advice mix for risk assessment. However, in responding to real-world environmental risks, the provision of knowledge is not the whole picture. The stakeholders in this mix are diverse: scientists, lobbyists, political decision-makers, media, advocacy groups and members of the public all interacting and all with their own interests to serve. This is the motivation for highlighting the human agency dimensions of uncertainty so prominently in this chapter.

15.3 Where social science matters

In this section we discuss some key areas where we feel social science matters: where improved engagement across knowledge communities would benefit environmental risk assessment and management, and where the take-up and integration of social research in recent experimental approaches has already started to shape the knowledge-production processes around natural hazards risk.

15.3.1 Relevance: defining and framing risk assessment objectives

The uncertainty implications of a lack of engagement with social issues are potentially serious for environmental risk management. Social science perspectives can elucidate some of these potential dangers. A kind of 'concept-blindness' can arise, where essential elements of the hazard are not seen or perceived (the infamous unknown unknowns), adding to risk. There is also a linked problem of spurious precision, where lots of information is given about just part of the issue. In risk management, if the risk assessment objectives are framed too narrowly, and in particular, if the human and social dimensions are not considered fundamentally within the process, there is an inability to respond to the 'whole' real risk.

Defining the risks to people arising from natural hazards seems self-evidently to require the involvement of a broad base of experts, yet in many contexts, there is still not enough engagement of interdisciplinary expertise. There is a pervasive view that risk identification and responses have been 'scientised' (Bäckstrand, 2003; Ekberg, 2004). That is, the normal methods of natural science – portrayed as a value-neutral, objective endeavour – are applied to characterise and predict environmental problems, for a separate, downstream political management response. Concerns are that this approach makes overly instrumental presumptions about how society works, and is insensitive to the potentially problematic nature of the socio-political context in which responses are implemented. Many areas of the social sciences invest a considerable amount of their time in considering the nature and implications of values and world-views in their investigations. Engaging in debates where this activity is omitted is alien to their disciplinary culture. It also asks something of knowledge production which it cannot give. Indeed, to assume that value-neutral, objective knowledge is possible is not only epistemically naive, but it is often an ideological sleight of hand that masks more than mere hubris. Knowledge is a product of communities of action and interest, and our role as social scientists is to render as transparently as possible the various inner workings of these communities, with the appreciation that our efforts too are themselves situated and give a fundamentally partial account.

There is an extensive literature on what constitutes a community of understanding (or epistemic community, as described by Haas, 1992), and significant analysis into why the earth sciences and social sciences operate so substantially in their own orbits (e.g. Demeritt, 2001; Nowotny *et al*., 2001). But when problems that require a decision about action, such as responding to natural hazards, are framed in the limited terms of one discipline or knowledge community, difficulties are known to arise (Owens, 2005; Petts and Brooks, 2006; Ricci *et al*., 2003). Here, we focus mainly on the interdisciplinary challenges.

Natural scientists deliver quantitative information on risk and uncertainty based on process models, observations of hazards and statistical analysis of past hazards data.

Quantitative risk assessments include some social data, such as demographic information, housing inventories and so on, in the development of tools such as risk loss curves. This detailed scientific and technical information is needed, but it is not sufficient for informed decision-making. Indeed, many factors in assessing risk and uncertainty are either unquantifiable or little more than educated guesses, and simply attempting to include them in quantitative models compounds a cascade of uncertainty and dilutes forecasting reliability (Smil, 2003: 179). While more knowledge is usually better (Cox, 1999), the value of this nuanced environmental understanding may in some cases be limited by the scientific narrowness of the framing. A risk assessment needs to be accurate (true to the real world), not just precise, and this requires an understanding of citizens' needs, of political processes and of wider public attitudes – all of which lie in the domain of 'the social sciences', but in order to be useful, cannot remain isolated there. They need to be deployed in concert with physical analysis, open to incorporation in knowledge-theoretic approaches too (see Odoni and Lane, 2010).

At a strategic level, more deliberative working for risk analysis has been strongly endorsed (HM Government, 2005a[3], 2011; Royal Society/FSA, 2006; HM Treasury/DTI/DfES, 2004; House of Lords Select Committee on Science and Technology, 2000; Stern and Fineberg, 1996). Good-practice guidance abounds on engaging in such a deliberative process (e.g. Renn *et al*., 1993; Stirling and Mayer, 2001; Petts *et al*., 2003; HM Government, 2005b), but good practice seems only now to be emerging. Thus, it is at the operational level that challenges still remain. What is the role of non-quantitative social research in the decision-making process? How, for instance, should insights from history be integrated? Clearly lessons can be drawn from the past (Kasperson and Kasperson, 2001; Harremoës *et al*., 2002), but designing a future is not a straightforward intellectual exercise. While there is a need for the integration of ethical, legal and social issues, the cultural and epistemological differences between the relevant expert communities for these issues are hardly less challenging than those between physical and social scientists.

There are some fields where theoretical debates are advancing well about new conceptualisations of the interactions between environment and society and about the changing nature of more socially engaged scientific research. These include 'restored geography' and sustainability science (Demeritt, 2001, 2008; Kates *et al*., 2001 – and further work since then by several of that paper's authors; Whatmore *et al*., 2008; and to some extent Hulme, 2008); and ecological economics (e.g. Costanza, 1991), although this emerging field tends to revert to numerical models as the 'common language'. Another rapidly growing field that merits closer attention in the context of natural hazards and environmental risk is that of socio-ecological systems and resilience (e.g. Young *et al*., 2006; Ostrom, 1997, Ostrom *et al*., 2007; Folke, 2006, Liverman and Roman Cuesta, 2008). The conceptualisation of the socio-environmental system explicitly considers people in their environment, and simultaneously considers the way that the environment shapes people. Analysing these relationships requires assumptions and simplifications to be made about both society and the natural

[3] These guidelines are currently being updated through a consultation process.

world, so there is a strong focus on both analytic and deliberative methods for the 'validation' of models, metrics and indicators that combine or integrate components of socio-environmental systems. Often, this requires a focus on different time and spatial scales to those that apply to the physical hazards themselves. Such work includes, for example, investigating the resilience of communities vulnerable to natural hazards and studying the long-term impacts of a disaster.

Macnaghten *et al*. (2005) draw particular attention to a practical matter that we regard as vital: uncertainty assessments need to be less sequentially and more collaboratively and deliberatively constructed than they generally are at present. 'Social science' should not be the end-of-pipe bolt-on to make the risk analysis more palatable or politic; cultural, economic and societal dimensions should be part of the problem-statement stage, engaged with at the outset. The research questions that are being asked will change as a result of attending to the ways that complex social and political relationships constitute what counts as evidence, to what ends data and findings are being put, to whom findings are directed and who is excluded in such processes, and so on.

15.3.1.1 Upstream integration: the UEKC case

In this section we draw on the experiences of the interdisciplinary research project, Understanding Environmental Knowledge Controversies, which proposed a methodological apparatus for 'mapping' uncertain and contested science in the contexts of flood prediction, hydrological modelling and community-centred natural hazards risk assessment (Whatmore, 2009). This endeavour, of course, did not map in the normal cartographic sense, but developed an effort to expose and explore more explicitly, and sometimes experimentally, the 'entanglements of scientific knowledge claims with legal, moral, economic and social concerns.' Although this project shares many features with other action-oriented and participatory socio-environmental risk research (e.g. Cobbold and Santema, 2008; Petts *et al*., 2003), we use it as a case study because it had an explicit focus on uncertainty in natural hazards and it documented its processes well, as well as its findings.

The three-year project, begun in 2007, examined the production and circulation of environmental knowledge, and explored the ways in which knowledge controversies could be productively utilised in the interests of public interdisciplinary science (Lane *et al*., 2011: 16). The project focused on the science of flood risk management, locating much of its energies in the flood-prone market town of Pickering in North Yorkshire, where recent severe flood events had let to the development of a proposed flood defence plan, which had met local resistance. The project's objective was to analyse how new scientific knowledge formations about flood risk could arise through the integration of lay and academic inputs, and shape different and more effective practices for 'doing science' about potentially divisive socio-natural issues (Lane *et al*., 2011: 17).

Core to the work of UEKC was the principle of experimentation through experience (Lane *et al*., 2010: 24). The departure from the norm was that community engagement was not seen as an 'end-of-pipe' phase following on from the scientific scoping and decision-making process. Instead, the project supported the 'upstream' involvement of the community of interest in framing the flood risk issue. In the first instance, the project set up what it termed an Environmental Competency Group, to collectively address the community's flood risk. This group was made up of interested members of the local public, academics, flood-risk managers, a facilitator and recorders of the proceedings. They worked together with the aim of learning about the local hydrological environment and, in doing so, producing a collaborative description of the risk ecology and possible responses to it. The representation of the hazard event emerged through negotiation among the Environmental Competency Group in the recognition that 'any attempt at representing the complex social-economic-political composition of communities is itself an act of framing around a pre-conceived notion of what that composition is' (Lane *et al*., 2011: 24). The project team emphasised five key aspects of this process, which it took to be distinctive in hazards risk science (pp. 24–26). First, it focused on the practices of knowledge production, rather than simply the results. Second, these practices manifested the risk research itself as an ongoing and collaborative process. The knowledge contributions of the lay and academic participants and the joint agency arising from the broad assemblage of people, places, techniques, and objects shaped the nature of the science itself. Third, the collaborative process of flood risk assessment focused its attention through the various events which cascaded from the collective experiences of the hazard. The result was that the flood hazard itself was framed as a multivalent event, through the various descriptions of flooding, and the different competencies of the actors involved. Fourth, rather than being narrowly defined by a more-often-than-not external academic view, the estimation of the risk was constituted by the collaborative and experiential narration of the hazard and its attendant consequences. The participants thus came to recognise their shared responsibility for the hazard and its risk assessment as an emergent property of the collaborative description with, fifth, the result that representation of the event also came to be shared as a responsibility of the community of concern, rather than simply a dissociated matter for institutional actors (i.e. regulatory bodies, advisors, etc.).

Through the iterative consultative processes, a more detailed qualitative understanding of flood-generating processes began to emerge. This multifaceted, locally informed understanding began to displace the earlier assessments made by the generalised hydrological and hydraulic models that are the workhorses of the flood risk management agencies. With the integration of the iterative, qualitative understanding generated from the collaborative consultative engagement, a new model emerged specific to the hydrological risk requirements of the local area. Termed the 'bund model' (see also Odoni and Lane, 2010), it and other iterative models were the product of the Environmental Competency Group and became scientific risk assessment objects through which the collective asserted its hazards risk response and its competence (Lane *et al*., 2011: 26).

The UEKC involved collaboration across disciplines, bridging hydrology, human geography, social theory, meteorology, social policy and rural economy. This brought multi-dimensionality to understanding, but necessarily also demanded often contentious dialogue and negotiation between the academic disciplines, regarding how problems were to be defined, framed, analysed and what actions brought to bear to address the risks. Findings from the UEKC and similar projects are now driving a transformation in risk assessment and management methods, including views about who contributes to knowledge framing and production, and the nature and desired robustness of evidence. Most importantly, in assessing and managing the uncertainty in risk assessments, there is increasing attention to the importance of a consideration of the dynamic, knowledge-transforming implications of reflexivity (Romm, 1998) in these steadily more integrated modes of working (Lane *et al*., 2011; Odoni and Lane, 2010; Whatmore and Landstrom, 2011).

15.3.1.2 Lessons for the framing of risk

What the UEKC project learned that became important to its risk analysis and response was that rather than taking scientific knowledge as a given, new co-produced knowledge-theoretic models emerged as collaborative products, which could be adjudicated according to community-specific needs and understandings. The UEKC project argues that 'the key consequence of co-production' (Lane *et al*., 2011: 31) is the 'sense of knowledge' produced:

> What we experienced was a shift from taking knowledge as a given, to being able to see model predictions as just one set of knowledge, against which they [i.e. interested residents] were entitled to compare and to use their own knowledge.

This enables parties to arbitrate the claims regarding risk and uncertainty made using models among their varied backgrounds of social knowledge. The value of these significant epistemic differences, as they are integrated into the predictive and descriptive scientific capacities, is manifest in 'better' models – both in the immediate sense of having better scientific representation of local flooding processes (and reduced epistemic uncertainty), and also in the broader sense of a co-developed, trustworthy and transparent model that provided a focal point for the community's engagement with the issues of flood hazard. Co-produced models thus become opportunities for innovative and targeted solutions for specific hazard risk problems, which hold the potential to be more materially effective and socially responsive than is now often the case (Odoni and Lane, 2010: 169–170).

However, this is not the way that knowledge is generally produced and transmitted. Clearly, there are implications for the role of the scientist. Becoming engaged with resident knowledge is a matter of collaborative trust. It is not simply a matter of unidirectional scientific communication. As the UEKC experiments attest, trust, which lies at the purposive heart of risk and uncertainty science, is a function of social assemblages which co-produce interested and specific strategies for decision-making and action. The purpose of effective communication (trust, engagement, safety, enhancement of well-being) is situated at the heart of the scientific process itself.

> Establishing trust in models is not just about the restricted kind of validation implied by comparison of predictions with data, but a wider set of practices through which a modeller makes a model perform.
> *(Lane* et al.*, 2011: 32)*

Deliberative, inclusive and participatory engagement is a lengthy and resource-intensive process, but it is an effective means of managing uncertainty in contested socio-environmental decision-making (e.g. O'Riordan *et al*., 1999; Prell *et al*., 2007; Petts *et al*., 2010). The necessary integrations – both across contributing academic disciplines and of other contributory expertise – require new conceptualisations, shifts in the normal modes of working, and a focused attention to the differences in worldview and ontology of the different epistemic communities. This last need is often considered alien to ostensibly objective, value-neutral scientists, although those working in practical ways in natural hazards are usually well aware of the multi-dimensional real-world complexities and do indeed reflect on their methods and findings in this context.

The UEKC project is not alone in its innovations, but there is still a great deal of scope for exploring and documenting what appears to work well. Another valuable example of where this has happened is the Trustnet-In-Action (TIA) network (trustnetinaction.com). TIA began in 1997, and ended in 2006, as a European research initiative to 'bring a fresh and pluralist thinking' to environmental risk decision-making, and to address the limitations of the mainstream approaches to risk assessment and risk management. TIA documented their emerging philosophy of inclusive governance (TIA, 2007), along with frameworks and tried-and-tested patterns for inclusive, experimental deliberative processes:

> [T]he TIA process is neither basic, nor applied research, but is close to research-in-action … which is, strictly speaking, more explorative than confirmative. TIA methodology is elaborated during the process itself through the cooperative inquiry of experts and actors, with an undeniable part of contingency. Its major contribution as a pragmatic methodology is to create the durable institutional conditions for a process of governance which will place the actors in a position of influence. For that, it is necessary to conceive a new role for the experts whose science must be dedicated to an ethical objective of helping the actors to be subjects of their own life.
>
> *(TIA, 2007: 77)*

In the next sections we step back from the lessons outlined from the UEKC and TIA examples to address communication and social learning as commonly understood by risk science, before returning again through the UEKC and related examples in the final section to address how co-productive efforts can help scientists meet the increasing calls for involvement in political advocacy or policy-relevant action.

15.3.2 Comprehensibility and communication

Good communication is essential if the research products of any discipline are to be of any value, and some insights from social research can be vitally important in improving the communication and comprehensibility of complex messages associated with natural hazard risks. Uncertainty in this context relates mainly to epistemic concerns – miscommunication, misreadings of the hazard situation – and its management is therefore responsive to training and technological investment.

Risk assessors routinely use concepts, mathematical techniques and probabilistic outputs – including uncertainty measures – that are often difficult for decision-makers and the public (and indeed other experts) to understand. And risk models are getting increasingly complicated. It is presumed that including more information in a risk model will not actually worsen the risk estimates it produces, but there are trade-offs associated with increasing the model complexity. As the numbers of model processes and parameters rise, the model may yield better descriptive capacities, but there is also an increase in the number of uncertain quantities needing to be estimated, and hence a rise in the overall uncertainties capable of being contained within the model's integrated system. Data paucity for model 'validation' (alert to Oreskes *et al*.'s (1994) objections to that term) is a problem dealt with elsewhere in this volume, but it is clearly imperative to ensure that users and the multidisciplinary co-developers of a risk assessment understand the models being used, and can communicate the uncertainty issues and model limitations embedded in them.

There is a need to address both *perceptual and cognitive* issues (e.g. what meanings do people give to particular words, concepts or images? How does this vary culturally? Linguistically? How does experience affect the response to information?), and the more *technical/operational* issues (how clear are the maps? Is information translated into local languages? How can complex, multi-dimensional information be presented clearly? And so on). The success of the latter often hinges on understanding of the former. Overall, there is still comparatively little research in the area of natural hazards risk and uncertainty of how comprehensible the information produced actually is. Research to date has largely focused on socio-technical risks and – with a growing focus – on climate mitigation (e.g. Moss, 2007; Nowotny *et al*., 2001).

There have been some examples of natural science 'overkill' in the communication and public understanding of science. For instance, a recent project (Public Awareness of Flood Risk) funded by the UK Economic and Social Research Council has investigated how the Environment Agency's flood maps affect public awareness and attitudes to flood risk (Clark and Priest, 2008). It found that although the public generally like the online maps and appreciated access to this kind of information, there were issues with managing people's expectations (and frustrations) about how specific the information might be to their own situations. Like many other studies, this project also came across the problems associated with people's handling of complex and probabilistic information. Important concepts such as return frequency or percentage likelihood are not well grasped by many members of the public. More prosaically, users often found navigating the online maps to be a complicated procedure, which detracted from their ability to access flood information within the maps.

Over-elaborated hazards maps have previously been distributed widely in Guatemala at times of volcanic threat, but communities and households were found to have inadequate understanding of what the maps were meant to represent, and remained exposed to avoidable risks (W. Aspinall, pers. comm.). More fundamentally, little attempt was made, on the part of scientists, to understand that the maps and their information were themselves highly complex products of particular social contexts. They assumed representational strategies and expectations, which in different social and cultural contexts might have very different meanings to those intended. Sometimes this kind of complex information can be transmitted better, with better effect: people in Montserrat living under threat of volcanic eruptions were also found to have poor skills in map-reading, but when presented with three-dimensional visualisations of digital elevation data of their island, they demonstrated good spatial awareness and were able to engage in discussions about their future in a more informed way (Haynes *et al*., 2007). But it needs to be understood, in any risk communication strategy, that the risk, its definition and its address all come from epistemic 'genealogies' and perspectives, which shape the knowledge and its applicability in particular ways. In the instance of the hazard maps in Guatemala, had local citizens been involved in the production of the hazard stories and their dissemination, the avoidance strategies embodied in the map might have been more effective.

Having ensured that risk communicators have the necessary understanding of the potential knowledge production and transfer challenges, widened engagement requires the targeting of audiences (e.g. Boiko *et al*., 1996), the development of mechanisms for stakeholder or public dialogue (e.g. Rowe and Frewer, 2005) and the establishment of functional communication structures (e.g. Cornell, 2006). The social sciences will not provide magic bullets for environmental scientists engaging in hazard communication, but the tools of the trade of social science, particularly qualitative research, are useful in these three stages. Interviews, focus groups, community workshops, observant participation, ethnography, language learning, archival analysis, deep involvement over long periods of time and 'thick description' all aid in framing effective and productive engagement. Applying the good practice developed in social research to these socio-environmental hazard contexts can help in assessing and reducing uncertainty. Indeed, several recent initiatives are attempting to integrate qualitative knowledge forms that are dynamic within stakeholder and partner communities into the parameterisations, structure and outputs of formal quantitative models (e.g. Siebenhüner and Barth, 2005; TIA, 2007; the UEKC project: Lane *et al*., 2011; Odoni and Lane, 2010; Whatmore and Landstrom, 2011). As these studies argue,

> The practice of modelling … needs to move 'upstream' into fields and farms, community halls, pubs, so that those who live with model predictions, and who have local knowledge to contribute, might become involved in generating them, and so trusting them.
>
> *(RELU, 2010: 4)*

A growing concern that merits more focused research is the interplay between risk, its communication, inequity and social injustice. Mitchell and Walker (2003) reviewed the links between the UK's environmental quality and social deprivation, leading to an Environment Agency research programme, Addressing Environmental Inequalities (Stephens *et al*., 2007; Walker *et al*., 2007). Empirical evidence for environmental inequality is still rather limited, even in the UK, so a key recommendation of this programme was to engage in longer-term case studies, with a particular focus on cumulative or multiple impacts. In the United States, Taylor-Clark *et al*. (2010) used Hurricane Katrina as a case example through which to explore the consequences of 'communication inequalities', finding that socio-economic position and the strength of social networks had a significant impact on both hearing and understanding evacuation orders. There is also international research on communication and social justice in the context of climate adaptation and mitigation. For example, Ford *et al*. (2006) carried out a study including informationexchange methods involving photography and voice recordings to explore how aboriginal human rights can effectively be incorporated in environmental and science policy in the Canadian Arctic. This study emphasised the value of community engagement in reducing vulnerability, and has been part of a steady evolution of more publicly engaged Arctic governance which has incorporated learning central to climate change impacts and mitigation, social and cultural resilience strategies, human rights legislations for environmental protection and biodiversity preservation.

15.3.3 Behavioural change and social learning

Human behaviour is often a critical element determining the impact of socio-environmental and socio-technical risks (OECD, 2009; Gardner and Stern, 2002): the volcanic eruption would not be a problem but for the illegal farming on its slopes; the storm surge would not cause such losses but for the beachfront hotel development boom, etc. Furthermore, human behaviour can present risk assessors with a 'catch-22' situation: uncertainty, often linked to social variability, can result in maladaption and accumulated or deferred risk. Reducing this social uncertainty can be achieved, but only at the cost of a degree of 'social engineering' or dictatorial action that is currently regarded as undesirable in democratic societies.

Thus, in risk research, interest has extended into the fields of human behaviour and the processes of social change. Research that is relevant to natural hazard management comes from economics, political science, psychology, management studies, healthcare and public health, and increasingly from education for sustainable development, which brings an ethos of empowerment and a concern for ideals and principles like human rights and sustainable livelihoods. Exploring these research areas in depth is beyond the scope of this chapter; instead, we select the following as illustrative challenges: first, how knowledge affects behaviour; second, the role of research in promoting social change as a means of achieving risk reduction; and finally, the growing recognition that the interface between knowledge and real-world action requires greater critical reflexivity, both in research and in governance.

15.3.3.1 Knowledge and human behaviour

As this volume indicates, the bulk of risk research has concentrated on technological and environmental risks from a quantitative and analytic perspective. As capability has grown in the prediction of the deterministic elements of risk, and the characterisation and representation of the contingent elements, attention has turned to the human elements that previously were considered too subjective to address within this 'objective' assessment of risk. Subjectivity, or an individual person's perceptions of risk and concerns about it, is often taken to be in opposition to 'real', objective risk, with the corollary that once adequate objective knowledge is provided, people will align their perceptions to the objective assessment. Throughout this chapter we have argued that the way to deal with the diversity of human experiences, values and preferences is not to eliminate them from the analysis, nor to attempt to bring them all into alignment, but to allow their multiplicity and often fraught negotiation to shape the landscape of the knowledge formation about the risks themselves. Zinn (2010), in reviewing and promoting biographical research in the context of risk and uncertainty, argues, like we do, that people's personal identities and life experiences are an important constitutive element in environmental risk analysis. Zin sets out the case for better integration of individual experience and institutional processes into our understanding of the management – and production – of risk and uncertainty.

The nub of the problem is that improving people's *knowledge* about environmental risks does not seamlessly improve people's *action* in response to those risks. To begin with, people are not purely rational beings. Irrationality and inconsistency are human traits, and a large body of research in the area of risk and decision-making confirms this (e.g. Otway, 1992; Kahneman and Tversky, 1996; Kahneman, 2003). Adding to this, people are exposed to many risks and opportunities simultaneously, and are always seeking some kind of life balance – 'an equilibrium of their experiences, abilities and feelings' (TIA, 2007: 25). To the extent that people do rationalise their decisions, the way that they may weight these different risks and opportunities in some kind of multiple optimisation algorithm will vary from person to person, and from context to context. In addition, an individual's scope to respond to risk and uncertainty is constrained by their social context.

In what can be considered the 'first wave' of cognitive and behavioural research in the context of environmental risks, the focus was on improving the understanding of individual interpretations (or misinterpretation) of risk in order to improve risk models. Often, this involved comparing lay people's 'mental models' or perceptions of an environmental hazard with those of experts (e.g. Pidgeon *et al*., 1992; Atman *et al*., 1994; Fischhoff, 1998). These mental models are efforts to map out the causalities and dependencies in a hazardous process. Essentially, the divergences between lay and expert perspectives were taken as a dimension of the risk model uncertainty, which could be corrected in a more efficient version of the risk model, or mitigated by changing the model of risk communication: by knowing better what people do not know, or do not understand, the risk manager is enabled to better direct people's behaviour towards a rational decision.

This body of research did indeed improve risk communication, but what it really highlighted was the complexity of the ways in which individuals construct and experience their social reality, and the extent to which they rely on strategies of social learning. Rational responses to (perceived) short-term or local risks may cause a higher exposure to other risks; people are unwittingly complicit in their own risk exposure (examples are listed in the *World Disasters Report*, 2009: 19). This interplay between responding to risk and altered exposure is at the root of potential moral hazard (e.g. Cutter and Emrich, 2006; McLeman and Smit, 2006; Laffont, 1995) and societal maladaptations (Niemeyer *et al*., 2005; Brooks *et al*., 2009) resulting from human behaviour change. These concepts have already received attention in some risk areas, notably in flood risk and the agriculture/agrochemicals context, but are less articulated across other important natural hazards, where more attention to policy analysis and the broader political economy is required.

Slovic (2001: 1, 5) illustrates the shift to the 'second wave' of behavioural risk research, in which a greater emphasis is given to people's life-experience within the risk definition process:

> Ironically, as our society and other industrialized nations have expended this great effort to make life safer and healthier, many in the public have become more, rather than less, concerned about risk. […] Research has also shown that the public has a broad conception of risk, qualitative and complex, that incorporates considerations such as uncertainty, dread, catastrophic potential, controllability, equity, risk to future generations, and so forth, into the risk equation. In contrast, experts' perceptions of risk are not closely related to these dimensions or the characteristics that underlie them.

One goal of these new approaches is not just to understand the perceptions of risk held by people living in a hazard situation, but also to obtain a better understanding of how and why people develop their world-views, identities, preferences and behaviours (e.g. Zinn, 2010; Henwood *et al*., 2010). The subject is not an abstract 'rational' person, but a 'concrete person who articulates and adapts the multiple dimensions of his or her identity, personality and existence', who in turn is rooted in a community in close interaction with a specific cultural and natural environment (TIA, 2007). This is a much more dynamic engagement with people as the subjects of research. It potentially confers a much richer understanding of the extent to which risk and uncertainty matter to people in their everyday lives, including the ebbs and flows of concern about risk that so profoundly affect people's practical responses to risk situations.

15.3.3.2 Social learning and social change

In the light of the recognition that individual knowledge and perceptions of risk and uncertainty are shaped by social interactions, there is growing attention to social responses to environmental risk.

The first dimension of this body of work that we want to highlight relates to society's response to the provision of information about risk. The questions of why and how a specific risk becomes a public social issue – or sometimes does *not* – are among the most perplexing challenges in risk assessment. Very often, these responses contrast sharply with the rational responses as assessed by technical risk experts. For example, people's agitated concern about the triple Measles–Mumps–Rubella vaccine in the UK was a regular feature in the news headlines for nearly a decade since the first suggestion of a link with autism was raised, despite a technically very low risk (Cassell *et al*., 2006). In contrast, inhabitants of the volcanic island of Montserrat were found to make frequent incursions into the danger zone during red-alert periods when risk was manifestly high (Haynes *et al*., 2007). Impacts on society and the economy can be profound, whether the social response to the risk is 'duller' and more attenuated than it should be, or is more heightened and amplified.

Kasperson *et al*. (1988) set out a conceptual framework for the 'social amplification of risk' that has proven very useful in bridging our understandings of risk perception and risk communication. Using the analogy of signal amplification in communications, they highlight the diverse 'signal processors' (such as risk scientists, risk management institutions, the media, peer groups and activists), and identify various stages in the amplification or attenuation of the risk information, including the selective filtering of (comprehensible) information; the use of 'cognitive heuristics' – conceptual short-cuts deeply embedded in the human psyche that are deployed to simplify complex problems; and of course, the multiple social interactions and conversations people engage in, to contextualise and validate their interpretations, and to collectively decide how to respond to the risk. Since then, others have looked at the phenomenon of 'herd behaviour' (including panic responses) and the role of information cascades in general socio-economic risks (e.g. Gale, 1996; Kameda and Tamura, 2007). In the socio-environmental context, Pidgeon *et al*. (2003) have reviewed the empirical and theoretical research on the social amplification of risk framework, which now addresses formal and informal information channels, the issues of individual understanding and behaviour already described above, and the behaviour-shaping forces in society – attitudes, political dynamics, social movements and so on.

In the climate context, there is a growing focus on the issues of the positive diffusion of knowledge in adaptation processes (e.g. Pelling and High, 2005; Pahl-Wostl *et al*., 2007; Ebi and Semenza, 2008; Jabeen *et al*., 2010; Mercer, 2010), also evidenced in the large numbers of non-governmental organisations that are particularly alert to their role as 'communities of practice', building the capability for accelerating and cross-fertilising knowledge flows into vulnerable populations. Clearly, knowledge diffusion is a requisite step in moving from individual to social learning and societal change. However, social learning based on collective memory of previous experiences is only adequate when deviations from the baseline situation are modest. When risks have high consequences (as in many natural hazards), or when new developments or requirements emerge (as in the case of climate change), then there is a need for society to change more radically or fundamentally – perhaps to a situation with no historical or geographic analogue – to avoid the worst consequences. Decision-making under these circumstances becomes a complex matter. The idea of 'conscientization' (Freire, 2005) involves a kind of critical consciousness of the world linked to action to resolve the perceived difficulties. It has been a helpful concept in health (Kilian, 1988; Cronin and Connolly, 2007), and features increasingly in environmental change (Kuecker, 2007), partly because it is alert to the frequent internal contradictions and 'wickedness' (Rittel and Webber, 1973) of real-world problems.

15.3.3.3 Reflexivity in research and governance of risk

> The limitations of risk science, the importance and difficulty of maintaining trust, and the subjective and contextual nature of the risk game point to the need for a new approach – one that focuses upon introducing more public participation into both risk assessment and risk decision-making in order to make the decision process more democratic, improve the relevance and quality of technical analysis, and increase the legitimacy and public acceptance of the resulting decisions.
>
> *(Slovic, 2001: 7)*

There are many mechanisms for changing people's individual and social behaviours in the face of environmental risk. These include incentives, regulation and, of course, persuasion and education. But the idea that experts of any discipline should actually deliberately try to change the values and beliefs that drive behaviour patterns, changing social norms, is loaded with ethical and political tensions. There is a delicate balance to be maintained. Knowledge, when available, should clearly shape action, but simply providing information about risks and uncertainty does not automatically lead to an optimal change of action. The role of the scientist in driving social transformations clearly requires attention, care and – many argue – new forums.

The role of the scientist in governance is therefore also a growing research field in its own right. Patt and Dessai (2005) and Grothmann and Patt (2005), operating in the climate adaptation context, have looked at the role of experts and the effect of uncertainty in expert assessments on citizens' choices in response to perceived risks. It is essential but not necessarily sufficient to follow good practice in risk communication, and deliver training in technical or cognitive skills to those receiving the complex messages of environmental risk assessment. Marx *et al*. (2007) distinguish between analytic versus experiential learning, and argue that both can and should be developed through participatory processes, to actively engage the public in the processes of risk assessment and management. There is a broad consensus that social learning interventions for environmental risks require transparent procedures (after all, research into people's complicity in environmental disasters is potentially a delicate task), iterative cycles and oversight by individuals or agencies with no perceived strongly vested interests. Collins and Ison (2006: 11) propose a list of 'systemic variables' that need attention if changed understanding and practices are needed, demonstrating that the integration of social science techniques is proving valuable as scientific research and risk assessment processes are opened to greater public scrutiny:

> The variables are: an appreciation of context; ecological constraints or conditions; institutional and organisational framings and practices; stakeholders and stakeholding; and appropriate facilitation. How a messy situation is understood and progressed with regard to these key variables is likely to determine the extent to which social learning can enable concerted action to emerge from changes in understandings and practices.

Ethical dilemmas clearly arise in this kind of 'messy situation', and researchers and risk managers are beginning to give them more explicit consideration. Pidgeon *et al*. (2008) explore the ethical issues associated with socio-cultural studies in risk research. These relate to the power asymmetry associated with expertise; the impact of the knowledge provided (or the process of information elicitation) on the participants; the repercussions for institutions involved, which may have their validity and authority questioned in the process of engagement, and so on. As they clearly state, there is no simple formula for dealing with these ethical challenges. Along with the other 'human dimensions' of multi-dimensional risks, they require places and times to be provided for deliberation and reflection.

Reflexivity has already been mentioned several times in this chapter. We draw on Romm (1998), Macnaghten *et al*. (2005), Doubleday (2007) and Scoones *et al*. (2007), who have translated the ideas of reflexivity from general social theory into the context of environmental risk and governance. Reflexivity involves a sensitivity to inputs from diverse perspectives, consciously recognising that there are alternative ways of seeing issues of concern. It involves a deliberate consideration of whether all the necessary voices are present, and are being listened to. It is a recursive and multi-directional activity of critical (and self-critical) thought and dialogue, taking place throughout the process. Since persuasion and the promotion of social change are often at the heart of responses to socio-environmental risks, there is a need for particular self-awareness on the part of the expert/researcher, at the stage of information provision, and during the negotiations that lead to the transformation. This should not be regarded as navel-gazing; it is part of the process of accounting for researchers', risk managers' and indeed all participants' involvement in the processes that shape or steer society. Reflexivity involves opening up the tacit assumptions, exposing the whole 'risk knowledge process' to public scrutiny, and as exemplified in the UEKC studies, involving those publics in the co-production of the knowledge base for societal action.

Because socio-environmental risks are characterised by a high degree of complexity, the process of change often needs to be provisional and adaptive, in the first instance. But through an experimental and iterative encounter premised on building trust competencies, the reflexive process provides the means for a structural pausing-for-thought, accommodates uncertainty and complexity into research design and output, and can result in radical transformations to how and what scientific knowledge is produced (Lane *et al*., 2011: 33), and for whom it becomes meaningful with 'the objective of helping the actors to be subjects of their own lives' (TIA, 2007: 77).

15.4 Conclusion: understanding scientific action

In this concluding section we reflect briefly on the fact that research in natural hazards has a dual motivation: to develop greater understanding of our environment, and to inform real-world action. Activism may be a strong or unpalatable term for some. Researchers, however, are increasingly being turned to for more than pure knowledge. They are being asked to deliver real-world results with policy impacts that can demonstrably be seen to affect economic and social outcomes. Such demands are often a very far cry from labs and field research, let alone much of the formal education histories of the researchers and their teams. Some of this expectation is the result of misunderstandings on the part of those calling for such applications (politicians, policy-makers, business leaders and the media), of the power of predictive modelling to forecast future climate or related earth surface events. Indeed, one of the risks of predictive modelling is that it can lend itself to such misappropriated expectations. However, it is also the case that public and publicly accountable bodies enshrine in their own prospects and responsibilities for scientists beyond those of mere objective description.

The framing of risk research in terms of promoting societal objectives is a relatively recent phenomenon. A decade ago, the Phillips Report (2001) on bovine spongiform encephalopathy emphasised precise demarcations of the scope and relevance of scientific expertise for the advisory panel, making a sharp distinction between the science and policy domains. This contrasts markedly with the UK Chief Scientific Advisor's 2005 guidance on evidence for policy (HM Government, 2005a), which presses for wider public dialogue in cases of uncertainty over risks to human well-being or the environment, and emphasises the need for scientific input to be embedded in departmental policies and practices. To facilitate this process, most UK government departments have appointed a scientific advisor, often supported by advisory panels. The unprecedented collaborative partnership among UK research councils and government departments that the research programme Living with Environmental Change represents is predicated upon improved ongoing dialogue among research funders, researchers and government stakeholders, explicitly 'to provide for significant impact on policy and practice' (NERC, 2009).

In its report on science in the public interest, the Royal Society (2006: 10) likewise argues that the 'research community … needs to shoulder two main responsibilities with respect to the public. The first is to attempt an accurate assessment of the potential implications for the public.… The second is to ensure the timely and appropriate communication to the public of results if such communication is in the public interest'. While the former is evidence of good ethical practice, the latter is more difficult to implement. We have spoken already of communication, but it is interesting to note that the Royal Society qualifies what it means by 'appropriate communication' to include 'indicators of uncertainty in the interpretation of results; expressions of risk that are meaningful; and comparison of the new results with public perceptions, "accepted wisdom", previous results and official advice' (Royal Society (2006: 11). We suggest that the social scientific insights that have been indicated in brief thus far, and perhaps as they manifest in the actual co-production of scientific knowledge in projects like the UEKC initiative, go a long way to addressing how natural hazards risk science can meet the Royal Society criteria of 'interpretive', 'meaningful' and integrative with other forms of knowledge and understanding.

It is thus not beyond the scope of this chapter to suggest that if natural hazards scientists were to implement truly interdisciplinary research co-production strategies around hazards risks and their uncertainty communication, like those exemplified by the UEKC project, neither the reticence about advocacy nor the loss of scientific privilege should be significant issues. Meaningful co-development of knowledge and communication of issues and their uncertainties would be built in from the start. Of course, for each specific project, the co-production strategies would differ, and some hazard situations might require a different balance of conventional scientific input than others. But adopting the principle of meaningful and relevant knowledge production in forms that better meet the challenges of accountability, transparency and impact would bring profound changes to risk management. Action, agency and – at least to some extent – political engagement would become explicit, and importantly, would be *negotiated* parts of the scientific method, whereas today these aspects might largely remain implicit. Hazards scientists should therefore, by all means, consider the extent to which they inform and shape action, and the means by which they do so.

We have, in this chapter, identified three broad challenges for uncertainty analysis in the natural hazards context. These are:

- Expanding the need for interdisciplinary working to understand the interactions between the natural and human systems that occur in emergencies and disasters.
- Involving a much wider range of knowledge inputs from the communities of interest (who bring important contributory, experiential expertise) and the academic social sciences (such as psychology, ethics, law, sociology and history, in addition to the more expected economics and political science).
- Developing theoretical and conceptual approaches that combine or integrate components of socio-environmental systems to produce knowledge-theoretic assemblage models for hazards risk analysis.

Expanding the networks and involving and developing new knowledge contributors within the scientific co-production processes demands an awareness of the many interrelated social and institutional contexts of natural hazards themselves, including their research. In turn, this requires that we focus on different time and spatial scales to those that apply to the physical hazards themselves, for the risks and uncertainties are themselves emergent properties of the socio-natural systems that face the hazards. As we have noted throughout, risk management in some sectors and domains already does this well. Notably, Europe's responses to flood risk have integrated social and political dimensions over the last one or two decades, with river basin and coastal cell management structures involving strategic trans-boundary and multi-administration partnerships in most countries.

Perhaps the greatest challenges, though, are those relating to the translation of knowledge to explicitly political action. The first is the building up of effective engagement with stakeholders of risk and uncertainty in natural hazards, starting with identifying who they are and what they need. The next, and arguably the most demanding, is the internal and cultural shifts that many scientists may need to face, as their societal role develops from 'detached investigator' to participant-observer or indeed activist.

Throughout this chapter we have emphasised that the co-production of knowledge – including the definition of risk and the identification and management of its uncertainty – emerges through the activity of an assemblage or interacting dynamic system of humans (who can think, make choices and act on them) and non-human factors. Scientific action (or any action for that matter), write Callon and Law (1995: 482), 'including its reflexive dimension that produces meaning, takes place in hybrid collectives'. The action is the product of the assemblage as a whole, and cannot be isolated in any one part. The elements that make up the collective expression of scientific knowledge production are an almost endless list: the hazardous events, risk scientists, related academics, lay people, policy-makers, administrators, natural processes, models, technical instruments, workshops, communication devices, maps, photographs, stories, museums, etc. Viewed in this way, the emergence of action and agency from these socio-natural assemblages goes some considerable way towards distributing responsibility and representation, in instances of activism and advocacy, from the locus of 'the scientist' to the co-productive system. We view this as an exciting development, in that increasingly literate and engaged publics, enrolled in their own enabling forms of scientific agency and self-understanding can shape, in specific but translatable ways, the social and natural meanings relevant to their lives, and their interrelated ecologies.

What we need to explore now is how this wide, powerful and interested socio-natural assemblage, different in each case and specific to particular social, cultural, political and environmental contexts, can be understood in its entirety – theoretically and methodologically. And we need to understand better how it can be asked, as a collective, to co-produce scientific understanding for hazards and their impacts. Social science has an integral role to play in the opening up of this new and potentially radical scientific method. We hope we have shown how it is already shaping the future of the risk research landscape.

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