[RISK: Health, Safety & Environment (1990-2002)](https://scholars.unh.edu/risk)

Volume 8 | Number 2 Article 7

March 1997

Environmental Decision Making and Risk Management for Groundwater Systems

Janet D. Gough

Follow this and additional works at: https://scholars.unh.edu/risk

Part of the Natural Resources Management and Policy Commons, Public Affairs, Public Policy and Public Administration Commons, and the Sustainability Commons

Repository Citation

Janet D. Gough, *Environmental Decision Making and Risk Management for Groundwater Systems*, 8 RISK 155 (1997).

This Article is brought to you for free and open access by the University of New Hampshire – Franklin Pierce School of Law at University of New Hampshire Scholars' Repository. It has been accepted for inclusion in RISK: Health, Safety & Environment (1990-2002) by an authorized editor of University of New Hampshire Scholars' Repository. For more information, please contact ellen.phillips@law.unh.edu.

Environmental Decision Making and Risk Management for Groundwater Systems*

Janet D. Gough**

Introduction

Since 1989, a major part of the responsibility for environmental decision making in New Zealand has devolved from central to regional governments. Also, changes in environmental legislation have shifted the emphasis in management from the application of standards or rules to the assessment of environmental effects, encompassing social, cultural, ecological and economic impacts. Environmental decision makers at all levels require new tools to fulfill their responsibilities.

This paper explores the use of risk management approaches for environmental decision making at four different levels. It is part of a long term project aimed at developing decision-making processes consistent with sustainable management.

Environmental Decision Making, Risk and Uncertainty

Underlying the development of policies for sustainable management is the assumption that policy decisions are based on a reasonably certain knowledge base, or the required knowledge can be obtained. However, the interdisciplinary research underpinning the study of sustainable management often lacks this knowledge base.

Basic criteria for "good" decision making are efficiency, effectiveness and equity. A further criterion specific to environmental decision making is flexibility. In the context of environmental decision-making, efficiency can be interpreted as good process (rather than economic efficiency), and effectiveness as good outcomes.[1] Ideally, if

* The author acknowledges contributions of the New Zealand Foundation for Research, Science and Technology and comments from Abbe Simpson, University of East Anglia; Jenny Boshier, Office of the Parliamentary Commissioner for the Environment; and Phil Driver, Lincoln Ventures.

** Ms. Gough is Senior Research Officer, Lincoln Environmental, Lincoln University, Canterbury NZ. She holds a B.Sc. (Mathematics) and M.Com. (Economics) from the University of Canterbury. Email: *goughj@lincoln.ac.nz.*

outcomes can be predicted with reasonable certainty, then good process *should* lead to good outcomes. In practice, the concept of a "good" decision depends on a combination of good process and good outcomes, and, according to the circumstances, different weights may be given to different aspects. In environmental situations, long lead time between action and outcome means that deducing effect from cause is not always possible; a decision maker must rely on judgment. Improving decision making therefore requires looking for ways of improving the quality of the judgment of the decision maker.[2]

Risk exists when there is the possibility of adverse outcomes. Decisions affecting the natural and social environment are characterized by uncertainty. Recent work has developed this taxonomy:[3]

> *risk:* where system behavior is essentially known and outcomes can be assigned a probabilistic value;
> *scientific uncertainty:* where significant systems parameters are known, but not probabilistic distributions;
> *ignorance:* regarding what is unknown;
> *indeterminacy:* where causal links, networks and/or processes are open and defy prediction.

Additional factors affecting environmental decision making include possible irreversible outcomes and the difficulties of balancing short term gain against long term, uncertain loss.[4]

Environmental risk is not simply risk to the natural environment. New Zealand's Resource Management Act (NZRMA)[5] defines "environment" as including people and their social and cultural beliefs, as well as the natural environment. Environmental risk, therefore,

---

1 Janet D. Gough & Jonet C. Ward, *Environmental Decision Making and Lake Management,* 48 J. Env'l Management (1994).

2 Baruch Fischhoff, *Understanding Long Term Environmental Risks,* 6 J. Risk & Uncertainty 315 (1990).

3 Steven R. Dovers & John W. Handmer, *Ignorance, the Precautionary Principle and Sustainability,* 24 Ambio 92 (1995); Silvio O. Funtowicz & Jerome R. Ravetz, Uncertainty and Quality in Science for Policy (1990); Silvio O. Funtowicz & Jerome R. Ravetz, *Three Types of Risk Assessment and the Emergence of Post-Normal Science,* in Social Theories of Risk (Dominic Golding and Sheldon Krimsky, eds. 1992); Silvio O. Funtowicz & Jerome R. Ravetz, *Science for the Post-Normal Age,* 25 Futures 735 (1993); Brian Wynne, *Uncertainty and Environmental Learning: Reconceiving Science and Policy in the Preventive Paradigm,* 2 Global Environ. Change 111 (1992); Brian Wynne & S. Mayer, *How Science Fails the Environment,* New Scientist, June 1993, at 33.

4 Fischoff, *supra* note 2.

5 Resource Management Act (1991) (N.Z.).

includes ecological risk, human health risk, social, and cultural risk. This is consistent with the approach taken by the U.S. Environmental Protection Agency (EPA) with their comparative risk assessment prioritization of environmental problems.[6]

Managing Environmental Risk

Recent emphasis on the preventative and precautionary approaches to decision making denotes a shift towards attempts to manage risks to the environment. Managing risk means finding ways to reduce (proactive), mitigate (reactive), or simply learning to live with risks. How this is done depends often on acceptability of the risk. The public considers some risks unacceptable; society is prepared to pay a high cost to avoid such risks. Other risks are more acceptable. Some of the main factors affecting people's willingness to accept risk are the degree to which they believe they are personally involved, judged unpleasantness, and the extent to which the risk is incurred voluntarily.[7]

Preventative approaches concentrate on eliminating waste and pollution at the source. Approaches based on the Precautionary Principle[8] are more demanding and require the adoption of control measures *before* harm is proven.

The latter has been adopted by the Economic Union and the United Kingdom as a guiding principle. It is used when information suggests cause and effect but cannot prove it, or when possible consequences are so undesirable that "business as usual" cannot be chanced. Justification is on grounds of complexity (inability to unambiguously identify all cause-effect relationships) or uncertainty.[9]

The NZRMA does not explicitly mention the Precautionary Principle; however both the definition of sustainable management it uses along with the explicit requirements to meet the "reasonably

6 Office of Planning & Evaluation, Environmental Protection Agency, Technical Report No. EPA/230/2-87/-25a Apps. 1–4 (1987); Office of Planning & Evaluation, Environmental Protection Agency, A Guidebook to Comparing Risks and Setting Environmental Priorities (1993).

7 Baruch Fischoff et al., *Weighing the Risks,* in Perilous Progress: Technology as Hazard (R.W. Kates et al., eds. 1985).

8 Timothy O'Riordan, Interpreting the Cautionary Principle (1993).

9 Joyce Tait & L. Levidow, *Proactive and Reactive Approaches to Risk Regulation: The Case of Biotechnology,* Futures, Apr. 1992, at 219.

foreseeable needs of future generations" and to "safeguard the life supporting capacity of the environment," arguably require the adoption of that principle.[10]

Risk Assessment and Risk Management

The term "risk assessment" describes part or all of a formal structured process of analysing risks. As used here, risk assessment comprises three steps: risk identification, risk estimation and risk evaluation. Risk identification attempts to identify all the possible outcomes that may eventuate from a particular action. Risk estimation uses analytical methods to estimate the probability of each outcome and the magnitude of the adverse effect associated with that outcome. Risk evaluation (which involves the decision maker) uses this technical information together with any additional relevant information, to evaluate the alternative actions available. Risk evaluation is concerned with judging the significance and acceptability of risks,[11] and should include consideration of risk perception and risk benefit studies.

Risk management is concerned with what we can do about risk, i.e., finding ways to eliminate, reduce, mitigate, transfer or simply learn to live with risks. Risk management can mean the integrated process of risk assessment and risk control or it can simply mean risk control as an optional "add-on," undertaken after assessment has been completed.

Sheila Jasanoff refers to risk assessment as "what we know about risk", and risk management as "what we wish to do about risk."[12] In the U.S., risk assessment and risk management are considered as separate processes.[13] Advantages of separation have been described as[14] permitting the expertise of scientists and engineers to be brought to bear without involvement in ethical judgments. Also, separated

---

10 Board of Enquiry, Report and Recommendations of the Board of Enquiry Pursuant to Sec. 148 of the Resource Management Act 1991 172 (1995).

11 Jennifer Boshier, *Public Perception and Response to Risk Assessment in New Zealand*, Proceedings IPENZ Annual Conference (1990).

12 Sheila Jasanoff, *Relating Risk Assessment and Risk Management*, 19 EPA J. 35 (1993).

13 Science Advisory Board, U.S. Environmental Protection Agency, Relative Risk Reduction Project Report (1990).

14 Joel Massman, *Risk Assessment and Groundwater Contamination: Methods and Relationships*, in Risk Assessment for Groundwater Pollution Control (William F. McTernan & Edward Kaplan, eds. 1990).

assessments are said to be more amenable to scientific peer review, more easily modified and useful to multiple parties who may disagree on evaluation.

These advantages hold only if the risk assessment is purely objective. In environmental decision making, the separation is not valid because of uncertainties involved in environmental risk and value judgments inherent in the assumptions of the modelling process.

The alternative view taken here and adopted by the Australian and New Zealand Standards Associations[15] is that risk management involves the whole process of risk assessment and risk control. Separating assessment and management can limit the utility of risk management. The advantages of viewing risk management as an integrated process are that it becomes iterative, and judgments required for the treatment and control of risks can be incorporated into, or directly linked to, scientifically based risk assessments.

Groundwater Management in New Zealand

Sustainable resource management is the basis of much of New Zealand's environmental legislation. The meaning of sustainable management for groundwater resources needs to be examined because their management is now ad hoc. Until recently most authorities with management responsibility have granted allocations of groundwater for irrigation and other uses with few restrictions.[16] As more pressure is put on the resource and fears of potential contamination and depletion grow, more systematic approaches are needed. For example, increased recognition of the Treaty of Waitangi[17] and the requirement to take account of bicultural attitudes has led to a growing demand for land disposal of effluent in New Zealand. In turn, this poses substantial additional risks of contamination of groundwater sources already facing stress from other land use practices.

---

[15] Standards Australia & Standards New Zealand, Risk Management (SA/SNZ 4360) (1995).

[16] Ruth Beanland et al., *Irrigation Water Allocation: An Issue for Planners,* Planning Quarterly, June 1994, at 6

[17] The Treaty of Waitangi was signed in 1840 between Maori Chiefs and the Crown. It is recognized in New Zealand law, and legislation such as the Resource Management Act requires that it be taken into account.

The application of classical risk formulations to environmental risk, in particular to issues such as quantity and quality of groundwater, is limited because probabilities are not appropriate where there is no frequency basis, and it is likely that there will be considerable uncertainty present in other variables.[18] Alternatives that emphasize the management of overall risk, including social, cultural and economic criteria, are likely to provide more sustainable solutions.[19]

Risk assessment has been used internationally for several years to assess different activities that impinge on the environment.[20] In most cases, environmental risk assessment has been limited to one type of risk and a restricted geographical area. Complex modeling processes that are difficult to verify are employed, and models seldom address wider social issues. Risk management provides an umbrella under which information from many different sources can be combined so that a "decision" can be implemented comprehensively. It can be applied at different levels: to managing the activities at either a single site or within an organization. Alternatively, it can be applied at a policy level, guiding activities or prioritizing areas for action to be taken.

Three different risk-based approaches were selected to assess their effectiveness as tools for managing groundwater.

Technical Risk Assessment

The first is referred to as "technical" risk assessment (TRA). Methods used for TRA vary between disciplines. The most important relevant methods can be grouped as engineering-based risk assessment, health risk assessment and environmental risk assessment.

The specific methods used for engineering risk assessment include fault tree and event tree analysis, the statistical analysis of past events, and extrapolation.

Health risk assessment is comprised of four steps: hazard identification; establishment of dose-response functions using

18 Istvan Bogardi et al., *Uncertainty in Environmental Risk Analysis*, in Risk Analysis and Management of Natural and Man-Made Hazards (Y. Y. Haimes & E. Z. Stakhive, eds. 1989).

19 James T. Baines et al., *The Sustainability of Natural and Physical Resources — Interpreting the Concept*, in Studies in Resource Management No. 5(1988).

20 Elizabeth L. Anderson et al., Risk Assessment for Use in Groundwater Management (1990).

laboratory experiments or epidemiology; exposure assessment including pathway analysis; and risk characterization, i.e., combining information to estimate the risk associated with each exposure scenario. The most common objective of human health risk assessment is to set acceptable levels of risk for possible harm causing substances.

Environmental risk assessment or ecological risk assessment requires making estimates of probability of harm to plant and animal life, and to ecosystem integrity. Environmental risk assessment uses both engineering and health risk assessment methods.

"Technical" risk assessment can provide considerable information about the system being studied. Although it is often purported to be value free, value judgments are an integral part of the analysis from the initial selection of the model and choice of data. TRA is appropriate: when the outcomes of the alternative actions can be clearly identified, there is sufficient data/information to allow for good quantitative or qualitative estimates of the probability and magnitude of the outcomes and risks are of similar "order" and type — and for assessing and comparing risks resulting from different actions or activities. It is best suited for assessing the impact of well defined activities at specific sites, when processes are well understood, and when consistent, high-quality data are available.

TRA should not be used to directly compare different types of risk or dissimilar risks when there is significant scientific uncertainty and ignorance or considerable variability in the quality of data for different risks being considered — or to compare high probability, low consequence risk with low probability, high consequence risks.

Decision Analytic Approaches

The second approach is based on the decision-analytic approach. Risk is not "regarded as an objective property of an object or situation but as a subjective mental construction based on personal beliefs about the occurrence of specific outcomes of an event or action."[21] Subjective evaluations are explicitly included along with statistical estimates. Different attributes or types of risk, such as social and cultural risks, can be included directly in the analysis, rather than

21 Harry J. Otway & M. Peltu, Regulating Industrial Risks: Science Hazards and Public Protection 118 (1985).

considered separately at the end. The main limitation is that analysts are required to interpret decision makers' preferences quantitatively, so as to assign weights to the attributes or risks being assessed.

The decision analytic (DA) approach derives from classical decision analysis and has been developed to allow the values and judgments of decision makers to be represented. First, the problem and the available options are identified. Decision makers are then asked to state option preferences based on their attributes or characteristics. These will include risks, as well as other characteristics that do not necessarily have risk features. Once preferences are established, decision makers assign weights based on their decision objectives. These are used to order the options. Cost-benefit analysis, where all the attributes are measured in the same units, is a special case. The DA method is more overtly value and judgment driven than TRA; it extracts decision makers' preferences directly and can include many attributes or criteria. It allows consensus building across disciplines and interest groups, and incorporates values.

The DA approach is appropriate when many stakeholders and decision makers or significant social costs are involved and when explicit recognition of values is required or a large number of attributes (or "risks") need to be taken account of.

The DA approach is inappropriate when quantitative or semi-quantitative estimates of the risk are required for comparison. It is best suited to situations with a number of different risks to be considered with variable quality data, where there may be significant social costs and when relative relationships between risks are more important than a precise estimate of a single risk.

Comparative Risk Assessment

The third approach is based on the EPA's comparative risk assessment (CRA). It is a means of directly reconciling the technical with the judgmental.[22] First, it identifies problem areas or issues of concern. Then, a set of risks is selected that will typically include ecological risk, human health risk and some (surrogate) measure of social risk. Groups of specialists use a coarse risk assessment process to rank problem areas within each risk type.

22 Office of Planning & Evaluation, *supra* note 6.

A group of decision makers or stakeholders takes these individual risk rankings and re-evaluates them, incorporating additional factors such as risk reduction and risk-benefit analysis. Part of this re-evaluation may include creating a composite ranking of the problem areas/issues over all risk types. The ranking process is a relative process, and no absolute measures of risk are calculated. Problem areas are grouped into priority categories. The CRA approach precludes the need to measure all risks in the same units and allows for all types of risk to be given equal weight in decision making.

The original "within risk" ranking, referred to as "risk assessment" is undertaken by groups of experts in individual areas, while the second "risk management" stage of including risk reduction criteria and attempting to reconcile the rankings over risk types is often the task of community based groups.[23] There is a tendency to consider risk assessment as "objective" as opposed to a "subjective" risk management.

Risks and "other" attributes are considered separately. The approach can incorporate values, allows consensus building and is suitable for situations where it is desirable to involve the community directly in decision making. It addresses residual risk, that is the risk remaining under current legislation.

The CRA approach is appropriate when there are many stakeholders and decision makers or several disparate types of risks, and the quality of information for different risk types is highly variable. It is also appropriate for making comparative judgments as to the greatest severity or for situations where explicit recognition of values is required

The CRA approach is inappropriate when quantitative or semi-quantitative risk estimates are required, scientific and value judgments are inseparable or the risk of a specific activity is required

This approach is best suited for large scale risk management problems where "problems" are defined in general terms, where the risks involved are varied and the data variable in quality, and when grouping of priority areas rather than specific ranking of risks is adequate. It requires the commitment of considerable resources.

---

[23] Rob Minard, Hard Choices: States Use Risk to Refine Environmental Priorities (1991).

Summary

The aims of the three approaches vary but are not inconsistent. TRA aims to compare options using risk criteria and select a preferred option (i.e., make a decision based on technical risk alone). DA aims to order options according to the "problem owners" objectives. The difference is that TRA uses a "scientific basis" for the ordering process whereas DA bases the decision explicitly on value judgments (that take account of scientific results). CRA aims to identify significant problem areas, to rank them, and to set priorities for taking preventative or ameliorating action. DA incorporates attributes other than risk in the analysis whereas TRA and CRA evaluates these other attributes separately. These approaches are not discrete and, in practice, overlap.

A Case Study Comparison

The three decision-making methods described were assessed in the context of a typical groundwater system using a two-step process. The first step consisted of comparing the approaches against a set of criteria for good decision making. These criteria were not used to rank or eliminate any of the approaches but rather to investigate their validity as decision-making tools. The second step consisted of matching the characteristics of each approach against the characteristics of a typical groundwater management problem.

Groundwater Systems

Groundwater systems are complex and characterized by several uncertainties relating to the structure and boundaries, transport mechanisms, and interactions between different sectors. Considerable effort has been put into constructing and testing models to provide information about different aspects of groundwater. The paper by Robert Friedman et al., provides examples of the types of issues tackled by groundwater models including available supply, conjunctive use, drinking water quality, agricultural pollution, movement of pollutants, and salt-water intrusion.[24] However, technical risk assessment methods need to be expanded to take account of the social, cultural and institutional factors that relate to groundwater.[25]

---

24 Robert Friedman et al., *The Use of Models for Water Resources Management, Planning and Policy,* 20 Water Resources Research 793 (1984).

Activities affecting typical groundwater systems in New Zealand include: general farming, land based effluent disposal, the siting of underground storage tanks, use of septic tanks, landfills, commercial activities such as timber treatment plants, forestry areas, and extraction and recharge. Point source and non-point source pollution may occur. Contamination may result from short term "incidents" or spills, from larger scale or longer term contamination that may be trackable, such as major chemical spills to groundwater or rupturing of underground tanks, or from cumulative smaller-scale activities over a long period. Over-extraction may lead to depletion of groundwater resources, with long term or irreversible results such as reduced stream flows, surface water (swamp) depletion, land subsidence and structural damage to the aquifer, and salt water intrusion.

Societies recognize a number of values and spiritual features related to groundwater. In New Zealand there is a strong belief in the purity of groundwater; any contamination, however minor, is judged as unacceptable. Activities impinging on groundwater pose risks associated with both the quantity and quality of groundwater.

A generalized scenario comprising a description of the physical, social, and institutional bounds of a "typical" New Zealand groundwater system was postulated based upon the Canterbury Plains area with a mixture of confined and unconfined aquifers.

Evaluating the Three Approaches

Basic criteria for "good" decision making were defined as efficiency, effectiveness and equity. Since it is difficult to measure outcomes, and good process is most likely to lead to good outcomes, criteria for assessing decision making concentrate on the procedural. Fischhoff et al. developed a set of criteria for evaluating approaches to determining acceptable risk.[26] Merkhofer adapted these criteria and used them within a framework for comparing decision-making approaches, given a set of risk-problem characteristics.[27]

25 Edward Kaplan & William F. McTernan, *Overview of the Risk Assessment Process in Relation to Ground Water Contamination,* 15 Env'l Professional 334 (1993).

26 Baruch Fischoff et al., Acceptable Risk (1981).

27 Miley W. Merkhofer, *Comparative Analysis of Formal Decision-Making Approaches,* in Risk Evaluation and Management (Vincent T. Covello et al., eds. 1986).

Criteria, based on those described by Fischhoff and Merkhofer and taking account of the characteristics of environmental decision making, were specified as correctness, completeness, consistency, openness, an appropriate level of detail, balance, political acceptability and flexibility. Cost and economic efficiency were not included because they are specific to particular applications.

The three approaches were assessed against a set of characteristics of groundwater management problems: outcome uncertainty with long lead times and the possibility of irreversibility, probability uncertainty, structural (problem) uncertainty, multiple stakeholders and decision makers, mixed objectives (quantity and quality), complexity (interactions), cumulative effects, and high environmental sensitivity.

Each approach was scored separately in an 8x8 table of characteristics versus criteria. Each problem characteristic was scored +1, -1 or 0 according to the approach's ability to meet each of the criteria. The scores indicated respectively that the approach was able to adequately address a problem with the characteristic being assessed; it could not do so; or the test was not appropriate or no definitive judgment could be made. For example, TRA scored "-1" on the criterion "correctness" for the characteristic "outcome uncertainty," on the grounds that if outcomes are unknown then the results of a technical risk assessment are likely to be inaccurate. The highest possible score was 64. No attempt was made to weight the criteria or characteristics or to rank the approaches. All approaches scored significantly above zero, and none was consistently preferable.

Although scoring is very subjective, it provides a useful demonstration of the general adequacy of all three methods and clarifies areas of strength and weakness. After a "first pass" assessment to ensure adequacy of the decision-making process, a "second pass" compared them and selected preferred options.

Levels of Decision Making

In New Zealand, decisions affecting groundwater are made at several government levels. Regional and district councils have direct responsibility for granting resource consents (for water extraction and recharge, and land use), for preparing management plans (rules), and for preparing policy statements (goals). Longer term planning is a joint responsibility of regional councils and central government agencies including the Ministry for the Environment.

The summary of the characteristics of the three risk management approaches identified that TA is best suited for assessing the impact of well defined activities at specific sites, or for specific activities, when processes are well understood, and when high quality consistent data are available. DA is best when there are several risks with variable quality data, there may be significant social costs and when relative relationships between risks are more important than a precise estimate of a single risk. CRA is best for large scale risk management problems where "problems" are defined in general terms, the risks involved are varied and the data variable in quality, and when grouping of priority areas rather than specific ranking of risks is adequate. CRA requires considerable resource commitment.

In addition to the general characteristics of groundwater management problems, features particular to the decision level will determine the most appropriate approach. The hierarchy inherent in the definition of the four levels means that decisions made at lower levels (those with shorter time frame) are dependent on decisions made at higher levels. At the same time, information received from impacts noted at the lower levels is fed back into the decision-making process at the higher levels.

- *Strategic,* level 1 decisions have long term implications and consequences associated with considerable uncertainty. The implications of ignorance and indeterminacy are greatest at this level. Decisions may lead to irreversible outcomes, involve many decision makers and stakeholders (including future generations), need to address cumulative issues, have high environmental sensitivity, have significant potential social costs, and show great variability in the quantity and quality of data available. Decisions made at the strategic level provide context and set boundaries for each of the "lower" levels. Precise estimates of risk are not required.
- *Policy,* level 2 decisions must be consistent with strategic level decisions and are similar. The main difference between the levels is spatial and is reflected in the national nature of strategic level decision making and the regional aspect of policy level decision making.

- *Management,* level 3 decisions are based on principles established at the strategic and policy levels. Information received from the outcomes of decisions made at level 4 allows for adjustments to be made to management plans. Where possible, estimates of risks (either qualitative or quantitative) should be used.
- *Activity,* level 4 decisions are based on rules established at the management level. Decisions are generally localized and well defined. Although they tend to be incremental by nature, the cumulative impact of the risks needs to be addressed. Nevertheless, the narrow nature of the definition of the "problem" means the impacts of decisions at this level are more easily measured and addressed. The number of decision makers and stakeholders is limited and hence there is less likelihood of mixed objectives. Estimates of risks are required.

To determine preferred approaches for each level, the requirements for decision making were matched against the characteristics of each approach, and the approaches were ordered at each level. The process is illustrated for the strategic level in the table below.

Selecting a Preferred Approach for Strategic Level Decision Making

	Risk Management Approach		
Decision Characteristics	*TRA*	*DA*	*CRA*
Long lead times and uncertain potentially irreversible outcomes (includes size of effect and timing and both quantity and quality)	x	b	b+
Probability uncertainty (includes statistical uncertainty and expert disagreement)	b	b	b+
Uncertainty as to which issues require to be addressed	x	b	b
Significant ignorance of technical and social implications	x	x	x
A potentially large group of decision makers and stakeholders to be considered (indirect political aspects need consideration)	x	a	a+
Mixed or multiple objectives (different types of risk, measured differently to be reconciled) — not well specified or able to be uniquely defined	x	b	b
Potentially significant cumulative effects about which little is known (value judgments required)	x	b	b
Complexity (interactions)	x	b	b
High environmental sensitivity	b	b	b
Significant potential social costs	x	b	b

Approach a is adjudged very good; b is adequate and x is inadequate either in terms of ensuring efficiency or good process. If two or more score the same, but one approach is preferred, + is used.

Grades were allocated after consultation with technical experts and decision makers with responsibilities at each of the four levels. It is a subjective system requiring continual reassessment.

Two further important considerations must be taken into account; the precision required, and the resources required and available.

DA and CRA approaches are both suitable for decision making for groundwater management at this level, and are significantly preferable to the TRA approach. The additional considerations of degree of precision of estimates and availability of resources do not affect the selection at this level; data quality will be mixed.

The main differences between the two approaches are the outcomes of the process, the way in which different aspects (attributes or risks) are incorporated, how decision makers and stakeholders are included, and the degree of separation between "objective" assessment and "subjective" management. The DA approach is concerned with *options* and hence the outcomes are actions. The CRA approach ranks problem areas and sets *priorities* for action. Although risk reduction (or the ability to reduce risk) is taken into account in the ranking process, the CRA approach does not assess options or actions.

In practice, both approaches separate the technical processing of data from the value judgments of decision makers and stakeholders. The DA approach considers all attributes (or risks) together. The CRA approach develops separate rankings within risk types and then considers composite rankings as a separate step. The latter approach is simpler to implement, but may produce distortions during the process of combining rankings because it does not take explicit account of interactions between risk types. Often rankings are not combined; however, at times this makes it more difficult to use the results.

Groundwater management and decision making at the strategic level have two basic requirements associated with the linkages between the decision making levels. The first requirement is to establish a framework or set of guidelines to aid effective and efficient decision making at the policy, management and activity levels. The second is for a procedure for incorporating feedback from lower level decisions to modify this framework. Flexibility has been identified as an important criterion for good environmental decision making. Comparative risk assessment relies on prioritizing "risks" according to existing conditions, and in this sense it can be described as primarily a reactionary approach.

For these reasons it is difficult to choose between the CRA and DA approaches at the strategic level. Ultimately, the CRA approach was selected because of its ability to incorporate multiple stakeholders and decision makers at different levels ranging from the lay public to politicians, as a result of the two-level structure.

Similar processes were undertaken for the activity, policy and management levels of decision making. At the *activity* level the three approaches are effectively equivalent but two other factors must be considered. Estimates or "measurements" of risks are required where possible, and therefore the TRA approach is preferred. At this level also, the resources available are most limited, hence the decision analytic approach is ranked second.

At the *policy* level, the arguments are similar to those mounted for the strategic level, however, the DA approach was selected as the decision makers and stakeholders are more homogeneous and identifiable. *Management* level decision making is more closely linked to activity level, and the assessment process resulted in the DA approach being the most preferred, followed by TRA.

Policy Implications and Conclusion

Recent changes in institutional structures and in environmental legislation in New Zealand have meant that there is a need for the development of improved tools for environmental decision making that allow for the management of adverse effects on the environment. Rule-based decision tools previously used are reactive and inflexible. Risk-based approaches are more flexible, cost-effective and directed towards the prevention of adverse effects.

The purpose of the NZRMA is "to promote the sustainable management of natural and physical resources". Consistent with the principle of risk management it places a duty on decision makers to avoid, remedy, or mitigate any adverse effects or activities on the environment. Therefore risk management is likely to be a useful tool for decision makers in meeting their legislative requirements.

This paper has examined three risk management approaches in the context of a particular environmental decision making problem, the management of groundwater resources.

The analysis was undertaken in two steps. The first step consisted of comparing each approach against a set of criteria for good decision making. Secondly, the advantages and disadvantages of the three approaches were determined and assessed in terms of the characteristics of groundwater systems for four levels of management; the *activity* level, the *management* level, the *policy* level, and the *strategic* level. An important aspect of the matching process was the ability of the approach to incorporate a variety of factors or risks.

Environmental decision making inevitably involves risk, and usually considerable uncertainty. Risk management provides a way of explicitly incorporating uncertainty in the analysis and decision making. It should be used in conjunction with other tools such as environmental impact assessment, technical assessments, and social impact assessments. Information from these different sources can be combined either in series or in parallel before decisions are taken. The former approach requires establishing a priority list, for example, technical assessment, financial assessment, environmental impact assessment etc., then using each of these as a filter to eliminate possibilities. If the most restrictive assessment is applied first then options can be quickly reduced.

Risk management procedures can be used to assess impacts in parallel. This approach is preferable because of the complex interactions between areas such as ecological environment and social environment that cannot be addressed by the filtering process. Risk management provides a consistent framework for the analysis of all potential adverse effects, and this allows different aspects of activities to be compared on a common basis. The incorporation of different types of risk allows various types of information to be included, such as social, cultural, economic, ecological and technical.

For each decision-making level, the three approaches were ranked in terms of preference. At the *activity* level, risk management based on TRA is an effective way of assessing applications because it can provide a consistent way of comparing potential risks with existing risks; risks are addressed at the margin. At the *management* level, the DA approach is preferred to technical risk assessment because it is better able to incorporate value judgments. At the *policy* and *strategic* levels TRA is less useful because it relies on being able to make assessments of individual risks, and is not able to address the increasing complexity, cumulative impacts, and potentially large groups of decision makers and stakeholders. The DA and CRA approaches are preferred for the policy and strategic levels respectively.

To test the validity of these rankings, the first two risk-based decision-making approaches selected for each level are currently being applied to a particular "real" groundwater system. This process has commenced at the activity level (level 4), where TRA and the DA approach are being applied to real groundwater decisions in the Canterbury area. Criteria based on the characteristics of good decision making (used in the first pass of this process) and the requirements for decision making at the particular level, including precision of estimates and requirements for, and availability of resources will be used to test the fitness of the ordering.