The next phase in information management: using risk to integrate data and facilitate social learning about sustainability

Kala Saravanamuthu*

Newcastle Business School,
Faculty of Business and Law,
University of Newcastle,
Callaghan 2308, New South Wales, Australia
Fax: +61-2-4921-6911
E-mail: Kalathevi.Saravanamuthu@newcastle.edu.au
*Corresponding author

Carole Brooke

Warwick Manufacturing Group,
International Management Centre,
University of Warwick,
Coventry CV4 7AL, UK
E-mail: cbrookepotf@googlemail.com

Michael Gaffikin

School of Accounting and Finance,
University of Wollongong,
New South Wales 2522, Australia
Fax: +61-2-42213097
E-mail: gaffikin@uow.edu.au

Abstract: Business intelligence (BI) for the 21st century should reflect the uncertainty inherent in emergent knowledge about complex causal relationships between elements of the ecosystem. However BI constructed by integrating data from multiple sources remain restricted to strong economic signals as its systems cannot cope with the amount and diversity of data about sustainability. BI's non-engagement with weak signals about the impact of unsustainable activities is aggravated by the absence of a single uncontested definition of sustainability. Ecosystem literature advocates grappling with sustainability's characteristic uncertainty-complexity by providing stakeholders with information that fosters capacities for social learning. Here we put forward socially constructed risk-based analytical-deliberative platform that integrates weak environmental signals, thus better representing the uncertainty and complexity aspects of sustainability. An Australian case-study of irrigators is used to examine how our platform integrates weak environmental signals with BI's strong signals, and fosters capacities for social learning among decision-makers.

Keywords: information management; business intelligence; social learning; integrated risk; systems; sustainability.

Reference to this paper should be made as follows: Saravanamuthu, K., Brooke, C. and Gaffikin, M. (2013) 'The next phase in information management: using risk to integrate data and facilitate social learning about sustainability', *Int. J. Business and Systems Research*, Vol. 7, No. 3, pp.266–291.

Biographical notes: Kala Saravanamuthu is an Associate Professor in Accounting at the University of Newcastle, Australia. Her primary area of research is in developing an alternative Gandhian-Vedic paradigm, which underpins the construction of management information that fosters the sustainability ethos. It has culminated in the development of a software that integrates multi-attribute data into risk-based discourse for stakeholders. She is currently involved in trialling this software in real-world conditions through pilot studies.

Carole Brooke has a PhD in Business IT at Cass Business School, an Archaeology/Anthropology MA in Cambridge and diverse commercial experience. She has taught at Durham, Lincoln, Salford and Sheffield, amongst other universities. She became a Professor of Organisational Analysis in 2007 and was nominated for an NTFS award in 2009. She developed international research networks in 'critical IS' (JIT, 2002; JIS, 2008) culminating in her edited volume, 2009. She is currently working for the University of Warwick's Manufacturing Group and has a guest role within the Centre for Computing and Social Responsibility at De Montfort University. She also runs her own business.

Michael Gaffikin is Emeritus Professor of Accounting and Finance at the University of Wollongong. His major research interests are in accounting theory and history with special interest in alternative approaches to research. He has published widely and he is on the editorial board of many leading international accounting journals. He has also worked closely with professional accounting bodies on matters of education and research policies. At his university he served as the Chair of his school for many years before taking on the role of Associate Dean in Research for the Faculty of Commerce.

1 Introduction

Decisions about sustainability are best arrived at through a participatory process of balancing human wants with nature's needs (Falkenmark, 2004; Walker et al., 2002). It is a radical change from traditional decision-making that is informed by top-down construction of expert knowledge. However, top-down decision-support is no longer appropriate for the 21st century: Beck (1993) explains that experts' and state authorities' legitimacy and authority have been whittled away by their failure to protect contemporary society from the excesses of technological advances. Environmental disasters, such as the 2010 BP oil spill in the Gulf of Mexico, have heightened society's unease about technological research being directed by the singular pursuit of profit (Beck, 1993). The Congressional inquiry into the 2010 BP spill disclosed that,

> "BP cut corner after corner to save a million dollars here, a few hours or days there and now the whole Gulf Coast is paying the price" (Democrat Henry Waxman quoted in Landers, 2010).

It is difficult to dislodge this financial mindset from top-down expert prescriptions firstly because its economic assumptions are embedded in organisational information systems. Secondly, the financial ethos is key to perpetuating economic globalisation in the face of its attendant social inequalities and environmental degradation. It gives rise to the following dilemma: on the one hand, management that ignores environmental signals is increasingly aware that it runs the risk of stricter regulations imposed on it by an alienated society (Ulrich, 2008). On the other hand, bottom-up approaches to balancing cannot replace top-down ones because lay-persons lack skills to evaluate complex technical data about degradation and the interconnectedness between elements of the ecosystem (Pellizzoni, 1999).

Hence, Reed et al. (2005; Funtowicz and Ravetz, 1993) advocate supplying stakeholders with integrated, coherent, transparent and meaningful accounts to help lay-persons interrogate, and thus socialise, measurements generated by experts. These expert-accounts include Elkington's (1997) triple-bottom line disclosures on the social, environmental and economic aspects of performance, and Gray's (2002) corporate social accountability. Whilst Bier et al. (2004) refer to this combined expert-lay phase as a social turn that should be assisted by the creation of 'analytical-deliberative' (p.91) spaces of communication, Dahl (1985, 1989) suggests using communication technologies to develop learning spaces that enable lay-communities to acquire technical competence. Funtowicz and Ravetz (1993, 1992a, 1992b) treat these learning oriented spaces as extended knowledge that is constructed by extended peer communities: this emergent knowledge is no longer confined to the expert-realm. Extended knowledge encourages participating stakeholders to take ownership of environmental issues, and embrace the sustainability ethos. It should motivate them to make radical changes to their production methods and consumption patterns (following Economic and Social Research Council, 2000).

Our objective is to construct extended knowledge spaces in information systems. We propose constructing analytical-deliberative spaces that represent the next phase in the evolution of data-driven support systems: these systems will employ social concepts of risk to combine strategic intelligence queries with its real-time data warehousing, and draw signals from current/historical data from within/without its organisational boundaries (following Petrini and Pozzebon, 2009, 2008).

We follow Dahl (1985) and posit our proposal in the context of intelligence systems: Howard Dresner of the Gartner Group coined the term business intelligence (BI) in 1989 to describe concepts and methods that to improve decision making by enhancing fact-based computerised support systems (Power, 2008). Business Intelligence Systems (BIS) scan and strategically harness databases for signs of potential opportunities and catastrophes, before integrating data from multiple sources into actionable information (Beal, 2000; Grove, 1999). They are a natural outgrowth of vast amounts of data about customers and competitors that are stored in integrated enterprise resource planning systems (Gibson et al., 2004; Powell and Bradford, 2000; Kudyba and Hoptroff, 2001). BI helps management gain better insight into organisational processes, strategies and operations by developing actionable information from transactional data that have been processed through ERP and other data systems (Ramakrishnan et al., 2012; Lonnqvist and Pirttimaki, 2006). In the case of green (or sustainable) strategies, BI should help decision-makers ensure the continued resilience of natural ecosystems by making sense of the changing needs and demands of complex adaptive systems and external stakeholders (Walker et al., 2002; Eckerson, 2006). Consequently, BI not only provides external stakeholders with access to information, but it also facilitates communication with management (Massa and Testa, 2005; Bose, 2006). These emergent green systems should enable useful stakeholder insight, support decision-making and enhance performance evaluation despite uncertainty and complexity about sustainable relationships, by ensuring that appropriate assumptions are made about the impact of the business on the natural environment.

Even though the success of BI depends on its ability to provide high quality integrated information (Yan et al., 2012; March and Hevner, 2007; Watson et al., 2004), BIS' actionable information is conventionally constructed from strong signals. BI includes weak signals, but only about competition and uncertainty in the marketplace (Walls et al., 1992): weak signals are "imprecise early indications about impending impactful events" that may mature into strong signals over time (Ansoff and McDonnell, 1990). It excludes weak signals from the natural environment because they are deemed to be outside the 'main game' of pursuing financial profits. Further, their inexactness makes it difficult to comprehend their implications. We now explain how environmental signals may be meaningfully integrated into intelligence: Reed et al. (2006; Falkenmark, 2004) suggest developing 'weak signals' mentalities' by enabling decision-makers to acquire capacities for social learning. These capacities are users' awareness of each other's competing-and-interdependent goals and perspectives, identification of shared problems, appreciation of the complex issues at hand, motivation to work collaboratively, trust and the creation of formal-informal relationships (Pahl-Wostl and Hare, 2004). Hence, we propose using integrated risk information to integrate weak environmental signals and foster social learning.

We use risk as the medium for integrating strong and weak signals because the International Standards Organizations (ISO) November 2009 pronouncement advocates using (non-probabilistic) risk discourse to cognitively reform the management culture. ISO 31000 calls for a whole of risk management approach to designing, implementing, maintaining and continually improving organisational processes (Standards Australia, 2009). Section two explains why non-conventional constructions of risk should be employed as the medium for integrating strong and weak signals through Beck's (1993) risk society thesis.

The rest of the paper is structured as follows: section three reviews the BIS literature and makes a case for the use of socialised, non-probabilistic concepts of risk in the interpretive phase of intelligence construction. Section four reviews the social risk literature before proposing a risk matrix for integrating weak and strong signals. Section five applies this risk discourse to a case-study before concluding with a discussion on the implications of socially constructed risk discourse that integrates weaker environmental attributes in BIS and facilitates social learning.

2 Beck's risk thesis and its implications for BI

This section makes a case for the use of socialised, non-probabilistic concepts of risk by couching arguments favouring the integration of weak environmental signals into BI in Beck (1993) risk society thesis. Beck describes contemporary society as risk society because it has to bear the consequences of economic prosperity that have been generated through the exploitative rationale of industrialisation, which have had little regard for the impact of economic activities on the natural environment. Industrial society's notion of safety thresholds justifies the pursuit of economic growth at the expense of the environment. These thresholds are constructed from large samples of recurring observations, which by definition, exclude low-probability/high-consequence risk events that are characteristic of the hazards confronting risk society (Beck, 1995). Consequently, conventional risk calculus and safety thresholds fabricate certainty by unrealistically presuming that harm attributable to human-activities may be contained within conventional notions of accountability. Not surprisingly, BP's low-probability/high-consequence threat of an oil spill in the Gulf was less likely to be included in the conventional risk toolkit. Consequently risk society distrusts state apparatus and institutional expert-systems because their accountability and safety mechanisms have failed to create a 'safe' society.

Beck distinguishes risk society from earlier communities as follows: risk society is less prepared to accept expertise and prescriptions promulgated by expert and state systems because these systems have failed to effectively regulate technological risks and protect society. He theorises that risk discourse becomes the medium of communication for society to transition from a trusting society that had accepted authoritative knowledge at face, to a 'reflexive modernity' which interrogates and questions the assumptions and values embedded in knowledge (also Pellizzoni, 1999). This emergent risk discourse should engender social learning about making ecological resilience central to development (Beck, 2001).

Next we examine the hurdles to social learning, and use these impediments to identify the attributes of a risk discourse that could facilitate social learning. Firstly, social learning requires a paradigm shift in approaches to decision-making: individuals should not expect to draw unambiguous 'hard' conclusions from BI because this intelligence would include weak signals, namely, uncertainty about the human impact on the environment, and shared nature of complex technological uncertainties-risks. For instance, a decade after the Chernobyl reactor imploded, radio-active contamination was detected in pastures and sheep in Cumbria, UK (Wynne, 1996): it reflects the multiple causes and cumulative consequences of the underlying causal reality. Consequently, the spatio-temporal attributes of this causal relationship cannot be reasonably reduced into strong linear relationships signals (Rayner, 1992). Secondly, people tend to process weak signals heuristically: it increases the likelihood of distortion when people cognitively process the multiple attributes of environmental degradation. Why? Because heuristic cues represent experiences of an unsustainable industrial era, which are not appropriate for mitigating risks in contemporary society (Rouibah and Ould-Ali, 2002). Thirdly, multiple-attribute environmental data tend to be standalone measurements: they provide fragmented accounts of degradation (Hak et al., 2007). Dahl (2007) calls for the development of communicative spaces that meaningfully integrate these indicators into a coherent framework to socially inform the process of reforming unsustainable production methods and consumption patterns. Gray (2002) calls for an imaginative accountability framework that makes human suffering and environmental degradation visible because they have been subsumed by the dominant financial perspective.

Here we follow Beck (1993) in advocating an integrated risk framework (Saravanamuthu, 2009) to add weak signals to actionable BI. Beck explains that socialised constructions of risk draw attention to the intermediate and intolerable categories of risks that emanate from environmentally-unfriendly technological advances (Klinke and Renn, 2002). By contrast the conventional rational-probabilistic risk calculus only represents normal risk. Section three's review of the BIS literature shows how using non-probabilistic risk discourse could facilitate social learning among managers, and between managers and external stakeholders.

3 BIS and emergent risk discourse

BIS informs management about an organisation's strengths/weaknesses whilst drawing attention to opportunities/threats by systematically targeting, tracking, communicating and transforming signals from the larger environment into actionable information (Gibson et al., 2004). Petrini and Pozzebon (2009) regard BIS as a means of integrating corporate social responsibility (by meeting the needs of the present generation without compromising the future: World Commission on Environment and Development, 1987) into business operations, supply chains and organisational decision-making processes. Society has to make adaptive decisions that consider the extent to which human activities stress the resilience of ecosystems (Reed et al., 2006) because sustainability is not a zero-sum game (Beck, 1993). We follow Beck in making the case for fostering reflexive adaptive decision making central to our case for greening BI. Risk society is a self-confronted community that has to face up to manufactured risks which emanate from its unsustainable norms and practices. However, the complexity of the underlying socio-ecological systems makes it difficult to manage: it is difficult to assign probabilities to the relationship between management decisions and environmental degradation in any meaningful way (Walker et al., 2002). Hence, Beck argues that socially constructed risk discourse should be employed to achieve Walker et al.'s (2002) goal of enabling management to learn to live within systems rather than control them.

3.1 Transformation of BI: engaging with risk in the next phase

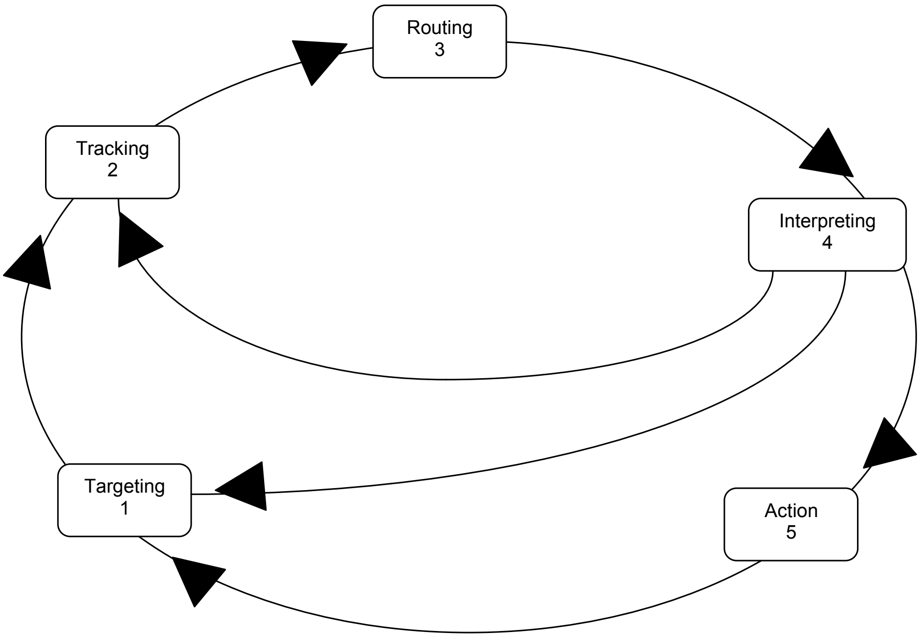
This section evaluates the extent to which conventional BIS constructs are equipped to reflect sustainability's characteristics of uncertainty and complex manufactured risks (following Beck, 1993).

BI has evolved over the last 35 years, from analytical software packages, to spreadsheet software, to executive information and decision support systems in the 1990s that provided decision-makers with easy access to internal and external information (Rasmussen et al., 2002; Volonino et al., 1995; Carlsson and Turban, 2002). Petrini and Pozzebon (2009) explain that BI subsequently emerged from advances in data warehouse technologies (Kimball, 2000; Devlin, 2010), extraction-transformation-and-loading tools and online analytical processing capabilities (Body et al., 2002; Grigori et al., 2004). Hence, BI refers to analytical and strategic information systems that include data mining, monitoring (via dashboards and scorecards), and reporting. Even though this emergent heterogeneous data is valuable BI, the amount and diversity of the data complicates the task of information management (Mikroyannidis and Theodoulidis, 2010).

Here we take a managerialist approach to BI because it is an informational approach that minimises the chances of creating a BIS blackbox, which alienates lay-stakeholders, by examining how internal and external data are integrated into relevant meaningful intelligence (Luckevich et al., 2002; Kalakota and Robinson, 2001; Liautaud, 2000). It reflects the political, social and technical aspects of organisational behaviour by engaging with social norms, rules and organisational procedures (Liang et al., 2007; Ke et al., 2009). By contrast a technical approach focuses on the technologies to record, recover, manipulate and analyse the information (Kudyba and Hoptroff, 2001; Watson et al., 2002; Hackathorn, 1999).

Managerially, BI is a cyclical process of systematically targeting, tracking, routing and interpreting signals into actionable information (Rouibah and Ould-Ali, 2002): Figure 1.

Figure 1 Phases in constructing BI



Source: Rouibah and Ould-Ali (2002) adapted from Lesca (1994)

Targeting/scanning identifies sources of strong and weak signals (Cyert and March, 1963). Tracking identifies, selects, constructs and monitors these signals. Routing channels external signals into an organisation's information system whilst interpretation transforms them into actionable intelligence. Interpretation modifies the targeting and tracking phases if these signals are imprecise, or if the scope is to be redefined. Interpretation is the most difficult phase because of its potential to distort BI (Rouibah and Ould-Ali, 2002), which is compounded by the inclusion of weak signals because of their anticipatory, uncertain, ambiguous, fragmentary, dynamic, cyclical and often, qualitative characteristics (El Sawy, 1985). Rouibah and Ould-Ali (2002) put forward a version of the software PUZZLE, which constructs less fragmented maps of social relationships between organisational players by combining weak and strong socio-economic signals. The generic term, puzzle, reflects the uncertainty and ambiguity inherent in weak signals.

Their emergent PUZZLE employs the actor/theme/information tracking system to collate pieces of data related to a theme or specific actor. Its visual map is "focused on a specific actor, where its nodes are small sentences (phrases) corresponding to weak signs [signals]; and edges are reasoning links (confirmation, contradiction, causality) which connect different modes" [Rouibah and Ould-Ali, (2002), p.142]. PUZZLE is used as a flexible "working agenda for discussions when interpreting weak" signals (ibid., p.144): it is continually reconstructed as new weak signals are collected. Several puzzles are constructed until the one that holds most meaning for its users is developed.

The authors assert that their PUZZLE could mediate conflicts between competing interests. We argue that it is not equipped to engage with the political aspects of how risk is perceived by competing-yet-interdependent interest groups in Beck's society because it fails to draw attention to risks associated with degradation of shared resources. Nevertheless PUZZLE's following constructs have the potential to address the intelligence needs of Beck's risk society. Firstly, PUZZLE has the capacity to facilitate bottom-up participation and collaboration in the interpretive phase through assimilation (i.e., the inclusion of new signals into an existing cognitive map), accommodation (the modification of a cognitive map to reflect new signals), and structuring (the construction of new cognitive maps). It may be extended to facilitate social learning because it is already couched in Piaget's (1996) and Norman's (1982) learning enablers and Simon's (1960) concept of bounded rationality.

Secondly, PUZZLE's five phases of BIS implementation (Figure 1) socialise weak signals: its database stores/retrieves signals and captures users' tacit knowledge, whilst its mapping tool uses a drawing graph to construct and analyse puzzles. These signals are linked through three descriptors, causality, confirmation and contradiction. These descriptors socialise contested signals by revealing the underlying cause-effect relationship, confirming the message embedded in the signals, or highlighting the contradictions between these signals. This process of socialising weak signals could be enhanced to acknowledge Beck's politics of risk. Thirdly, PUZZLE's visual representation of weak signals acknowledges that people are better able to cognitively process visual information (Meyer, 1991). Its design could be enhanced to increase the likelihood of (Beckian) reflexivity by recognising that short-term memory can only process 7 ± 2 pieces of information at a time (Miller,1956).

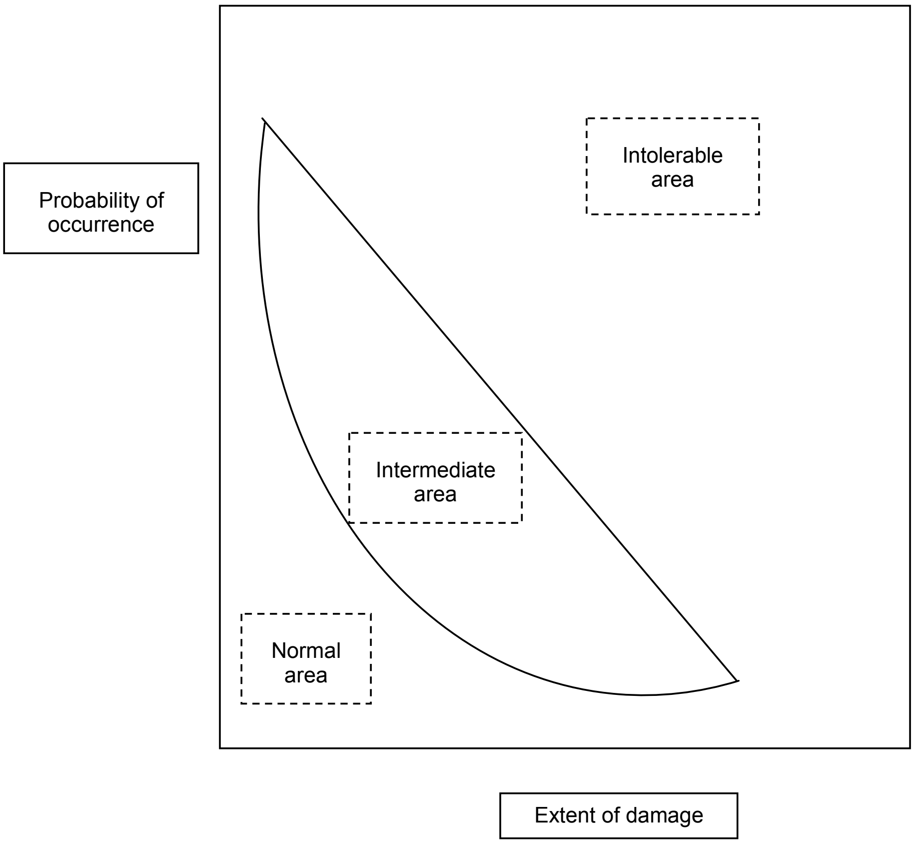
Next we develop a language of socialised risk that could be used by BIS to reduce the potential for distortion caused by the inclusion of weak environmental signals in its interpretive phase. This language would

1. recognise the politics inherent in risk society
2. draw attention to the sustainability characteristics of complexity, uncertainty and shared risks
3. enable participating actors to acquire capacities to socially learn to care for shared resources despite the underlying complexity and uncertainty about the sustainability ethos.

4 Socialised risk discourse

Beck calls for a "different ontology and aetiology of risk" to complement risk society's heightened sensitivity to the social and political consequences of manufactured risks and uncertainties [in Ekberg, (2007), p.347]. Bier et al.'s (2004) review of classical approaches to risk modelling concludes that discursive ‘analytical-deliberative’ (p.91) risk discourse would assist people respond to threats confronting risk society. Piechowski (1994 cited in Klinke and Renn, 2002) uses normal, intermediate and intolerable categories of risks (Figure 2) to represent these threats.

Figure 2 Risk zones



Source: German Advisory Council on Global Change (WBGU) (2000, p.19)

Normal risks represent a category with little statistical uncertainty. They are ubiquitous but they have low catastrophic potential, and hence may be managed through conventional safety-oriented regulations. Risks that fall into the intermediate and intolerable area include the high-consequence/low-probability events that symbolise the cumulative consequence of multiple environment-degrading activities. Beck (1993) argues that conventional regulations and expertise have failed to protect society from these manufactured risks because they cannot be reduced to probabilistic quantifications. Emergent risk discourse should reflect his three pillars of manufactured risk: the first pillar acknowledges that the causal relationship between humans and nature is a complex interrelated one which is couched in uncertainty. The second pillar highlights the catastrophic potential of manufactured risk, whilst the third pillar concedes that the sustainability ethos is not compatible with modernity’s assumptions of growth. Discourse that disregards these pillars would fabricate certainty and delay the urgent need to radically change unsustainable production methods and consumption patterns (Economic and Social Research Council, 2000).

Beck's pillars manifest as his continuum of risk and danger: danger refers to the inescapable consequence of the lifestyle of an unsustainable society, whilst risk is a controllable construct that may be managed through individual actions (Beck, 1999). Risk remains related to the danger as danger is caused by the "threatening force of modernization". Hence discourse constructed on a risk-danger profile for the larger catchment creates a discursive space that enables the local community to become 'politically reflexive' [Beck, (1993), p.21] as it acquires social learning capacities which enable it to adapt strategies to prioritise the resilience of the ecosystem (Reed et al., 2006). We show the practical relevance of Beck's continuum by restating the earlier-mentioned ISO 31000 in the context of BIS' interpretative phase: manufactured risk's characteristic complexity-uncertainty should be reflected in BI that includes environmental signals.

At this juncture we evaluate 2 practical frameworks that apply Beckian constructs in developing 'analytical-deliberative' spaces for engaging with intermediate and intolerable risk whilst facilitating social learning: Klinke and Renn (2002) and Saravanamuthu (2009).

4.1 Analytical-deliberative risk management

Klinke and Renn's (2002) analytical-deliberative decision tool relies on the force of reason to generate community consensus on how sustainability indicators should be socialised. Although they concede that this search for the "right discourse" amidst uncertainty is "clouded by misinformation, biases, and limited experience" (p.1075), they maintain that it is a journey worth embarking on as it addresses gaps in conventional knowledge about intermediate and intolerable areas of risk.

Unfortunately, their notion of 'deliberation' is contingent on stakeholders participating equally in discursive dialogue (following Webler and Tuler, 1999). They circumvent problems associated with entrenched asymmetrical power relationships by randomly selecting citizens to participate in their decision-making panel. This contrived depoliticised solution does not reflect the social process through which uncertainty becomes risk (following Beck, 1993). It undermines their aim of developing a decision tool that reflects "social diversity and political feasibility" [Klinke and Renn, (2002), p.1072].

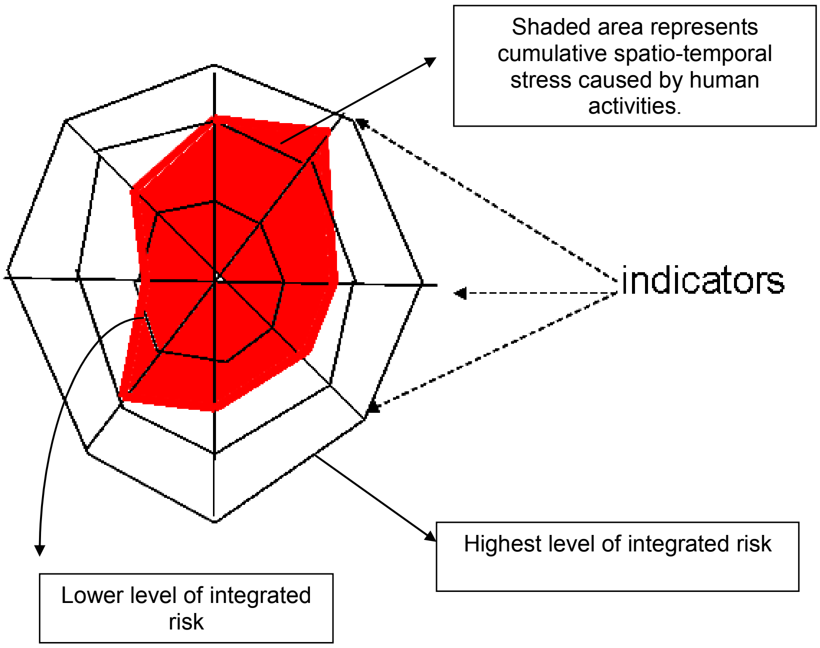
Next we evaluate Saravanamuthu's (2009) risk management accounts that seek to engender greater reflectivity by combining strong and weak environmental signals in a participatory manner. The participatory process empowers stakeholders to contest the partisan assumptions used in the construction of conventional knowledge in favour of values that inflict less harmful on the environment.

4.2 Integrated risk management

Saravanamuthu's (2009) multi-attribute risk accounts reflect Gandhi's politico-economic strategies for social reforms – *satyagraha and swaraj* – that were used to secure India's independence. These accounts operationalise Beck's politics of risk because they aim to enable competing voices to shape the sustainability discourse.

Satyagraha refers to Gandhi's assertive search for truth by creating discursive spaces for people to emancipate themselves and society. The aim of the *satyagrahic* discourse is *swaraj*, that is, emancipation from contradictions that are caused by (human) activities that are out-of-sync with nature's rhythm of life. Both Gandhi (2001) and Beck problematise the notion that an ecosystem may be 'safely' sacrificed for economic growth and assert that sustainability is not a zero sum game. Hence, the *satyagrahic* methodology states that humans are an integral part of nature: it implies that people should take responsibility for their decisions.

Figure 3 Visual accounts reflecting interconnectivity between multiple-dimensions of sustainability (see online version for colours)



The risk discourse used in *satyagrahic* accounts is constructed from expert and lay-community perceptions of the extent to which socio-commercial activities collectively stress a catchment's carrying capacity by fragmenting nature's spatio-temporal dimensions. For instance, if native forests were logged once every 80 to 120 years but the forests required 500 to 600 years to regrow (Donovan, 2009), it is obvious that the forests' renewal cycle is being stressed by the commercial logging practices. We use the mid-point of renewal cycle, 550 years, as the baseline to calculate the stress factor:

$$\frac{\textit{Commercial timeline}}{\textit{Baseline}\ 550} = 100 = 0.18$$

0.18 implies that the logging operations could be unsustainable. Other causes of forest degradation would have to be monitored, measured and converted into stress factors to present a more complete picture of degradation. *Satyagrahic* accounts use the radar plot to visually represent stress factors for each cause/attribute of environmental degradation: Figure 3.

Each of the spokes of the radar plot represents a cause of environmental degradation, whilst the shaded area from the origin represents the cumulative integrated risk posed to nature. In other words, *satyagrahic* accounts represent Beck's risk-danger profile as a dashboard display of strong and weak environmental indicators. These accounts normalise the precautionary ethos by encouraging stakeholders to overcome a defensive urge to prioritise private interests, and engage with shared risks that would ultimately impinge on private interests. The *satyagrahic* methodology counters hegemonic growth assumptions embedded in BIS by transparently revealing the contestable nature of its account of performance. It also mitigates distortion emanating from heuristics by opting for relative rather than absolute representations of risk (Hux and Naylor, 1995; Rottenstreich and Tversky, 1997).

However, Saravanamuthu (2009) does not demonstrate how this multi-attribute data is socially translated into the risk-danger profile. We do so (below) through our semi-qualitative risk matrix.

Table 1 Generic categories to describe the likelihood of a hazard

Level	*Likelihood*	*Description*
A	Almost certain	Based on hindsight, expect that risk event *will* occur
B	Likely	Event has occurred in the past, and *could* occur again – lived experiences
C	Possible	Event *might* occur once in the future
D	Unlikely	Could occur but not expected
E	Rare	Only occurs rarely in exceptional circumstances

Source: Risk Management Guidelines (2005, Table 6.4, p.54, adapted)

Table 2 Generic classifications to describe the anticipated consequence of a hazard

Level	*Consequence descriptor*	*Definition*
I	Severe or catastrophic fragmenting impact	An impact that seriously affects the environment, changing the eco-system significantly
II	Major	An impact that is less than I above but still poses significant loss of habitat to ecological communities. Recovery possible in the long term
III	Moderate	An impact that is confined to certain areas in the catchment only. Recovery possible
IV	Minor	Local impact and recovery possible in short term
V	Insignificant fragmenting impact	Extremely localised with insignificant impact on catchment ecology

Source: Risk Management Guidelines (2005, Table 6.3, p.54, adapted)

4.3 Semi-qualitative risk matrix

We construct our semi-qualitative from the wholly qualitative risk matrix advocated by Standards Australia's AS/NZS 4360 (2004) and its companion Risk Management Guidelines (2005) because they recognise the difficulty in representing the complexity and uncertainty associated with sustainability.

The guideline reflects non-linear relationships by opening up the linear representation of risk, risk = a function of (consequence and likelihood), into a wholly qualitative matrix. Table 1 shows the narratives it uses to describe the likelihood of occurrence of a risk event, whilst Table 2 expresses consequences in terms of levels of severity.

The risk that emanates by 'multiplying' Table 1 and Table 2 are represented through a matrix, Table 3.

Table 3 wholly qualitative risk matrix

Likelihood	*Consequences*				
	I	*II*	*III*	*IV*	*V*
A	Medium	High	High	Very high	Very high
B	Medium	Medium	High	High	Very high
C	Low	Medium	High	High	High
D	Low	Low	Medium	Medium	High
E	Low	Low	Medium	Medium	High

Source: Risk Management Guidelines (2005, p.55)

The Guideline recognises that these qualitative narratives could be increasingly quantified as more knowledge is accumulated. Our semi-qualitative matrix is one such shift towards greater quantification. Due to space constraint, we use a case-study to demonstrate how our risk matrix uses the *satyagrahic* logic to transform Table 3 into a semi-qualitative matrix that provides an analytical-deliberative platform for experts and lay-people to participate in integrating strong and weak environmental signals into actionable BI.

5 A case-study on the environmental impact of irrigation practices

The case-study was located in the Lower Course of Australia's primary river system, the Murray-Darling. This longitudinal case-study began in 2004 and concluded in 2010. The purpose of the study was to use real-life irrigation data to firstly construct a semi-qualitative risk matrix which would provide a platform for experts and lay-irrigators to participate in integrating strong and weak environmental signals into actionable BI: here BI took the form of annual *satyagrahic* accounts for the period 1998/1999 to 2007/2008. Secondly, we evaluated the effectiveness of this participation by assessing the extent to which these matrices and accounts enabled irrigators to acquire social learning capacities. This study is based on triangulated evidence from semi-structured interviews with seven irrigators, regulatory bodies, reports issued by a regional supervisory body (the River Murray Catchment Management Board) and scientific interest groups, irrigation statistics from 1997/8 to 2007/8, newspaper articles and insights gained from regional water management workshops.

5.1 Background

Local irrigators had extracted water from an underground artesian basin and from the Murray-Darling River since the 19th century. Over time, their irrigation practices culminated in two environmental hazards: firstly, extreme degradation of the River because its waters had long been overallocated for human consumption, with catastrophic consequences for surrounding ecosystems. Secondly, irrigators' over-reliance on the artesian water caused the water-table to fall, and soil salinity to increase.

By 1993, these hazards became so obvious to irrigators that they voluntarily banded together to form a Water Committee to monitor attributes of efficient usage of surface and ground water – in the form of volumes of ground/artesian and River water extracted, area irrigated, average irrigation and types of crops cultivated. These monitored attributes were collated into Annual Irrigation Accounts (AIA). The AIA was constructed from strong signals on efficient utilisation of water. It did not consider weaker signals on the impact of irrigation on the resilience of the natural water cycle. Consequently, the AIA discourse culminated in 'bare minimum thinking' because it did not contest taken-for-granted norms about water efficiency:

> "So we are looking at water statistics, and asking how we can do it to maintain the [water] licence, and how we can do it better. I think when you look at that, we just have to do this to keep our [water extraction] licence. …. this is the bare minimum" (Irrigator D).

Ideally AIA should have enabled the community to reflexively learn to minimise the extent to which irrigation practices stressed the natural water cycle. Irrigators were aware of how AIA's vocabulary of efficiency dichotomised the financial from ecological aspects of sustainability:

> "Sustainability is keeping our investors happy and going about that, obviously they need to make some money. The way they do that is by having a vineyard that is producing quality fruit at the best quality price. Sustainability is having a local biodiversity which covers fauna, flora, insects…" (Irrigator D).

Consequently, the process of monitoring and reporting irrigation statistics became an end in itself (also de Bruyn, 2009); it did not galvanise social learning.

5.2 First purpose of study: constructing a semi-qualitative risk matrix

A risk-danger matrix was constructed (in a participatory manner through discussions with the irrigation community and hydrological experts) to reflect normal, intermediate and intolerable risks posed by irrigation: Table 4. Hydrological experts refer to specialists who possessed technical knowledge about salinity and water-table issues; they were employed by regulatory bodies but till now, their input into irrigation monitoring was restricted to top-down, rather than participatory, prescriptions.

The body of Table 4 represented the catchment's risk-danger profile (following Beck, 1993): it provided the context for translating individual stress factors into estimates of perceived risk inflicted on the catchment. A scale of perceived integrated risk, from (i) to (v), was constructed by iteratively consulting all stakeholders.

Table 4 Integrated risk matrix for case-study catchment (see online version for colours)

Likelihood of occurrence: descriptors	*CONSEQUENCES Expressed as extent to which irrigation stresses natural water cycle*				
↓	*Most stressed*	*More stressed*	*Status-quo baseline*	*Less stressed*	*Least stressed*
	More than 1.25	*More than 1, but less than 1.25*	*1*	*Less than 1, but more than 0.50*	*Less than 0.50*
Almost certain	(v)	(v)	(iii)	(ii)	(ii)
Likely	(v)	(v)	(iii)	(ii)	(ii)
Possible	(v)	(iv)	(iii)	(ii)	(i)
Unlikely	(iv)	(iv)	(iii)	(i)	(i)
Rare	(iv)	(iv)	(iii)	(i)	(i)

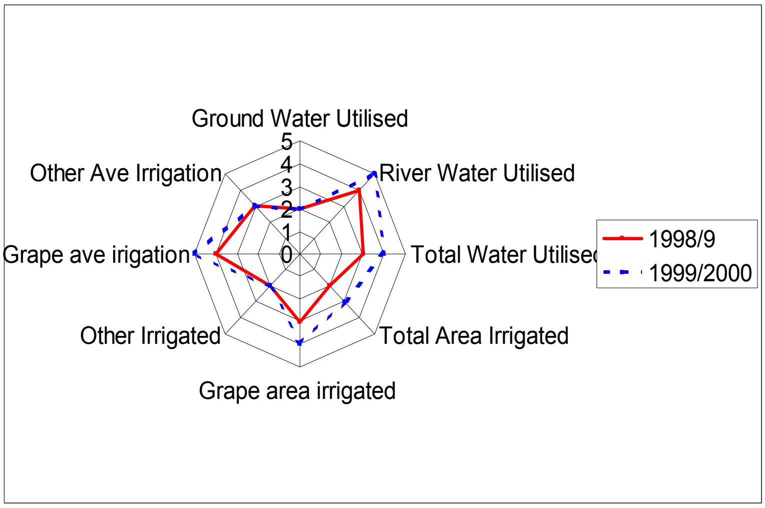
Notes: Legend for integrated risk estimates (see body of matrix above):
(i) represents low risk;
(ii) represents moderate risk;
(iii) represents high risk;
(iv) represents very high risk;
(v) represents extreme risk

This risk-danger profile is used to evaluate the impact of each contributing stress factor, thus forcing decision-makers to engage with big-picture environmental concerns. The profile was constructed as follows. We began with a profile that would represent a (hypothetical) balanced catchment: 50% of the body of the matrix would represent higher risk zones, and the remaining 50% would reflect lower risk zones. However this case-study was not a balanced catchment; it had been degraded by decades of over-irrigation. We subsequently modified this balanced risk-danger profile to reflect local circumstances by iteratively socialising top-down expertise of salinity and water-table issues, with lay-persons' lived experiences of these hazards. A highly degraded catchment has proportionally more extreme and high risk boxes in the body of the matrix – it means that each contributing stress factor could more easily tip the danger profile into intolerable risks. The iterative construction process mitigates hegemonic influences of expert knowledge because it empowers lay-participants to contest embedded notions of externalities, and deliberate about the implications of resulting risks. The resulting risk-danger profile shows the cumulative context for evaluating stress associated with every known (and measured) cause of degradation risk. This matrix is the start of a longer journey of learning from past experiences to mitigate the amount of stress inflicted in the natural environment.

We now demonstrate how irrigation statistics for year 1998/1999 were processed through the matrix. Appendix 1 shows the data for the base year 1997/1998, and two subsequent years 1998/1999 and 1999/2000. The extent to which irrigation in 1998/1999 stressed the baseline was calculated as a fraction or multiple of the baseline data. So, in 1998/99, the stress factor for Measure 1 (Ground Water Utilised) was 0.88 as less water (i.e., 2107 ML) was extracted than in the base year (2392 ML): it was deemed to have placed less stress on the water cycle. The stress factor was similarly calculated for the major categories of irrigation statistics that have been numbered (from 1 to 8) in Appendix 1, and crops' thirst-index (or water consumed).

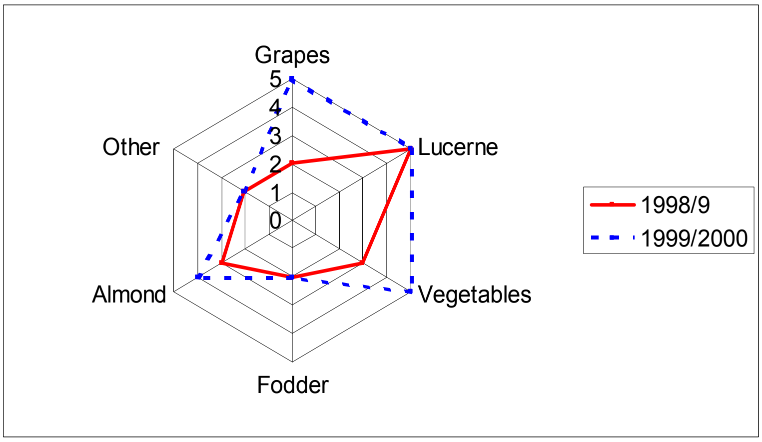
The irrigation community and experts were consulted in the social process of translating each stress factor into an indicator of perceived risk through the risk-danger matrix. Continuing with the stress factor of 0.88 for Measure 1, it appears as a ‘raw measure’ in the third row of the matrix in Appendix 2. It was subsequently socialised and translated into a category (ii) risk, that is, a ‘possible’ likelihood of occurrence of danger (of salinity and water-table fluctuation) and, ‘less stressed’ consequence rating. The reasons noted below Appendix 2 provide real world context why the ‘possible-less stressed’ rating was assigned.

Figure 4 Comparative overall integrated risk profile for 1998/1999 and 1999/2000 (see online version for colours)



Notes: Baseline = 1997/8 rated as 3, i.e., high integrated risk

Figure 5 Comparative water consumption by crops for 1998/9 and 1999/2000 (see online version for colours)



The measures of risk for each of the monitored attributes were then represented together through a radar plot: due to space constraint, we provide comparative *satyagrahic* risk accounts for 1998/1999 and 1999/2000 only in Figure 4 and Figure 5. The area from the origin to the tips of each of the radar plots refers to the overall risk-danger profile of irrigation practices with respect to the catchment's salinity and water-table.

5.3 Second purpose of study: assess the extent to which irrigators acquired social learning capacities

We now assess the extent to which irrigators acquired Pahl-Wostl and Hare's (2004) social learning capacities by using semi-qualitative risk matrices (based on Table 4) and *satyagrahic* accounts (Figure 4 and Figure 5) to mitigate stress inflicted on the natural water cycle. In-depth interviews were conducted with seven irrigators to ascertain the extent to which this integrated risk information caused them to collectively rethink their irrigation practices.

Four irrigators readily accepted the *satyagrahic* mode of representation as they were already familiar with risk management tools:

> "How do we rate, in the scheme of things, in our vineyard and give it a rating? Basically there are two areas of rating. One is the probability of it and the other is consequence: basically you look at the risk management…the naturalness of the water resource, and the probability it is going to happen" (irrigator D).

These irrigators were conscious of the need to go beyond bare minimum thinking associated with strong (efficiency) signals:

> "…[there is a need to] collect more integrated data that can then be used to set quantifiable benchmarks…There is definitely benefit in any data which takes a macro view of our environment down here. I think it would assist in our decision making going forward with our water resources. We all understand at the moment that our ground water aquifer is under some level of stress" (Irrigator B).

> "I like the word risk – it sort of invokes a little bit more attention than other terminology used. I suppose we need to define, as growers and as irrigators, what are the consequences of that risk. I think that the risk is pretty clear on some of those things, but there is probably a lot of risk that we probably don't think about. Clarifying what the consequences are would be good" (Irrigator C).

These irrigators took advantage of the transparency accorded by the semi-qualitative risk matrix to interrogate its underlying assumptions, and in the process, socialise technical irrigation metrics to better represent their lived experiences:

> "As you said, looking at salinity issues and crop use efficiencies and the like, really makes growers think, 'Well what if I am doing isn't sustainable?'….For me the big issue for growers here is the sustainability issue. And that ties very well into the whole risk profile that you have developed. I think that to aim for a sustainable level of risk would be where we would be going because in any business you are always going to have levels of risk, but in agriculture the breaking point is obviously very clear and we just need to understand this" (Irrigator D).

Three irrigators, who were less familiar with formal risk management tools, displayed different responses: two began to appreciate the need to prioritise the natural water cycle once the workings of the risk-danger matrix and profile was explained to them. An irrigator wanted to enhance the analytical aspects of these accounts by using scientifically derived baseline data from a recently formulated hydrological model. This data would become available in 2011, after the conclusion of this study. He interrogated the use of irrigation data for 1997/1998 as the baseline in Table 4:

> "I can see where you are headed with these matrices: that is just normal risk management matrix. But I would see that growers – and I have trouble with it – would have a lot of trouble with the consequence column that just uses a multiplying factor from a baseline year say that it was more stressed or is most stressed. But I think in the meantime, they will have a lot of trouble with risk scales, a lot of trouble accepting that once it gets over 1.25 that you call it most stressed…. I think it is going to be useful but they are going to demand that those [consequence scale] columns be accurately defined through a tool such as through the Dept of Water Land Biodiversity and Conservation model" (Irrigator E).

The remaining irrigator, a member of the older generation of growers, was uncomfortable with using a risk matrix to formalise the process of assessing risk. He had always implicitly and subjectively considered the risk posed by irrigation practices. He did not reject the information outright but preferred younger employees be interviewed as they would be more familiar with formal qualitative risk-management tools.

Our study demonstrates the potential for risk matrices (and *satyagrahic* accounts) to sow the seeds of social learning by providing an analytical platform for discursive deliberations about the risk associated with irrigation technologies. The quotations show irrigators appreciating each other's competing-and-interdependent goals and perspectives, identifying their shared problems, and engaging with the complexities of the salinity-watertable challenges. In the long run, these capacities should motivate this community to work collaboratively, adding an informal dimension to their formal membership of the Water Committee. These developments should result in greater trust among irrigators with competing irrigation perspectives and technologies.

6 Discussion and conclusion: reducing distortion in BIS' interpretive stage

Management has to develop new insights if it is to respond appropriately to risk society's hazards. Beck's risk-danger ontology provides the platform for socially constructing an analytical-deliberative risk discourse that better reflects the uncertainty and complexity inherent in knowledge about environmental degradation. This platform creates spaces for competing voices to interrogate taken-for-granted hegemonic assumptions, problematise unsustainable practices, and thus construct adaptive management practices. This paper suggests using BIS to implement this discourse because BIS is one of the 'disruptive technologies' that have the capacity to initiate radical changes (Goleman, 2009).

Our BIS literature review builds on this potential for change: we advocate using socialised, non-probabilistic concepts of risk in BIS' interpretive phase to integrate weaker signals. Our non-probabilistic risk is socially constructed via a semi-qualitative risk matrix. It provides an analytical-deliberative platform for experts and lay-people to participate in integrating strong and weak environmental signals into actionable BI. This matrix applies Beck's risk-danger concepts: it

1 reinforces the concept that environmental degradation is the cumulative outcome of multiple causal activities

2 creates spaces for competing stakeholder concerns to be heard

3 embeds the precautionary ethos in management culture despite the uncertainty inherent in environmental discourse.

In practical terms, our matrix is a vehicle for reducing the potential for distortion in BIS' interpretive phase that emanates from the process of integrating weaker environmental signals into BI. Whilst the matrix and the multi-attribute *satyagrahic* information could be used for simulation exercises, it is better used as a platform for empowering stakeholders to put forward competing meanings of environmental intelligence as they learn about the causes and effects of environmental degradation in their local catchment. These outcomes were illustrated through the irrigation case-study.

Our case-study was located in a community that had become aware that their irrigation technologies unduly stressed the natural water cycle and consequently undermined the long-term sustainability of their farms. However, they lacked a politico-informative space that would allow them to engage with each other and collectively deal with issues about managing shared resources. The *satyagrahic* accounts and proposed risk matrices were constructed as the next logical step (for integrated information) from existing AIAs (that contained un-integrated irrigation indicators). Our integrated accounts supplied dashboard displays of multiple performance indicators: they created spaces for irrigators and hydrologists to collaborate together to mitigate the effect of irrigation practices on the catchment's salinity and water-table.

The relevance of this study to business: even though corporations are reticent to collaborate with non-equity interests, companies cannot afford to disregard public opinion. Transparent risk-based accountability recognises the absence of a single uncontested definition of sustainability and allows other actors to participate in the construction of business priorities. Nonetheless, our contribution is not the final and ultimate solution to sustainability challenges. It is part of the longer journey of incrementally improving how an organisation engages with uncertainty caused by unsustainable norms and practices, which brings us to the limitations of our methodology. Firstly, our risk matrix increases the level of quantification in the Risk Management Guidelines' (2005) wholly qualitative matrix because we aim to construct an analytical-deliberative platform: it implies that we have a data-rich methodology. On the one hand, the presence of scientifically-valid data enhances the credibility of the analyses, and enables lay-persons to become more technically proficient. On the other hand, the tool cannot be applied in risk communities that do not have an environmental monitoring programme. Implementing such a programme from scratch is a costly exercise. Secondly, the risk matrix is used to assess risk by iteratively interacting and consulting participating stakeholders. This information is then represented as *satyagrahic* accounts: a significant amount of time involved in constructing the very first set of accounts because of the time involved in explaining how the matrix works.

References

Ansoff, H.I. and McDonnell, E. (1990) *Implanting Strategic Management*, 2nd ed., Prentice Hall, NY.

Beal, R.M. (2000) 'Competing effectively: environmental scanning, competitive strategy, and organisational performance in small manufacturing firms', *Journal of Small Business Management*, Vol. 38, No. 1, pp.27–47.

Beck, U. (1993) *Risk Society. Towards A New Modernity*, Trans. Ritter, M. Sage Publications, London.

Beck, U. (1995) *Ecological Politics in an Age of Risk*, Polity Press, Cambridge.

Beck, U. (1999) *World Risk Society*, Polity Press, Cambridge.

Beck, U. (2001) 'Ecological questions in a framework of manufactured risks', in Seidman, S. and Alexander, J.C. (Eds.): *The New Social Theory Reader: Contemporary Debates*, pp.267–275, Routledge, Taylor & Francis, London.

Bier, V.M., Ferson, S., Haimes, Y.Y., Lambert, J.H. and Small, M.J. (2004) 'Risk of extreme and rare events. Lessons from a selection of approaches', in McDaniels, T. and Small, M.J. (Eds.): *Risk Analysis and Society. An Interdisciplinary Characterization of the Field*, Cambridge University Press, Cambridge, UK.

Body, M., Miquel, M., Bedard, Y. and Tchounikine, A. (2002) 'A multidimensional and multiversion structure for OLAP applications', in the *Proceedings of the 5th ACM International Workshop on Data Warehousing and OLAP*.

Bose, I. (2006) 'Deciding the financial health of dot-coms using rough-sets', *Information Management*, Vol. 43, No. 7, pp.835–846.

Carlsson, C. and Turban, E. (2002) 'DSS: directions for the next decade', *Decision Support Systems*, Vol. 33, No. 2, pp.105–110.

Cyert, R. and March, J. (1963) *A Behavioural Theory of the Firm*, Prentice Hall, Englewood Cliffs, NJ.

Dahl, A.L. (2007) 'Integrated assessment and indicators', in Hak, T., Moldan, B. and Dahl, A.L. (Eds.): *Sustainability Indicators. A Scientific Assessment*, SCOPE 67, Island Press, Washington DC.

Dahl, R. (1985) *Controlling Nuclear Weapons: Democracy versus Guardianship*, Syracuse, Syracise University Press, NY.

Dahl, R. (1989) *Democracy and its Critics*, Yale University Press, New Haven, CT.

de Bruyn, L.L. (2009) 'Reasons, means and consequences: monitoring soil condition for 'the proper use of land' in agricultural landscapes', *Advances in Public Interest Accounting*, Special issue on 'Extending Schumacher's total accountability into the 21st century: the accountability interface between the science of climate change and the sustainability discourse', Vol. 14, pp.261–296.

Devlin, B. (2010) 'Beyond business intelligence', *Business Intelligence Journal*, Vol. 15, No. 2, pp.7–16.

Donovan (2009) 'Felled old-growth tree '500 years old'', *ABC News* [online] http://www.abc.net.au/news/stories/2009/04/02/2532783.htm?section=justin (accessed April 2).

Eckerson, W. (2006) 'New ways to organize the BI team', *Business Intelligence Journal*, Vol. 11, No. 1, pp.43–48.

Economic and Social Research Council (2000) 'Summary: what have we learnt about sustainable production and consumption?', in the *Global Environmental Change: Re-thinking the Questions Programme,* UK [online] http://www.gecko.ac.uk/doc-c/coredoc-c-summary.html (accessed January 2001).

Ekberg, M. (2007) 'The parameters of the risk society. A review and exploration', *Current Sociology*, May, Vol. 55, No. 3, pp.343–366.

El Sawy, O. (1985) 'Personal information systems for strategic scanning in turbulent environments: can the CEO go on-line?', *MIS Quarterly*, March, Vol. 9, No. 1, pp.53–60.

Elkington, J. (1997) *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*, Capstone, Oxford.

Falkenmark, M. (2004) 'Towards integrated catchment management: opening the paradigm locks between hydrology, ecology and policy making', *Water Resources Development*, September, Vol. 20, No. 3, pp.275–282.

Funtowicz, S.O. and Ravetz, J.R. (1992a) 'The good, the true and the post-modern', *Futures*, Vol. 24, No. 10, pp.963–976.

Funtowicz, S.O. and Ravetz, J.R. (1992b) 'Three types of risk assessment and the emergence of post-normal science', in Krimsky, S. and Golding, D. (Eds.) *Social Theories of Risk*, pp.251–274 Praeger Publishers, Westport, CT.

Funtowicz, S.O. and Ravetz, J.R. (1993) 'Science for the post-normal age', *Futures*, Vol. 25, No. 7, pp.739–755.

Gandhi, M.K. (2001) *India of My Dreams*, Compiled by Prabhu, R.K. Ahmedabad: Navajivan Publishing House, Ahmedabad, India.

German Advisory Council on Global Change (WBGU) (2000) *World in Transition. Strategies for Managing Global Environmental Risks. Annual Report 1998*, Springer, Berlin [online] http://www.wbgu.de/wbgu_jg1998_engl.pdf (accessed January 2006).

Gibson, M., Arnott, D. and Jagielska, I. (2004) 'Evaluating the intangible benefits of business intelligence: review and research agenda', *Conference Proceedings, Decision Support in an Uncertain and Complex World: The IFIP TC8/WG8.3 International Conference*, Stockholm, Sweden.

Goleman, D. (2009) 'Green intelligence: towards true ecological transparency, analysis', *Yale Environment 360*, 15 September [online] http://e360.yale.edu/feature/green_intelligence_toward_true_ecological_transparency/2190/ (accessed June 2010).

Gray, R.H. (2002) 'The social accounting project and accounting organisations and society: privileging engagement, imaginations, new accountings and pragmatism over critique?', *Accounting, Organizations and Society*, Vol. 27, No. 7, pp.687–708.

Grigori, D., Casati, F., Castellanos, M., Dayal, U., Sayal, M. and Shan, M.C. (2004) 'Business process intelligence', *Computers in Industry*, Vol. 53, pp.321–343.

Grove, A.S. (1999) *Only the Paranoid Survive: How to Exploit the Crisis Points that Challenge Every Company*, Currency-Doubleday, New York.

Hackathorn, R. (1999) 'Farming the web for systematic business intelligence', *Proceedings of the 5th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, San Diego, USA.

Hak, T., Moldan, B. and Dahl, A.L. (Eds.) (2007) *Sustainability Indicators. A Scientific Assessment*, SCOPE 67, Island Press, Washington DC.

Hux, J.E. and Naylor, C.D. (1995) 'Communicating the benefits of chronic preventative therapy: does the format of efficacy data determine patients' acceptance of treatment?', *Medical Decision Making*, Vol. 15, No. 2, pp.152–157.

Kalakota, R. and Robinson, M. (2001) *E-business 2.0 – Roadmap for Success*, Addison-Wesley, NY.

Ke, W., Liu, H., Wei, K.K., Gu, J. and Chen, H. (2009) 'How do mediated and non-mediated power affect supply chain management system adoption? The mediating effects of trust and the institutional pressures', *Decision Support Systems*, Vol. 46, No. 4, pp.839–851.

Kimball, R. (2000) *The Data Warehouse Toolkit: Practical Techniques for Building Dimensional Data Warehouses*, Wiley, NY.

Klinke, A. and Renn, O. (2002) 'A new approach to risk evaluation and management: risk-based, precaution-based, and discourse based strategies', *Risk Analysis*, Vol. 22, No. 6, pp.1071–1094.

Kudyba, S. and Hoptroff, R. (2001) *Data Mining and Business Intelligence: A Guide to Productivity*, Idea Group Publishing, PA.

Landers, K. (2010) *US Congressional Panel Roasts BP Chief*, Australian Broadcasting Corporation, June 18 [online] http://www.abc.net.au/news/stories/2010/06/18/2930221.htm.

Liang, H., Saraf, N., Hu, Q. and Xue, Y. (2007) 'Assimilation of enterprise systems: the effect of institutional pressures and the mediating role of top management', *MIS Quarterly*, Vol. 31, No. 1, pp.59–87.

Liautaud, B. (2000) *E-Business Intelligence: Turning Information into Knowledge into Profit*, McGraw-Hill, NY.

Lonnqvist, A. and Pirttimaki, V. (2006) 'The measurement of business intelligence', *Information Systems Management*, Vol. 23, No. 1, pp.32–40.

Luckevich, M., Vitt, E. and Misner, S. (2002) *Business Intelligence*, Microsoft Press, Washington.

March, S.T. and Hevner, A.R. (2007) 'Integrated decision support systems: a data warehousing perspective', *Decision Support Systems*, Vol. 43, No. 3, pp.1031–1043.

Massa, S. and Testa, S. (2005) 'Data warehouse-in-practice: exploring the function of expectations in organizational outcomes', *Information Management*, Vol. 42, No. 3, pp.709–718.

Meyer, A.D. (1991) 'Visual data in organizational research', *Organisation Science*, Vol. 2, No. 2, pp.2108–2136.

Mikroyannidis, A. and Theodoulidis, B. (2010) 'Ontology management and evolution for business intelligence', *International Journal of Information Management*, Vol. 30, No. 6, pp.559–566.

Miller, G.A. (1956) 'The magical number seven, plus or minus two: some limits on our capacity for processing information', *Psychological Review*, Vol. 63, No. 2, pp.81–97.

Norman, D.A. (1982) *Learning and Memory*, Freeman, W.H., San Francisco, CA.

Pahl-Wostl, C. and Hare, M. (2004) 'Processes of social learning in integrated resources management', *Journal of Community and Applied Social Psychology*, Vol. 14, No. 3, pp.193–206.

Pellizzoni, L. (1999) 'Reflexive modernization and beyond: knowledge and value in the politics of environment and technology', *Theory, Culture & Society*, Vol. 16, No. 4, pp.99–125.

Petrini, M. and Pozzebon, M. (2008) 'What role is 'business intelligence' playing in developing countries? A picture of Brazilian companies', in Rahman and Hakikur (Eds.): *Data Mining Applications for Empowering Knowledge Societies*, pp.237–257, IGI Global, Chp XIII.

Petrini, M. and Pozzebon, M. (2009) 'Managing sustainability with the support of business intelligence: integrating socio-environmental indicators and organisational context', *Journal of Strategic Information Systems*, Vol. 18, No. 4, pp.178–191.

Piaget, J. (1996) *Epistemologie genetique*, Press Universitaire de France, Paris, France, Cited in Rouibah and Ould-ali. (2002).

Piechowski, M. (1994) *Risikobewertung in der Schweiz. Neue Entwicklungen und Erkenntnisse*, Unpublished paper cited in Klinke and Renn (2002).

Powell, J.H. and Bradford, J.P. (2000) 'Targeting intelligence gathering in a dynamic competitive environment', *International Journal of Information Management*, Vol. 20, No. 3, pp.181–195.

Power, D.J. (2008) 'Understanding data-driven decision support systems', *Information Systems Management*, Vol. 25, No. 2, pp.149–154.

Ramakrishnan, T., Jones, M.C. and Sidorova, A. (2012) 'Factors influencing business intelligence (BI) data collection strategies: an empirical investigation', *Decision Support Systems*, Vol. 52, pp.486–496.

Rasmussen, N.H., Goldy, P.S. and Solli, P.O. (2002) *Financial Business Intelligence*, John Wiley & Sons Inc., New York.

Rayner, S. (1992) 'Cultural theory and risk analysis', in Krimsky, S. and Golding, D. (Eds.): *Social Theories of Risk*, pp.83–116, Praeger Publishers, Westport, CT.

Reed, M.S., Fraser, E.D.G. and Dougill, A.J. (2006) 'An adaptive learning process for developing and applying sustainability indicators with local communities', *Ecological Economics*, Vol. 58, No. 2, pp.406–418.

Reed, M.S., Fraser, E.D.G., Morse, S. and Dougill, A.J. (2005) 'Integrating methods for developing sustainability indicators that can facilitate learning and action', *Ecology and Society*, Vol. 10, No. 1, p.r3, [online] http://www.ecologyandsociety.org/vol10/iss1/resp3 (accessed July 2010).

Risk Management Guidelines for Standards Australia AS/NZS 4360: 2004 (2005) *Handbook HB: 436: 2004*, Standards Australia, Sydney.

Rottenstreich, Y. and Tversky, A. (1997) 'Unpacking, repacking and anchoring: advances in support theory', *Psychological Review*, Vol. 104, No. 2, pp.406–415.

Rouibah, K. and Ould-Ali, S. (2002) 'PUZZLE: a concept and prototype for linking business intelligence to business strategy', *Journal of Strategic Information Systems*, Vol. 11, No. 2, pp.133–152.

Saravanamuthu, K. (2009) 'A journey of socialising the risks associated with global warming: a Gandhian insight into Schumacher's total accounting and accountability', *Advances in Public Interest Accounting*, Vol. 14, pp.121–189.

Simon, H. (1960) *The New Science of Management Decision*, Prentice Hall, Englewood Cliffs.

Standards Australia (2004) *AS/NZS 4360*, Standards Australia, Sydney.

Standards Australia (2009) *Risk Management – Principles and Guidelines*, AS/NZS ISO 31000:2009, Standards Australia, Sydney.

Ulrich, P. (2008) *Integrative Economic Ethics: Foundations of a Civilized Market Economy*, (Trans.) Fearns, J., Cambridge University Press, Cambridge, UK.

Volonino, L., Watson, H.J. and Robinson, S. (1995) 'Using EIS to respond to dynamic business condition', *Decision Support Systems*, Vol. 14, No. 2, pp.105–116.

Walker, B., Carpenter, S., Andries, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G.D. and Pritchard, R. (2002) 'Resilience management in socio-ecological systems: a working hypothesis for a participatory approach', *Conservation Ecology*, Vol. 6, No. 1, p.14 [online] http://www.consecol.org/vol6/iss1/art14 (accessed February 2005).

Walls, J.G., Widmeyer, G.R. and El Sawy, O.A. (1992) 'Building an information system design theory for vigilant EIS', *Information System Research*, Vol. 3, No. 1, pp.36–59.

Watson H., Goodhue, D. and Wixon, B. (2002) 'The benefits of data warehousing: why some organizations realize exceptional payoffs', *Information and Management*, Vol. 39, No. 6, pp.491–502.

Watson, H., Fuller, C. and Ariyachandra, T. (2004) 'Data warehouse governance: best practices at Blue Cross and Blue Shield of North Carolina', *Decision Support Systems*, Vol. 38, No. 3, pp.435–450.

Webler, T. and Tuler, S. (1999) 'Designing an analytic deliberative process for environmental health policy making in the US nuclear weapons complex', *Risk-Health, Safety, and Environment*, Vol. 10, No. 1, pp.65–87.

World Commission on Environment and Development (1987) *Our Common Future*, Oxford University Press, Oxford.

Wynne, B. (1996) 'May the sheep safely graze? A reflexive view of the expert-lay knowledge divide', in Lash, S., Szerszynski, B. and Wynne, B. (Eds.): *Risk, Environment and Modernity – Towards a New Ecology*, pp.44–83, Sage, London.

Yan, S.L., Wang, Y. and Liu, J.C. (2012) 'Research on the comprehensive evaluation of business intelligence system based on BP neural network', *Systems Engineering Procedia*, Vol. 4, pp.275–281.

Appendix 1

Translating irrigation statistics into stress factor

That is, extent to which non-base year metrics fragment baseline data. (see online version for colours)

Ground water utilised	Pre drought: base 1997/1998		
(Measure 1)	1997–1998	1998–1999	1999–2000
cal: ML	2,392/2,392	2,107/2,392	2,129/b
# of times to base yr	1	0.88	0.89
River water utilised			
(Measure 2)	1997–1998	1998–1999	1999–2000
cal: ML	13,900/13,900	14,402/13,900	14,831/b
# of times to base yr	1	1.04	1.07
Total water utilised: river and ground for crops			
(Measure 3)	1997–1998	1998–1999	1999–2000
cal: ML	16,292/16,292	16,509/16,292	16,960/b
# of times to base yr	1	1.01	1.04
Crops – acreage of irrigated area			
	1997–1998	1998–1999	1999–2000
Changes in total ha irrigated			
cal: total ha of grape and others	6,502/6,502	6,153/6,502	6,625/b
# of times to base yr	1	0.95	1.02
(Measure 4)			
Changes in grape ha irigated	3,645/3,645	4,084/3,645	4,665/b
# of times to base yr	1	1.12	1.28
(Measure 5)			
Changes in other ha irrigated	2,857/2,857	2,069/2,857	1,960/b
# of times to base yr	1	0.72	0.69
(Measure 6)			
Irrigation stats			
	1997–1998	1998–1999	1999–2000
Ave irrigation: mm/yr by crops i) Grapes			
Ave ML per yr	167	217	238
cal: ave ML per yr	167/167	217/167	238/b
# of times to base yr	1	1.3	1.43
(Measure 7)			
ii) All other crops			
Ave ML per yr	1,863	1,665	1,951
cal: ave ML per yr	1,863/1,863	1,665/1,863	1,951/b
# of times to base yr	1	0.9	1.05
(Measure 8)			

Crops – thirst index			
	1997–1998	1998–1999	1999–2000
Grapes: ave ML per ha			
Ave ML for grapes per ha:	1.65	2.17	2.15
cal: ave ML per yr	1.65/1.65	2.17/1.65	2.15/b
# of times to b. yr	1	1.3	1.3
Lucerne: ave ML per ha	1997–1998	1998–1999	1999–2000
Ave ML for Lucerne per ha	4.22	5.05	5.96
cal: ave ML per yr	4.22/4.22	5.05/4.22	5.96/b
# of times to b. yr	1	1.2	1.41
Vegetable: ave ML per ha			
Ave ML for vegetable per ha	3.93	4.55	6.29
cal: ave ML per yr	3.93/3.93	4.55/3.93	6.29/b
# of times to b. yr	1	1.16	1.6
For vegetables - acreage to explain extent of stress above			
Ha	679	518	121
Times increase/decrease over b		518/679	121/b
equals		0.76	0.18
Total water use for vegetables			
ML	2670	2355	761
Times increase/decrease over b		2355/2670	761/b
equals		0.88	0.29
Potato: ave ML per ha			
Ave ML per ha	not grown	not grown	3.74
cal: ave ML per yr			3.74/3.74
# of times to base yr			1
	1997–1998	1998–1999	1999–2000
Fodder: ave ML per ha			
Ave ML per ha	4.14	3.76	3.73
cal: ave ML per yr	4.14/4.14	3.76/4.14	3.73/b
# of times to base yr	1	0.91	0.9
Almond: ave ML per ha			
Ave ML per ha	2.41	1.95	2.83
cal: ave ML per yr	2.41/2.41	1.95/2.41	2.83/b
# of times to base yr	1	0.81	1.18
Other crops: ave ML per ha			
Ave ML per ha	2.58	1.33	1.74
cal: ave ML per yr	2.58/2.58	1.33/2.58	1.74/b
# of times to base yr	1	0.52	0.68

Appendix 2

Ground water utilised for 1998/9 (see online version for colours)

Likelihood of occurrence: descriptors	*CONSEQUENCES Expressed as extent to which irrigation stresses natural water cycle*				
	Most stressed	*More stressed*	*Status-quo baseline*	*Less stressed*	*Least stressed*
	More than 1.25	*More than 1, but less than 1.25*	*1*	*Less than 1, but more than 0.50*	*Less than 0.50*
Raw measure				.88	
Almost certain	(v)	(v)	(iii)	(ii)	(ii)
Likely	(v)	(v)	(iii)	(ii)	(ii)
Possible	(v)	(iv)	(iii)	(ii) *	(i)
Unlikely	(iv)	(iv)	(iii)	(i)	(i)
Rare	(iv)	(iv)	(iii)	(i)	(i)

Risk rating given: POSSIBLE / LESS STRESSED that is, (ii)

Reasons:

- Assumed change of emphasis away from ground water to river water usage. Cannot continue to lower the watertable. Need to balance overall water usage.
- Could be possible because of vineyard plantings replacing other crops as well as a drop in total area irrigated.