

Better environmental decision-making – recent progress and future trends

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Abstract

Recent trends in risk-based decision-making are reviewed in relation to novel developments in comparative risk analysis, strategic risk analysis, weight of evidence frameworks, and participative decision-making. Delivery of these innovations must take account of organisational capabilities in risk management and the institutional culture that implements decision on risk. We stress the importance of managing risk knowledge within organisations, and emphasise the use of core criteria for effective risk-based decisions by reference to decision process, implementation and the security of strategic added value.

Keywords: decision, analysis, environmental, risk, policy, management

1. Introduction

Environment ministries and their regulatory agencies make decisions today that affect our long term future. Increasingly, the remit of these bodies is articulated in terms of an improved quality of life for current and future generations, and improved

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25 societal resilience against environmental threats (for example, Defra, 2003; US
26 Environmental Protection Agency, 2006; Environment Canada, 2007). Risk
27 management plays a central role in securing environmental safety and, within a
28 modern culture of risk governance, a government's responsibilities for managing risks
29 are shared with its stakeholders, its regulated communities, its partner departments in
30 government and with citizens. Modern environmental policies need to be evidence-
31 based and risk-informed, so that prioritised, high quality and implementable decisions
32 can be made with the confidence of stakeholders. For policy makers, risk
33 management is transdisciplinary, applied and practical. To be effective, risk
34 management must be supported by peer-reviewed science that underpins an evidence
35 base for a specific course of risk management action. When assembled in concert, the
36 overall weight of evidence from individual threads of evidence then supports
37 decisions on how risks are best managed; for example, on the selection and operation
38 of radioactive waste management facilities, on the design of flood risk management
39 strategies, or on the environmental safety of engineered nanomaterials released during
40 manufacture.

41 In this paper, we are concerned with recent developments and future trends in
42 environmental decision-making, particularly within the policy/regulatory landscape.
43 The field of environmental decision-making has been moving apace since the 1990s,
44 and the sustainable development agenda has had a marked impact on environmental
45 decision tools; in that it has correctly forced the incorporation of economic and social
46 issues, alongside environmental impacts that have historically had greater attention.
47 Some of the important features of the debate discussed in this review are: (i) recent
48 attempts among practitioners to grapple with risk comparisons where impact end
49 points (benefits or detriments) differ markedly; (ii) the growing influence of strategic

risk assessment for informing high-level policy priorities; (iii) the interaction between risk analysis and the evidence that supports risk assessments; and (iv) the development of participatory decision-making. In drawing together the literatures on these aspects, our review starts with a recent overview of risk-based decision-making, recording recent developments and setting the scene for the analysis that follows.

2. Risks and values

At their core, most environmental decisions are about balancing risk and reward; loss versus gain. For risk-informed decisions, we seek to understand the significance of a risk, decide whether it requires management and what that might cost, and then implement the decision effectively, so reducing the risk to an acceptable residual level; recognising that zero risk is not achievable. Though perhaps outmoded and admittedly reductionist in approach, practitioners still find it helpful to begin by considering risks as a combination of the consequences of an event occurring multiplied by the likelihood of those consequences. A managed risk that is reduced is one where either the probability of the event, or its consequences, or both, have been reduced (Figure 1) from what they were originally.

Figure 1. Risks and values

To manage risk well, we need to make judgements about the significance of initial levels of risk, about acceptable levels of residual risk (our risk appetite, post management), about the various strategies for risk reduction (P_2C_2 to P_1C_1 ; Figure 1), about the cost of risk reduction in light of the benefits that a managed risk brings, and critically, on our ability to implement risk management effectively and efficiently

(Figure 1). Whilst Figure 1 provides analytical rationality, most debates about risk boil down to discussions on individual and societal values (what is it we wish to protect, and why this particular subject of protection should have priority over other deserving subjects). Several valuable contributions exist (see, for example Wynne (1997); Stirling (1997); Löfstedt and Frewer (1998); Fischer, 2000; Kasperson and Kasperson, 2005). Defensible decisions on managing risk should generate confidence among stakeholder communities. Whilst zero risks are unattainable, most stakeholders seek confidence in the environmental safety of human activities, and so their perceptions of the likelihood of securing safety and their trust in its ‘guarantors’, is never far from the centre of debate. Increasingly, stakeholders are unconvinced by the risk management intentions of governments without an accompanying discussion of the motivations for risk management. They require an explanation of who will bear the cost and what the benefits will be to those who bear the risk, as well as demonstrable evidence on the long-term effectiveness of risk management actions and responsibilities for monitoring this. In times of economic trade-offs, there is a continual need to express the points at which risks are regarded as intolerable and risk reduction viewed as mandatory, without regard to cost.

An important technical development has been the need to consider risks to the total environment (air, water, soil, biota) within regulatory assessments, with the attending need to integrate risks from the source of a hazard through to a range of receptors (subjects at risk of detriment). We have progressed, over the last 30 years, from single-point deterministic risk analyses to sophisticated probabilistic expressions of risk for multiple ecological impacts, basing our environmental guidelines (for drinking water, air quality and land remediation, for example) on quantitative human health risk assessments. Alongside, contributions from the social sciences have

highlighted the psychology of risk-taking, the centrality of good risk communication and have challenged our hitherto technocratic approach, calling for the democratisation of environmental decision-making (Figure 2).

Figure 2 Proposed decision framework for ‘democratic science’ (redrawn from Charnley, 2000)

The modern risk management frameworks (Stern and Fineberg, 1996; US Presidential Commission, 1997; Charnley, 2000; Petts *et al.*, 2003) that have emerged re-emphasise the critical role of evidence and institutional knowledge, a theme to which we return later. Implementing these frameworks, however, has proved challenging (Fischer, 2000). Whilst we approach 2010 having understood the limitations of quantitative analysis, the complexity of environmental decisions (Figure 3) and the essentiality of involving others in decisions that affect them, we do so with an ever pressing need to set and implement priorities that will secure our long term future, frequently having to make these decisions on incomplete and/or contradictory evidence. Do we have the risk management tools, capabilities and institutional capacities to meet this need?

Figure 3. Categorising incertitude within environmental decision-making (redrawn from Stirling, 2001)

3. Making better environmental decisions

A common a practical requirement for policy makers and regulators is to express and compare the value of environmental harm that might arise from a multitude of

sources to a range of receptors. Comparisons have to be scientifically defensible, practical and offer demonstrable outcomes for a better environment (Environment Agency, 2000). However, the expression of environmental harm is by its nature controversial because it requires an explicit statement of values: (i) the value one places on environmental components at risk; (ii) the detriment in value that a risk, once realised, brings; and (iii) the relative value one assigns between receptors at risk (Pollard *et al.*, 2004).

3.1 Comparing and ranking risks

The issue of comparing different risks with disparate characteristics is not new. The difficulty is not so much the comparison of the relative likelihoods of occurrence, but the (adverse) impacts that may ensue; for example, how to compare ecosystem stress with the potential human health effects that might ensue from prolonged environmental exposure. The situation is difficult for environmental hazards because their consequences are felt both in a spatial and a temporal context, and multiple effects are expressed when hazards are realised – frequently to many receptors at any one time. The situation is complicated further by the latency of certain impacts and the irreversibility of others.

Like many tools in environmental policy and regulation, comparative risk assessment has had its advocates and critics over the years following its emergence in the USA in the late 1980s. Most practitioners accept a compromise from theory in order to reap the benefits of application, although decision analysts continue to offer improved metrics and elegant approaches (Long and Fischhoff, 2000) to the combination of risks that allow a more justifiable and transparent presentation of risk priorities. New developments in comparative risk analysis tend to be controversial

because they force an explicit statement of values and infer (rather than evidence) varying degrees of understanding about the system under study. Comparative risk assessment tools can suffer from (i) an over-simplification of the problem through the use of user-selected surrogates for harm; (ii) over-sophisticated analysis through the use of complex metrics at levels of analytical precision that exceed the level of information available about the risk being assessed; (iii) a poor expression of probability (perhaps because quantification is seen as too difficult, i.e. tools become solely impact-focussed and thus lose their analytical power); (iv) a lack of empirical rigour to the comparison of risks; and (v) poor user-friendliness and a tendency to become bogged down in detail during application.

This said, these tools have seen wide application across the policy and regulatory arenas, and are being used internationally to target regulatory and other institutional resources towards key risks requiring management. There is a long-standing debate as to whether they prove useful as a communication tool and their application is usefully summarised for chemical exposures in the public health context by Williams (2004). Similarly, risk-ranking matrices have been employed that adopt simple probability consequence scores. Frodsham and Cardew (2000) used such an approach for evaluating new technologies for water treatment. In their work, risk scores for a number of technologies were informed by a failure mode and thus allow analysis of the treatment technology combined with expert judgement on the likely impacts of failure. Similar comparative analyses have been used widely in a range of forms, for example, in:

- technology assessment for:
 - energy supply technologies (Ramanathan, 2001);

- 174 – the reliability of bridges (combined with reliability assessment) (Stewart,
175 2001; Stewart *et al.*, 2001);
- 176 – environmental remediation technologies (Bonano *et al.*, 2000).
- 177 • managing chemicals and pathogens in the environment, e.g.
 - 178 – by ranking pollution inventories (Gamo *et al.*, 2003; Lerche *et al.*, 2004);
 - 179 – by ranking pesticide products (Finzio *et al.*, 2001; Lee *et al.*, 2002; Low *et*
180 *al.*, 2004);
 - 181 – assessing the relative risk from exposures to volatile organic compounds in
182 drinking water (Williams *et al.*, 2002), and to consumers from seafood
183 (Sumner and Ross, 2002) and chicken products (Brown, 2002);
 - 184 – for ranking the risk of pharmaceuticals in surface waters (Sanderson *et al.*,
185 2004) and exposures from landfills (Vrijheld *et al.*, 2002)
 - 186 – for prioritising contaminated site remediation (Grumbly, 1997).
- 187 • comparing ecosystem impacts (only) in catchment-level impact assessments
188 (Serveiss *et al.*, 2004).
- 189 • Developing the basis for environmental health policy priorities (Wong *et al.*,
190 2003).
- 191 • in policy development:
 - 192 – informing the health impact assessment of transport policies in Australia
193 (Dora, 2003; Kjellstrom *et al.*, 2003);
 - 194 – as input to bans on asbestos (Camus, 2001);
 - 195 – for informing pollution reduction strategies (Pennington and Bare, 2001;
196 Lerche *et al.*, 2002);
 - 197 – for informing regional catchment management plans (Tran *et al.*, 2002).
- 198

Informed by the comparative risk analysis carried out by the US Environmental Protection Agency in 1987 (USEPA, 1987) and application to a myriad of policy problems, consensus is developing on the relative merits and challenges of applying these techniques. Andrews *et al.* (2004a,b) note the use of spurious precision in risk rankings – so-called ‘analytical over-reaching’; calls for normative approaches that are rarely applied in practice; and an unease among practitioners regarding the presentation of uncertainty in strategic level analysis with a tendency, having acknowledged uncertainty is inherent, to then ignore it in practice.

Perhaps the most comprehensive attempt to tackle the issue of metrics and uncertainty under authentic conditions was undertaken by the New Jersey comparative risk project (NJDEP, 2003). This study identified 88 individual environmental stressors in 11 broad hazard categories. In their summary, Andrews *et al.* (2004b) concluded that, despite considerable analysis and interrogation of data by multiple expert panels, the analytical ‘constructed aggregation’ methodology adopted threw little new light on the multiplicity of these risks. The project steering committee resorted to a risk sorting approach whereby the 88 threats were assessed using a range of risk prioritisation techniques, *e.g.* environmental threats with high human health, ecological and socio-economic impacts were ranked higher than those with lower impacts. The results of the individual techniques used were compared and those threats of consistent high priority across a range of techniques identified as high priority overall. Four clusters of threat were deemed of greatest importance; those associated with land use change, indoor pollution, outdoor pollution and invasive species. Andrews *et al.* (2004a) assert that a ranked list of priorities has only limited value when the science is not in place to support such a list and that, for future exercises, emphasis should be on gathering evidence in support of the prioritisation.

Recent developments in cumulative effects assessment (CEA) as required under the EU environmental impact assessment (EIA) directives (85/337/EEC and 97/11/EC) and strategic environmental assessment (SEA) directive (2001/42/EC) are requiring practitioners to manage the aggregation of environmental effects past, present and in the reasonably foreseeable future. At the strategic level (Therivel, 2004), a plan or programme of activity (e.g. a large multistage development) may be linked to infinite cumulative effects. The aggregation of impacts is usually focussed at the receptor level (James and Stewart, 2004) because the capacity of the receptor to accommodate the additional stress associated with a plan, project or programme of development, is a principal concern in a CEA. Critical factors, from a receptor standpoint, are the sensitivity and vulnerability of receptors to withstand the additional stress caused by the activity. Taken together, these represent the vulnerability of a receptor. Much of the guidance on the aggregated (cumulative) effects of past, present and future stresses, however, is light on the metrics of aggregation. The reflections of long-standing observers of comparative risk analysis are noteworthy, e.g. Fischhoff, 1995; Morgan *et al.*, 1996; van Asselt, 1999; Morgenstern *et al.*, 2000; DeKay *et al.*, 2001; Andrews *et al.*, 2004b Linkov *et al.*, 2005:

- Risk rankings are necessarily imperfect. At the strategic level, uncertainties are huge and stakeholder involvement in metrics and process offer no guarantee of the removal of this ambiguity.
- Few current exercises afford the time required to understand the process of ranking risks, let alone the data on which risks should be ranked. Morgan *et al.* (1996) suggested an approach involving five meetings and taking 9–11 days to complete. This contrasts with the 0.5–1 day workshops typically

used to rank a plethora of strategic risks. The clustering of issues as performed in the New Jersey Comparative Risk Project (NJDEP, 2003) may offer real merits in terms of time spent on these exercises.

- There is a danger, as with all risk analyses, that prioritisation becomes the end in itself rather than what is done to manage the risk.
- Notwithstanding the myriad of metrics and project-specific approaches, there appears to be a developing consensus of the value of the following approach to ranking risks (Figure 5).

Figure 4. Steps in a risk ranking model (after Florig *et al.*, 2001)

- There appears to be a move towards adopting multicriteria analysis (MCA) in preference to comparative risk analysis – perhaps in recognition of the analytical complexities and the ready availability of methods for MCA (Linkov *et al.*, 2005). These authors reject the concept of a risk optimised option or set of priorities in favour of an adaptive management style, where the dynamics of knowledge and data on risks are acknowledged and management strategies adapted accordingly.

3.2 Involving others

The modern analytic–deliberative approach to risk management (Stern and Fineberg, 1996; US Presidential/Congressional Commission, 1997a,b; RCEP, 1998; Charnley, 2000) suggests that wider stakeholder participation should be considered during the initial framing of the issue or problem; during the identification of data and information needs; as risk assessors discuss how uncertainty will be managed in the

assessment; during the risk assessment itself; and during evaluation of risk estimates. There remains a need to establish at which of these stages, and in what ways, participation can be most meaningfully incorporated. The challenge is to develop informed processes that enable decisions involving science to be debated widely in a social context (Sexton *et al.*, 1999; Fischer, 2000). Even at the international level experience is limited, though there are increasing attempts to apply participative processes to policy, plan and project-level decisions involving risk, with many projects now incorporating participative approaches to the framing of risk problems. These processes can be effective in reaching decisions, but a more inclusive and deliberative process does not automatically secure consensus. Indeed, involving publics may result in more diversity in opinion rather than consensus.

Criteria for effective participatory decision processes have been developed where risk is an important issue within the decision (Homan *et al.*, 2001). These reflect broader criteria for effective public participation incorporating the key principles of (i) clarity of objectives; (ii) representativeness; (iii) inclusivity; (iv) openness; (v) deliberation; (vi) social learning; and (vii) decision responsiveness. For environmental regulators, these are complex issues with far reaching consequences for policy, resources and practical issues, which require careful consideration. With participation an accepted feature of better environmental decision-making (Fischer, 1995; Perhac, 1998; Apostolakis and Pickett, 1998) the quality of participatory decisions and tools for incorporating stakeholder views has been subject to scrutiny. Beierle (2002) presents an account of 239 published case studies of stakeholder involvement in decision-making, ranking the quality of the decisions by whether:

- decisions were more cost-effective than likely alternatives;

298 • decisions increased joint gains among parties compared with the likely
 299 alternatives;

300 • participants contributed innovative ideas, useful analysis or new information;
 301 and whether

302 • participants had access to scientific information and expertise.

303 In this analysis, the more intensive forms of stakeholder involvement (processes
 304 involving negotiations and mediations) produced higher quality decisions, suggesting
 305 that more effort and time are required to engage stakeholders in strategic risk issues
 306 than is currently provided. The companion papers by Florig *et al.* (2001) and Morgan
 307 *et al.* (2001) discuss the value of deliberation itself within a group. Using a
 308 deliberative quantitative method for ranking 22 high school health and safety risks,
 309 first by individuals and then following a group discussion, these authors demonstrate
 310 the value of group discussion to fostering consensus. They make the point that where
 311 risk rankings are to be used by regulatory agencies they must be both normatively
 312 justifiable and empirically validated if the rankings are to have credibility. The
 313 authors set out criteria for good ranking methods. For Florig *et al.* (2001), a good
 314 ranking method should:

315 • make use of available theory and empirical knowledge in behavioural social
 316 science, decision theory and risk analysis;

317 • encourage those ranking risks to systematically consider all relevant
 318 information;

319 • assist individual participants in expressing (or constructing) internally
 320 consistent rankings;

321 • ensure that participants understand the procedures and feel satisfied with both
 322 the process and products of a ranking exercise; and

- describe the level of agreement and the sources of disagreement among participants.

English (2000) argues that a shift towards emphasising the ‘long term common good’ in a spirit of ‘collaborative learning’ is required for those strategic risk issues commonly addressed by policy-makers, regulators and their advisers. However, it is also argued that the possibility of adequate representation for each stakeholder type and of securing an equal balance of types within the decision-making process diminishes substantially at this level. This is a long-term project that lacks methodological guidance. Meanwhile, policy-makers and regulators face the practical challenge of how to defensively and robustly take account of a multitude of stakeholder views on risk issues of strategic importance – many of which are viewed by interest groups as contentious single issues in their own right. In response, the gathering, structuring and presentation of evidence in support of risk-based decisions has gathered new momentum.

3.4 Direction, strength and weight of evidence

Policy decisions are required to be risk- and evidence-based, not least because stakeholders expect to see, and be able to critique the supporting science upon which decisions are based. Decision-makers need to assemble lines of evidence for complex, multi-attribute decisions (*e.g.* the long term performance of radioactive waste repositories, the viability of carbon capture and storage technology, the environmental safety of nanomaterials), make judgements on the direction (supportive of a hypothesis or not) of individuals lines of evidence, and then on the overall weight of evidence as a whole. This process in itself requires methodology and structure. There is an established literature on weight of evidence (WOE) approaches developed

in the fields of medical evidence, forensic science and radioactive waste management, with some applications to environmental risk (Mayo and Hollander, 1991; US Nuclear Waste Technical Review Board, 2001; Smith *et al.*, 2002; Hrudey and Leiss, 2003; Weed, 2005; Krimsky, 2005). Among some users, presenting complementary and/or discordant lines of reasoning has been enhanced by the use of influence diagrams, evidential support logic (Benbow *et al.*, 2006) and belief nets, that act as visual mechanisms to support the presentation of interwoven evidence. Valuable examples exist. For example, Gray *et al.* (2004) provide an authoritative example of a WOE evaluation for the reproductive toxicity of bisphenol A, and Popp *et al.* (2006) offer a similar appraisal for the cancer dose-response characteristics of 2,3,7,8-TCDD. Burton *et al.* (2002) set out a WOE framework for assessing ecological detriment.

Environmental decisions make use of data, concepts and assumptions for which a range of evidence of varying quality exists. In these cases, the assessor may need to choose between competing theories (e.g. in low dose extrapolation), a range of individual baseline studies (e.g. arsenic in drinking water) or a palette of future environmental scenarios (e.g. climate change). Such analyses involve evaluating both complementary and potentially conflicting lines of reasoning, the direction and individual strength of which must be assessed in support of a specific line of argument (see Bowden, 2004). Assembling such evidence within a framework of precaution, has long been a requirement of the safety cases prepared for large process plant and radioactive waste disposal, but equally has application to emerging threats where there exists a paucity of supporting science, such as the management of exposures from engineering nanomaterials (Linkov *et al.*, 2007; Rocks *et al.*, *in press*). Generic questions on evidence and lines of reasoning pertinent to the risk assessment must be answered (US Nuclear Waste Technical Review Board, 2001):

- How does a policy advisor weigh/prioritise quantitative evidence alongside qualitative lines of reasoning that support other types of argument?
- How does this weighting change with time and the introduction of new evidence?
- Which arguments are most and least convincing to publics, in which formats, and why?
- How do policy implementers (e.g. regulators, operators) manage the integration of evidence?
- In what depth should policy advisors and or regulators develop an independent view of the evidence that support a specific policy outcome?

Criteria for evaluating the strength of evidence are published. For example, Bradford Hill's criteria (Hill, 1965) attempt to separate causal from non-causal associations between agents and disease (Hofler, 2005) by reference to:

1. strength of association (a strong association is likely to have a causal component);
2. consistency (reproducibility);
3. specificity;
4. temporality (effect succeeds action or factor);
5. biological gradient (dose response);
6. plausibility (biological explanations);
7. coherence (agrees with current knowledge);
8. randomised experiments (good study design); and
9. analogy (effect has already been shown).

Klimisch *et al.* (1997) present a systematic evaluation of the quality of toxicological data, adopting a ranking system:

1 = reliable without restrictions. Where the data was generated according to internationally accepted (or validated) testing guidelines and preferably secured under good laboratory practice (GLP) or where the test parameters are closely related to a guideline method;

2 = reliable with restrictions. Where the data was secured mostly according to GLP and where the test parameters do not totally comply with the testing guideline, but are considered sufficient to accept the data;

3 = not reliable. Where there were interferences between the measuring system and the test substance, or in which the test systems were used which are not relevant in relation to the exposure, or were generated using an unacceptable method;

4 = not assignable. The experimental details provided were not sufficient and were only listed in short abstracts or secondary literature.

These evaluation criteria have been applied to many chemical risk assessment methods and have proved to be an acceptable method of determining the quality of the data supporting chemical risk estimation and characterisation.

Bowden (2004) presents a valuable suite of quality indicators for scientific evidence (Table 1), stressing the criticality of well-managed knowledge and describing the *sufficiency* (relative significance), *dependency* (commonality between contributing lines of evidence) and *necessity* of evidence.

Table 1 Quality indicators for scientific evidence (after Bowden, 2004)

In seeking to explicitly account for uncertainty, the evidence support logic proposed allows for evidence that supports a hypothesis; that which does not support a hypothesis and importantly, for a residual amount of uncommitted belief (Figure 6;

Bowden, 2004; Benbow *et al.*, 2006). Individual lines of evidence, simplified and illustrated in part for carbon capture and storage in Figure 6, may then be structured and evaluated in concert.

Possessing the institutional capacity to perform these evaluations of evidence is rare in practice. Further, evidence alone is insufficient for sound decision-making – there is an organisational cultural component that becomes increasingly important as the ‘shelf-life’ of organisational knowledge on how risks are best managed shortens. The practical and preventative management of environmental risk can only be secured by wise organizations that manage their science and evidence base, and that understand the institutional factors that influence the success of risk management measures (Pollard *et al.*, 2007; MacGillivray and Pollard, 2008).

Figure 5. Basis for, and application of, evidence based (3-value) logic to carbon storage and capture decisions (partial tree for illustration; after Benbow *et al.*, 2006)

4. Institutional issues

The delivery of risk management, be it in the design and build of new flood defences, in the operation of new technology for managing wastes as resources, or in the authorisation of new chemicals or novel materials, ultimately relies on institutional capabilities to assess, manage and communicate risk. People, the institutions in which they work, organisational structures and the management of knowledge all impact on the efficiency and effectiveness of risk management. Good environmental decisions are those that can be readily implemented and ‘best-in-class’ organisations are better at managing risks and opportunities wisely, learning from

failure, and they exhibit resilience (robustness to shock) and agility (adaptive and forward-looking) within a changing business climate (Pollard *et al.*, 2007). They recognise that a maturity of capability is not secured solely through having risk frameworks, risk assessment tools, audit trails, risk champions and risk registers in place. Government departments are no different, in that they strive to develop policies that can have most effect, alongside other strategic objectives. The management of risk knowledge becomes central (Figure 6).

Figure 6. Managing risk knowledge is central to effective risk management.

For an organisation to make effective risk-based decisions it must be able to operate effective risk management processes, including the articulation of clear objectives and problem definition; it must be able to evaluate the implementation of risk management; and it must be able to secure, among other benefits, the strategic added value that comes with mature risk management - all this, within an organisational context in which decisions are made by people with access to data, information, knowledge and evidence.

Many authors view the organisation as a complex social system composed of a variety of organisational facets (Beer, 1998; Senior, 2002). Subsequently, when attempting to implement change at an organisational level there are many perspectives to consider. 'Organisational culture' is a term frequently used to describe the core personal, communal and organisational views, values and norms of an organisation (Denison, 1984; Cameron and Quinn, 1999). It is suggested that a strong organisational culture has the ability to influence behaviours including organisational

performance, staff commitment, motivation and efficiency, and job satisfaction to name a few (Denison, 1984; de Gilder, 2003; Fischer, 2005).

The literature suggests that developing relationships with external organisations and the maintenance of a strong social network is a key component to sustained growth and the ability to respond to opportunities, challenges, risks and limitations presented by the external environment (Mullins, 2002). This is particularly crucial within environmental management where organisations are required to constantly keep up to date with rapidly developing requirements and legislation. Maintaining a well-built internal social network, supporting both formal (e.g. role based) and informal (e.g. casual, opportunistic interaction), is also central to the implementation of a risk based culture. Internal ties can have a substantial impact upon the commitment, motivation and performance of staff (Smith, 2007) and are possibly the most effective tool for the capture, assimilation and sharing of knowledge within an organisation (Claver-Cortes *et al.*, 2007). For this reason authors suggest that human relations should be valued above any technological tools or mechanisms for effective knowledge management (Pyoria, 2007).

Valuable knowledge is often tacitly tied to individuals within an organisation (Marouf, 2007); subsequently it has been suggested that organisations must adopt organisational structures that allow them to create and transfer as much knowledge as possible. Typically it has been suggested that adopting a flatter structure encourages the effective integration of knowledge (Claver-Cortes *et al.*, 2007). Effective communication, leadership style and the development of trust also have a substantial influence over how knowledge is managed within an organisational context. Effective communication is crucial within the context of a risk based culture as issues relating to risk are frequently misunderstood. By extension, communication has a

strong influence over processes of organisational change. A transparent network (Moenaert *et al.*, 2000), face to face interaction (Pyoria, 2005) and a shared context of understanding are all thought to aid improved decision making and enhanced communication skills between members of a team or organisation.

Research into management and leadership within organisations has varied results (Andersen, 2006). The traits required of apparently successful leaders are vast (Senior, 2002) and the effects of individual behaviour and personalities of leaders upon organisational success are unclear. However, leaders do have influence over individual and organisational behaviours (Sadri and Lees, 2001) and this should be acknowledged within the implementation of effective risk management. The utility sectors (energy, water, waste) are currently expressing substantial interest in the mechanics of implementing risk management within their organisations because of the issues of security of supply, the perceived vulnerability and aging of national infrastructures and a re-emergence of the public health imperative, within drinking water supply for example. An executive lead on risk management is seen as crucial within these sectors and essential to setting the tone of the organisation.

Trust has also been highlighted as a component that has a strong influence over the other factors presented within this process (Burke *et al.*, 2007); enabling cooperation (Tyler, 2003), creating high morale and efficiency (Pyoria, 2007), and maintaining a competitive advantage (Young, 2006).

5. Conclusions - core criteria for better environmental decisions

Having reviewed the organisational aspects of decision-making and summarised the development of risk-based regulation, it would seem appropriate to pose the question: ‘what makes for a high quality, risk-informed decision?’ A substantive

522 literature exists on decision analysis. Good decisions deliver the aims and objectives
523 they set out to achieve. Better decisions adopt a participative approach and deliver
524 costed options. The definition of the problem (what are we trying to achieve and
525 why?) and identification of decision attributes are universal requirements. For risk-
526 based decisions, these translate into a need to articulate the ‘risk of what to whom?’
527 and a level of tolerable residual risk (post management) – the risk appetite. Risk
528 assessments should identify those features of the problem that contribute most to the
529 risk and so, properly applied, an effective risk management process should deliver
530 costed options and provide direction on the targeting of resources towards a
531 prioritised set of risk management actions.

532 Decisions that are not implemented well are of little value. The project,
533 programme and appraisal literature places a firm emphasis on the importance of
534 implementation and post-implementation evaluation. All too often, risk analyses are
535 undertaken, risk management actions designed and their effectiveness left unchecked.
536 Thus implementation and evaluation are critical to ensuring the desired outcomes are
537 secure.

538 Finally, effective decisions secure benefits and thus value. ‘Value trees’ are one
539 means of presenting the benefits of a decision alongside the costs and thus allowing a
540 qualitative weighted average of the benefits assigned to a decision. However
541 captured, it is important that the collation of benefits from a decision is complete and
542 suitably aggregated. Organisations frequently miss the strategic added value to the
543 organisation itself that comes with risk-based decision-making, yet this is increasingly
544 critical to securing executive buy-in to decisions. Organisations manage risks
545 preventatively because they understand that prevention is better than cure, that threats
546 to business interruption must be managed, and increasingly, because intangible

consequences, such as reputational damage, can sometimes overwhelm monetisable losses. Most organisations manage risk in a climate of constrained resources however, and need to make risk-informed decisions because they have to target their top risks and apply resources to the features of a risk that makes the most contribution to reducing business exposure. Environmental policy makers and regulators are no different, in that they need to focus regulatory effort where they can have most effect, alongside other objectives. In adopting this approach, organisations seek the strategic added value of these decisions over and above the loss avoided through preventative risk management (Figure 1). In evaluating the quality of risk-based decisions, the authors seek to fulfil these basic criteria:

Criterion 1: an effective decision-making process has been adopted, complete with unambiguous problem definition;

Criterion 2: the decision has been subject to implementation and evaluation to ensure the intended outcomes have been secured; and

Criterion 3: that strategic added value has been secured as a result.

In setting out these base criteria, we emphasise the need to be very clear about the starting and finishing points for risk reduction – one must understand what the residual risk will be, post management – and the need to accrue both the monetisable and non-monetisable costs and benefits, in order that the true value of the decision can be evaluated. Further, an emphasis on the strategic added value of risk management is representative of the observation that best-in-class organisations turn a high capability in risk management to their strategic advantage. Their risk management capability becomes a strategic asset; their stakeholders have greater confidence in the

572 decisions the organisation makes; and the organisation correspondingly finds it easier
573 to secure investment and support for their future business strategy. This should not be
574 underestimated for government organisations, which are increasingly under the behest
575 of spending reviews and efficiency savings in times of expanding regulatory remits
576 and reduced public finance.

577 Good environmental decision-making is more than being risk-informed and
578 evidenced-based. It embodies the expectations of participative involvement, of
579 technical competency in decision analysis and of organisational maturity that ensure
580 that decisions ‘stick’ and that residual risk is monitored. Risk analysis has contributed
581 much to the field, allowing us to focus on the critical parts of the problem and so
582 prioritise actions. We expect the issues raised in this review to develop further – with
583 more in-depth exploration of risk comparisons, bespoke weight of evidence
584 frameworks for individual risks and the benchmarking of organisational risk
585 management capabilities. The language of risk remains a problem for most audiences
586 and despite a wide literature, risk managers, researchers and policy specialists
587 continue to become unseated in media and public settings when explaining risk
588 management actions. Publics understand ‘safety’ as a concept and imbue the term
589 with notions of confidence and responsibility. In contrast, risk is often negatively
590 associated with official attempts to ‘soften the blow’ from something hazardous and
591 likely to cause harm. In some settings, risk assessments themselves have become
592 highly contentious. We view this as a critical ongoing issue on which to provide
593 advice to Governments, as they seek to better explain their actions to citizens and their
594 stakeholders.

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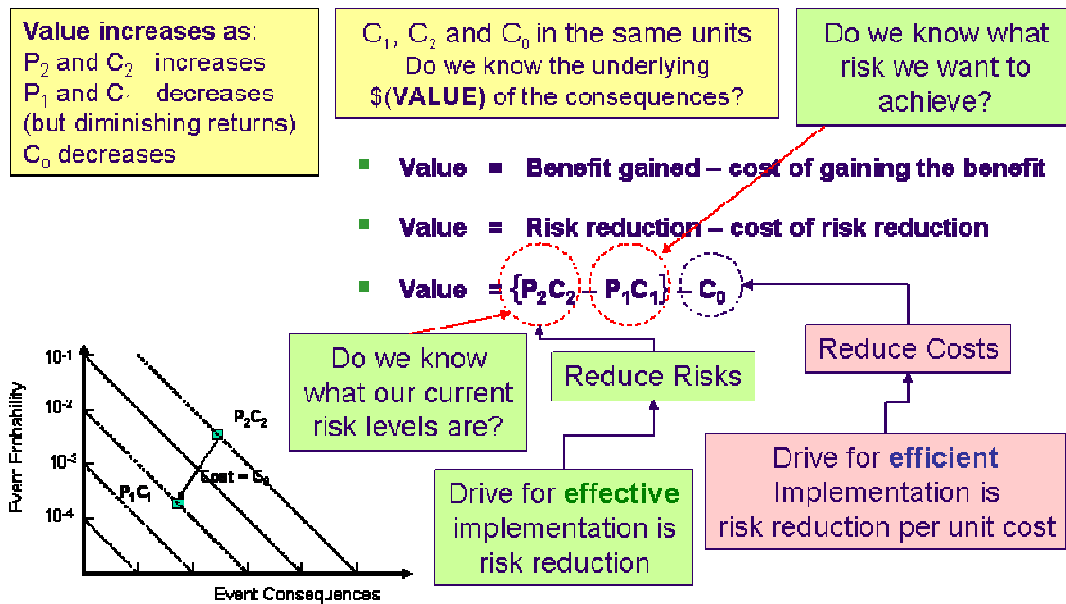


Figure 1 Risks and values

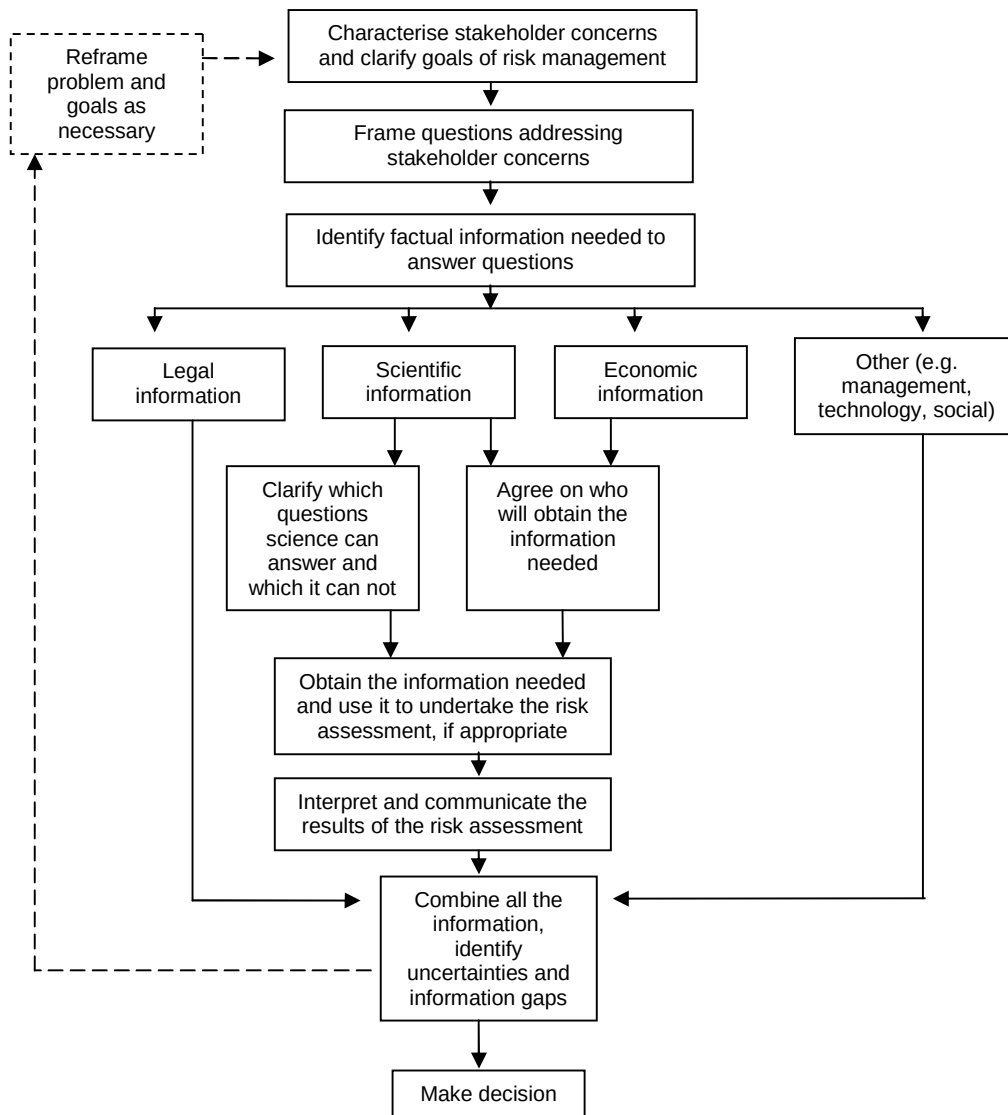


Figure 2 Proposed decision framework for ‘democratic science’ (redrawn from Charnley, 2000)

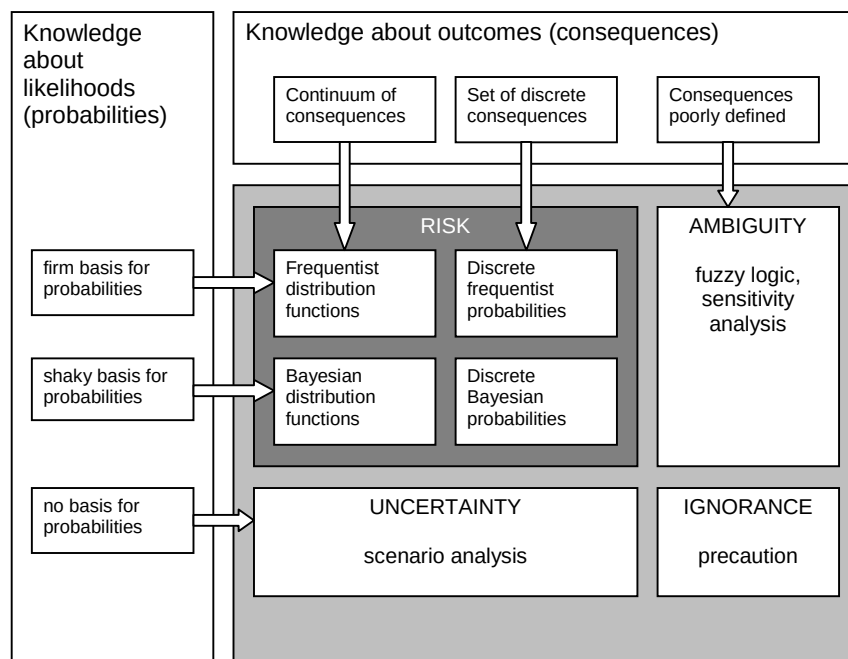


Figure 3. Categorising uncertainty within environmental decision-making
(redrawn from Stirling, 2001)

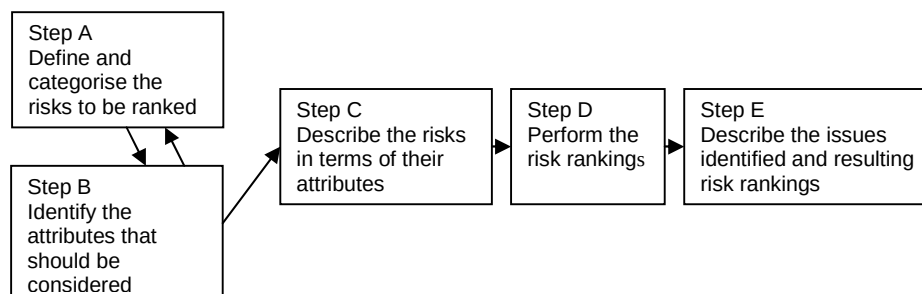


Figure 4. Steps in a risk ranking model (after Florig *et al.*, 2001)

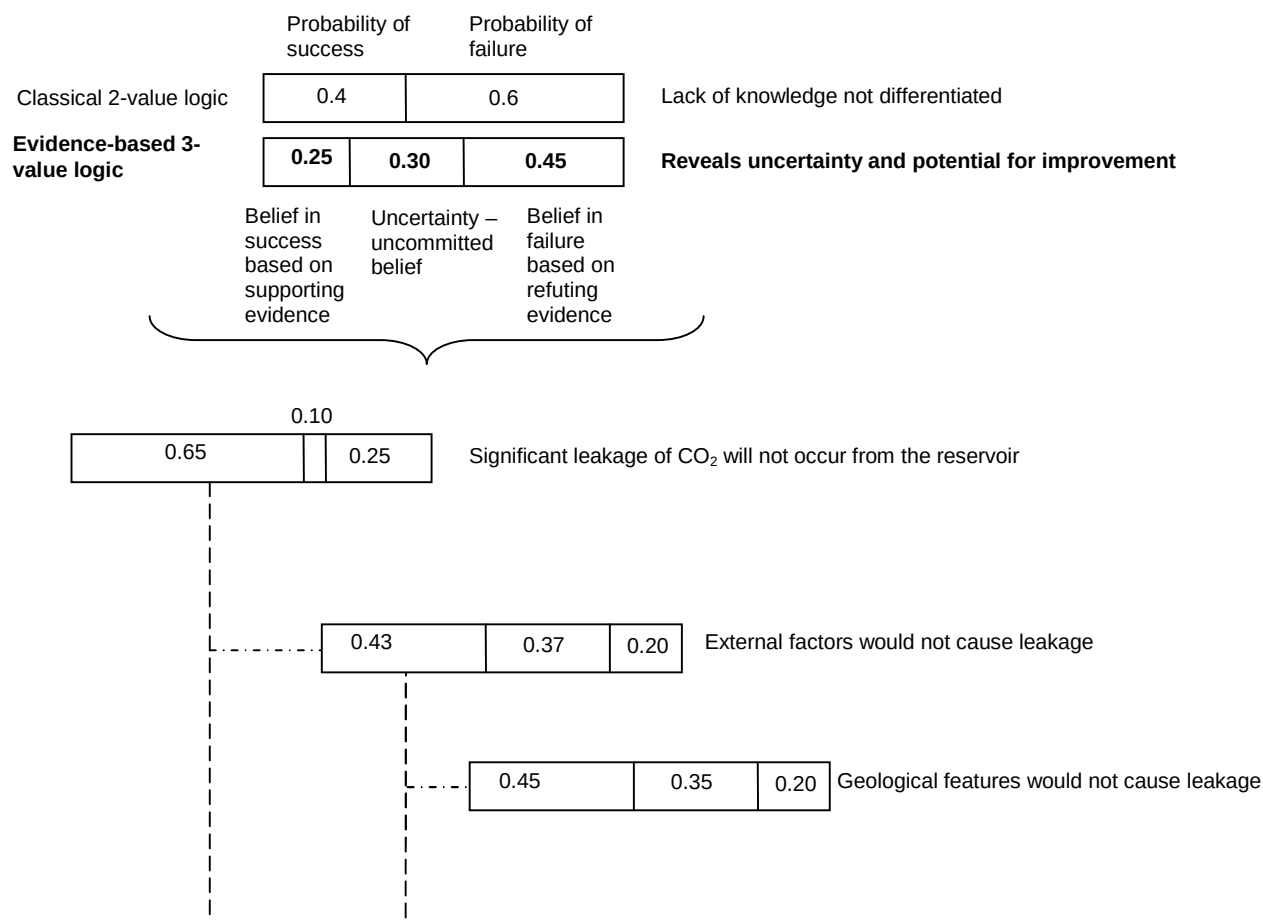


Figure 5. Basis for, and application of, evidence based (3-value) logic to carbon storage and capture decisions (partial tree for illustration; after Benbow *et al.*, 2006)

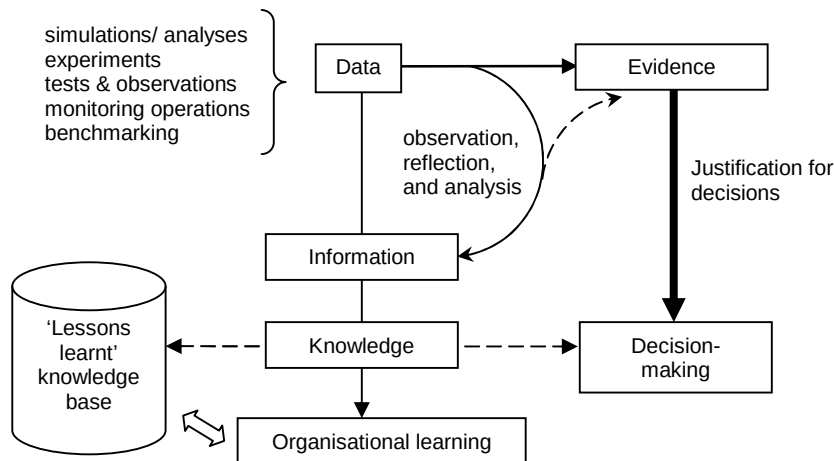


Figure 6. Managing risk knowledge is central to effective risk management.

Table 1 Quality indicators for scientific evidence (after Bowden, 2004)

Indicators of evidence quality							
Quality rank		Theoretical basis	Scientific method	Auditability	Calibration	Validation	Objectivity
	Very high (1)	Well established theory	Best available practice; large sample; direct measure	Well documented trace to data	An exact fit to data	Independent measurement of same variable	No discernable bias
	High	Accepted theory; high degree of consensus	Accepted reliable method; small sample; direct measure	Poor documented but traceable to data	Good fit to data	Independent measurement of high correlation variable	Weak bias
	Moderate	Accepted theory; low consensus	Accepted method; derived or surrogate data; analogue; limited reliability	Traceable to data with difficulty	Moderately well correlated with data	Validation measure not truly independent	Moderate bias
	Low	Preliminary theory	Preliminary method of unknown reliability	Weak and obscure link to data	Weak correlation to data	Weak indirect validation	Strong bias
	Very low (0)	Crude speculation	No discernable rigour	No link back to data	No apparent correlation with data	No validation presented	Obvious bias



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