A Meta-theory of risk: Risk as reflexive, social learning[1]

Dr. Yim Ling Siu
Sustainability Research Institute
School of Earth & Environment
University of Leeds, Leeds, U.K.
Tel: +44 (0)113-3436717
Fax: +44 (0)113-3436716
Email: Y.L.Siu@Leeds.ac.uk

ABSTRACT

There are diverse views and interpretations of risk. In the literature, risk is often regarded as "analysis", "social constructs", "feelings" and so forth. Limited studies were devoted to exploring the diversification of the meanings and there is a lack of (meta-)risk theory which explains their co-existence. This research paper depicts the development of a meta-theory of risk to fill these intellectual gaps and identifies a number of essential elements of the developed theory.

The research found that risk exists only by virtue of the knowledge people have of it. This knowledge (known as risk knowledge) encompasses the scientific knowledge (e.g. risk analysis or estimation) and social knowledge (e.g. people's perception, social/cultural norms, gut feelings). The intrinsic duality of the risk knowledge explains the diversification and co-existence of risk definitions in the risk literature. Furthermore, from the desktop study of the waterborne health threat such as Cryptosporidium in drinking/tap water in England and Wales, the meta-theory of risk demonstrates that risk is not static but dynamic. It evolves and changes over time. People's perception of risk also changes over time and across different spatio-cultural dimensions, depending on the development and acquisition of risk knowledge via social learning processes. Because of this, risk is regarded as risk knowledge that people have of it. The development and evolution of people's risk knowledge is via reflexive, social learning process. Based on the current research findings, implications to the existing risk theories, methods and tools, and risk management are discussed in addition to suggestions of future research areas.

[1] Paper submitted to ESRC's SCARR International Conference on "Managing the social impacts of change from a risk perspective", 15th – 17th April 2009, Beijing Normal University, People's Republic of China.

1. INTRODUCTION

There has been widespread recognition of shortcomings in the founding paradigm of risk analysis as a basis for risk management (e.g. Thompson, 1989; Fischhoff, 1998; Klinke and Renn, 1999; House of Lords, 2000; Bijl and Hamann, 2002; Tippins, 2004). At issue have been the conditions required for decision making and action taken in accordance with a rational evaluation of estimates of relative risk magnitudes and related intervention costs and benefits (see Figure 1.1). The implicit demands of these conditions include trusted sources of data and information, an availability of robust estimates, and consensus over meaning, problem definition, option evaluation, and due decision process. These demands often cannot be met, as expounded, for example, in the work of Frewer et al (1994) and Hunt et al (1999 & 2001) on the issue of trusting different sources of risk information, Funtowicz and Ravetz (1990) on the matter of estimation uncertainties, Wynne (1989) on the issue of non-compatible problem definitions, Stirling and Mayer (1999) on the existence of divergent option evaluations, and Bloomfield et al (1998), Loewenstein et al (2001), Slovic et al (2004) and Poortinga and Pidgeon (2004) on challenges on decision procedures. Tangible evidence of the problem is writ large in contemporary risk controversies such as those over climate change, terrorism, homeland security and defence, Genetically Modified Organisms (GMOs), nanotechnology, Bovine Spongiform Encephalopathy (BSE), nuclear waste and reprocessing, transport safety, health threats and patient safety. In addition to that, new paradigms emerged and they regard risk as social construction (e.g. Douglas and Wildavsky, 1982; Perrow, 1984), analysis and feelings (Slovic, P. et al, 2004).

One may wonder whether all these risk issues, including individual risk such as skiing, recreational boating, etc., share a common generic structure in terms of which of their various different characteristics can be systematically represented and understood (i.e. "one-size fits all" theory)? Or, are risk issues inherently disordered, inevitably different from each other, and open to unaccountably different interpretations and actions by different people (i.e. risk is situational, site-specific and context-specific)? The former question is often less asked and explored while the latter question has been and continues to be intensively discussed and researched into in the field of risk studies[2].

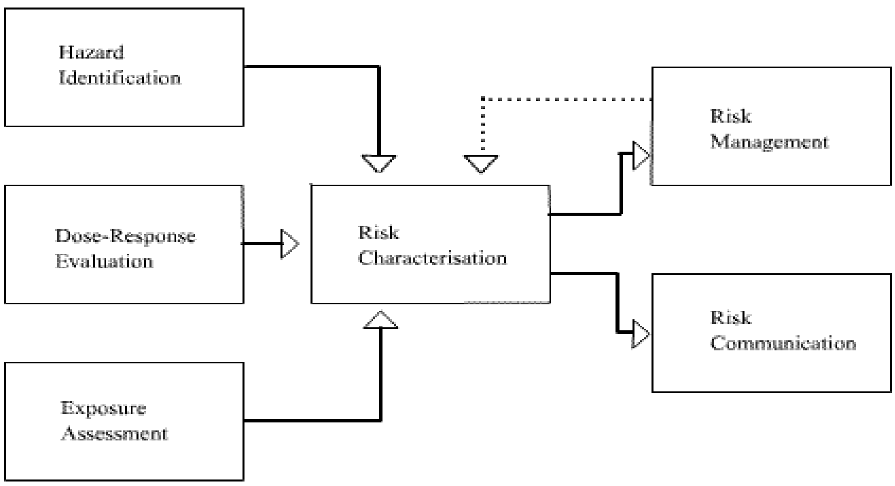

Figure 1.1: The founding paradigm of risk analysis

[2] For instance, the emergence of ration-actor risk paradigm, social and cultural theories, risk as analysis, risk as feelings, risk as emotion, intuition, trust or rules of thumb, life-cycle risk assessment, etc.

Given the prevalence of exceptions to the conditions required to legitimate the founding paradigm of risk analysis, that paradigm itself is in need of renewal. This is the chosen focus of this paper: to begin to articulate and develop a new conceptual framework for risk analysis. The precepts of this paper are set out more fully in section 2, the suggested framework is introduced in section 3, and then illustrated in section 4 with respect to waterborne health threats. There is an evaluation in section 5. Discussions and conclusion are given in sections 6 and 7.

2. PRECEPTS

The identity of risk analysis is as yet insufficiently prescribed. In 1985, the US Society of Risk Analysis set up a definitions committee to examine the term 'risk' (Beer and Ziolkowski, 1995). After two years of work, a list of thirteen possible definitions was produced (Table 2.1). Each is a variant of a theme whose common elements are:

- a time frame over which the risk or risks are being considered
- a probability (or likelihood) of occurrence of one or more adverse events
- a measure of the consequences of those events

1.	Possibility of loss, injury, disadvantage or destruction; to expose to hazard or danger; to incur risk of danger.
2.	An expression of possible loss over a specific period of time or number of operational cycles.
3.	Consequence per unit time = Frequency (Events per unit time) x Magnitude (Consequences per event)
4.	Measure of the probability and severity of adverse effects.
5.	Conditional probability of an adverse effect (given that the necessary causative events have occurred).
6.	Potential for unwanted negative consequences of an event or activity.
7.	Probability that a substance will produce harm under specified conditions.
8.	Probability of loss or injury to people and property.
9.	Potential for realisation of unwanted, negative consequences to human life, health or the environment.
10.	Product of the probability of an adverse event times the consequences of that event were it to occur.
11.	Function of two major factors: (a) probability that an event, or series of events of various magnitudes, will occur, and (b) the consequences of the event(s).
12.	Probability distribution over all possible consequences of a specific cause which can have an adverse effect on human health, property or the environment.
13.	Measure of the occurrence and severity of an adverse effect to health, property or the environment.

Table 2.1: Definitions of risk, U.S. Society of Risk Analysts[3]

Analysts who approach the subject from a social perspective (see for example the edited collection by Krimsky and Golding, 1992) will immediately note, amongst other things, the exclusion from the list in Table 2.1 of anything with other than a technical or engineering foundation, and may even be tempted to offer a further list in an attempt to reflect the broader scope of the field (Table 2.2).

While the juxtaposition of sets of definitions can usefully establish a set of foci of interest, it cannot establish the intrinsic nature of a field any more than bricks and mortar alone can adequately convey the nature of building. As stated by Ostrom (1986), phenomena are often more complex than the labels used to describe them.

[3] Information is extracted from Beer & Ziolkowski, 1995, Chapter 2, pp 5-6.

1.	Probability of an adverse event amplified or attenuated by degrees of trust, acceptance of liability and/or share of benefit
2.	A combination of opportunity and danger
3.	A code word that alerts society that a change in the expected order of things is being precipitated
4.	Something to worry about
5.	Something to have hope about
6.	A threat to sustainability/current lifestyles
7.	Uncertainty
8.	Part of a structure of meaning based in the security of those institutional settings in which people find themselves
9.	Very much a moral issue.
10.	Someone's judgement on expected consequences and their likelihood.
11.	Something different to different people
12.	Financial loss associated with a product, system or plant
13.	The converse of safety.

Table 2.2: Alternative definitions of risk

***The fundamental design problem of risk analysis needs to be addressed* ab initio.** The interactions between human activities and risk have a complexity and at the same time a uniqueness that existing risk analytical approaches have not yet captured. If a first principles approach were to be adopted instead, it may be possible to uncover a unitary identity for risk analysis that has hitherto been hidden. It should be less concerned with sticking together existing approaches (such as is done when creating inventive contraptions – Figure 2.1), or transferring aspects from one approach into another (such as when making do – Figure 2.2) than with articulating a new level of integrative pragmatic thinking to add both depth and breadth relative to existing approaches. The suggestion here is that over the last decades there has been an overproduction of lean knowledge, and an insufficient appreciation of the 'fundamental picture'. What has been missing has been a universal conceptual model accommodating all schools while providing practical tools of analysis and prescription. The development of such a model should inevitably be informed by existing approaches. However, opportunity for choosing a new starting point can be taken - a first principles approach and a relatively clear canvass.

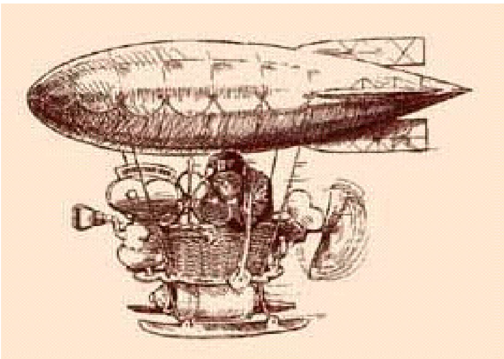

Figure 2.1: An inventive contraption

Figure 2.2: Making do

Science matters. People matter. Knowledge matters. Science here is taken to be characterised by keywords such as measurement, estimation, verification, explanation, probability and prediction. In risk analysis it is manifest in the use of mathematical and statistical models, parameterised in the physical, chemical, biological and medical sciences, to estimate causal relationships between measured hazard sources and actual or potential adverse effects. It is also taken to include engineering approaches which analyse potential system malfunctions via digraphs, fault trees and event trees. The mission is to determine how big the risks really are, and what are the causes and effects.

There are many variants of the social science dimension (people matter – perceptions, culture, politics, emotions, trust). They include psychological approaches which seek to understand people's cognitive and mental states, sociological perspectives which focus on the importance of social and institutional processes, anthropological perspectives which look for explanations of people's positions based on religious, cultural and ethnic origins, and economic approaches which evaluate monetary and non-monetary values of a risk within cost-benefit or multi-criteria frameworks. They also include work on the sociology of science.

Epistemologically (knowledge matters - keywords include reasoning, heuristics, truth, understanding, uncertainty, ignorance) both science and social science approaches are concerned with the development of knowledge about risk. At the same time it can be deduced from previous points above that none alone captures all observable aspects, nor do any fundamentally recognise this commonly shared bond (knowledge). It can also be added that there is not a shared basis for dealing with gaps in knowledge: there are idiosyncrasies in the way uncertainty is treated. In seeking to establish a knowledge-based framework which can adequately encompass the multi-dimensionality of risk, the role of uncertainty in undermining the strength of an existing knowledge base must be addressed. Risk knowledge is incomplete as well as being multifaceted.

"Risk analysts of the world unite: you have nothing to use but your brains"[4]. If it is accepted that science, people and knowledge all matter and that the differing schools of thought reflected in Tables 2.1 and 2.2 all have a place in risk analysis, then the challenge is to produce an integrated conceptualisation which accommodates them all. If it can be achieved, such a conceptualisation will be a basis for redressing an existing tendency towards fragmentation among different risk analysis approaches: technical, engineering, scientific, psychological, cultural, and many others. Risk analysis can be more than a co-existence of different approaches. As an interdisciplinary (as distinct from multidisciplinary) subject of knowledge it can aspire to a distinct, federal coherence which in turn should be a basis for improved communication and the challenging search for win-win synergies between the current co-existing approaches.

Integrated multidimensional knowledge should become the focus of a new risk analysis paradigm. As noted in the Introduction, it is now widely recognised that technical (scientific) approaches alone provide too narrow a basis for risk identification, risk evaluation and risk management. What different people perceive as an undesirable effect depends on their own values and preferences. Their freedom to choose their own positions is fundamental in any democratic society. At the same time perceptions alone do not provide a robust basis for risk management. Rather than simply choosing between 'scientific' and 'lay' views, a more productive way forward may be to create a meaningful web of discourse between them, through progressive exchanges between the knowledge bases of scientists and of lay people. Although consensus may not be achievable, the different constituencies should at least be able to appreciate each other's positions and understand their mutual differences. Until such a shift is achieved and fundamentally institutionalised, then the status quo (including the fuelling of risk controversies by inadvertent suppression of lay values) will be set to continue. It is as much for scientists to understand the public, as for the public to understand science (House of Lords, 2000; Irwin and

---

[4] Corruption of 'Workers of the world unite you have nothing to lose but your chains' following Bragg (2000)

Wynne, 1995). The focal paradigm of risk analysis should in turn reflect this interest in multidimensional risk knowledge.

Knowledge is not an end point but a milestone in an open-ended evolutionary process. The quest for risk knowledge should in principle entail the same core activities as are involved in other spheres of explicit knowledge construction and development:

- discovery: the uncovering and justification of new truths about states of the (physical and social) world – the production of scientific knowledge.
- dissemination: the spreading of awareness of new discoveries through various channels and networks, both among professional scientific communities, and to the public more generally via the mass media.
- discourse: the processing of information among and between different constituencies – scientists and public - including heuristics, risk aversion, after-the-fact justification of behaviour, and efforts made by lay people to understand science for their own ends.

Each of these three activities, binding science, society and knowledge, has a compelling claim for representation in a new conceptual framework for risk analysis. In practice however, the current dominant paradigm in risk analysis treats knowledge as an endpoint on a single dimension (Figure 2.3). The model developed in this paper proposes a shift to a more holistic, recursive approach.

Uncertainty, uncertainty, uncertainty. Recognition, characterisation and inclusion of the once marginalised concepts of uncertainty have been one of the more enlightened movements within professional risk analysis circles over recent decades. Different generic typologies of uncertainty are now more widely appreciated, including those finding formal expression in probability (outcome a priori unknown), in estimation error, in statistical confidence bands and sensitivity analyses, in completeness disclaimers, and in recognition of trans-scientific problems (Weinberg, 1972). However, the very different demands on knowledge by lay people (relative to scientific experts) carries with it different ways of dealing with what might be unknown, including tacit belief, hope, anxiety, trust, demands for assurances, and readiness to attribute blame. To the extent that these differences between lay and scientific communities are in conflict, this presents further issues to be mediated and resolved.

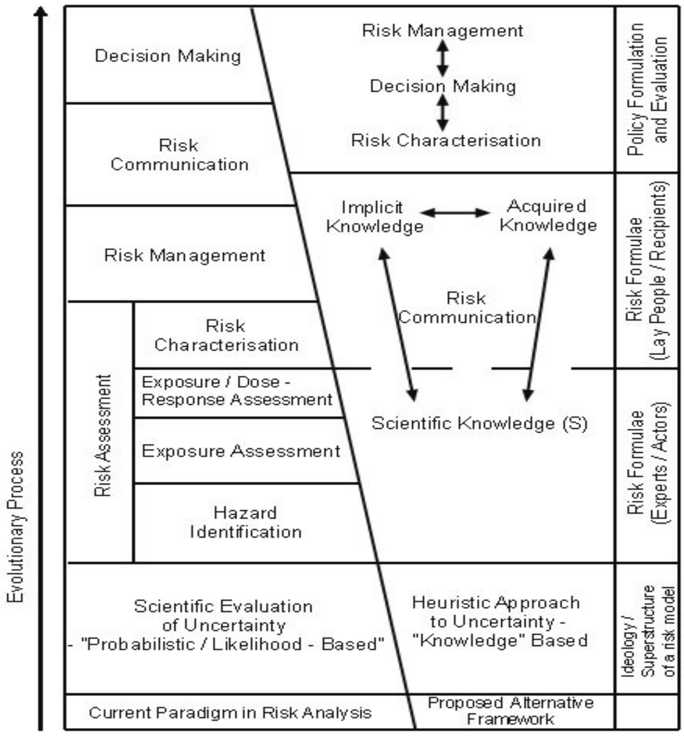

Figure 2.3: The current paradigm in risk analysis and a suggested alternative

Risk analysis can be re-defined as the study of people's knowledge of risk. This proposed re-definition is intended to provide a gestalt appreciation of the natural scope of the field of risk analysis – science, society and knowledge as they each relate to risk. It constructively challenges the suggestion by Fischhoff, Watson and Hope (1984) that no single definition of risk is suitable for all problems. It places knowledge at a high level in recognition of its inherent status (through the role of epistemology) within any field of scholarly inquiry, while at the same time identifying it as a natural integrative focus. This conceptualisation of a 'risk knowledge economy' recognises an equality of standing between lay and expert knowledge as subjects of inquiry, in turn rejecting tendencies for social dimensions to be at best afterthoughts to scientific studies of risk, or for scientific findings to be marginalised from the social world. It recognises the importance of understanding what people want from risk analysis, together with how, why and when they want it. It also asks who these people are and what forces are driving them.

Risk management is the application of risk analysis knowledge to deal with risk problems. This corollary to the previous point is added for completeness. It recognises risk analysis as a strategic discipline – producing knowledge to inform human action (in this case to promote improved management of risk) – as distinct from being concerned with the pursuit of knowledge only for its own sake. It also recognises that in order to pursue knowledge, it is not always expedient simply to observe passively, but actively to intervene in or manipulate the situation to be observed.

Knowledge as ideology. Growing demands for knowledge in society are both inevitable and appropriate. Their inevitability stems from the progressive development of the information age and information and communications technologies more generally including, of course, the Internet. Their appropriateness stems from the same ideological roots as promote lifelong learning, or the preceding of action with fact-finding, and the lasting values of truth, thought, conscience and wisdom. Elevation of knowledge – in the present context meaning both scientific and social knowledge of risk – is the underpinning ideology of this paper. While the justification for this ideology may be revered, the implications of such elevation, were it to be widely realised (e.g. in terms of the future forms of politics and governance that unprecedented future knowledge states and exchanges may engender), are inevitably as yet unknown.

3. A NEW CONCEPTUAL FRAMEWORK OF RISK

The research questions are: What is risk? How does risk evolve?

The starting point of developing a new conceptual framework of risk (or known as a new risk paradigm) is the idea that risk exists only by virtue of the knowledge people have of it: scientific knowledge (broadly, risk estimation based on probability and consequence) and social knowledge (broadly, risk perception based on gut feelings, cultural and social values, and organisational norms, etc.). Investigation is carried out based on a set of four frequently asked questions on risks by risk analysts, practitioners, governmental officials, the mass media and the general public. The risk questions are: "how big are the risks?", "are there any doubts?", "are the risks acceptable" and "does everyone agree?".

The aim of this paper is to locate a minimal but necessary set of properties of risk that are common in all risk issues and identifies the interplay of these properties.

In order to examine the fundamental elements of risk and develop a conceptual model to represent the subject of risk analysis as people's knowledge about risk, it is necessary to distinguish, with reference to actual, potential or perceived risk scenarios:

- who these people are
- the possible nature and sources of their knowledge
- the extent to which they affirm these sources

It will also be necessary to consider the dynamic of possible changes in risk knowledge through time. These considerations produce the 'essential components of risk analysis' which are listed in Table 3.1 and considered more fully below. As with all models, and in particular with their initial, unrefined, articulation, there is inevitably a degree of simplification.

Scenario	A set of scenarios of risk events under consideration.
Constituencies	People who are fabricated from different levels of a society (such as scientists, technicians, engineers, government officials, industrialists, businessmen, producers, consumers and lay public etc.) but organise themselves into 'fashionable' groups like institutions, organisations, interested parties and on-looking public.
Scientific knowledge	The justified knowledge or truth belief through deductive, inductive and abductive reasoning.
Attributes	A measure of the characteristics and/or consequence of those events
Chance	A probability (or likelihood) of the occurrence of one or more events.
Ignorance	Total ignorance or true indeterminacy.
Acquired knowledge	The acquired social experience or knowledge from teaching, training, and information acquisition, flows and exchange.
Implicit knowledge	The inherent experience or knowledge from the past or from the previous successors.
Certitude	Level of assurance (or confidence) which, to a large extent, reflects degree of credibility, reliability, flexibility, bias, prejudice and belief in systems and knowledge bases (which includes sources of information, knowledge acquisition, information flows and exchange)
Time	A time frame over which the risk or risks are being considered.
Decision making process	An iterative process including a set of defined working rules, participation and dialogue to reach an outcome.

Table 3.1: The essential components of risk analysis

Risk scenarios. The term 'risk scenarios' is used here simply to establish the substantive focus of attention, typically possible states of risk together (if appropriate) with their possible evolution over time. Examples may include states of risk reflected in generic classifications of risk types, for example, the 81 risk types considered by Fischhoff et al (1984) (Table 3.2) or the 6 risk classes identified by Klinke and Renn (2001) (Table 3.3).

Examples may also include possible future trajectories from a given hazard source such as pathways of potential harm from concentrations of copper in drinking water supplies, or from spillage of highly flammable substances (Figure 3.1).

DNA technology	Large dams	Elevators	Auto exhausts
Electric fields	Skyscraper fires	Swimming pools	Trampolines
SST	Nuclear warfare	Skiing	Valium
Fossil fuels	Underwater construction	Electric appliances	Tractors
Nitrogen fertilisers	Coal mining	Recreational boating	LNG storage
Cadmium usage	Parachuting	Electric shock	Antibiotics
Radioactive waste	General aviation	Bicycles	Nerve gas accidents
Nuclear reactor accidents	High construction	Motorbikes	Chainsaws
Nuclear weapons fallout	Rail crashes	Bridges	Lead paint
BSE	Commercial aviation	Microwave ovens	Vaccines
2,4,5-T	Alcohol abuse	Water fluoridation	Aspirin
Pesticides	Car racing	Nitrates	Caffeine
Uranium mining	Road accidents	Saccharin	Coal burning
Asbestos insulation	Handguns	Water chlorination	Snowmobiles
PCBs	Dynamite	Hexachlorophene	Diagnostic X-Rays
Mercury	Skateboards	Coal tar hairdyes	Power mowers
DDT	Smoking	Polyvinyl chloride	Oral contraceptives

Table 3.2 Array of risk types (after Fischhoff et al 1984)

Risk class	**Characteristics**	**Examples**
Damocles	Low probability, high consequence	Nuclear energy, dams, large-scale chemical facilities
Cyclops	Uncertain probability, high consequence	Nuclear early warning systems, earthquakes, volcanic eruptions, AIDS
Pythia	Uncertain probability, uncertain consequence	Greenhouse effect, BSE, genetic engineering
Pandora	Uncertain probability, uncertain consequence, high persistence	POPs, endocrine disruptors
Cassandra	High probability, high consequence, delayed effects	Anthropogenic climate change, destabilization of terrestrial ecosystems
Medusa	Low probability, low consequences, high social concern	Electromagnetic fields

Table 3.3: Six risk classes (Klinke and Renn, 2001)

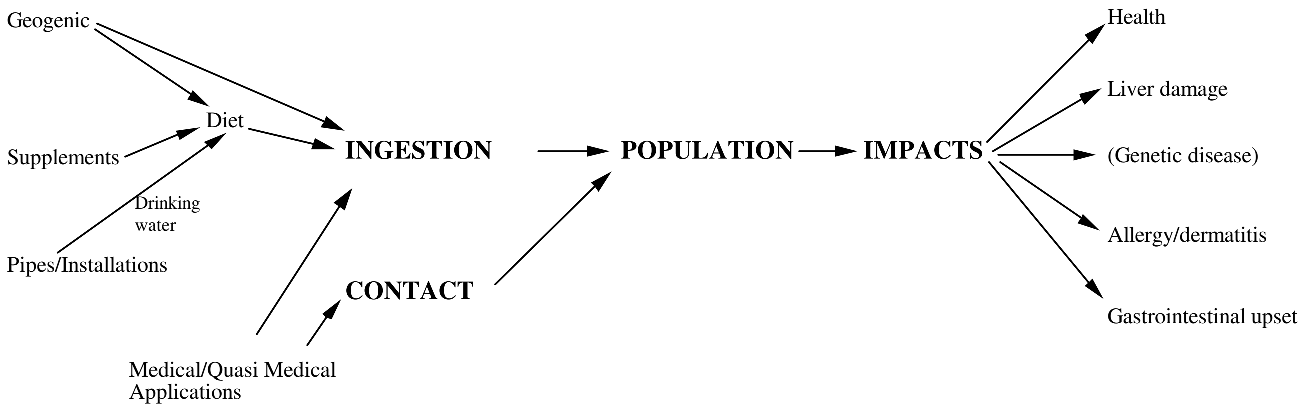

Figure 3.1: Logic tree for human exposure to copper

Formally, risk scenarios will simply be represented at this stage as follows:

$R = \{X_i\}$ Equation (1)

Who are these people? In principle, everyone should be included. Pragmatically, it is useful to distinguish four core sets of constituencies, according to the nature of their relationship to the focus of attention (Table 3.4).

Experts	-	having access at first hand to scientific justification (or otherwise) of the truth-claims of the scenarios represented in Equation 1.
Officials	-	society's agencies of governance and regulation.
Stakeholders	-	having a direct interest in the risk issue in question – whether as affected populations, special interest groups, mass media or whatever.
The public	-	The 'audience' (Palmlund, 1992).

Constituencies	**Examples**
Experts	Specialists, consultants and professionals in particular sphere of interest/subject.
Officials	Government representatives, officials or bodies.
Major stakeholders	The affected people (or population) who arrange and organise themselves into groups, institutions or organisations to share common views, and to act and re-act upon specific issues. Includes media organisations.
General public	Public masses.

Table 3.4. Illustrative examples of constituencies

What is the nature and source of people's knowledge? Answers to this profoundly philosophical question are found in the contemporary epistemological literature, and are in principle very extensive indeed. Again, there is a necessity for pragmatism, and three types of knowledge will be identified here, according to their provenance, with the following labels:

Scientific knowledge	–	the justified true belief of experts in specialist fields.
Acquired knowledge	–	the wisdom and meanings within society developed through learning, information flows, social experience, pro-active reasoning.
Implicit knowledge	–	people's tacit, unquestioned beliefs and pre-dispositions.

The scientific knowledge base can be represented more explicitly in terms of the formal evaluation of a number of measurable attributes $\{M_i\}$ of risk scenarios (Table 3.5), and associated chance, likelihood or probability P_i. It may also be circumscribed by attributes or characteristics $\{\varepsilon_i\}$ which cannot be measured (representing true uncertainty or total ignorance) at this point of time.

Attributes	Examples
Space	Geographic dispersion
Diffusion	Persistence; delay.
Reversibility	Recovery of initial state; change from initial state
Incidence	Types of impact on social, economic, political, cultural, ecological, ethical, moral, and living and non-living entities.
Magnitude	Level of damage; numbers of living and non-living entities affected.
Benefits & detriments	Social, economic, political, cultural and ecological gains and losses.
Critical boundaries	Thresholds for mitigation or litigation.

Table 3.5: Examples of measurable attributes

Different constituencies select for their own attention, or have access to, particular risk scenarios and not others. In other words, from the universe of scenarios known or knowable to science (modulo ignorance), subsets are of interest, concern, relevance to different constituencies k.

$\{S^k{}_i\} = \{M^k{}_i \cup P^k{}_i\}, \{\varepsilon^k{}_i\}$ Equation (2)

where $\cup$ denotes a set union.

Acquired knowledge and implicit knowledge will be represented via further sets $\{A^k\}$, and $\{I^k{}_i\}$. Brief characterisations of these set are given in turn in tables 3.6 and 3.7. Acquired knowledge is continuously open to pro-active development, including for example, through the exercise of people's ability to choose how to respond to any given set of circumstances. The potential for control over the gap between stimulus and response is argued, for example by Covey (1989) following Frankl (1984), and in turn Knight (1999) as perhaps the most fundamental of human freedoms. The latter, dominant when people do not exercise their inherent ability to make conscious choice, exerts anchoring effects towards prior positions – prejudices, cultural stereotypes, gut feelings.

Attributes	Examples
Attitudes/values	(Optimistic/pessimistic) world's views; learning;
Relevance	Salience of causes, effects, impacts, consequences, magnitude; extent of involvement.
Acceptability	Willingness to pay; view of governance; perceived degree of accountability.
Social and physical environment	Interactions with colleagues, peer groups, neighbours, friends and family; effects of living surroundings.
Vulnerability	Person-types; openness to influence;
Media triggers	News, newspapers, radio broadcasts, journals/magazines, sources/materials from the Internet.

Table 3.6: Outline characterisation of Acquired knowledge {A}

Attributes	Examples
Personal/Group experience	Past experience; old man's wisdom; rules of thumb;
Cultural/Religious traits	Beliefs, religions, social and cultural taboos or ways of doing things.
Political interest or group labels/brand names	Health; the Environment; animal welfare; corporate images.

Table 3.7: Outline characterisation of Implicit knowledge {I}

This produces the following conceptualisation of risk:

$R^k = f\ (\{A^k_i\}, \{I^k_i\}, \{S^k_i\})$ Equation (3)

Affirmation of knowledge sources. Associated with each base of knowledge, there is an issue of certitude (or level of confidence) about its reliability, credibility and trustworthiness. This certitude reflects the strength (or weakness) of each sphere of constituted knowledge $\{A^k_i\}$, $\{I^k_i\}$ and $\{S^k_i\}$, as received and/or perceived by different constituencies k at any particular point in time. Levels of certitude can change over time owing to changes of circumstances (e.g. new information, new technology, the discovery of faults). Three parameters, $\{\iota\}$, $\{\alpha\}$ and $\{\sigma\}$, are added to equation (3) to denote levels of certitude of implicit, acquired and scientific knowledge, respectively (Tables 3.8 - 3.10).

$R^k = f\ (\{\iota^k_i\}\cup\{I^k_i\}, \{\alpha^k_i\}\cup\{A^k_i\}, \{\sigma^k_i\}\cup\{S^k_i\})$ Equation (4)

Dimensions	Examples
Personal/Past experience	Degree of familiarity
Cultural/Religious beliefs	Level of belief about purity; strength of social and cultural taboos
Political/interest group label/brand name	Depth of environmentalism; strength of opportunism; degree of gambling tendency; strength of corporate images

Table 3.8: Outline characterisation of the certitude of Implicit knowledge $\{\iota\}$[5]

Dimensions	Examples
Attitudes/values	Importance of dread and fright factors; strength of cultural prejudice
Relevancy	Importance of direct or in-direct impacts; significance of no impacts at all
Acceptability	Extent to which current practices in terms of habits, lifestyles, employment status, health conditions, mobility etc. are affirmed or violated
Immediate surroundings	Importance of colleagues or peer pressure; influence from the immediate family, relatives, friends or neighbours; living area and surroundings.
Vulnerability	Significance of age & gender, and familial, marital & employment status.
Media triggers	Strength of media influence

Table 3.9: Outline characterisation of the certitude of Acquired knowledge $\{\alpha\}$[6]

[5] See also Appendix A
[6] See also Appendix B

Dimensions	Examples
Theory	Theoretical base; state of the art
Measurement	Techniques/methods of measuring; accuracy/precision; error terms
Sensitivity	Robustness
Data availability	Quantity of data; quality of data; variable data; invariable data
Models	Statistical; mathematical; conceptual
Framing assumptions	the limiting assumptions or conditions

Table 3.10: Outline characterisation of the certitude of Scientific knowledge {σ}[7]

There has been an increasing amount of research into the formal modelling of {σ} (Funtowicz and Ravetz, 1990; Rowe, 1994; Macgill et al, 2001). There is also an existing base of work on credibility and trust (relating to α), albeit presented in less formal terms (Douglas, 1985).

Time and dynamics. The representation of processes of change in risk knowledge is more problematic, and can barely be sketched at this stage. Stimuli include:

- new scientific discoveries (research findings), changing S (ΔS), and in due course also possibly A and possibly I
- news of major risk events or risk controversies, changing A (ΔA), and possibly S (by presenting new research agendas) and potentially also causing revision of I
- social experience, affecting A directly, and possibly S (new agendas again) and I (bifurcation at a critical threshold)
- major decisions – the outcome of interactions of different stakeholder groups and other constituencies in some defined institutional setting

Whereas the first three processes here operate directly on terms already introduced, the fourth entails a different level of interaction between them. Following Ostrom (1986) decision making can be modelled as an iterative process using a set of defined working rules, participation and dialogue to reach a (policy) decision. The essential components of the process are defined in Table 3.11. Decision outcomes may provide new stimuli (new knowledge) $\{\Delta A^k_i\}$ for further social interactions over risk.

[7] See also Appendix C

1.Boundary	Define the entry, exit, and domain conditions for each person/constituency.
2. Scope	Specify what is managed and what can be decided (e.g. states of the entity can be affected or sets the range within which these can be affected).
3. Hierarchy	Define positions, assign participated constituencies to positions, and specify who has control over tenure in a position.
4. Authority and Procedure	Prescribe which positions can take which actions and how actions are ordered, processed, and terminated.
5. Information	Establish information channels, state the conditions when they are to be open or closed, and prescribe how information is to be processed.
6. Dialogue	Establish an interactive, two-way discourse or communication, create a universal language for both officials and lay publics.
7. Participation	Define how to respond. For instance, implicit knowledge will impose an anchoring effect which may inhibit changes. Acquired knowledge is more dynamic and variable. It may require stimuli to invoke or provoke actions or reactions. Scientific knowledge can be anywhere between a very mature and an embryonic stage of development.
8. Trade-offs	Prescribe how costs and benefits are to be distributed to constituencies in positions given their actions and those of others.

Table 3.11: Essential components of the process of decision making after Ostrom (1986)

It is envisaged that six possible outcomes (i.e. actions) may arise within the stages of a decision process (i.e. decision nodes) namely:

1. Deadlock – Constituency decisions are mutually exclusive.
2. Exclusion – One or more constituency is excluded.
3. Integration – One or more constituency adjusts to accommodate the other.
4. Aggregation – Constituencies are mutually accommodated or reached consensus
5. Win-win – Constituencies gain added advantage from mutual agreement
6. Status quo – Nothing happens.

Summary. The 'system of interest' of risk analysis has been depicted above as the quality and evolution of both 'scientific' and 'social' risk knowledge bases. Risk can now be formalised with the identified essential elements. It is defined as the union of the scientific knowledge about expected physical detriment (determined from scientific findings), scientific certitudes (i.e. the degree of confidence of scientists in those findings), acquired (i.e. active, socially constructed) and implicit (i.e. intuitive & inner, gut feelings) knowledge of constituency (expert to lay people) in society, and the certitudes of that acquired and implicit knowledge. A formal risk model can be developed based on the new risk conceptual framework and new risk definition. A possible representation of the risk model is suggested and depicted as follows (see also Figure 3.2):

$$R^k(t+1) = f\left(\{\iota^k_i\}\cup\{I^k_i(t), \Delta I\}, \{\alpha^k_i\}\cup\{A^k_i(t), \Delta A\}, \{\sigma^k_i\}\cup\{S^k_i(t), \Delta S\}\right) \qquad \text{Equation (5)}$$

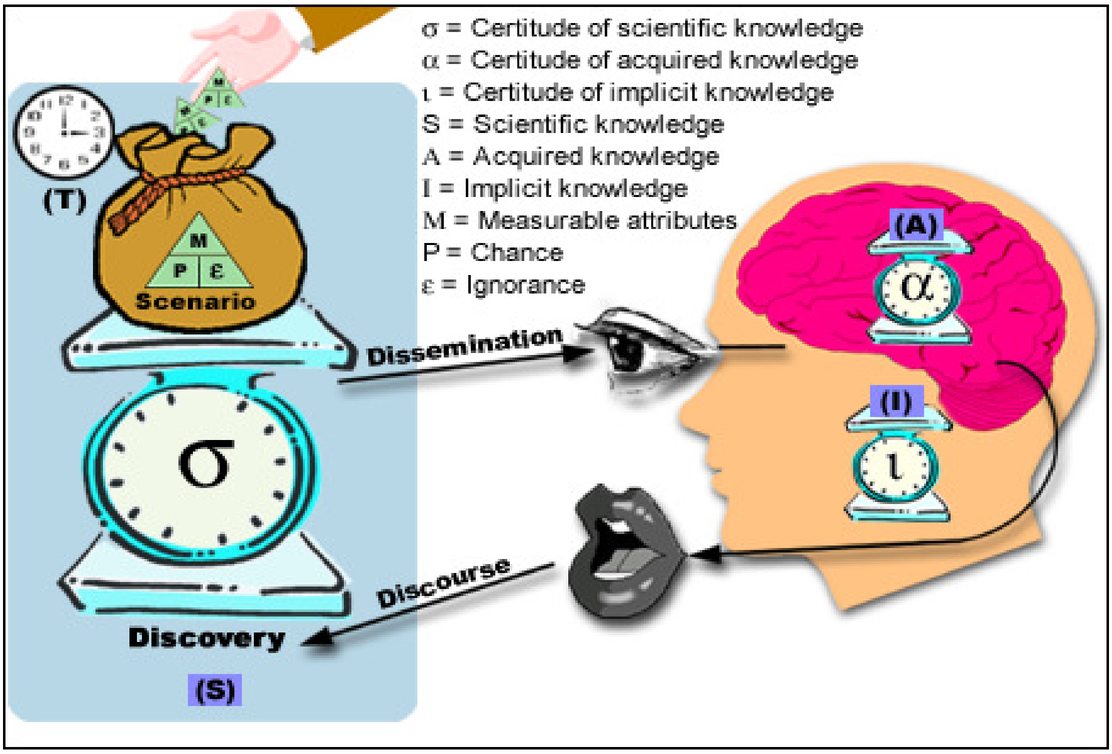

Figure 3.2: Schematic representation of risk knowledge bases and interactions

4. ILLUSTRATION – *CRYPTOSPORIDIUM* IN DRINKING WATER

In principle, it should be possible to apply the above conceptual framework and model to any risk issue such as genetically modified (GM) food and crops, BSE, nuclear waste and reprocessing, transport safety, health threats and patient safety. In practice, and for expediency, the initial choice for illustration is an issue that is significant, but not overwhelmingly complex: the scenario of possible health threats from *Cryptosporidium* in drinking water supplies in England and Wales.

Cryptosporidiosis has long been a veterinary problem, predominantly in young farm animals such as calves. *Cryptosporidium* was first recognised as a cause of human disease in 1976 (Atherton, Newman and Casemore, 1995) but was rarely reported in humans until 1982 (US Department of Agriculture). Relative to others, this risk issue is one of relatively high probability, but low consequence. It has attracted comparatively little research from the social science community, and yet has significant impacts on present water quality standards.

Water quality standards. In England and Wales, drinking water supplies are now governed by the Water Supply (Water Quality) Regulations 1989. These regulations require water companies to supply only water that is 'wholesome' at the time of supply, and lay down a number of numerical standards against which wholesomeness can be measured. It is notable that the use of specific microbiological agents (pathogens) in standard setting is less well established than is the case for chemicals, with the traditional approach being to monitor for the presence of indicator organisms (Macgill et al., 2000). These indicator organisms are not pathogenic but their presence indicates that contamination may have occurred or that water treatment processes are inadequate (or deteriorating). The indicator approach, while still important, is gradually being supplement by monitoring selected pathogens. *Cryptosporidium* is one example of this.

Constituencies and their knowledge base. The various constituencies, and elements of their scientific, acquired and implicit knowledge bases, are summarised in Tables 4.1 - 4.4.

Constituencies {K}		
Experts	K1	
		microbiologists
		hydrologists (water scientists)
		medical scientists (epidemiologists, especially experts in Parasitic Diseases)
		clinical/ laboratory studies
Officials	K2	
		Drinking Water Inspectorate (dwi), DETR
		the Office of Water Services (Ofwat) for England and Wales
		the Department of Health (DoH)
		the Ministry of Agriculture, Fisheries and Food (MAFF)
		the Environment Agency (EA)
		Countryside Commission
		English Nature
Stakeholders	K3	
Water industries	K31	
		water companies
Medical/private health industries	K32	
		Health care providers and medical insurance companies
Agriculture and Food industries	K33	
		National Farmers' Union
Academic communities	K34	
		UK National Cryptosporidium Research Steering Committee (NCRSC)
		Foundation for Water Research (FWR), Buckinghamshire
		Chartered Institute of Environmental Health (CIEH) (http://www.cieh.org.uk/crypto/)
		Cryptosporidium Research Group, University of Coventry
		UK Water Industry Research (UKWIR)
		Centre for Research into Environment & Health (CREH), Aberystwyth.
		Institute for Food Science & Technology (UK) (http://www.ifst.org/)
Public interest groups	K35	
		Friends of the Earth
Mass media	K36	Media
The audience	K4	The general public

Table 4.1: Illustrative examples of constituencies {K}: *Cryptosporidium* in drinking water

Dimensions	Examples of measurable attributes {M}	Examples of chances {P}
Space	Number and size of (possible) contaminated water catchment areas; Number and size of (possible) contaminated water distribution areas Number and size of (possible) infected agriculture and farming locations; Number and size of (possible) infected wildlife habits and wildlife; Number and size of (possible) infected population (including person types) and locations;	Probability of occurrence in each node of the event-tree analysis
Diffusion	Speed of transmission (from contacts to the development of illness); Rate of dispersion within and across species (humans to humans, humans to animals; animals to human) Number of prolonged period of extremely hot and dry weather; Coverage of river runoffs from flooding in the (possible) contaminated areas;	Likelihood of humans and animals infected by the disease; Likelihood of infection across species; Probability of climatic change at national, regional and local levels; Frequency of accurate weather forecasts
Reversibility	Immunity from infections;	Probability of life-time immunity to the disease
Incidence	Scientific: current state-of-the-art; laboratory/clinical testing methods; new scientific research agenda (e.g. MRC, NERC)	Scientific: possibility of new laboratory/clinical trials; likelihood of new cures or preventive methods;
	Social: credibility of safety standards/levels; trustworthiness of water companies and government officials;	Social: probability of switching new suppliers and new governing bodies
	Economic: loss of working days; medical insurance; costs of new water treatment plants;	Economic: likelihood of increasing production costs; chance of losing income/earnings; possibility of receiving compensations or introducing new penalties
	Political: loss of political position; loss of confidence in prescribed standards; resources re-allocation;	Political: probability of changing new governing bodies and/or new regulations
Magnitude	Severity of illness and (human and animal) loss of life;	Vulnerability of people by person types (e.g. young, elderly)
Beneficiaries	New methods of laboratory/clinical techniques; Methods (e.g. drugs) of immunisation; Methods of eliminating the disease;	Chance of new or increase research funding; probability of new scientific discovery
Critical states	Critical doses from developing illness to life-threatening effect	Possibility of advanced research technologies

Table 4.2: Illustrative characterisation of scientific knowledge {S}: *Cryptosporidium* in drinking water

Dimensions	Examples
Attitudes	Learning that tap water it is safe; Perceiving purity and safety of bottled water Feeling of control via home water treatment devices (e.g. filters)
Relevancy	Presuming that everyone is susceptible to *Cryptosporidium* infection.
Vulnerability	Awareness that impacts to certain types of people (e.g. young children, elderly people, immuno-compromised persons such as those receiving cancer chemotherapy, kidney dialysis, steriod therapy, people with HIV/AIDS and patients with Crohn's disease) are more serious (even life-threatening) than others
Acceptability	Receiving official advice to boil water for at least 1 minute with a rolling boil to kill Cryptosporidium, contrary to previous habits & lifestylies
Personal/Past experience	Awareness of infected cases in the past - people & animals
Media triggers	Media influence and/or broadcast of the cryptosporidiosis outbreaks

Table 4.3: Illustrative characterisation of acquired knowledge {A}: *Cryptosporidium* in drinking water

Dimensions	Examples
Cultural or religious belief	Belief about purity
Personal/group ideology	Strength of environmentalism – clean water campaign/movement

Table 4.4: Illustrative characterisation of implicit knowledge {I}: *Cryptosporidium* in drinking water

Evolution of the knowledge base. Evolution of this risk scenario through changes in the knowledge base of the key constituencies is taken to be determined via the decision making set-up indicated in Table 4.5.

Working rules	Experts {k1}	Officials {k2}	Major stakeholders {k3}	General public {k4}
1.Boundary	Science (microbiology)	Administrative, regulatory and facilitative interests	Economic interest	Health interest
2. Scope	Scientific investigations and research	Public administrations, regulatory roles	Cost consciousness and domination in consumer market	Constant, reliable supply
3. Hierarchy	High	High	Medium	Low
4. Authority and Procedure	Medium – Low	Total	Medium	Low
5. Information				
Channels	Limited but open	Average and partial open	Limited and closed	Unknown
Media influence	None	Unknown – Obscure	Obscure	Obscure
Rate of information exchange	Medium – Low	Unknown	Unknown	Unknown
Speed of information processing and assimilation	Medium – Fast	Low – Medium	Unknown	Unknown
6. Dialogue	Interactive and two-way communication	One-way communication	Unknown	Unknown
7. Participation	Active	Re-active	Unknown	Unknown
8. Trade-offs	Not yet known	Not yet known	Not yet known	Not yet known

Table 4.5: Indicative decision making set-up: *Cryptosporidium* in drinking water

The initial year – 1977. The starting point (the initial conditions) is the situation in the year 1977 (Table 4.6). It was identified by health experts {k1} that *Cryptosporidiosis* is caused by infection by the protozoan parasite, *Cryptosporidium parvum*, a species common to lambs, calves, many other mammalian species including humans, and also birds, fish and reptiles. It is assumed here that scientific interests were developing and research was undertaken to improve understanding of the risks of *Cryptosporidium* to humans, including the provenance of the disease, the nature of transmission methods, and the associated symptoms and illnesses. However, there were deficiencies in available data about human cases, and weaknesses in model building and sensitivity analysis. Scientific knowledge {S} was at the embryonic stage. Although government officials {k2} and some of the major stakeholders {k3} (e.g. water companies) were aware of the risk of *Cryptosporidiosis*, no human cases were reported. Also, monitoring and testing of indicator micro-organisms was not a normal requirement at this point of time. There was therefore no case for altering current practices and water quality legislation. Acquired knowledge {A} of the risks of Cryptosporidium to humans on the part of the officials, the major stakeholders and the general public was minimal. It is further assumed that it was the belief of the general public {k4} that tap water was safe to drink without any special treatments (e.g. boiling before consumption). This unquestioned belief constitutes the implicit knowledge {I} of the general public. Table 4.6 depicts the initial state of knowledge base in each constituency in 1977.

Constituencies {k}	Implicit knowledge {I}	Certitude of implicit knowledge {ι}	Acquired knowledge {A}	Certitude of acquired knowledge {α}	Scientific knowledge {S}	Certitude of scientific knowledge {σ}
Experts {k1}	Not known	Not Applicable	Not known	Not Applicable	Knowledge is developing in understanding the nature, origins/ sources, transmission method, and types of illness and symptoms but limited in data collection, assumptions making, modelling, sensitivity test and level of certainty in occurrence/re-occurrence.	Embryonic
Officials {k2}	Not known	Not Applicable	Weak	Negligible	Not known	Not Applicable
Major stakeholders {k3}	Not known	Not Applicable	Weak	Negligible	Not known	Not Applicable
General public {k4}	Tap water is safe to drink in UK (no need to boil before consumptio n)	Not Applicable	Not known	Not Applicable	Not known	Not Applicable

Table 4.6: Knowledge base of *Cryptosporidium* in drinking water: initial conditions 1977

The first snapshot – 1992. The first human case of Cryptosporidium was officially reported by the U.S. Department of Agriculture in 1982. In 1983, there were approximately 16 cases reported in Surrey in England. From then onwards, there was a steady increase of Cryptosporidium throughout the country, particularly in the late 1980s and early 1990s. Table 4.7 gives a brief overview of the outbreaks of Cryptosporidiosis in England and Wales between 1980s and early 1990s.

Year	Locality	Estimated cases	Suspected cause	Key references
1983	Cobham, Surrey	16	Contaminated spring	Barer & Wright, 1990
1986	Great Yarmouth	36	Unknown	Brown et al., 1989
1988	Ayrshire	27	Treatment deficiencies of spring water	Smith et al., 1989
1988	Yorkshire	67	Sewage contaminated swimming pool	Barer & Wright, 1990 Joce et al., 1990
1989	Swindon/ Oxfordshire	516	Treatment deficiencies of river water	Dick, 1989 Richardson et al., 1991
1990-91	Isle of Thanet	47	Treatment deficiencies of river water	Joseph et al., 1991
1991	South London	44	Treatment deficiencies of tap water	Maguire et al., 1995
1992	South Devon	Unknown	Contaminated drinking water	CCN, 1998, 3(4): 7-8
1992	NW	42	Contaminated drinking water	Furtado et al., 1998
1992	NW	63	Contaminated drinking water	Furtado et al., 1998
1992	SW	108	Contaminated drinking water	Furtado et al., 1998
1992	Yorkshire	125	Contaminated tap water	Furtado et al., 1998
1992	Mersey	47	Contaminated tap water	Furtado et al., 1998
1992	Bradford	125	Contaminated tap water	Atherton et al., 1995

Table 4.7: Occurrence of *Cryptosporidiosis* in England and Wales: 1980 and 1992.

An increase of Cryptosporidiosis incidence over time in England and Wales acted as an important stimulus to induce major changes in the knowledge bases of different constituencies. For instance, after the outbreak of waterborne cryptosporidiosis in Swindon and Oxfordshire in 1989, a Group of Experts, under the Chairmanship of the late Sir John Badenoch, was established jointly by the Secretary of State for the Environment and the Secretary of State for Health. In 1990, the Group published a report, 'The First Report' (DETR, 1990), which made a number of recommendations and identified areas where more research was required. This induced changes not only in scientific knowledge (ΔS) by presenting new research agendas, but also in acquired knowledge (ΔA) by raising spheres of interests and awareness from all the other constituencies (i.e. k2 to k4) through a national research programme in Cryptosporidium jointly funded by the water industry and by the government.

In 1992, there were multiple outbreaks of Cryptosporidiosis in different locations in England and Wales including South Devon, North West and South West of England, Merseyside, Yorkshire and Bradford. It was estimated that 500 cases were reported in the year of 1992. Following these multiple outbreaks the level of consciousness of the risks among the constituencies (i.e. k=1 to 4) became very high. The National Cryptosporidium Survey Group was formed by five English water service companies with the primary objective of determining the level of risk to human health from the presence of Cryptosporidium oocysts in drinking water supplies in the U.K. because there were no regulations or standards governing the presence of this micro-organism. The Survey Group adopted the measurement of 4 oocysts per litre as the benchmark concentration of Cryptosporidium in raw water. This was based on isolation using cartridge filters (nominal volume 100 litres), concentration and staining following by microscopic examination. Table 4.8 gives sample results from the 1992 Survey Group.

Following the work of the 1992 National Cryptosporidium Survey Group, it was realised that current practices and regulations governing the water quality and supplies in England and Wales were inadequate. There were diverse views over the benchmark concentration of Cryptosporidium in drinking water among the first three constituencies (i.e. k1 to k3). Because of this, the general public {k4} was in doubt about the safety of the drinking water. This imposed a potential revision of the implicit knowledge {I} of the general public. Tables 4.9 and 4.10 illustrate the changes in the decision making set-up and knowledge base of each respective constituency in 1992.

Water Type	**Samples (n)**	**% Positive**	**Range of Oocyst Concentration (oocysts/Litre)**	**Mean Concentration (oocysts/Litre)**
River[1] (2 sites)	375	4.5	0.07-4.0	0.95(g)
River[1] (4 sites)	691	55.2	0.04-3.0	0.38(g)
River[1] (4 sites)	430	4.4	0.007-2.75	0.5(g)
Deep pristine[2] groundwater well	120	0	-	-
Groundwater well	138	5.8	0.004-0.922	0.23(g)

Notes:

River[1] = affected by domestic or agriculture waste

Pristine[2] = Little or no human activity in the watershed or water, restricted access, no agricultural activity within the watershed and no sewage treatment facility discharges impacting the water upstream from the sampling site (Lisle & Rose, 1995)

(g) = geometric mean

\- = Nil

Table 4.8: Sample results of The National Cryptosporidium Survey Group (1992) in the UK.

Working rules	**Experts {k1}**	**Officials {k2}**	**Major stakeholders {k3}**	**General public {k4}**
1.Boundary	Science (microbiology)	Administrative, regulatory and facilitative interests	Economic interest	Health interest
2. Scope	Scientific investigations and research	Public administrations, regulatory roles	Cost consciousness and domination in consumer market	Constant, reliable supply (?)
3. Hierarchy	High	High	Medium	Low
4. Authority and Procedure	Medium – Low	Total	Medium	Low
5. Information				
Channels	Open and active	Average and partial open	Limited and closed	Limited
Media influence	Unknown	Unknown – Obscure	Obscure	Medium – High
Rate of information exchange	Medium	Slow – Medium	Slow – Medium	Unknown
Speed of information processing and assimilation	Medium - Fast	Medium	Slow – Medium	Unknown

6. Dialogue	Interactive and two-way communication	Two-way communication	Establish links with government officials and academia communities	One-way communication
7. Participation	Active	Re-active	Unknown	Passive
8. Trade-offs	Scientific breakthroughs and new research contracts	Resources re-allocation (e.g. new funding & research programmes)	Resources re-allocation (e.g. Funding & research projects)	Not yet known

Table 4.9: Changes in the decision-making set up: 1992.

Constituencies {k}	**Implicit knowledge {I}**	**Certitude of implicit knowledge {ι}**	**Acquired knowledge {A}**	**Certitude of acquired knowledge {α}**	**Scientific knowledge {S}**	**Certitude of scientific knowledge {σ}**
Experts {k1}	Not known	Unknown	Not known	Unknown	John Badenoch's (experts) report and The National Cryptosporidium Survey Group examined the past events and tried to define a baseline for comparison study	Developing
Officials {k2}	Not known	Unknown	Indicator micro-organisms may not be adequate and/or sufficient; new national research programmes and clinical trials	Embryonic – Low	Human cases: largely (e.g. 96% from a study) associated with waterborne infection which was unusual	Embryonic - developing
Major stakeholders {k3}	Not known	Unknown	Insufficiency of current practices; (new) Laboratory testing; new research projects	Embryonic – Low	Data collection and develop research interests	Embryonic
General public {k4}	Tap water may not be safe to drink	Low to Medium	Media coverage (Badenoch's report & the	Embryonic – developing	Not known	Unknown

	(without boiling)		multiple outbreaks in different localities over the country); friends and family influence; violate the common practices (e.g. boil water before consumption)			

Table 4.10: Knowledge base of *Cryptosporidium* in drinking water: 1992

The second snapshot – 1995. After 1992, there were even more frequent and substantial outbreaks of Cryptosporidiosis. Table 4.11 shows the number of occurrences between 1993 and 1999. Government agencies and water companies issued public warnings (e.g. boiling water before consumption) and mass media debated the sufficiency and reliability of the water regulations and safety standards. In 1994, the UK Expert Group was reconvened under the chairmanship of the late Sir John Badenoch to re-examine the situation. The Group published its "Second Report" (DETR, 1995), suggesting that current treatment processes might not prevent all *Cryptosporidium* oocysts from reaching drinking water supplies. However, the general view of the Group was that the level of removal achieved by a well-operated conventional treatment plant should be sufficient to prevent the widespread illness that was characteristic of a water-borne infection. Recommendations were made as to the proper operation of plants and for checking operations to ensure that best practice was maintained (e.g. by monitoring for changes in the turbidity of the water within the treatment process). Further advances in scientific and implicit knowledge (i.e. ΔS and ΔI) were gained.

Year	**Locality**	**Estimated cases**	**Suspected cause**	**Key references**
1992-93	Warrington	47	Contaminated tap water	Bridgman et al., 1995
1993	Wessex	40	Contaminated tap water	Goldstein et al., 1996
1993	Northern UK	At least 5	Contaminated water at University	Furtado et al., 1998
1993	Yorkshire	97	Contaminated tap water	Furtado et al., 1998
1994	SW Thames, Wessex, Oxford	224	Contaminated tap water	Furtado et al., 1998
1994	Trent area	33	Contaminated tap water (?)	Furtado et al., 1998
1995	South and West Devon	575	Contaminated drinking water	CCN, 1996, 1(5): 7-8 CCN, 1998, 3(4): 7-8 Patel et al., 1998
1995	SW	575	Contaminated tap water	Furtado et al., 1998
1995	Northumberland	55	Contaminated drinking water	Duke et al., 1996
1996	England	Ca 226	Contaminated drinking water	CCN, 1996, 1(12):8 CCN, 1997, 2(11): 1-3 CDR, 1996, 6(34): 301-302

1996	Wirral peninsula	52	Contaminated river water	Hunter & Quigley, 1998
1997	North Thames	345	Contaminated borehole water	CCN, 1997, 2(6): 1-4 CCN, 1997, 2(7): 3 Patel et al., 1998 Willocks et al., 1998
1997	England & Wales	>4,321	Multiple outbreaks & causes	CCN, 1997, 3(1):1 CCN, 1998, 3(6):6 CDR, 1998, 8(11): 95-96
1999	NW England	Ca 360	Unfiltered surface water	CCN, 1999, 4(8):1 CCN, 1999 4(9): 1-2

Table 4.11: Occurrence of Cryptosporidiosis in England and Wales: 1993 and 1999

In the "Second Report", the experts explicitly stated that the conventional water treatment processes were not designed to deal specifically with *Cryptosporidium*. The oocysts are unaffected by chlorine in the concentrations that it is practicable to use. In this stage, although scientific knowledge was advancing, media and public attention was concentrated on the insufficiency of current practices within the water industry and the weakness of the present water supply regulations. These concentrations helped to alter the knowledge base, particularly the implicit knowledge (ΔI), of some constituencies. Table 4.12 outlines changes in the knowledge base of the constituencies in 1995.

Constituencies {k}	**Implicit knowledge {I}**	**Certitude of implicit knowledge {ι}**	**Acquired knowledge {A}**	**Certitude of acquired knowledge {α}**	**Scientific knowledge {S}**	**Certitude of scientific knowledge {σ}**
Experts {k1}	Not known	Unknown	Not known	Unknown	Risk type, possible contamination sources, probabilities of occurrence, testing methods and cures	Mature: High
Officials {k2}	Institutional image	Embryonic	Political interest and institutional credibility drives the need to change or amend current practices and water quality regulations	Developing – Mature : Med – High	Scientific steering groups formed and reports produced	Med - High
Major stakeholders {k3}	Organisational interests	Embryonic	Open up new arenas and	Developing – Mature: Med – High	Research findings	Developing

			challenges with respect to legislation, regulations, risk manageme nt and public governanc e			
General public {k4}	Trust, legal system, present regulations on water supply and water quality are in question	Med – High	More frequent outbreaks attract even more attention from media and public; prosecution of a private water supplier brought to the attention to all constituenc ies	Developing – Mature: Med – High	Information from different channels (e.g. mass media, experts, environme ntal-ists and sources from Internet)	Developing

Table 4.12: Knowledge base for *Cryptosporidium* in drinking water: 1995

The third snapshot – 1999. Following a large Cryptosporidium outbreak on the outskirts of London (contamination of water from groundwater source) in 1977, a further Group of Experts was established under Professor Ian Bouchier to review the current state of knowledge. This would induce further change in scientific knowledge (ΔS).

In the same year, public and official attention was diverted to the failure of a prosecution against Southern Water for supplying unwholesome water following an outbreak of *Cryptosporidiosis* in Northumberland in 1995. The court case failed because epidemiological findings relating to the outbreak were ruled inadmissible as evidence. This inevitably caused revisions in the acquired knowledge {A} and implicit knowledge {I} of all constituencies. The result of this court ruling imposed significant impacts on the beliefs, jurisdictions and political position of the officials {k2}. As a consequence, the Department of the Environment, Transport and the Regions (DETR) released a consultation paper entitled “Preventing Cryptosporidium getting into Public Water Supplies” proposing amendments to water supply regulations in June 1998. The publication of this consultation paper indicated that the officials {k2} intended to re-gain control of the present situation by exercising one of the defined working rules, i.e. authority and procedure.

The consultation paper proposed that finished water must contain less than an average of 1 Cryptosporidium oocyst per 10 litres. The proposed amendments would also allow prosecution of (water) companies even when there was no evidence of illness associated with a breach of the prescribed standard. Furthermore, the consultation paper contained an assessment of the costs of compliance with the proposals. It was estimated that for each treatment plant, the non-recurrent cost was £2,000 per plant and the annual recurrent cost was £65,000 per plant. The estimated total cost for compliance with the proposed regulations would be £540,000 (non-recurrent) and £7 millions (annual recurrent) across all 121 affected treatment plants in England and Wales. If the regulations were implemented, it was estimated to reduce 330 cases per year on average cost of £24,000 per case (as there were approximately 2000 cases of cryptosporidiosis attributed to waterborne outbreaks in England and Wales between 1990 and 1997) and increase water bills by 1.5%.

In November 1998, the Expert Group published its 'Third Report' (also known as the 'Bouchier Report') (DETR, 1998) providing further advice on protection of water resources (including surface and ground waters), provision of additional water treatment, monitoring programmes and strategies, management of outbreaks of drinking water related illness, and the need for further research. Comments were also made in response to the DETR's consultation paper, particularly the proposed maximum concentration of Cryptosporidium in drinking water. Experts estimated that the daily risk of infection from drinking water containing 1 oocyst per 10 litres was 9.3 x 10^{-4} at 95% confidence interval (or 3.9 x 10^{-4} to 19 x 10^{-4}) (Rose et al., 1995). The report stated that it was not possible to recommend a health-related standard for Cryptosporidium in drinking water.

Notwithstanding the diverse views among constituencies and substantial financial implications, the proposed amendments released by DETR in 1998 were laid before Parliament on the 9th June 1999. The Water Supply (Water Quality) (Amendment) Regulations 1999 No. 1524 came into force on the 30th June 1999. The regulations require water undertakers to ensure that the average number of *Cryptosporidium* oocysts per 10 litres of water is less than one. Water undertakers must also ensure that the water leaving their treatment works is continuously sampled for *Cryptosporidium* oocysts.

It is notable that in the final stage of decision making process, other constituencies were overwhelmed by one player -the officials. Table 4.13 outlines the various stimuli which led to a change in the knowledge base of all constituencies by the end of 1999.

Constituencies {k}	**Implicit knowledge {I}**	**Certitude of implicit knowledge {ι}**	**Acquired knowledge {A}**	**Certitude of acquired knowledge {α}**	**Scientific knowledge {S}**	**Certitude of scientific knowledge {σ}**
Experts {k1}	Not known	Unknown	Not known	Unknown	Possible prevention and testing methods; richer data collection	Mature: High
Officials {k2}	Political interest; institutional credibility and assurance	Embryonic	Change and amend current practices and water quality regulations	Developing – Mature : Med – High	Scientific steering groups formed and consultatio n paper produced	Med - High
Major stakeholders {k3}	Organisationa l image	Developing	Great cost involved for the total compliance ; implication s of shifting costs to consumers	Developing – Mature: Med – High	Only laboratorie s with specialised testing capabilities can detect the presence of	Developing - Mature

					Cryptosporidium oocysts in water	
General public {k4}	Quality and safety of treated and untreated (tap) water	Threats to belief and trust : Med – High	Failure of a court ruling leading to amendments of water regulations	Developing – Mature: Med – High	Information from different channels (e.g. mass media, experts, environmentalists and Internet)	Developing - Mature

Table 4.13: Knowledge base of *Cryptosporidium* in drinking water: 1999

What next? There is a further twist to the illustration. According to Fewtrell et al. (2001), the certitude of scientific knowledge about Cryptosporidium risks in drinking water is markedly different at different points along the pathways through which human health risks may be generated. In brief, the science is considerably weaker in terms of determining possible contamination levels at the consumer's tap (the point of exposure to risk) than at the treatment works, or in monitored raw water sources. If this is the case, the scientific knowledge base ranges from mature to developing, depending on the chosen node in the pathway (i.e. raw water, water treatment and water distribution). If the focus of public concern is on the last node of the water supply pathway (the consumer's tap), then recent changes to the regulations might not be sufficient to assure the public. Health fears, locational differences, doubts about value for money, and losses of trust in the ability of the water industry to protect public safety, may fuel their concerns. As reflected in Table 4.14, the science in this area is still developing or unknown. In such circumstances, it is envisaged that scientific knowledge will undergo similar stages as shown previously but accompanied by additional (may be richer) information about the acquired and implicit knowledge base.

Constituencies {k}	**Implicit knowledge {I}**	**Certitude of implicit knowledge {ι}**	**Acquired knowledge {A}**	**Certitude of acquired knowledge {α}**	**Scientific knowledge {S}**	**Certitude of scientific knowledge {σ}**
Experts {k1}	Not known	Unknown	Not known	Unknown	Raw water:	Mature: High
					Water treatment:	Developing – Mature: medium – High
					Water distribution:	Embryonic: Low
					Water out of the tap:	Unknown
Officials {k2}	Political interest; institutional credibility and assurance	Embryonic - developing	The need to clarify the procedures via the Amendment	Mature : High	Laboratory tests not very reliable; they cannot tell whether	Embryonic – Low

					the oocyst is alive or dead	
Major stakeholders {k3}	Not known	Unknown	New or additional costs (e.g. new treatment plants, new testing methods, new medical procedures)	Developing – Mature: Med – High	Not known	Unknown
General public {k4}	Our/my drinking water may not be safe	Med – High	4759 cases recorded in England and Wales in 1999 (source: Communicable Disease Report 10(2):11, 2000)	Developing – Mature: Med - High	Information from different channels (e.g. mass media, experts, environmentalists and Internet)	Unknown

Table 4.14: Knowledge base of *Cryptosporidium* in drinking water at the turn of the 21st Century

5. EVALUATION

It has been shown how a risk issue (in this case Cryptosporidium in drinking water) can be modelled using the categories introduced in section 3. The force of the illustration depends on the deemed importance of concepts of 'knowledge' as the fundamental matter of risk analysis. The tenet of this paper is that a more systematic understanding of the different knowledge bases of different constituencies for different risk issues (and ultimately of the interactions between them) is the proper focus of risk analysis and a necessary foundation for its development as a holistic, inclusive discipline.

The illustration presents four snapshots of the risk knowledge economy for the chosen risk issue over the period 1977-2000 (tables 4.6, 4.10, 4.12, 4.13, 4.14). In 1977 the scientific knowledge base was weak – pre-conditions for controversy, and for the emergence of dichotomous trends. On the one hand, and notwithstanding the variable scientific certitude in the year 2000 noted above, since 1977 there has in general been an improvement in the base of scientific knowledge about *Cryptosporidium* health threats (see Table 5.1 for what is now known). On the other, there has been a deterioration in public confidence in that knowledge base over the same period. To the extent that such trends have previously been acknowledged in other contexts (e.g. improvement in nuclear science accompanying a deterioration in public confidence in the nuclear industry?) then this in itself is not so remarkable. The force of the illustration lies in the formal, systematic framework of analysis through which this disclosure has been revealed – a replicable and holistic 'best practice' analytical approach. This is in contrast to the less formal, more partial, or discipline-specific paradigms through which similar observations may hitherto have been made.

Risk source:	Sources of contamination (at the important nodes of water pathway such as raw water, water treatment and water distribution)
Risk type:	All people are presumed susceptible to infection with Cryptosporidium when drinking water supplies are contaminated but mortality rate is low. However, consequences may be traumatic to certain types of people (e.g. young children, elderly people, immunocomprised persons such as those receiving cancer chemotherapy, kidney dialysis, steriod therapy, people with HIV/AIDS and patients with Crohn's disease)
Transmission means:	The faecal-oral route (infected by ingesting the organism)
Dispersion mechanism:	Person-to-person or person-to-animal
Reversibility:	The parasite has a direct life cycle (i.e. initial state is recoverable)
Critical (dose-response) thresholds:	There is no consensus on thresholds from mild to serve illness, depending on person types. Although cryptosporidiosis often occurs in combination with other pathogens (e.g. rotavirus), it is able to cause diarrhoea on its own if a large dose of the parasite are taken.
Immunity/Cures:	No cures except treatments to symptoms. Some immunity appears to follow infection but the degree to which a previously infected person is immune to subsequent Cryptosporidium infection is unclear. Exposure to a large dose of the parasite could result in recurrent illness.

Table 5.1: The current scientific knowledge base of *Cryptosporidium* in drinking water

The dichotomous trends foreshadow difficult times ahead for those involved in the management of waterborne health threats. Public confidence is difficult to regain once it has been lost, and although the base of scientific knowledge in this field is currently better than ever before, there remain significant gaps, and in turn there are relatively simple questions about potential health threats which are currently unanswerable by science. In addition to the need for further research to improve the base of scientific knowledge, there is also a need for research to improve understanding of the 'implicit' and 'acquired' knowledge bases as these are as much a part of this issue and should accordingly be given no lesser standing. As noted at the start of this section, there has been relatively little social science research in this area, a position exacerbated by the relative lack of (official) historical data records.

More widespread application of the model across different risk issues should begin systematically to illuminate the fundamental nature of differences and similarities between them. Which are stable, and why? Which are set to generate social conflict and why? What might be done in such situations? The vision is of a structured classification of different risk issues, enabling the characteristics of specific issues to be more cogently understood, and appropriate risk management strategies more readily focused. Risk issues have such a contemporary prominence. Coupled with increasing demands for knowledge, and the increasingly rapid exchange of knowledge among and between different constituencies, this position will put unprecedented demands on risk analysis in the future, and an appropriately broadened paradigm and sharper analytical tool kit might be the minimum expectations of that field.

6. INTO THE FUTURE

Enabling technology. The case for analysis of complex problems based on formal systematic frameworks is in general well rehearsed (Weaver, 1948; Wilson, 2000): transparency, accountability, clarity and rigour in description of the system of interest; a foundation for informed model-based prediction and scenario exploration of future problems and needs; a basis for identification of typologies of situation to which generic solution approaches may be applicable (and not applicable); in short an enabling technology for 'better management'. There is a formidable research agenda here in the context of risk. Its pursuit at the present time will inevitably be mediated by the progressive development of communications and information technology. The format of specification of the formal model above was conceived in part with this in mind.

Inclusiveness. The case for a holistic approach lies in the need for completeness and for appreciation of the 'whole system'. It can embrace existing approaches, and turn to them to explain particular aspects (e.g. cultural/anthropological approaches or social amplification and attenuation to formulate and record the development and change of acquired and implicit knowledge) while placing them as but part of the fuller picture.

Knowledge architecture. Although different types of knowledge (A, I and S) have previously been acknowledged and examined elsewhere, it is believed that the developments in this paper represent the first time that they have been articulated, formalised and, more importantly, assessed (via α, ι and σ) within a systematic and coherent framework, taking into account the multi-faceted nature of risk analysis. More importantly, the nature of the framework that has been articulated is such that knowledge can be traced, stored and shared within a single architecture. It is envisaged that, within this architecture, processes or mechanisms will need to be defined to organise, manage and facilitate analysis of the knowledge. It opens up a new avenue for risk researchers - to explore the procedures and techniques required in constructing and managing this knowledge architecture.

If it is accepted that each type of risk and each approach to risk analysis can be accommodated within the proposed framework, then it should be possible to develop a comprehensive risk portfolio (a risk knowledge database) for reference purposes. This would be a valuable asset to the field of risk research, as the knowledge pertaining to any single risk problem is currently scattered in many different sources.

Barriers, enablers and thresholds. The dynamics of knowledge evolution will be affected both by barriers and disincentives which inhibit knowledge sharing, and by enablers and leverage points which promote knowledge dissemination and acquisition. There are also likely to be critical thresholds (points of bifurcation) at which these influences may operate. The understanding and modelling of these forces and effects will be a further challenging aspect of the research agenda.

Autonomous social agents? Another research issue spinning off from the proposed framework is the extent to which agent-based simulation can be used to produce a practical toolkit of computable risk knowledge-based society. To a large extent, the proposed framework shares similar notions and ideas with the agent-based computing. Also, methods used to define procedures, influence processes and interactions between agents or constituencies are similar. The agent-based computing is based upon the notion of an agent as an autonomous, internally-motivated entity that is situated within a dynamic and not entirely predictable environment from which it receives perceptual inputs and to which it effects changes by performing actions. Agents are autonomous. It means that they have a high degree of self-determination (like the constituencies in the proposed framework) - they decide for themselves when and under what conditions their actions should be performed. Despite this self-determination, agents are often required to attain goals that are only possible, made easier or satisfied more completely by interacting with other, similarly autonomous, agents (similar to those defined in the decision making process of the proposed framework). Whereas the behaviour of an asocial agent is entirely determined by its internal drivers and their interplay with the environment as seen through its precepts, the behaviour of a social agent can additionally be influenced by the interactions in which it is or, it could be engaged.

e-knowledge. It is envisaged that the proposed conceptual framework can be developed into practical analytical tools with the help of current computing technologies (especially the Internet computing and applications), and advance in the field of telecommunication. For instance, values of different types of knowledge can be displayed, examined, assessed, evaluated and (may be) altered on-line throughout the progress of the examination of a specific risk issue.

7. CONCLUSION

The field of risk analysis currently spans a wide range of high profile issues (including GMOs, BSE, nuclear waste and reprocessing, transport safety, health threats and patient safety), a wide range of interests (including scientists, regulators and affected populations) and a variety of different disciplinary approaches (from the social, medical, engineering and natural sciences). Although there are many existing approaches from different disciplines to advance our understanding of risk, it is paramount important that the genetic make-up of risks should be explored. Thus, this represents one of the major analytical challenges of our time. The critical assault on the founding paradigm of risk analysis referred to at the start of this paper set the case for renewal of that paradigm. The crucial change needed has been argued to be a shift from the narrow delimitation of the knowledge base which that paradigm currently identifies for risk characterisation (scientific or technical knowledge).

In this paper, a formal, holistic conceptual framework and model of risk were developed, in which the current range of interests and approaches for any given risk issue are cogently integrated. In particular, the model proposes a gestalt reformulation of the classic elements of risk assessment (and related uncertainty analyses), risk communication, risk perception and risk management into a single, recursive specification which captures the intrinsic multi-faceted nature of risk. It is suggested that this model demonstrates an understanding of risk that is unusually general, while at the same time being clear and ordered. It is also amenable to progressive development through computing and information technologies. The applicability of the model to waterborne health threats was depicted and illustrated.

> *"We must not cease from exploration and the end of all our exploring will be to arrive where we began and to know the place for the first time"*
> T. S. Elliot

The developments reported in this paper are offered in the spirit of setting the direction of the first small step which may be the beginning of a very long journey. That initial small step has been identified as the proper articulation of the system of interest of risk analysis – the quality and evolution of the social and scientific knowledge bases on risk. By moving instead towards a broader and formal model-based conceptualisation – embracing both social knowledge and scientific knowledge bases – then a profound shift in perspective is gained, together with a new starting point for the development and application of a new generation risk analysis tool-kit.

REFERENCES

Atherton, E., Newman, C.P. and Casemore, D.P. (1995) An outbreak of waterborne cryptosporidiosis associated with a public water supply in the UK. ***Epidemiology & Infection***, 115, 123-131.

Atherton, F., Newman, C.P.S. and Casemore, D.P. (1995) An outbreak of waterborne Cryptosporidium associated with a public water supply in the UK. ***Epidemiology and Infection***. 115(1), 123-131.

Barer, M.R. and Wright, A.E. (1990). ***Letters In Applied Microbiology, 11***, 271-277.

Beer, T. and Ziolkowski, F. (1995) Environmental risk assessment: an Australian perspective. Paper presented in "the 1995 Australian Academy of Science Fenner Conference on the Environment: Risk & uncertainty in environmental management. 13-16 November 1995, Becker House, Canberra." Commonwealth of Australia.

Bijl, M.G., and Hamann, R.J. (2002) Risk management literature survey: An overview of the process, tools used and their outcomes. Technical Report; August 2002. The Faculty of Aerospace Engineering, Delft University of Technology, The Netherlands.

Bloomfield, D., Collins, K., Fry, C., and Munton, R. (1998) Deliberative and inclusionary processes: Their contribution to environmental governance. Paper presented at a conference in the University College London "Environmental governance: responding to the challenge of deliberative democracy" in December 1998.

Bragg, M. (2000) **Reporter - Commemorative Issue: Installation of Chancellor.** The Press Office, University of Leeds, Leeds, LS2 9JT, United Kingdom. pp. 6.

Bridgman, S.A., Robertson, R.M.P., Syed, Q., Speed, N., Andrews, N. and Hunter, P.R., (1995) Outbreak of cryptosporidiosis with a disinfected groundwater supply. ***Epidemiology and Infection***. 115(3), 555-566.

Chartered Institute of Environmental Health (CIEH) Internet Resources. Cryptosporidium – previous outbreak.

Covey, S. R. (1989) **The 7 habits of highly effective people.** Simon & Schuster, London.

Department of Health (1998) **Communicating about risks to public health: pointers to good practice**. Department of Health, HMSO, Great Britain.

Department of the Environment, Transport and the Regions (DETR) (1990) **Cryptosporidium in Water Supplies. Report of the Group of Expert.** Chairman: Sir John Badenoch. July 1990. Department of Health/Department of the Environment. HMSO, London 1990.

Department of the Environment, Transport and the Regions (DETR) (1995) **Cryptosporidium in Water Supplies. Second Report of the Group of Experts. 1995.** HMSO, London 1995.

Department of the Environment, Transport and the Regions (DETR) (1998) **Cryptosporidium in Water Supplies. Third Report of the Group of Experts. Chairman: Ian Bouchier. November 1998.** Department of Health/Department of the Environment. TSO Ltd.

Department of the Environment, Transport and the Regions (DETR). (1998) DETR consultation document: "**Public health and drinking water: preventing Cryptosporidium getting into public drinking water supplies**" June 1998.

Dick, 1989, Report. Thames Water Dist., 1989.

Douglas, M. (1985) **Risk acceptability according to the Social Sciences**. Routledge & Kegan Paul, London.

Douglas, M. and Wildavsky, A. (1982) **Risk and Culture: an essay on the selection of technical and environmental dangers**. Berkeley, California: University of California Press.

Duke, L.A., Breathnach, A.S., Jenkins, D.R., Harkis, B.A, and Codd, A.W. (1996) A mixed outbreak of Cryptosporidium and Campylobacter infection associated with a private water supply. ***Epidemiology and Infection***. 116(3), 303-308.
Frewer, L. and Shepherd, R. (1994) Attributing information to different sources: effects on the perceived qualities of information on the perceived relevance of information and effects on attitude information. ***Public Understanding of Science, 3(4),*** 385-401.
Fewtrell, L., Macgill, S. M., Kay, D. and Casemore, D. (2001) Uncertainties in risk assessment for the determination of drinking water pollutant concentrations: Cryptosporidium case study. ***Water Research, 35***(2), 441-447.
Fischhoff, B., Watson, S.R. and Hope, C. (1984) "Defining Risk". ***Policy Science***, 17, 123-139.
Frankl, V.E. (1984) **Man's search for meaning**. Washington Square Press, New York.
Furtado, C., Adak, G.K., Stuart, J.M., Wall, P.G., Evans, H.S. and Casemore, D.P. (1998) Outbreaks of waterborne infectious intestinal disease in England and Wales, 1992-5. ***Epidemiology and Infection***. 121(1), 109-119.
Haerlin, B. and Parr, D. (1999) How to restore public trust in science. ***Nature***, August 1999.
Hunt, S., Frewer, L. and Shepherd, R. (1999) Public trust in sources of information about radiation in the UK. Journal of Risk Research, 2(2), 167-180.
Hunt, S. and Frewer, L. (2001) Trust in Source of Information about Genetically Modified Food Risks in the UK. British Food Journal, 103(1), 46-62.
Hunter P. and Quigley, C. (1998) Investigation of an outbreak of Cryptosporidiosis associated with treated surface water finds limits to the value of case control studies. ***Communicable Disease and Public Health***. 1(4), 234-238.
Irwin, A. and Wynne B. (Eds) (1995) **Misunderstanding Science? The public reconstruction of science and technology**. Cambridge University Press. Cambridge.
Joce et al. (1991) ***Epidemiology and Infection***, 107, 497-508.
Johnson, B. B. (1993). Advancing understanding of knowledge's role in lay risk perception. ***RISK: Issues in Health & Safety***, 4, 189- 212.
Joseph, C. et al. (1991) Cryptosporidiosis in the Isle of Thanet; an outbreak associated with local drinking water. ***Epidemiology and Infection***. 107, 509-519.
Kaplan, F. and Garrick, B.J. (1981) On the quantitative definition of risk. ***Risk Analysis***, ***1***(1), 11-27.
Knight, S. (1999) **NLP Solutions**. Nicholas Brealey Publishing, London.
Klinke, A. and Renn, O. 2001. Precautionary principle & discursive strategies: classifying and managing risks. ***Journal of Risk Research*, 4**(2), 159-173.
Krimsky, S. and Golding, D. (1992) ***Social Theories of Risk.*** Praeger Publishers. Westport, Conn.
Lisle, J.T. and Rose, J.B. (1995) Cryptosporidium contamination of water in the USA and UK: a mini-review***. Journal of The International Water SupplyAssociation – Aqua***. 44(3), 103-117.
Loewenstein, G., Hsee, C., Weber, E., and Welch, N. (2001). Risk as Feelings. ***Psychological Bulletin. 127(2),*** 267-286.
Macgill, S.M., Fewtrell, L. and Kay, D. (2000) Standards for Standards: an evaluation of water quality regulation in England and Wales. School of the Environment, University of Leeds, Leeds, LS2 9JT, UK.
Macgill, S.M., Fewtrell, L. and Kay, D. (2001) Quality audit and the assessment of waterborne risk. In: Lorna Fewtrell & Jamie Bartram (eds) **Water quality: Guidelines, standards and health : Assesment for water-related infectious disease. London**. 191-206.

Maguire, H.C., Holmes, E., Hollyer, J. and Strangeways, J.E.M., 1995, ***Epidemiology and Infection***. 115(2), 279-287.
National Cryptosporidium Survey Group. (1992) A survey of Cryptosporidium oocycts in surface and groundwaters in the UK. ***Journal of the Institute of Water and Environmental Management (IWEM)***. 6(6), 697-703.
North, D. W. (1998) Comments on 'Three decades of risk research'. ***Journal of Risk Research***, 1(1), 73-76.
Ostrom, E. (1986) A Method of Institutional Analysis. In: F. X. Kaufmann, G. Majone, and V. Ostrom (eds.) **Guidance, Control, and Evaluation in the Public Sector**. Berlin and New York: de Gruyter, 459-475.
Otway, H. and Ravetz, J. (1984) Technology: examining the linear model. ***Futures***, June 1984.
Palmlund, I. (1992) "Social drama and risk evaluation". In: **Social Theories of Risk**. Krimsky, S. and Golding, D. (Eds) Praeger Publishers. Westport, Connecticut. 197-212.
Patel, S., Pedraza-Diaz, S., McLauchlin, J. and Casemore, D.P. (1998) Molecular characterisation of Cryptosporidium parvum from two large suspected waterborne outbreaks. ***Communicable Disease and Public Health***. 1(4), 231-233.
Perrow, C. (1984) Normal Accidents: Living with High-Risk Technologies. New York: Basic Books.
Poortinga, W. and Pidgeon, N.F. (2004) Trust, the asymmetry principle, and the role of prior beliefs, Risk Analysis, 24(6), 1475-86. DOI: 10.1111/j.0272-4332.2004.00543.x
Renn, O. (1990) Risk perception and risk management: a review. ***Risk Abstracts***, 7(1): 1-9 (Part 1) and 7(2): 1-9 (Part 2).
Renn, O. (1998) Three decades of risk research: accomplishments and new challenges. ***Journal of Risk Research***, 1(1), 49-71.
Richardson et al., 1991, ***Epidemiology and Infection***. 107: 485-495.
Rosa, E.A. (1998) Metatheoretical foundations for post-normal risk. ***Journal of Risk Research***, 1(1), 15-44.
Rose, J.B., Lisle, J.T. and Hass, C.N. (1995) Risk assessment methods for Cryptosporidium and Giardia in contaminated water. In: **Protozoan Parasites and Water**. Betts, Caspre, Fricker, Smith and Watkins (Eds.) Special Publication - Royal Society of Chemistry, Cambridge. 238-242.
Rottenstreich, Y., and Hsee, C. (2001). Money, Kisses and Electric Shocks: On the Affective Psychology of Risk. **Psychological Science. 12(3),** 186-190.
Rowe, W.D. (1994) Understanding Uncertainty. ***Risk Analysis***, ***14(5)***: 743-750.
Short, J.F. (1989) On defining, describing, and explaining elephants (and reactions to them): hazards, disasters, and risk analysis. ***Mass Emergencies and Disasters***, **7(3),** 397-418.
Shrader-Frechette, K.S. (1990) Perceived risks versus actual risks: managing hazards through negotiation. ***Risk: Health, Safety and Environment***, Vol. 1 (Fall), 341-363.
Slovic, P. (1986) Information and educating the public about risk. ***Risk Analysis***, 6(4), 403-415.
Slovic, P. (1987) Perception of risk. ***Science***, 236(4799), 280-285.
Slovic, P. Finucane, M.L., Peters, E. and MacGregor, D.G. (2004) Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk, and Rationality. *Risk Analysis, 24*(2): 311-322. DOI: 10.1111/j.0272-4332.2004.00433.x.
Smith et al., 1989, ***Epidemiology and Infection***. 103, 703-715.
Stirling, A. (1998) Risk at a turning point? ***Journal of Risk Research***, 1(2): 97-109.

Stirling, A. and Mayer, S. (1999) Rethinking risk: A pilot multi-criteria mapping of a genetically modified crop in agricultural systems in the U.K. SPRU (Science and Technology Policy Research), SPRU Publication Office, Brighton, U.K.
Thompson, M. (1989) Postscript: Engineering and anthropology: Is there a difference? In: **Environmental Threats – Pereception, Analysis and Management.** Brown, J. (Ed.) Belhaven Press, London. pp. 138-150.
Thompson, P.B. and Dean, W. (1996) Competing conceptions of risk. ***Risk: Health, Safety & Environment***, 1996, Vol. 7 (Fall), 361-384.
Tippins, S.C. (2004) Risk management: Where is it and where does it belong? ***An International Journal of Risk Management, 6***(3), 9-11.
US Department of Agriculture. Cryptosporidium: a waterborne pathogen. The water quality information center at the National Agricultural Library, Agricultural Research Service, U.S. Department of Agriculture.
Weaver, W. (1948) Science and complexity. ***American Scientist, 36***: 536-44.
Weinberg, A.M. (1972) Science and trans-science. ***Minerva***, ***10***, 209-222.
White, D. H. (1994) Concepts of risk management. ***Agricultural Systems & Information Technology***, ***6***, 7-8.
Willocks L., Crampin, A., Milne, L., Seng, C., Susman, M., Gair, R., Moulsdale, M., Shafi, S., Wall, R., Wiggins, R. and Lightfoot, N. (1998) A large outbreak of cryptosporidiosis associated with a public water supply from a deep chalk borehole. ***Communicable Disease and Public Health***. 1(4), 239-243.
Wilson, A.G. (2000) **Complex spatial systems: the modelling foundations of urban and regional analysis**. Pearson Edition (Prentice Hall) Harlow, Essex.
Wynne, B. (1989) Frameworks of rationality in risk management: Towards the testing of Naïve Sociology. In: **Environmental Threats: Perception, Analysis and Management**. Brown, J. (Ed.) Belhaven Press, London. 33-48.

Appendix A: Illustrative framework for evaluating the level of certitude of implicit knowledge {ι}

Anchoring effect	Question
Cultural/religious belief or difference	What is the degree of cultural/religious difference influencing the result?
Individual up-bringing	To what extent the individual up-bringing and personal experience has an effect on the result?
Individual/group special interest	To what extent does the individual or group special interest have influence on the result?
Genetic imprints	Will the genetic make-up of individuals have influence on the result?

Appendix B: Illustrative framework for evaluating the level of certitude of acquired knowledge {α}

Aspect	Issue
OBSERVATION	
Measure	Closeness of match between what is given in 'science' and perceived socially and/or personally
Trust	Strength of belief in the information/data being received
Sensitivity	Criticality of measure to the justification of belief
METHOD	
Information channels	Extent of availability and use of the channels to convey information
Media influence	Accuracy of scientific results/findings being conveyed to the receivers (e.g. the society, communities, individuals)
Rate of information exchange	Speed of the flows of information exchange
Speed of information process and assimilation	Speed with which people can pick up, process and digest received information
Clarity of information	Level of clarity in information discourse
OUTPUT	
Acceptance	How widely accepted the result
State of social collective consensus or an individual's mind	Degree of consensus about current state of collective or individual mind
VALIDITY	
Relevance	Relevance of the problem to an individual, a community or a society
Completeness	Sureness that the ultimate findings/solutions are found

Appendix C:
Illustrative framework for evaluating the certitude of the scientific knowledge {σ}

Aspect	**Issue**
OBSERVATION	
Measure	Closeness of match between what is observed and the measure being adopted to observe it
Data	Strength of the empirical content
Sensitivity	How critical is the measure to the stability of the result?
METHOD	
Theory	How strong is the theoretical base?
Robustness	How robust is the result to changes in methodological specification?
OUTPUT	
Accuracy	Has a true representation of the real world been achieved?
Precision	Is the degree of precision as good as it can be for the phenomenon being measured? Could it be finer? Should it be coarser?
PEER REVIEW	
Standing	How widely reviewed and accepted is the process and the outcome?
State of the art	What is the degree of peer consensus about the state of the art of the field?
VALIDITY	
Relevance	How relevant is the result to the problem in hand?
Completeness	How sure are we that the analysis is complete?