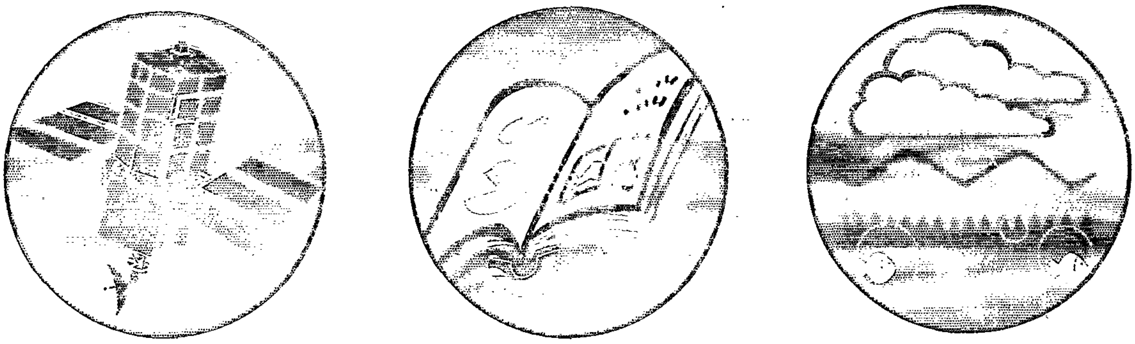
Costs and Benefits Associated with Remediation of Contaminated Groundwater: A Review of the Issues



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Costs and Benefits Associated with Remediation of Contaminated Groundwater: A Review of the Issues

R&D Technical Report P278

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1. INTRODUCTION

Land and groundwater contamination exists throughout most industrialised countries, including the U.K. In many cases, groundwater contamination has resulted from leaks, spills or improper disposal of wastes and products. The remediation of groundwater is often justified, since the contamination can present an unacceptable risk to human health or the surrounding environment, or because contamination may hinder use of this valuable resource. As pressures on water resources increase, protection of groundwater quality from further deterioration, and remediation of previously impacted resources, becomes even more important. The decision to remediate groundwater at a site, the remedial objective selected, and the methods used to achieve that objective, lie at the core of successfully and economically implementing remediation.

The Environment Act 1995 makes it a statutory duty of the Environment Agency to take account of the likely costs and benefits in exercising its powers. However, when considering the subject of the remediation of polluted groundwater, there is a lack of guidance in the UK on the issues that need to be considered in respect to overall cost-benefit, and for the selection of the most cost-effective remedial method. Previous research conducted by the Environment Agency has shown that this lack of guidance has resulted in a patchy and inconsistent application of cost-benefit techniques for contaminated land and groundwater remediation. This study provides the first step towards development of such guidance for the remediation of contaminated groundwater for the UK, by providing a review of issues relevant to the subject. The results of this study may be used to develop a guidance framework, which will assist both agency personnel and other stakeholders in reaching consistent and transparent decisions relating to groundwater remediation proposals.

This report is produced under Environment Agency R&D Project P2-078 and is intended to support guidance being produced as part of the CLR-11 MP 2 Model Procedures (DETR 1999). This phase I report considers the issues associated with costs and benefits of groundwater remediation, and the subsequent phase II is intended to provide a framework guidance for the subject. Environment Agency R&D project P5-015 (Cost-Benefit Analysis of Remediation of Land Contamination - Phase II) provides a complementary report to phase II of this project. Both projects support the overarching guidance provided by CLR11: Handbook of Model Procedures for the Management of Contaminated Land. The project context is shown schematically in Figure 1.1.

1.1 Terms of Reference

The terms of reference, as stated in the Agency's project specification document, are:

- to consider the issues that are relevant to remedial works undertaken under section 161a of the Water Resources Act 1991, as amended by the Environment Act 1995, and the general provision of the Environment Act 1995.
- to scope out the issues related to a cost-benefit consideration of groundwater remediation (this report). A second phase of the project may be implemented, based on the findings of this report, to develop a framework guidance for the assessment of cost-benefit issues as they relate to the remediation of polluted groundwater.

The specific project objectives are discussed in more detail in the following chapter.

1.2 EA Guidance On Remediation Of Contaminated Land

The present issue review report, and the recommendations for what to consider when developing a framework guidance (phase 2 of the project), are developed within the context of the existing EA guidance on contaminated land. The following guidance documents are considered particularly relevant:

- DETR (Department of the Environment, Transport and the Regions) Draft 1998 Discussion Document for Statutory Guidance on Contaminated Land. This document enshrines the role of risk assessment in developing appropriate solutions for contaminated land, and broadly defines what is acceptable and not acceptable in terms of risk. The need to consider costs and benefits is included under Part C, the “Reasonableness of Remediation”.
- Cost-Benefit Analysis for Remediation of Land Contamination, (Environment Agency, 1999b). (Prepared by RPA) This is the draft supporting model procedure for the parallel study into land contamination, and covers groundwater to some degree.
- Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources. (Environment Agency, 1999a), (prepared by Aspinwall & Co)
- Handbook of Model Procedures for the Management of Contaminated Land, CLR-11, series, which includes procedures for Risk Assessment and Selection and Evaluation of Remedial Measures.
- DETR Review of Technical Guidance on Environmental Appraisal (EFTEC, 1998).
- Agency Methodologies for Deriving Groundwater Clean-Up Standards (R&D Technical Report P12), and Methodology to Determine the Degree of Soils Clean-Up Required to Protect Water Resources (R&D Technical Report P13).

2. OBJECTIVES

The objectives of this scoping study, as specified in the Environment Agency terms of reference, are as follows:

- Produce a fundamental review of the cost and benefit issues of groundwater, with focus on remediation of groundwater contamination. This includes a review of current thought on how groundwater contributes to human welfare, and the practical implications of considering costs and benefits. The review includes financial, environmental, and other socio-economic costs and benefits;
- Review the state of current practice in cost benefit analysis of groundwater contamination problems;
- Review issues related to the degree to which groundwater should be remediated, such that the overall project is cost-effective;
- Review issues that need to be considered once it is decided that remediation is to be undertaken.

This study comprises phase I of a two-part study, eventually leading to the development of a model procedure for consideration of costs and benefits for groundwater remediation, in support of site-specific remedial decision making. Together, the studies would provide a tool with which to fulfil the Agency's duty to take account of likely costs and benefits in its actions.

This study does not seek to repeat the phase I scoping study for the companion project on costs and benefits for remediation of land contamination (Martin, Privett and Bardos, 1997). That study involved an extensive consultation exercise, reviewing the current UK practice and research into land contamination cost - benefit analysis. Remediation of groundwater associated with land contamination sites was implicitly included in the review. The authors concluded that the little work being done in the UK on the subject was "informal, subjective and not-transparent."

Groundwater remediation presents several additional issues for cost benefit analysis, to those which are relevant to land contamination. This study discusses the relevant issues, from a practical and philosophical perspective, and provides recommendations for a conceptual economic framework for integrating these issues into decision making.

Throughout, this review attempts to highlight elements of previous studies and current frameworks and guidance that are relevant to the groundwater issue in the UK. In this way we seek to reveal and make the best use of existing work, particularly where it has been Agency funded. It is our intent to present this discussion, as much as possible, as a synthesis between the economic and technical perspectives.

3. METHODOLOGY

3.1 Overview

As described in the terms of reference, this study is intended to provide a review of the issues associated with the costs and benefits of the remediation of contaminated groundwater, and the protection of groundwater from future contamination. The intent is to provide the broadest possible consideration of economic issues, from the perspective of all likely stakeholders, including problem-holders, business, the public, government and regulatory agencies, financial institutions, public action groups, the environment and future generations. Both internal and external costs and benefits are considered, as are use and non-use values.

3.2 Report Structure

To encompass this broad scope, the study begins with a brief review of the complex subject of groundwater contamination, risk assessment and remediation. Groundwater is often called an "invisible" resource, as it lies hidden beneath the ground, the only evidence of its existence a well or spring. Its occurrence and patterns of movement are most often complex, and the rocks through which it flows are heterogeneous on all scales. A whole science, hydrogeology, has developed in an attempt to understand and harness this valuable resource. As such, it is important for the reader to understand some of the basic concepts of hydrogeology, especially as they relate to groundwater contamination, and the often difficult task of remediating an aquifer once it has been contaminated.

However, the review is limited, and the reader is directed to other Agency guidance and references for more information on the subject. Also, this study must necessarily consider the issues of groundwater protection, the prevention of future impacts. Although the primary focus of this study is contamination from point-sources, specifically land contamination, the issues presented are also relevant to non-point sources.

Importantly, this section will reveal some of the major differences between land contamination and contaminated groundwater, both in terms of the fundamental behaviour of contaminants, and from the perspective of future impact prediction and risk assessment.

Following the technical review of hydrogeology and groundwater contamination, a similar brief overview of the basic principles of cost-benefit analysis and economic analysis is provided. Economists have developed a range of different methods for assessing costs and benefits, based in part on the availability and reliability of data. The terminology and conventions used in the two disciplines are quite different, and a firm set of conventions is proposed for use throughout this study. Throughout we attempt to use terminology consistent with the parallel study on cost-benefit for land contamination remediation.

Next, a review of the literature is presented, focusing on the analysis of costs and benefits of groundwater contamination, restoration and protection. The intent is to understand the state of current practice, and glean as much as possible from what previous workers have done. A key objective of the review was to compile a comprehensive view of the breadth and scope of the issues associated with the topic, to complement the one which the authors have developed. A discussion of the limitations of current practice follows.

In alignment with the study objectives set out above, the issues are considered for two main activities: 1) the role of economics in developing an appropriate remedial objective for contaminated groundwater, or an appropriate level of groundwater protection, and 2) the use of economic techniques in selecting the best way of reaching that objective. Each major group of issues, such as uncertainty, the effects of time, the impact of economic factors such as the discount rate, contaminant mobility in groundwater, and the different ways in which groundwater contamination can generate risk, are discussed with respect to these two areas. Issues are broadly categorised as philosophical, technical, economic, and practical.

Then, a preliminary set of conceptual frameworks for the consistent and rational analysis of these issues is presented. The frameworks are preliminary only, are intended for discussion, and are provided to illustrate the many competing factors involved, and the complexity of dealing with a moving, changing contaminant in a heterogeneous, dynamic medium, with uncertain data, in changing and imperfect market conditions.

4. BACKGROUND

Contaminant hydrogeology and economics are two very different disciplines, with their own literature, terminology, and history. Rarely do practitioners in one field cross-over to the other, and so while many of the intended audience of this report may have intimate knowledge of one subject, it is likely that they may not for the other. For this reason, a brief review of the main concepts and terminology used in the fields of contaminant hydrogeology, remediation, and economic analysis are presented in this Chapter. This is intended as an introductory overview only, and readers who are interested in more detail on any of these subjects are referred to other more complete references.

4.1 Contaminant Hydrogeology

Contaminant hydrogeology encompasses the disciplines of hydrogeology, hydrology and environmental geochemistry. It is the study of the way contaminants behave in groundwater. Fundamentals include:

- The hydrologic cycle. Groundwater forms an important part of a cycle of water movement between the atmosphere, the oceans, surface fresh-water, snow and ice, and the subsurface. Groundwater is recharged by rainfall and snow melt, and discharges into lakes, rivers, streams and wetlands. As such, it can make an important contribution to surface water flows.
- Groundwater flows in the subsurface at velocities which typically range from a few centimetres to a few metres per year. The geologic media through which groundwater travels are usually very complex and heterogeneous, making detailed prediction of groundwater and contaminant behaviour difficult. Most hydrogeologists feel that groundwater flow velocities, travel times and similar parameters can only be realistically estimated within an order of magnitude. All groundwater calculations are subject to inherent uncertainty.
- Contamination of groundwater can occur from a variety of sources, including surface facilities (tanks, vessels, pipelines), arial application of chemicals (in agriculture), landfills and orphan sites, spills and tipping. Figure 4.1 shows a range of sources, and how they may affect groundwater. Common contaminant types include hydrocarbon liquids, organic solvents, heavy metals, inorganic compounds, fertilisers, pesticides and herbicides, and radionucleides.
- Once in the subsurface, concentrated accumulations of contaminants may remain for long periods of time, bound into the soil or rock, essentially immobile. These are commonly termed “sub-surface sources”, and are illustrated in Figure 4.1. If any of these contaminants has an appreciable solubility in water, dissolved phase contamination will be produced from the sub-surface sources, and it will then migrate away with groundwater flow.
- Contaminants in groundwater are subject to various physio-chemical and biological processes which will effectively retard their movement, or reduce their concentration over time. These include adsorption onto geologic materials, biodegradation, chemical breakdown, dilution and dispersion.

- Adequate site investigation is critical for providing the data with which to understand the groundwater flow regime, delineate contamination, and identify the types and concentrations of contaminants.
- Prediction of the rates and patterns of contaminant movements in groundwater is difficult, and subject to considerable uncertainty, despite the advent of sophisticated computer modelling techniques. Sensitivity analysis is often used to explore the likely possible range of predictions.

Additional information on contaminant hydrogeology can be found in Fetter (1992), Freeze and Cherry (1979), Domenico & Schwartz (1990), and Pankow and Cherry (1996).

4.2 Groundwater Remediation

The successful remediation of groundwater requires a that a number of critical steps be performed before reaching the remedial design stage. The inherent complexities and uncertainties of groundwater contamination mean that implementing groundwater remediation programmes can be expensive and time consuming. In some cases, groundwater contamination is beyond our technological capability to clean-up, and so alternative solutions must be found. These realities dictate that a rational step-by-step decision making process be followed.

The decision making process

In approaching a groundwater contamination problem, the following basic steps should be followed (Gossen et al, 1997), and are reflected in the Model Procedures:

1. *Understand the problems at the site.* Through proper site characterisation, a picture of the types, distribution and concentrations of contaminants and wastes is provided. The characteristics of the groundwater regime are identified. This information serves as the basis for all other activities.

2. *Assess the risks posed by the problem.* Using the tools of risk assessment, either in a qualitative or quantitative fashion, the implications of the problem are determined. Many different types of risk exist (human health, ecological, economic, public relations, personal and corporate liability), and one or more may be important at the site. Agency guidance is available for this step. These risks can be valued and expressed in financial terms.

3. *Set remedial goals and constraints for the site.* Once the problem, and the risks posed by it, are understood, a remedial objective can be set. Constraints which apply to the situation must also be identified. EA guidance is available for this task, but does not yet include an economic component. Two of the most important are cost (what maximum expenditure is warranted to solve the problem), and time (how long is the firm willing to wait for a satisfactory resolution).

4. *Identify best practicable remedial approach*. Using technical and economic analysis, various possible remedial approaches can be evaluated and compared. The approach best able to reach the set goal within the applied constraints is selected, and detailed designs are prepared. EA guidance is provided for this step.

5. *Implement the remediation programme.* This can best be achieved by fully integrating technical and project management functions.

6. *Monitor Results.* Assess remedial progress through careful monitoring, and modify as necessary for efficient improvements.

7. *Validate.* Confirm and document that remediation has achieved the objectives.

Risk Assessment

Risk assessment forms a key step in the remedial decision making process. It is based in the source-pathway-receptor concept. The potential for risk exists if there is a source of contaminants (a hazard), a sensitive receptor, and a pathway linking the two. A potential risk is said to exist only if all three (source, pathway and receptor) exist. This is termed a SPR (or pollutant) linkage. Risk is defined as the probability that the receptor is adversely affected by the contaminant. End-point receptors may include controlled waters, humans, wildlife, ecosystems, buildings and valuable resources. Figure 4.2 shows a simple schematic of the risk-assessment process. Figure 4.3 shows a simple schematic example of various ways in which SPR linkages can be created by groundwater contamination. Valuable references on risk assessment include Environment Agency (1999a), DETR (1995), USEPA (1992a and 1992 b). Specific guidance on risk assessment for the management of contaminated land is provided in the DETR/Agency's Model Procedures.

4.3 Environmental Economics

This section provides a brief overview of some of the more important and relevant economic principles as they apply to the issue of groundwater contamination and remediation. A considerable body of literature exists on environmental and ecological economics, and interested readers are urged to refer to Pearce and Warford (1993), Costanza (1991), Pearce (1993), and Winpenny (1995).

Introduction

Pearce and Warford (1993) state that " the world economy is inextricably linked to the environment because societies must extract, process and consume natural resources". As a renewable resource, groundwater can be considered from the point of view of sustainability, defined as a state where the natural resource base is not allowed to deteriorate. We can further distinguish between so called 'strong sustainability' (which requires that the natural resources base must not be deteriorated), and 'weak sustainability' (which requires that a critical level of natural resource base be protected, with the rest depleted so long as the proceedings from this depletion are used in creating another form of capital (man-made, human or other natural)). Environmental economics are mostly based on the concept of weak sustainability.

Groundwater is a valuable resource. It contributes to overall welfare in three main ways (as shown in Figure 4.4):

- as a resource in its own right (through abstraction of groundwater for domestic, agricultural, or industrial use);
- as a contributor to surface water resources which are used to generate economic value (via discharge to surface water features);
- as a key part of the hydrologic cycle, contributing to the existence of ecosystems and natural areas of beauty (aesthetic value).

Thus, if groundwater is contaminated, part of the resource base is damaged, or if the pollution is irreversible, eliminated entirely. This will have economic impacts for society.

Key concepts

Among the key concepts of environmental economics which are particularly relevant to groundwater are *sustainability, optimality, and intervention.* Sustainability means that per-capita welfare increases (or at least stays constant) over time. Therefore, only those projects which increase welfare should go ahead. Sustainable development implies that there is no net reduction of the resource base. Groundwater is usually considered to be a renewable resource, and so its sustainable use is preferred. Contamination of groundwater may have the effect of destroying the resource, or eliminating it from use, and so can be seen as an unsustainable activity. Economic theory distinguishes between the private optimum (where the net present value of private welfare is maximised) and the social optimum (where society's net present value of welfare is maximised). In a private project analysis, the effects of the project on third parties are not taken into account. These uncompensated effects on third parties are known as *externalities.* In the case of groundwater contamination, the polluters optimum may not include the loss of welfare experienced by society as a whole, including users of impacted groundwater and surface water. The concept of present value accounts for discounting of future welfare gains, which are considered less important the further in the future they occur. Figure 4.5 shows a schematic of the relationships between sustainable and unsustainable policies or practices, private and social optima, and the results various types of intervention. Pearce and Warford (1993) explain that, typically, "private and social optima diverge: the most desirable rate at which to deplete resources from the standpoint of their owner is unlikely to be the best rate for society as a whole". However, achieving the social optimum does not necessarily provide sustainability.

Economic analysis is the assessment of changes in *total economic value* (defined as the contribution to human welfare). Such analyses consider the costs and benefits of a given project, gauged according to the value placed on the resource or commodity being produced or used. In the case of groundwater, value includes (Kulshreshtha, 1994):

- direct use value: uses of groundwater that lead to activities that would not take place if that quantity and quality of water did not exist, including domestic, industrial and commercial water use, and irrigation for the production of crops or animal feed.
- indirect use values: the value of the contribution made by groundwater to tourism, recreation, and support of the natural ecosystem, including contributions to the hydrologic cycle (discharge to lakes, rivers, streams, wetlands, and other important surface water features).

- option values: since all direct and indirect use values are associated with the current use of water, they do not include values stemming from future use of groundwater. Option value represents the premium which certain users may be willing to pay to secure access to and use of groundwater at some time in the future;
- Existence value (non-use): Individuals may derive values simply from the knowledge that uncontaminated pristine groundwater, and the ecosystems and hydrological cycle it contributes to, exists, irrespective of whether it will ever be used.
- Bequest value (non-use): Individuals may affix a certain value to groundwater because of their desire to pass on the resource to future generations.

These different types of values are assessed in different ways. Figure 4.6 shows a schematic of the main *valuation techniques* which apply to the various benefit categories. Broadly they fall into four categories:

- direct market value, where the good itself is priced on the open market as a saleable commodity. Groundwater sold as drinking water has a price per unit volume;.
- surrogate market techniques, in which a market good or service is found that is influenced by the non-market good. Hedonic pricing is based on this concept. Where groundwater is not directly sold as a commodity, it might be used to irrigate crops which are sold at market prices - this would be the surrogate market. The travel cost method identifies the expenditures made by travellers who come to experience a particular area of natural beauty (which may depend, in part, on groundwater for its existence) as the surrogate market.
- market creation techniques, in which individuals' Willingness to Pay (WTP) for a specific outcome is determined. The contingent valuation method (CVM) is the most common market creation technique.
- dose-response relationships, in which a link is established between a contamination incident or level, and a measurable physical response, such as morbidity. If consumption of contaminated groundwater is linked to morbidity or health effects, these can be valued, and assigned as costs of aquifer pollution.

In practice, at the project appraisal level, it is often not possible to undertake original valuation exercises to estimate the total economic value of a resource. What is often done is *'benefits transfer'*: adjusting and adopting the estimates of values from previous studies to be used in the analysis of the costs and benefits of the project in question. Although benefits transfer is unlikely to produce exact estimates, it is widely used in situations where the generation of project-specific valuation data is cost or time prohibitive.

Economic assessment of a policy or project can be conducted on a variety of levels. The most common analysis techniques are:

- *Cost benefit analysis* (CBA) is a framework for comparing the monetary value of benefits of a project or policy with the monetary value of costs. The optimal remediation level, then, is the level where the net benefit (benefits minus costs) of remediation is maximised. A benefit is defined as anything (financial, environmental and social) that increases human wellbeing, and a cost anything that decreases human wellbeing. In the context of the proposed project, the factor affecting human wellbeing is the risk of groundwater contamination and its related impacts on human health and ecosystems. In turn, human wellbeing is determined by whatever people prefer. Preferences are either revealed through choices and market behaviour (eg. increase in the value of the land that is no longer contaminated) or are stated through survey questionnaire procedures (eg. What

people are willing to pay to avoid an increase in the risk of cancer due to contamination of land or water). In short, CBA requires monetary information on financial, environmental and social costs and benefits of a project.
- *Cost-effectiveness analysis (CEA).* CEA is different to CBA only in that benefits of remediation are not monetised. It requires that a level of remediation for a given site is agreed either due to regulatory, political or social reasons. CEA then becomes a framework to establish the least cost method to achieve this given level of remediation. When benefits of remediation are difficult or impossible to estimate in monetary terms, CEA can be used. However, it cannot answer the crucial question of whether the initial level of remediation given is the socially optimal level.
- *Multi-criteria analysis (MCA)* is a two-stage procedure. The first stage identifies a set of goals or objectives (eg. different levels of remediation) and then seeks to identify the trade-offs between those objectives for different policies or for different ways of achieving a given objective (eg. different engineering alternatives for remediation). The second stage seeks to identify the best policy by attaching weights to the various objectives. A set of such weights can be the monetary values of financial, environmental and social costs in question. Therefore, MCA is capable of combining monetary and non-monetary values for different costs and benefits.

All three tools require information on the costs and benefits of remediation whether this may be expressed in monetary (eg £) or non-monetary (eg reduction in risk of off-site contamination by 1%) terms. Site investigation and risk assessment (together with identification of engineering alternatives) help to gather information on financial, environmental and social costs and benefits.

The linkages between various economic assessment techniques (including CBA, CEA and MCA), and the initial environmental assessment (or site characterisation), and risk assessment, are shown in Figure 4.7. This illustrates the integral relationship between the technical data collection and risk analysis stages, and the economic analysis.

Glossary of economic terms

The following selected economic terms are used throughout this document. We have attempted to use terminology consistent with the parallel Agency study on cost-benefit assessment for remediation of land contamination (Environment Agency, 1999) undertaken by RPA:

- Consumer surplus: The difference between the amount paid for a good or service and the maximum amount that an individual would be willing to pay.
- Contingent valuation method: A social survey technique used to derive values for environmental change by estimating people's willingness to pay (or to accept compensation) for a specified effect.
- Cost-benefit analysis: A form of economic analysis in which costs and benefits are converted into money values for comparison.
- Discounting: Converts future costs and benefits into comparable units (present value). The discount rate is currently set by the Treasury at 6%.
- Dose-response technique: Determines the economic value of changes in, say, pollutant concentrations by estimating the market value of the resulting changes in output.

- Economic analysis: Aimed at evaluating all of the effect of a policy or project and valuing them in national resource terms. Takes place in a with and without framework.
- Existence values: Values which result from an individual's altruistic desire to ensure that an environmental asset is preserved and continues to exist into the future (a non-use value).
- Externalities: Goods which remain un-priced and thus are external to the market (i.e. free goods such as those relating to the environment, with an example being pollution).
- Financial Analysis: Aimed at determining the cash flow implications of a policy or a project to the commissioning organisation and ensuring that these are sustainable in that sufficient funds are generated to meet overflows.
- Hedonic pricing method: An implicit price for an environmental attribute is estimated from consideration of the real markets in which the attribute is effectively traded (e.g. water quality improvements and property values).
- Intrinsic/inherent values: Related to existence values and are those which are said to reside in non-human biota and which are not related to any form of human satisfaction.
- Irreversible effects: e.g. the loss of a unique natural feature, an ecosystem or species and very long-term changes to the natural environment.
- Market price approach: In a perfectly competitive market the market price of a good provides an appropriate estimate of its economic value. In markets which are not perfectly competitive, economic value is calculated by removal of subsidies or other price distortions.
- Net present value: The present value (i.e. in year 0) of the difference between the discounted stream of benefits and the discounted stream of costs.
- Non-use value: Values which are not related to direct or indirect use of the environment (option, existence and bequest values).
- Opportunity cost: The value of a resource in its next best alternative use.
- Option value: Value to a consumer of retaining the option to consume a good.
- Replacement costs approach: Impacts on environmental assets are measured in terms of the cost of replacing or recreating the asset.
- Resource cost/values: Cost of marketed goods or services (adjusted to economic prices) used as inputs to, or consumed as a consequence of an action.
- Scarce resources: Resources available are insufficient to satisfy wants.
- Sensitivity analysis: Key assumptions and values are varied so as to determine their effect on the choice of best option.
- Social benefit: the sum of the gains or benefits from an activity.
- Social cost: The sum of money which is just enough when paid as compensation to restore all losses to their utility level.
- Sustainable development: Some acceptable measure of national well being (e.g. gross national product or some other agreed measure of welfare) which is at least constant and preferably rising over time.
- Total economic value: The sum of use values (direct and indirect) plus non-use values (option, bequest and existence).
- Transfer payment: A payment for which no good or service is obtained in return, e.g. a tax or subsidy.
- Travel cost method: The benefits arising from the recreational use of a site are estimated in terms of the costs incurred in travel to the site.
- Uncertainty: Stems from a lack of information, scientific knowledge or ignorance and is characteristic of all predictive assessment.

- Use value: A value related to the actual direct or indirect use of the environment (e.g. recreational values).
- Utility: The satisfaction an individual receives from the use, access to or existence of a good.
- Willingness to accept (WTA): (also willingness to sell). The amount an individual will take in lieu of being able to partake in an activity for a given length of time (usually a year, or a season).
- Willingness to pay (WTP): The valuation placed by an individual on a good or service in terms of money.

5. REVIEW OF CURRENT PRACTICE

5.1 Overview

In their recent Agency-commissioned report on the current state of application of CBA for contaminated site remediation in the UK, Martin et al (1997) found that even basic techniques of economic analysis were not being widely applied. Their survey of practitioners in the UK revealed a lack of consistency in approaches, and significant variability in methodologies and techniques being used. The few points of consensus among those surveyed seemed to be a favouring of qualitative or semi-quantitative approaches, and a hesitation to include "wider environmental impacts" within a remedial technology selection process. Most workers seemed to agree that the whole question of costs and benefits was strongly site-specific, and any approach to the question had to be on a site-by-site level.

Interestingly, as will be discussed in the following chapters, the findings of Martin et al (1997) reflect in many ways the inherent difficulty of assigning values to environmental benefits for groundwater remediation, and the relative lack of available guidance or substantive research in this area. This section presents a review of some of the more relevant work on valuation of groundwater resources, and attempts to quantify external costs and benefits of groundwater protection and remediation. Although some excellent work has been completed, particularly in the United States and Canada, the lack of substantial experience in this area is clearly a limitation to the application of cost - benefit techniques in the UK.

Accordingly, the literature is relatively replete with work describing detailed analysis of the costs of various groundwater and soil remediation techniques, covering capital costs, operation and maintenance costs, and case histories comparing the cost and performance of two or more treatment technologies on the same site. Several such studies are described below. The ready availability of this information clearly lends itself to the application of semi-quantitative approaches, where costs are monetised, but environmental benefits are considered only in a qualitative manner. This may explain to some degree the findings of the Martin et al (1997) UK survey.

Another approach to the problem of valuation data scarcity for groundwater and groundwater contamination and remediation, is to consider similar analagous resources. Clearly, surface waters (particularly as the potential receptors of discharged groundwater or baseflow) are relevant, and several studies of cost-benefit of water resource projects are available. Similarly, air pollution and groundwater have several similarities of relevance: mobility (albeit at different rates), wider value as a common good (in some jurisdictions), the potential for contamination from several different sources to become co-mingled to the extent that attributing responsibility is difficult, and their ability to act as dilution sinks over time.

Throughout the literature review and the following sections, a clear theme is the wide gulf between the technical and economic. The technical literature is written by hydrogeologists and engineers, the economic literature by economists. The language and terminology is different, the perspectives and attitudes are different. Rarely do economists publish in the scientific technical literature, and even less frequently does work reflecting the perspective of those actually designing the remediation schemes cross over into the world of the economists. This may also be a barrier to the wider application of cost-benefit techniques to groundwater problems.

The following sections provide a brief overview of some of the more relevant literature, in an attempt to provide a view of the current state of knowledge. The literature review is then used as a basis for a more in depth cataloguing, characterisation and discussion of the issues seen to be relevant to the application of economic tools to groundwater protection and restoration projects.

5.2 Land Contamination

Although not the focus of this study, the economics of land contamination is nevertheless associated, since in many cases land contamination is the source of groundwater pollution. Indeed, this study is coupled to the Environment Agency's contaminated land cost benefit studies, comprising the Phase I issue paper (Martin et al, 1997), and the recently completed framework for considering costs and benefits during remediation of contaminated land (Environment Agency, 1999b) developed by RPA.

Martin et al (1997) found that the use of cost-benefit analysis (CBA) for land contamination in the UK was limited to approximately ten groups. Problem holders and consultants were using some elements of CBA to assess commercial preferences in remedial design, largely however without reference to external costs and benefits. Regulatory and government groups were using CBA concepts primarily to assess policy with respect to selecting different environmental options. At present, the use of CBA for contaminated land, which implicitly included groundwater remediation, was found to be informal, subjective and non-transparent. However, the wider issues particular to groundwater, such as its value as a resource, and its potential role as a pathway within a S-P-R linkage, were not discussed. Martin et al (1997) found that among practitioners in the UK, most favoured a semi-quantitative approach, involving ranking and scoring schemes, rather than explicit monetisation of all costs and benefits. They recommended that the qualitative Dutch STEPS approach (part of the NOBIS programme) be investigated as a possible template for the UK, citing its ease of use, transparency of decision making, and provision of common reference points for all stakeholders. Interestingly, they found that the inclusion of wider environmental impacts within a technology selection process was rejected by most current UK practitioners, who felt that such externalities were already accounted for by society in tax and regulatory schemes, and that procedures were not available for the consistent evaluation of the wider issues. The concept of environmental merit was put forward as a non-monetary substitute for explicit calculation of monetised costs and benefits of remedial schemes.

Following from the Martin et al (1997), the Environment Agency (1999b) have had developed a draft model procedure for standardised and transparent economic decision making for contaminated land. The procedure involves a tiered analysis, consisting of a preliminary screening stage, an intermediate qualitative analysis of costs and benefits, and if required, a full CBA stage. At each step, the need and justification for a further level of analysis is determined. For smaller, less complex sites, the screening level may be sufficient. For more complex problems, involving wider impacts and larger sums of money, a full CBA may be warranted. Guidance is provided at each step through a set of standard questionnaires, evaluation matrices, and decision charts. Although the model procedure does include groundwater remediation, it does so only on a very basic level, and deals exclusively with groundwater contamination incidental to the wider site (soil and contaminant source) remediation. No provision in the procedure is provided for the wider issues of groundwater mobility, off-site migration potential, or value as a resource in its own right. Those areas are the mandate of this current study.

Several groups involved with land contamination research are developing software packages which provide support to users in conducting cost-benefit analysis. The USEPA Interagency Cost Estimation Support Group (ICEG), provides a system based in part on historical cost analysis (HCAS), involving multi-criteria analysis (MCA). A tiered approach, very much akin to the RPA draft guidance framework, is used. The TNO STEPS system also uses a similar tiered approach, and can be used at a variety of information levels to compare between a number of remedial alternatives. This is essentially a criteria analysis approach. The opinions of a panel of experts is used to provide weights to a number of criteria which are evaluated qualitatively. A more detailed review of these and other land contamination research initiatives can be found in the companion Agency issue paper (Martin et al, 1997).

It is clear from this brief review that the land contamination literature is only partially applicable to the groundwater problem. Fundamental differences exist between the two situations, on many levels. The main differences are listed in Table 5.1, below.

Table 5.1 Comparison of Economic Issues: Contaminated Land and Groundwater

ISSUE	**CONTAMINATED LAND**	**CONTAMINATED GROUNDWATER**
Problem boundaries	property or site boundaries - fixed in time and space	Hydrogeological boundaries - large scale, not associated with property boundaries
Contaminant mobility	soil contamination relatively immobile, although may act as source of groundwater contamination.	Groundwater contamination mobile, and can travel large distances.
Time	Extent and volume of contaminated soil is relatively static over time. Soil contamination unlikely to move substantially to impact a new set of receptors unless site use changes (contaminant vapours may be an exception).	Extent of groundwater plume may increase substantially over time, volume of contaminated groundwater may increase substantially over time (dilution). Plume may impact new receptors in the future.
Environmental and Health Risk	Main risks posed by soil contamination are via dermal contact or direct ingestion of soil or dust/vapour (inhalation). Contaminants in soil may cause ongoing groundwater contamination.	Risks posed by groundwater contamination are via damage to a resource (aquifer or surface water body), ingestion (drinking water), dermal contact (potable water, bathing), inhalation of vapours, damage to ecosystems (recharge to surface waters, marshes, wetlands), or discharge to other surface features (beaches, fields, forests).
Economic Risk	Property devaluation, urban blight, "stigma" devaluation of neighbouring sites.	Resource damage (aquifers, rivers), crop damage (contamination of irrigation water), known and unknown.
Responsibility	Relatively simple to determine ownership of a site, and ascribe responsibility for soil / site	May be difficult to determine responsibility for historical groundwater contamination. Difficult

	contamination. Site investigation relatively straightforward.	to apportion responsibility for co-mingled plumes. Site investigation can be difficult and expensive.
Remediation	Soil contamination (unsaturated zone) can be removed relatively quickly and easily in many circumstances.	Groundwater contamination may be irreversible. Remediation where possible can take long periods of time, few quick remedies are available.
Replacement	Contaminated land can, if needed, be left derelict (subject to risk management measures). Replacement sites are relatively abundant in most circumstances.	Aquifers are generally less readily replaced, especially in areas where water supplies are under stress.
Uncertainty	Site / soil contamination is more readily characterised, at lower cost, in general. Level of technical uncertainty of risk assessment results is generally lower.	Groundwater contamination, because it is mobile, is subject to greater uncertainty in terms of behaviour, occurrence and future migration. Risk assessment results are thus less certain.

The Agency's draft Methodology for Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources (Environment Agency, 1999a), provides a four-tiered risk-based procedure for assessing risks to controlled water and defining remediation target concentrations for risk-producing compounds, on a site-specific basis. The conventional source-pathway-receptor system is used, whereby a target concentration at the receptor is assigned, in relation to its use and sensitivity. A compliance point is then selected. The first tier uses simple advection only, and is thus conservative. If required, the analysis can be taken to the second tier, where dilution in groundwater is considered. If the predicted concentration still exceeds the target concentration, a more sophisticated analysis involving attenuation and sensitivity analysis can be conducted. The guidance explicitly mentions that cost-benefit studies have a role to play in the final decision making, but how and to what level are not described.

5.3 Analogous Media - Air And Water

Several studies examining the costs and benefits of water policy in the UK are available. EFTEC (1998) completed a major study for the Agency examining relevant environmental externalities for total water management options. A framework for analysis was developed, involving a tiered decision making process leading to identification and allocation of monetary and non-monetary values for the proposed scheme. They found that the procedure was in general constrained by a lack of valuation studies for environmental externalities, limiting ability to assign monetary values. Accordingly, development of currently available methodologies awaits more research into valuation of water resources and environmental costs and benefits of the consequences of water projects.

IVM and EFTEC (1998) consider the questions of economic valuation of waste and water investments, defined as changes in society's well-being due to environmental effects, and provides guidelines for the monetary and non-monetary valuation of the external effects of water and waste related projects. The study considers water distribution, wastewater management, landfill and waste management and treatment methods. Their overall recommended approach to establishing the environmental costs and benefits of water and waste projects is reproduced in Table 5.2, below. They conclude that "uncertainty is inherent in all stages of the appraisal: monetary valuation, environmental appraisal and indeed financial analysis." Clearly, uncertainty will be a constant feature of any environmental economic analysis. The role of uncertainty in groundwater remediation and protection issues is perhaps even more striking, as is discussed in the following sections. In general, however, this overall framework appears to be well-suited to groundwater-related projects, and is discussed in more detail in Chapter 7 of this report.

Table 5.2 Overall approach to Assessment of Environmental costs and benefits of water and waste projects (from IVM and EFTEC, 1998).

Environmental Appraisal
STEP I Identify residual environmental effects of the project
STEP II Translate residual environmental effects to well-being effects
Valuation
STEP III Perform benefit transfer & estimate total monetary cost or benefit
STEP IV Allocate non-monetary indicators
STEP V Compare and combine monetary and non-monetary results
Evaluation & Interpretation
Compare with financial costs and benefits and other appraisal criteria

For step I, IVM and EFTEC (1998) suggest that water projects lead to environmental issues falling into the general broad categories of the water environment, biodiversity, visual amenity, recreation, heritage and archaeology, traffic, noise and vibration, waste management and contaminated land, and community effects. Clearly, not all of these are relevant to groundwater remediation or protection projects, but many are. Table 5.3 lists broad categories of environmental issues for water and waste projects (after IVM and EFTEC, 1998), and suggests those which might apply to groundwater

Table 5.3 Issues relevant to water and waste projects

Water Project Issues	Waste Project Issues	Applicability to Groundwater Protection and Remediation Projects
water environment	health effects	water environment
biodiversity	global warming	biodiversity
visual amenity	visual and odour amenity	visual, odour and use amenity
recreation	buildings	recreation
heritage and archaeology	traffic	groundwater environment
traffic	groundwater environment surface water environment	waste management and contaminated land
noise and vibration	community effects	traffic
waste management and contaminated land		noise and vibration
community effects		

Significance of the environmental effects of a project are judged against a range of criteria, including the effects on the natural, human and physical environment, the location and scale of the effects (local, regional, national, global), the timing of the effect, whether the effect is reversible or irreversible, and whether the effect is positive or negative. All of these criteria are directly relevant to the groundwater case, and will be discussed in more detail in the issues chapters (Chapters 6 and 7). Mitigation measures are then considered, and used to develop residual effect scenarios. Step II of the EFTEC approach translates the residual effects into well-being effects, by assigning monetary values to each effect where possible, depending on: 1) whether they can be translated into effects causing changes in society's well being, 2) whether any valuation studies of the effect exist, and 3) the credibility of using relevant literature that may exist (benefits transfer). Steps III and IV of the approach focus on estimation of total costs and benefits, through a variety of available techniques. EFTEC suggest that a benefits transfer approach will be required for most projects, since willingness-to-pay (WTP) values are rarely available for the specific effect or good being examined. They present a summary of currently available monetary valuation literature for the most common environmental effects of water and waste projects. Selection of an appropriate and defensible study on which to base the analysis requires good judgement and experience. Where suitable valuation studies do not exist, effects cannot be monetised. Qualitative judgement is then required, the level of significance of each effect being ranked (from major positive to major negative effects). The document provides several case histories illustrating the application of this approach.

The Industrial Combustion Co-ordinated Rulemaking (ICCR) body in the United States has prepared a framework for economic and benefits analysis for industrial air emissions (ICCR, 1998). The relevance to groundwater issues lies in the similar behaviour of contaminants in air and groundwater, to the extent that in some cases, groundwater contaminants can migrate significant distances, diluting and dispersing within the medium, and impacting receptors at some distance from the source. As such, groundwater and air can be seen, in certain circumstances, as being a public good. In addition, responsibility for off-site groundwater contamination may be difficult to place, particularly if several other sources are active, and plumes have co-mingled. The ICCR framework provides a broad model for consideration of the economics of air emissions on the facility level, and then aggregates impacts to the national level. The study focuses on the impacts of environmental regulations, and uses computer modelling techniques to simulate responses of affected entities. Several industry profiles are presented, identifying affected commodities, price and market structures, and baseline conditions in areas where producers are located. The framework includes external and private costs and benefits of regulation. Wherever possible, benefits and costs are monetised. Benefits of pollution control (regulation) are defined as increases in human welfare that result from improvements in environmental quality. Specifically, linkages are developed between reductions in air emissions and human welfare enhancements.

A key component of the ICCR framework lies in the analysis of air dispersion modelling results with respect to risk. From the risk analysis, health and environmental effects are predicted, given a range of uncertainty, and then the benefits or costs of those effects estimated. For this part of the process, the parallels with groundwater are evident. Groundwater contamination leaves a point (or non-point) source, and then migrates away, subject to the processes of dilution and dispersion. The collection of data with which to assess the rate and direction of migration, and concentrations of contaminants, is an essential input for any predictive modelling in air or groundwater. If there is uncertainty at this early stage of the process, subsequent predictive estimates are subject to increasing levels of compounded uncertainty. Indeed, James et al (1996) include a "data worth" analysis sub-routine into their framework for assessing groundwater remedial costs and benefits, to determine if the costs of additional data collection are warranted by savings resulting from improved certainty of analysis. Risk assessment has already been adopted by the Agency as the basis for groundwater remedial objective definition in the UK. Clearly, future guidance on cost-benefit analysis for groundwater protection should follow the ICCR and other similar models, and explicitly incorporate the results of risk assessment into the decision making framework.

5.4 The Value Of Groundwater

As discussed in the background section to this report, the issue of groundwater protection and remediation can be discussed by considering the three modes of potential environmental impact with respect to groundwater: 1) impacts to groundwater as a resource in its own right (exploited or exploitable aquifers), 2) impacts to surface water resources which are fed wholly or in part by groundwater, and 3) impacts to the environment caused by migration of contaminants via groundwater (groundwater as a risk pathway). In each of these roles, groundwater will have a value. In the case of groundwater resources, values may be high. In the case of shallow groundwater of poor quality which is acting as a risk pathway for a sensitive receptor, the value of the groundwater itself may be negligible, but the value of the affected receptor high. The literature contains several studies which provide analyses of the value of groundwater resources.

Kulshreshtha (1994) presents one of the few detailed and comprehensive analyses of the economic valuation of groundwater, examining the Assiniboine Delta Aquifer in Manitoba, Canada. He estimates the total economic value of groundwater in the aquifer by considering all use and non-use values. Direct uses include irrigation, domestic supply, industrial and thermal uses of groundwater. Indirect uses include recreation and tourism (in the form of groundwater contribution to nearby lakes and streams), and environmental use. Option values, or the difference between the WTP for the option of future use and the expected consumer surplus, is also considered. Non-use values considered were existence value and bequest value. Kulshreshtha (1994) considers that an aquifer must be considered as a renewable resource, whose benefits to society continue indefinitely. Thus annualised net present values for each use category can be summed over a given period of time to produce an estimate of total economic value, as:

$$NPW_w = \sum_{i=1}^{s} NPVW_i$$

and,

$$NPVW_i = \sum_{t=1}^{L} \frac{VW_{it}}{(1+r)^t}$$

where NPW_w is the net present worth of the aquifer, $NPVW_i$ is the net present value of water in the i^{th} use ($i=1....s$), VW_{it} is the total value of water in the i^{th} use for the year t ($t=1...L$), and r is the discount rate.

In this way, Kulshreshtha estimated a range of direct use values for groundwater in the aquifer, based on the value to rural households; small non-farm communities, larger communities, and commercial and industrial users. Table 5.4 presents the values (in 1990 Canadian Dollars; approximately \$2.3 CDN = £1) determined by this study. Indirect use (recreational value) was assumed to exist by virtue of groundwater recharge to a major river which runs through a National Park within the study area. The river and park support a diverse and valuable ecosystem. The park is a major visitor attraction in the area, and contributes significantly to the economy of the area. Indirect use was estimated by the value of the recreational activities supported by the river in the park, expressed as the number of visitor-days to the park (a readily available statistic), and WTP for the park amenity (surveyed at CDN \$ 5.17/person/day). The value of the aquifer was also estimated by considering the opportunity cost of groundwater, namely the cost of developing alternative water supplies of similar quantity, quality and reliability. The costs of various alternatives were estimated, including accessing a nearby lake by pipeline (CDN \$ 2573/Ml).

Table 5.4 Summary of average water values for different uses in carberry aquifer region in 1990, from Kulshreshtha, (1994)

Type of Use	Average Value of Water (CDN $/Ml)
Irrigation	485
Other Farm Use	621
Domestic	119 - 556
Industrial	17 - 33
Commercial	94 - 385
Defense (Military Base)	179 - 950

Based on his studies, Kulshreshtha (1994) suggests that the value of a given aquifer reflects "economic welfare of people living in the region served by the aquifer. If the aquifer were not present, or was destroyed, the economic welfare of society would diminish by this amount, on an annual basis, for the remaining productive life of the aquifer". Clearly then, if we accept the author's earlier definition of an aquifer as a renewable, long-term resource, it can be seen that the economic implications of irreversible aquifer damage could be considerable. The paper also brings forward the notion that an aquifer may also have additional value in a regional development context. The economic activity generated by virtue of the existence and use of the aquifer at a local scale, may also create a multiplier effect in the region.

Boyle et al (1994) examined the state of groundwater valuation information available, and concluded that up to 1994, only eight original studies were available considering the economic benefits of protecting groundwater quality. The authors examined these studies statistically and probabilistically and concluded that the data were difficult to use in a systematic way. Definitions of what constituted contamination were inconsistent amongst the studies. Benefits transfer approaches were difficult to use because problems were inherently too site specific. They found that results of contingent valuation (CV) studies were highly dependent on the design of the survey instruments, and thus were generally not accepted by non-economists. This, in part, reinforces our introductory statement about the gulf between practitioners in the technical and economic fields. However, they conclude that despite these limitations, CVM studies were not producing "random noise", but are reflecting fundamental attitudes. Despite this, they end their discussion by stating that in their opinion the currently available data are insufficient in term of quality and quantity to be used for a rigorous benefits-transfer valuation of groundwater resources.

Powell et al (1994) investigated the use of contingent valuation (CV) information as a tool to persuade government decision makers to implement water supply protection policies. They conducted a CV survey in three north-eastern states in the US, of annual household willingness to pay for increased groundwater supply protection. Results showed a mean WTP of US $ 61.55/household/year, but with a relatively high standard deviation (84). Interestingly, they found that knowledge of groundwater issues was not a significant predictor to the outcome of the survey. However, household WTP could be predicted based on income, experience of a previous contamination incident, and type of water supply (public or private). Powell et al (1994) confirmed the findings of other CVM studies, finding a very low correlation coefficient for the data. Again, the authors make reference to the limitations of the CV method, which relied on mailed questionnaires. The study concludes that CV can indeed persuade government decision makers of increased public support for groundwater protection measures, as measured by WTP.

In contrast, Abdalla (1994) argues that avoidance costs be considered as a WTP proxy when valuing groundwater. The concept of valuing groundwater based on the avoidance of damage or loss is considered in more detail in the following section. The author reinforces the view that "our current knowledge about the economic value of groundwater is quite limited", stating that most studies have been focused on drinking water sources. The author was aware of no study valuing ecological or recreational impacts on groundwater.

Significantly, Abdalla (1994) feels compelled to note that in his opinion, compartmentalisation and specialisation of economic studies in the realm of resource valuation, means that economists are limiting their ability to help policy makers integrate information about the value of groundwater and the costs of impacts on the resource. He fears that broader, more innovative economic approaches could be overlooked as specialists delve ever deeper into their own sub-disciplines. This again echoes one of the themes of this report, the need for a rapprochement between economists and technical groups working in this area.

5.5 Benefits Of Groundwater Protection And Remediation

Above, the literature is reviewed which deals specifically with valuation of groundwater in its own right. In this section, research is reviewed which attempts to value the benefits of groundwater protection or remediation. The difference is that here, the attempt is to assess the wider benefits of implementing a policy, programme, or action which results in a net improvement in groundwater quality, either now or in the future. The amount of available information cannot yet be described as substantial, although it is clear that considerable effort has been put into the subject in the last few years. The need for this type of work has been expressed by several authors, including the National Research Council (1997), who state that what is most relevant for groundwater pollution policy decision making is knowledge about how economic values are affected by the implementation of those decisions. Again, we come back to one of the central themes of this report, the need to include economic considerations in the setting of groundwater remediation and protection objectives.

Conceptual frameworks for benefits assessment

Raucher (1983), in a landmark paper, describes a conceptual framework for measuring the benefits of groundwater protection. The discussion focuses on benefits, concluding that the costs and feasibility of various groundwater protection measures were, (even at that time), relatively well understood. The framework presented is best expressed in a simple equation:

$$E(NB_i) = E(B_i) - X_i$$

where $E(NB_i)$ are the expected net benefits of an activity that would enhance groundwater protection, $E(B_i)$ denotes the expected social benefits of groundwater protection strategy i, and X_i denotes the social costs associated with implementation of that strategy. The social costs X_i are approximated by the cost of executing the protection measure (relatively well understood). The benefits of groundwater protection, the focus of the discussion, are defined by the change in expected damage (E(D)), expressed by Raucher (1983) as:

$$E(D) = p[qC_r + (1-q)C_u]$$

where p is the probability, in the absence of policy i, that contamination will occur, q is the probability that groundwater contamination would be detected before tainted water was used, C_r is the cost of the most economically efficient response to the problem, and C_u is the cost incurred if contaminated water continued to be used in the same way as prior to the incident. Raucher (1983) uses this framework to put forward some very powerful arguments. First, the inclusion of a probabilistic component to the framework explicitly recognises the role of uncertainty in the decision making process. He notes that both p and q are highly dependent on a sound understanding of the hydrogeological regime and the behaviour of the contaminants within the groundwater system. The role of predictive modelling would be key in applying this framework in practice. Much information is available on the uncertainties and limitations of groundwater flow and contaminant fate and transport modelling (Freeze and Cherry, 1979; Bear and Verruijt, 1987, and Fetter, 1992). Also, the literature dealing with quantitative risk assessment is replete with discussions of the limitations and uncertainties inherent in assessing the risks posed by groundwater contamination (ASTM, 1995). The possibility that groundwater contamination may not be detected for a considerable period, during which it migrates over potentially large distances, affecting a greater number of receptors, is a key issue. This highlights the value of investment in monitoring and investigation programmes. Raucher argues that the probability of detecting contamination q is not fixed in time, and will increase as the plume moves and affects a greater area, and also if policies are put into place which are likely to improve the possibility of detection. The framework can thus be used to estimate the net benefits expected from the implementation of a detection policy. The end-points of the argument reveal some interesting points. If in the worst case contamination is certain (p=1) but impossible to detect (q=0), groundwater would continue to be used in the same way, and damage would result. The expected damage $E(D) = C_u$. Alternatively, if contamination remained certain, but there was full certainty of detection (q=1), then the least cost remedial solution would be implemented, and so $E(D) = C_r$. Hence, for a monitoring policy that improved q, the expected net benefit would be C_u-C_r.

Second, Raucher's framework brings forward the possibility that economic analysis might reveal conditions where C_r is greater than or equal to C_u, in which case it may be better, from an economic standpoint, to do nothing. This simple model shows how the setting of a remedial objective can be framed in economic terms. This subject is a key focus of this report, and will be discussed in detail in chapter 6, below. Definition of the costs of contamination are strongly site-specific. In considering C_u, described by the author as the cost of "using and suffering the consequences", factors such as site hydrogeology, contaminant type, toxicity and behaviour in the aquifer, and the use of the water, are important. Response costs (C_r) should be valued as the lowest-valued of all feasible options which will prevent or remediate the contamination. However, we note that this assumes full information and rationality of decision making, and does not explicitly include the uncertainty associated with remedial system performance and the likelihood that aquifer remediation may lead to only a *partial* clean-up. Raucher groups response options into three categories: 1) restoration, 2) containment, and 3) avoidance. Restoration is not considered in the paper, as it is deemed technological infeasible. Containment refers to control of the spread of contamination, and includes pump-and-treat and physical barriers. Avoidance options deal with treatment at point of use, or development of alternative sources of water.

Raucher (1983) presents an important discussion on the issue of time, as it applies to his framework. The author found that the choice of planning horizon had a significant impact on the cost-benefit calculations. Over time, growth of a plume would tend to affect a greater number of receptors and thus, result in increased damage costs. Longer planning horizons allow for accrual of greater total benefits, all other factors remaining equal, simply by virtue of summing benefits over a greater number of years. More subtle time - benefit relationships may also exist. Over a longer period of time, for instance there may be increased likelihood of contamination occurring (due to waste container degradation, for example).

Intrinsic (non-use) benefits are also discussed by Raucher (1983). The author points out that his benefits formulation framework does not incorporate a premium accounting for option value (the WTP to ensure access to a resource at some point in the future, regardless of whether it is currently being used). This may lead to a "significant understatement of the benefits of protection,", especially when the potentially irreversible nature of groundwater contamination is considered (Kavanagh and Walcott, 1982). Raucher, however, presents two alternative formulations in an appendix, designed to allow incorporation of non-use values into the framework. One option involves direct incorpotaion of non-use benefits as a separate term from the use values. Another involves addressing the non-use values through extending the time horizon indefinitely, and/or reducing the discount rate to zero.

Finally, Raucher (1983) presents a series of hypothetical examples, illustrating the workings of the framework. The results show that altering the discount rate and water use for two types of groundwater plume (large+slow, and small+fast) changes the response deemed to be most economic. These findings reinforce the broad conclusions of the work: that economic analysis of the benefits of groundwater protection and remediation is extremely site specific, that the calculated best response is highly sensitive to time and the discount rate, and the uncertainties associated with the lack of full hydrogeological knowledge, risk assessment limitations, and the lack of research into non-use groundwater values, make practical application of this type of framework quite difficult.

Benefits as damage avoidance costs

Abdalla (1994) argues that from a public decision-making standpoint, the benefits of groundwater protection can be viewed as a damage avoided, or avoidance costs. Major damage categories can be categorised after the nomenclature of Spofford et al (1989):

1. human health effects, occurring due to exposure to contaminated groundwater;
2. increased fear and anxiety, as a result of worry over actual or suspected groundwater contamination, and a lack of knowledge of the probable impacts;
3. avoidance cost and property value loss, such as government requirements to secure alternate water supplies, or households installing their own end-of pipe treatment devices, or potential "stigma" damage to property seen to lie on a contaminated site, or affected in some way by subsurface contamination;
4. ecological damage and loss of recreational use, stemming from groundwater's role as a contributor to surface water flows;

5. reduction or loss of non-use values, through impact on option or bequest value.

Government-run water supply systems have been the focus of some avoidance cost studies. For example, Nielson and Lee (1987) calculated annual pesticide removal costs from groundwater at between US $ 333 and $67 per household for water supplies serving 5000 and 500,000 customers respectively. However, little published information exists for the commercial sector. Household avoidance cost (AC) studies from various parts of the US are discussed. Household AC are estimates of the costs of activities which avoid or mitigate the impacts of pollution. This infers benefits by measuring consumption of goods and services that substitute for the environmental quality change. However, the inference is clearly not perfect, since the actions are unlikley to be perfect substitutes for the pollution impacts. Abdallla (1994) reviews 5 ACM studies which attempted to measure household costs resulting from groundwater contamination. Typical actions taken by households included purchasing bottled water and installing water filtration systems. Abdalla et al (1992) examined a community in Pennsylvania served by a public water supply that was contaminated with organic chemicals. Of the households, 96% were aware of the contamination, and 76% were undertaking their own averting actions. Costs averaged US $ 252 / annum for each household choosing to avoid the contamination. Rural communities in Virginia (US) served by private groundwater wells were studied by Collins and Steinback (1993). They found that 85% of households informed about groundwater contamination engaged in some form of averting action, including hauling water, and end-of-pipe treatment. Weighted average economic avoidance costs were estimated at US $1090 per household for organic contamination problems. Thus, the study concludes that economic avoidance costs, as a measure of the benefit of groundwater protection, are highly dependent on local conditions, and the knowledge that a problem exists. However, it is clear that avoidance actions of households can be significant in economic terms.

Hardisty et al (1998) use the ACM (avoidance cost method) to determine the private (internal) benefits of remediation. In the case of a firm or problem holder contemplating remediation, avoidance costs can be seen as potential benefits of going ahead with remediation. These include avoiding the risk of litigation (and the considerable costs which may be involved), fines avoided, averting public relations damage which could result in loss of sales revenue, and preventing control orders or shut-downs which may result in lost production and revenue.

Non-use benefit estimation - contingent valuation

The issue of valuing the non-use benefits of groundwater remediation is the subject of a USEPA study (McClelland et al, 1992). The study found that the paucity in reliable information on valuation of non-use benefits was a major impediment to rigorous economic appraisal of groundwater contamination problems, specifically with respect to assessing the US Superfund (CERCLA) and Resource Conservation and Recovery Act (RCRA) programmes. The study focused on CVM as the only method presently available for measuring non-use benefits, which are considered by the USEPA to potentially comprise a large part of the value of environmental commodities. The study found that careful survey design is critical to the proper estimation of values. For instance, if the method of payment is not specified, double counting may result. They also found an inherent confusion between bequest and existence values, and suggested that they be measured jointly to avoid double counting. In general, they found a fundamental difference between measurement of use and non-use benefits, largely because a large proportion of respondents were uninformed about water as a commodity. They conclude that for non-use values the burden of informing respondents about the commodity lies with the survey instrument itself. Thus, the design of the survey may bias the results - clearly providing perfect information for a full and rational decision within the survey instrument is not always possible or practical. However, they conclude that CVM does indicate a strong WTP for non-use benefits, and suggest that this fact alone is sufficient to mobilise political support for groundwater protection policies.

Several other studies deal with the uncertainties and biases inherent in the CVM approach. Powell at al (1994), also describe the weaknesses of CV, but conclude that in general the approach demonstrates a broad public WTP for groundwater protection, and that this fact can be used to help guide policy and decision making. This study also found that WTP was influenced strongly by education on groundwater issues.

Measuring Willingness to Pay for Groundwater Protection from Nitrate Contamination

Several studies are available in the literature dealing with the benefits of protecting groundwater from non-point source pollution from agricultural fertiliser application leading to nitrate contamination (Delavan, 1996; Poe, 1993; Giraldez and Fox, 1995). These studies are useful, in that they reflect very similar conditions that might be experienced through releases of contaminants from industrial sites into aquifers. Edwards (1988), in one of the first studies of its kind, studied the WTP to protect a water supply aquifer in Cape Cod, USA, from nitrate contamination. His survey determined a WTP of US $1623/household/year, but also found that the uncertainty associated with valuation was so great that he could form no clear conclusions from the results. Hanley (1989) used CV to show that individuals in the UK had a WTP of £12.97 /person/year to guarantee that water supplies meet nitrate standards, and commented that Edwards' (1988) WTP value was much too high. We must assume, however, that the WTP for protection from other more toxic forms of contamination (such as organic chemicals from industrial sites) would be as least as much as for nitrate contamination.

Poe (1998) studied CV to estimate a damage function for nitrate exposures based on actual water test results on groundwater supply wells. Damages were estimated as WTP for protecting individual well supplies to a 10 mg/L health-based standard. In a review of the available literature, Poe concludes that "people simply do not have well-informed reference conditions, and thus it is unlikely that values collected under these conditions would reliably predict WTP for a population *actually experiencing* groundwater contamination". He argues that alternatives which provide respondents with hypothetical exposure scenarios also have limitations. Again, the link to setting groundwater protection *policy* is stressed - economics must play a key role. Poe (1998) conducts his own WTP survey for private wells in Wisconsin, USA, using actual groundwater nitrate values measured by kits provided to each respondent. With knowledge of the nitrate levels in their own wells, and armed with information describing the health effects of nitrates in drinking water at various concentrations, respondents provided their WTP for groundwater protection. This approach contrasts with previous WTP studies which are based on hypothetical conditions ("suppose your tap water is contaminated by nitrates to a level of X ..."). Poe argues, with some success, that when faced with actual conditions, respondents are more likely to provide realistic WTP values. Interestingly, the study of 332 households found a concave relationship between nitrate level and WTP. Willingness to pay for protection initially rises quickly at low levels of contamination, and then levels off markedly above the health-based threshold concentration (at about US $500/household/year). The author concludes that this result, featuring a WTP that has an upper bounds, is consistent with the opportunities for ready substitution, such as bottled water.

The issue of taste and odour effects on water supplies has been well documented (American Water Works Association, 1987). Contaminants such as MtBE, for instance, creates taste and odour problems in water at concentrations well below current health-based concentration limits (Brown et al, 1997). Economic impacts from non-toxic taste and odour effects must also be considered.

The literature reviewed is consistent in its view that the wider benefits of groundwater protection and remediation can be estimated, at least partly. However, it is clear that monetisation of the benefits is fraught with uncertainty, and requires significant effort and expense in its own right. All of the research reviewed included statements highlighting the need for more research, particularly into non-use benefit valuation (which many felt could be quite significant), valuation techniques themselves (particularly CVM), and the need for more case studies and real data.

The following section reviews literature pertaining to the costs and benefits of groundwater remediation projects themselves, and so narrows the focus to individual problems and the approaches and technologies which are available for solving those problems.

5.6 Costs And Benefits Of Remediation - Choosing A Solution

The costs of actually implementing technical remedial solutions at specific sites where groundwater contamination exists, are relatively well documented. The USEPA (1995) for instance provide a comprehensive guide on the costs of implementing various remediation techniques at sites across the US. Here, the literature is almost exclusively found in the technical (scientific and engineering) realm; very little on this aspect of the problem is discussed in the economic literature. In addition, it is the authors' experience that many UK environmental consultancies, and some of the major corporations involved in managing and remediating contaminated sites, have developed extensive databases on the costs of various remedial techniques for groundwater.

Remedial technology costs and cost comparisons

Several studies compare the costs and "benefits" of two or more remedial methods or technologies for a particular contamination problem at a particular site. Not surprisingly, pump-and-treat (P&T) seems to be a favourite datum for comparisons with newer or more innovative remedial technologies. This is largely due to the significant number of P&T case histories which are available (mostly from the US), many of which include cost (and sometimes effectiveness) information. Unfortunately, many of the P&T remedial programmes undertaken in the US over the last 20 years have not proven successful in terms of meeting the original remedial objectives. However, the consensus of current research into

P&T is that in very many cases, P&T was applied incorrectly, or was being asked to achieve an objective to which it was not suited (Hoffman, 1996). This illustrates a major weakness in much of the literature which compares the costs of various techniques - the methods being compared do not actually perform the same remedial functions, or were not designed to achieve the same results. In assessing such studies, it is important to make the distinction between remedial approaches, and remedial technologies, as was discussed in the background section of this report (Chapter 4).

Nyer and Rorech (1992) provide an overview of the elements of pump-and-treat systems designed to treat BTEX (benzene, toluene, ethylbenzene, and xylenes) contamination in groundwater. Indicative costs of each component are provided, along with recommendations on cost-saving measures. Gatliff (1994) compares the cost of phytoremediation using selected species of trees to deal with shallow groundwater contamination by nitrates, pesticides and heavy metals, to traditional pump-and-treat techniques. Sittler and Peacock (1997) considered different applications of air-sparging for achieving different groundwater remedial objectives, and so compares the costs and effectiveness of one technology applied in different ways. Petersen et al (1993) compared the cost-effectiveness of soil vapour extraction, air sparging and air-stripping technologies for dealing with petrol station contamination in the US. Atwood and Stevens (1987) compare the cost effectiveness of ion exchange and precipitation as methods for removing heavy metals from pumped groundwater (a comparison of water treatment technologies). Wolff and Kidd (1989) compare the costs and effectiveness of technologies for removing VOC's from pumped groundwater.

James et al (1996) compare the cost-effectiveness of two remediation alternatives (containment and monitoring only) for radioactive waste affecting groundwater at the Oak Ridge National Laboratory in the US. They include the concept of "data-worth" analysis, to estimate maximum justifiable expenditures on data collection. Despite the title "Allocation of Environmental Remediation Funds Using Economic Risk-Cost-Benefit Analysis: A Case Study", the discussion does *not* consider the benefits of the remediation, as the term is understood by economists, and as it is used in this report. Rather, the study is one of cost-effectiveness analysis (CEA), with the term "benefits" actually used in the context of the ability of the technique to provide a certain level of remediation, or reach a pre-defined remedial goal. In most of the literature reviewed, the term "benefits" was taken in a very narrow and limited context, primarily associated with the ability to achieve a set remedial target. These studies are more accurately described as cost-effectiveness analyses (CEA), or simple cost-comparisons, and pertain to the second overall objective of this study (determining the most cost effective remedial solution to achieve the objective). This confusion between the term "benefits" as used in the technical and economic literature is widespread in the literature

Decision making frameworks

The literature contains only scarce work on the formal application of cost-benefit analysis, in its wider context, to the problem of selecting the most appropriate remedial solution for a groundwater contamination situation. Several studies consider optimisation of the design and operation of remedial systems, but almost exclusively from the technical perspective (optimal placement of pumping wells for plume capture, optimal flow rates for treatment, groundwater level management for maximising total LNAPL recovery, etc). Some of these studies also include costs and cost-effectiveness as optimisation criteria. Yoon and Shoemaker (1999) compare the performance of several optimisation algorithms used to identify the most cost-effective strategy for bioremediation of contaminated groundwater, and Minsker and Shoemaker (1998) describe a methodology for quantifying the effects of uncertainty in biological parameters when applying in-situ bioremediation. Massman et al (1991) provide a framework for hydrogeological decision analysis, focusing on groundwater contamination problems. They couple simple cost - effectiveness analysis (again termed cost-benefit analysis, but considering only a narrow range of benefits), with stochastic modelling of groundwater contamination. These methods only consider costs, and thus escape the limitations of attempting to monetise benefits discussed above.

Hardisty et al (1998) present a methodology for determining the optimal remedial solution which includes a basic consideration of the wider benefits and costs of remediation. The method explicitly incorporates time as a constraint in decision making, against which discounted remedial life-cycle costs are plotted for various alternatives which meet a specific remedial objective. The method also provides for application of a cost constraint to the analysis, by assuming that wider economic costs and benefits are used in determining the level of remediation required (remedial objective). The authors avoid the problems of explicit monetisation of the wider range of benefits by considering a "threshold" value approach, where readily monetised benefits are used to describe a threshold cost constraint - "we know that the benefits of remediation are at least this much...". The framework is aimed primarily at private sector decision makers (problem holders).

The USEPA has published a series of studies into the use of CEA and CBA in the analysis of state and local groundwater protection programmes (USEPA, 1993). The document provides guidance on the reasons for using economic analysis, the types of data and expertise which are required, and an introduction to the economic tools which are available (Cost assessment, CEA, and CBA). A framework guidance is provided which includes a number of steps: 1) establishing a baseline, 2) assessing the costs of alternatives, 3) analysing the cost-effectiveness of alternatives, and 4) analysing the costs and benefits. Benefit analysis techniques discussed include the avoided cost method, risk assessment, CVM, and Hedonic pricing. The guide provides a useful model, which is discussed in more detail in Chapter 7 of this report. Significantly, however, the guide does not follow a tiered approach, such as has been adopted by the Agency in other studies (Environment Agency, 1999b), nor does it include a framework for the more qualitative multi-criteria approach to economic decision making.

6. GROUNDWATER REMEDIATION COST-BENEFIT ANALYSIS: THE ISSUES

Based on the findings of the literature review, this section lists and discusses the main relevant issues which pertain to the setting of remedial objectives for contaminated groundwater, and the use of economic techniques to help in selection of the most cost-effective remedial method.

6.1 Philosophical Issues

As mentioned in the Agency's terms of reference for this study, current opinions on the degree to which groundwater should be remediated range from full clean-up to pristine conditions, regardless of the end-use of the resource, to requiring point-of-use treatment, to remediating only those problems which are causing demonstrable harm.

Does economics have a role in setting groundwater policy?

The first and most obvious issue is whether economics should be considered in the setting of remedial objectives for groundwater, or whether costs and benefits should only be considered when selecting the best way to achieve a remedial objective which has already been set by *policy* or *law*. There appears to be considerable public support for the "polluter pays" principle, and the notion that if contamination has occurred that exceeds pre-defined standards, it should be cleaned-up by those responsible, regardless of cost. In other words, the polluter is "punished", by having to repair the damage caused, and incur the costs involved - whether the repairs are cost effective, for the polluter or for society as a whole, is not relevant. There is, in this view, considerable moral force.

However, it is clear that society as a whole does not benefit if remedial objectives are more stringent than necessary to protect human health, the environment, and the needs of future generations. In the 1980's, the United States embarked on a massive programme of cleaning-up contaminated sites and groundwater, based on reaching set numerical concentration targets, regardless of the use of the groundwater or the location of the site. In short, risks associated with the contamination were not considered in deciding the level of remediation required, and so neither were economics. As a result, large amounts of money were spent in the US cleaning up contamination which posed little or no risk. Society was certainly not finding its economic optimum. Funds better spent on activities which would have resulted in far more net benefit to society were poured into low value projects. From this legacy grew the concept of risk-based corrective action (RBCA), which sought to balance remedial response with demonstrated risk, and thus focus scarce resources on problems where they would create the most benefit (ASTM, 1995). This concept of determining remedial response based on risk has now gained almost universal support amongst technical practitioners the world over, and forms the basis of UK policy on the management of land and groundwater contamination (DETR, 1999), (DOE, 1995). The connection between risk and economics is implicit in the risk-based policy being adopted in the UK and many other countries. By inference, then, it is clear that economics does have a role in determining the level to which groundwater should be remediated or protected. In addition, the literature supports the role of economics in formulating policy for groundwater protection and restoration. The authors concur with these views.

The economic implications of risk-based remediation

The new draft Agency guidance on determining remedial targets for soil and groundwater to protect water resources (Environment Agency, 1999a) is particularly relevant to this discussion. While providing a sound technical approach to the problem of determining numerical contaminant concentration targets to be achieved during the remediation of a particular site, it has a number of limitations with respect to providing the remedial targets that optimise human welfare.

This Agency guidance document provides a critical framework for determining risk-based remedial goals for contaminated soil and groundwater at a site in order to protect water resources. However, the final risk-based target eventually determined using this guidance is heavily dependent on the selection of the receptor, and the definition of an acceptable level of exposure to that receptor. At its most sophisticated, this could mean invoking quantitative risk assessment, involving dose-response analysis and toxicological assessment of cancer risks. However, it is important to note that in the final analysis, society's definition of what an "acceptable" level of risk is (1 in 100,000 cancer deaths, or 1 in 1,000,000 cancer deaths), can eventually be traced back to economics - the value that society puts on a human life, and the cost-benefit of enforcing regulations designed to save lives (Fisher, 1989). The implicit message is that optimisation of human welfare in a society involves spending on risk-reduction where it achieves maximum benefit. If reducing risk thresholds to 1 in 1 million for groundwater exposure costs society £ 5 M per life saved, while acting on cigarette smoking or traffic safety costs society £1 M per life saved, resources are either reallocated to the more efficient programmes, or risk thresholds for the less efficient policies are relaxed.

In addition, the issue of the technical feasibility of reaching the defined target, and the economic attainability of such a target, are not considered. The target of a given concentration of a given contaminant at a specified compliance point may be what is required to achieve a given level of protection for the identified receptor, but achieving that goal may be cost prohibitive, to the degree that society finds it unacceptable. Thus, implicit in this argument is the consideration of the value of the receptor to society, and benefits accrued from its protection. In other words, defining an "unacceptable" risk of harm, must in part be based on the economics of the situation. Again, this reinforces the need for some level of cost-benefit consideration during the setting of remedial objectives.

Uncertainty of the future

As discussed in Chapter 4 of this study, groundwater problems must be considered as dynamic (changing with time). We must also accept the real possibility that other conditions will also change over time - regulations, markets, public perceptions and attitudes, governments and environmental imperatives. Thus, it is prudent to assume that remedial goals could change over time. Particularly for cases involving deep, chronic aquifer contamination, a series of sequential objectives might well be formulated, and revised over time based on the progress and success in meeting each of the staged goals. The possibility that the fundamental remedial goal could change over time must be built into our thinking about such problems.

For instance, risk assessment may show that contamination of a presently un-used and marginal quality aquifer poses no direct threat to human health or the environment. Present evaluation of the use and non-use values of the aquifer as a resource shows that the present costs of initiating remediation are far greater than anticipated benefits, based on present and projected market conditions and water demand sources. However, it may be that in 20, 50 or 100 years time, circumstances have changed substantially.

One possible example is that the effects of global climate change have begun to take effect in the UK, and water resources (particularly in the South) are in high demand, and under increasing stress. Shortages loom, and the market value of water (even of marginal quality) has increased beyond any predictions. Baseflow recharge to rivers and wetlands has dropped during periods of draught, and sensitive ecosystems are under real threat. A re-analysis of the costs and benefits may show, that under those conditions, some form of remedial action is worthwhile, despite the fact that the contamination is by now well dispersed within the aquifer. Thus, given the inherently long-term nature of some groundwater contamination problems, the ability to re-examine particular situations must be kept open. For situations involving deep-seated contamination of major aquifers, any guidance framework should include a provision for changing objectives over time.

Uncertainty analysis may provide a means of rationalising and comparing possible future outcomes. The cost-benefit analysis would be repeated for different scenarios (defined by different assumptions about the potential use of the aquifer, the effects of global warming on water resources, etc) over different time horizons. The outcomes of the different project alternatives can then be compared probabilistically. Selection alternatives could include maximisation of net benefits, or use of the maximin criterion (consider the minimum pay-offs under each project/assumption and then choose the largest of these).

Responsibility for the future

Water is one of the most basic and important requirements for life. There is no substitute for water. As such, we have a moral responsibility to safeguard high quality water supplies, including groundwater, for future generations. This simple concept implies that non-use values of groundwater be considered when policy is developed and remedial objectives set. As discussed in chapter 4, several workers feel that non-use values of groundwater have been understated, and may be quite significant. The issues of inter-generational equity and shifted irreversibility are discussed in more detail below.

The language of money

Groundwater remediation raises a wide range of environmental, social and economic issues. Rationalising and quantifying these diverse considerations requires a common unit. Economic appraisal uses money as that common unit. Projects, policies, business transactions, and the decisions of individual consumers are assessed, discussed and recorded in monetary terms. Protection of the environment and valuable resources are no exception. For a long time, the environmental damage that resulted from industrial production and resource exploitation was not considered in the economic accounting. Environmental costs were external, and until the last few decades, were not considered when evaluating a project or indeed a nation's GNP. Only through explicit accounting for the wider environmental costs and benefits, can a true assessment of a project's contribution to improvement in the well-being of society be measured (Pearce and Warford, 1993).

Explicit consideration of environmental costs and benefits provides a practical and powerful way of explaining and defending the need for groundwater remediation and protection to the broadest range of potentially involved stakeholders. In any given situation, stakeholders could include small and large businesses, special interest groups, charities, NGO's, government officials, regulators, lawyers, financial institutions, and individual members of the public. Each will have a different perspective of the issues, and a different agenda, when faced with a potentially serious groundwater contamination problem. Economic analysis of the problem provides a common language that everyone can understand, and in a unit of measurement with which everyone is familiar. By reducing all of the relevant issues to a standard unit (money), the involvement of all stakeholders is encouraged - barriers to involvement are removed, and thus a more complete and fair decision making process is possible. This in turn may provide additional incentive to all sectors to seriously consider and act on their legitimate environmental responsibilities, in the knowledge that at the end of the day, environmental pollution and resource damage has a financial impact on all of us. This reinforces the view that economics does have a role to play in the setting of remedial objectives. A more complete and explicit analysis of the economics of groundwater contamination and remediation may also be useful when setting penalties or fines for groundwater-related pollution. An understanding of the costs and benefits of the contamination would allow authorities and stakeholders to set and understand an economically appropriate penalty which adequately reflects the true cost of the damage.

6.2 Technical Issues

Assigning costs and benefits to a groundwater remediation project will depend in part on our technical understanding of the problem. An understanding of the nature, type and distribution of the contamination is required to calculate risks, and assess damage costs. Knowledge of future movement of the plume can be used to calculate future expected impacts and thus predicted future damage costs. Estimating the benefits of remediation depends in part on a view of which ecosystems and surface water bodies will be spared if remediation occurs. This section provides a listing and discussion of the main relevant technical issues which will have a bearing on the use of economic analysis as a tool in determining the degree to which groundwater should be remediated, and in choosing the best method to achieve the objectives.

Remedial objectives, approaches, and technologies

It is important to distinguish between the different levels at which remedial decisions need to be made.

- *Remedial objectives* describe the overall intent of the remediation project. Objectives could include the degree to which groundwater is to be remediated, the protection of specific receptors, or the elimination or reduction of certain unacceptable risks.

- *Remedial approaches* are the conceptual manner in which the objective is to be reached. For example physical containment, source removal, replacement, natural attenuation and monitoring,
- *Remedial technologies* are the specific tools which form the components of the approach. For example, physical containment can be achieved through use of slurry walls, sheet pile walls, or liners, often in conjunction with groundwater pumping and treatment. Source removal can be achieved through excavation and on-site treatment of contaminated soils (by a variety of techniques), or through many available in-situ techniques. A remedial solution will very often involve the use of several different remedial technologies.

Remedial objectives should be known before detailed design (technology selection) occurs. The choice of a remedial approach is a critical intermediate step, which can be used both as a tool to help set objectives (by considering and comparing various approaches at the conceptual level), and to guide the selection of the technological components which will make up the final design.

Groundwater, risk, and uncertainty

As discussed in Chapter 4 of this report, the risks associated with groundwater contamination can be classified into three categories:

1) risks of damage to groundwater resources themselves (aquifers), and thus to the users of that groundwater (humans, crops, animals);
2) risks of impact to surface water resources, as a result of groundwater's contribution to the resource (via baseflow discharge) , and thus to the users of the surface water (humans, crops, animals, ecosystems);
3) risks of impact to receptors as a result of contaminant migration via groundwater (as a risk pathway), including ecosystems, property, natural amenity features, and possibly humans and animals).

Since groundwater, and the contaminants within it, are mobile, impacts may occur at substantial distances from the original source of the contamination. Due to the heterogeneity of geological materials, the patterns and velocities of contaminant movement in groundwater are difficult to predict, and there is significant uncertainty involved in any prediction of future impacts.

Because groundwater is mobile, there is potential for contamination to spread considerable distances. If multiple sources are involved, as could be the case in an industrial area, co-mingled plumes could result. Several such situations have been documented in the US (USEPA, 1980). These could involve several sources, with several different responsible parties. The issues of apportioning responsibility for the damage, and assigning costs for remediation to each party, are fraught with complications.

Analysis of the risks associated with groundwater contamination will usually involve application of the source-pathway-receptor (SPR) concept, discussed in Chapter 4. For a potential risk to exist, a complete SPR linkage must exist. Estimation of the costs of damage associated with a particular risk will involve some level of analysis of the probability of the risk, and the likely impacts to the receptor.

Uncertainty is introduced into the risk analysis through the following:

- uncertainty in prediction of contaminant behaviour within the subsurface (distribution and concentration of contaminants, migration direction and velocity, the effects of retardation and attenuation mechanisms);
- incomplete site characterisation information due to limited resources, leading to uncertainty of information regarding source concentration, mass, and composition;
- assumptions required in formulating the SPR linkages;
- assumptions, incomplete information, and uncertainty regarding dose-response behaviour of receptors in the SPR linkage;
- the limitations of toxicological science, especially with respect to the wide range of contaminants present in the environment, the understanding of cumulative effects, and the limited available information on ecological toxicology.

Another important consideration is the likelihood that more than one SPR linkage exists at a given site. One source, for instance, may contribute contaminants which move through different pathways to different receptors. For example, a spill of volatile organic compounds (VOC's) may result in 1) DNAPL (dense non-aqueous phase liquid) density-driven migration along the top of a shallow bedrock horizon, towards a river, 2) dissolved phase contamination of groundwater being used for irrigation, and 3) vapour phase transport in the unsaturated zone, which eventually contaminates shallow groundwater at some distance from the source point, and in a different direction to 1) and 2) (Mendoza and McAlary, 1990). In such a case, three separate SPR linkages exist, all of which have the potential to cause damage, and which need to be accounted for separately. Each of the three risks will require separate estimates of damage costs.

Multiple SPR linkages also have implications for remedial decision making:

- The decision on the level of remediation required (setting the remedial objective) is *complicated by having to consider the three linkages as separate issues, to some extent.* In our example, for instance, the impact of DNAPL to the river may be ranked as the most urgent immediate problem, and a remedial objective might be to prevent DNAPL discharge to the river. However, dissolved phase contamination, which could be migrating in a completely different direction (to irrigation wells), might be a longer-term problem, requiring a different objective.
- *at one site, remedial decision making needs to consider three separate problems, to which the solutions may be quite different.* In our example, the remedial techniques which apply for the DNAPL problem will not likely be effective for dissolved phase contamination, or for the vapour-phase migration.
- *The technical feasibility of dealing with the different SPR linkages may also be vastly different.* At present, for example, remediating DNAPL, especially in deep, heterogeneous or fractured systems is extremely difficult, if not impossible, with present technology. A "remedial feasibility index" of some sort should be considered as part of any framework which is considering remedial decision making.
- *The costs and benefits of dealing with each SPR linkage may have to be considered separately*; in which case the decision making process may involve a ranking of the risks, costs and benefits of dealing with each separate problem.

Uncertainty will also be introduced into the decision making process as a result of incomplete understanding of contaminant distribution, types, behaviour and mobility. This inherent uncertainty has a number of implications:

- *attempts to reduce technical uncertainty will generally involve increased data collection.* The costs of data collection may be high, and there will clearly be a point of diminishing marginal returns in expenditure on data. This concept of "data worth" was discussed in the literature review. However, it is important to note that in the author's experience, the point of diminishing marginal returns on data collection is rarely reached, in practice. Many remedial decisions in the UK and other countries are routinely made with insufficient data. The value of sufficient high quality data cannot be under-estimated. The results of risk assessment, the choice of remedial goal, and selection of remedial approach and technology, are all based on the data collected at the outset. It is our experience that, in general, remedial activities cost at least one or more orders of magnitude more than data collection and review activities. We recommend that a data worth analysis be considered for each groundwater contamination case. Even if the analysis is basic and cursory, it will highlight the value of high quality information to decision makers.
- *Uncertainty can mean that groundwater contamination may not be detected for some time.* The probability of detection of a given problem will tend to increase over time, and with increased scale. The possibility that groundwater contamination is not detected, and that damage results, was discussed by Raucher (1983) in some detail (see Chapter 5). This type of uncertainty should be considered in any cost-benefit analysis framework.
- *Once detected, uncertainty may result in delays in determining the cause of contamination, the original source, and in identifying responsible parties.* Delays may result in additional costs and damages.

Any framework for incorporating cost-benefit analysis into remedial decision making must, in our opinion, include the ability to account for:

- incorporation of the results of risk assessment, on which current remedial guidance is based;
- the existence of multiple SPR linkages on a given site;
- the co-mingling of contaminant plumes, possibly involving several sources, and several responsible parties;
- the three fundamental modes by which groundwater-related risks may be generated;
- situations where remedial objectives are set first, and then approach and technology options are evaluated to determine which reaches the objective most economically, or situations in which the costs and benefits of a range of fully developed remedial options are assessed to determine the remedial objective and which option should be chosen;
- the inherent uncertainties associated with predicting groundwater contaminant behaviour and the associated risk.

Time and scale

Groundwater flows, and contaminants move with it. Typical groundwater flow rates are in the order of centimetres or metres per year. Thus, the impacts of a groundwater contamination episode may not manifest themselves for several years or decades, reflecting the time it takes for the plume to migrate to the receptor. In the same way, as a plume migrates and spreads through an aquifer, covering a larger and larger area, the probability increases that more receptors will be impacted. However, as time goes on, contaminant concentrations (and thus the risk-generating potential of the plume) may decrease, as a result of dilution, dispersion, adsorption, biodegradation, and chemical breakdown.

These facts mean that groundwater contamination issues must be seen in the context of time and space, and are inherently dynamic in nature. This presents a number of issues for the setting of remedial objectives and assessing the most economic remediation alternative:

- *Objectives must be framed in a temporal context* - the level of risk associated with a given problem, and thus the predicted economic consequences should no action be taken, will change over time. In many cases, the longer we wait to deal with a problem, the worse it can get, and the more it may cost to deal with.
- *Technology changes with time.* The last twenty years have seen a significant amount of research into the detection, understanding and remediation of groundwater contamination. What was considered technologically infeasible a decade ago may be wholly practicable and affordable today. This trend is bound to continue. In addition, the costs of remedial technologies may change with time. For instance, the cost of air-strippers for removing VOC's from pumped groundwater has dropped significantly over the last ten years, while performance, ease of maintenance and dependability have improved.
- *Regulations change with time.* In the UK, the regulations dealing with groundwater contamination have been evolving for the last two decades. The new guidance packages being issued by the Agency are fundamentally changing the way such situations are reviewed, evaluated and dealt with. Considering that planning horizons for serious groundwater contamination issues may be in the order of decades, or sometimes centuries (in the case of radioactive wastes, for instance), the likelihood is that relevant regulations and guidelines will change over the course of the project. Future changes at European Union level (eg. Water Framework Directive) will ensure continued evolution of the regulatory climate in the UK in future.
- *Many deep groundwater contamination problems require long term remedial solutions.* In many cases, the only feasible remediation alternatives for groundwater contamination are containment or damage-limitation, which involve long-term operation and maintenance of remedial systems. Pump-and-treat for plume control (hydraulic containment) for instance, is only effective while the pumps are running and the extracted groundwater is being treated at surface. In cases where deep sub-surface sources exist, pumping may have to continue indefinitely. Clearly, in these cases, time is a critical decision making factor. Choosing an inappropriate planning horizon could compromise the decision making process, and result in selection of an infeasible and uneconomic remedial objective.

In the same way, the *scale* of a groundwater problem is not necessarily fixed. A spill which is initially concentrated to a small area, may over time affect a considerable area, as groundwater carries the contaminants away, and brings them into contact with other media and receptors. The scale of a contamination problem may have significant impact on how it is valued by society:

- larger scale problems are likely to affect more people, and a greater number of other receptors, all other things being equal;
- Larger scale issues are more likely to involve a larger number of more diverse stakeholders, all of whom may wish to participate in decision making. Figure 6.1 provides a schematic illustration of the types of stakeholder groups who may be involved in decision making;

- larger scale issues are more likely to attract public attention, which may be reflected in media, public and political scrutiny, and may shift the economic and social perspectives of the stakeholders;
- Larger scale problems are more likely to involve issues which transcend individual site decision making. Problems which cover large areas, or cross jurisdictional boundaries, may come to be seen as regional, or even national in importance.

Decisions on remedial objectives may, in some cases, need to reflect more than just the site-specific or problem-specific issues. For example, loss of any one aquifer may not be significant on a national or regional scale. Suitable, cost-effective alternatives may be available. In such cases, as argued by Raucher (1986), economic analysis may reveal that remediation or restoration is not cost-beneficial, and no action should be taken. However, if this decision, taken in isolation, is repeated throughout the country or a particular region, the cumulative effect of the loss of several aquifers could be devastating. Thus the scale of consideration of the problem is vitally important. This again reflects the need to consider the wider economic picture when setting remedial objectives.

Another major implication of time and scale issues for remedial decision making is that *remedial objectives may change with time*. As discussed in Chapter 4, the temporally variable nature of groundwater contamination problems may require a set of evolving remedial objectives, which suit the conditions at the time. As regulations, public perceptions, technology, and global environmental conditions change, so too may remedial objectives. Any framework developed for groundwater remediation decision making should provide this type of flexibility. Clearly, a tiered system would be preferred, where small, readily-remediated problems can be assigned a relatively short planning horizon, and a single-point remedial objective. Larger more complex problems may require a more detailed analysis, and may require definition of several remedial objectives over various planning horizons.

Groundwater quality and quantity

It is important to note that in many situations, the quantity of available groundwater is just as important as its quality. Measures or actions designed to protect or remediate groundwater quality may also affect the quantity of groundwater available for use or as contribution to the hydrologic cycle. Examples of effects on groundwater quantity include: 1) pumping for remediation or containment, which lowers groundwater levels in an aquifer, reducing flows available to other users, and affecting the water balance of surface water systems, 2) placing restrictions on groundwater use to prevent inducing movement of contaminants towards wells or well-fields; and 3) damage to aquifer recharge zones, eliminating or reducing the effective recharge to an aquifer, and limiting the safe yields of groundwater for users. Economic analysis of remedial objectives should consider the possible effects on groundwater quantity as well as quality.

Irreversibility

In the worst case, groundwater contamination may be irreversible, for all practical purposes. Examples include situations involving deep contamination of highly heterogeneous media by non-aqueous phase liquids (such as hydrocarbons, organic solvents, and coal tar), radioactive contamination, and extensive contamination by compounds which tend to adsorb to the aquifer matrix material and are only released again slowly over time by diffusion. In these situations, there is little that can be done to reverse the damage, and restore the affected aquifer. In most such cases, the best approach is to isolate the damaged area, contain the contaminants, and prevent them from affecting a greater volume of the aquifer. These may be termed conditions of "perpetual maintenance", where for the foreseeable future, an isolation or containment system will have to operated, maintained and monitored.

In such situations, the benefits of remediation may be clear, both on an intuitive level, and based on a wider economic analysis. Irreversible damage is by definition beyond repair. However, care must be taken when using the term "irreversible". In the final analysis, almost any subsurface contamination problem can be remedied if sufficient resources are put to the task. Even the examples listed above could be remediated by excavating out the subsurface sources, as would be done in an open-pit mine. Even then, the removed aquifer material would have to be carefully replaced by a substitute material. Clearly, the costs of these types of extreme solutions would be prohibitive. What is implicit in the term "irreversible" is an upper limit on society's WTP for a solution. As discussed above, however, the future is uncertain. Should conditions change substantially or catastrophically, creating severe and life-threatening shortages of clean water, such "irreversible" damage could well be seen as 'reversible'.

6.3 ECONOMIC ISSUES

Private costs and benefits

Most of the literature reviewed in Chapter 5 of this report dealt with the environmental costs and benefits of remediation. This is in part because private firms have developed considerable experience and knowledge of their costs and benefits in this area, and so researchers have tended to focus on the wider issues. Despite this, very little literature actually exists on the private benefits of groundwater contamination and remediation.

However, both the private (internal) and larger public (external) costs and benefits should be considered during remedial decision making and setting of remedial objectives. The private benefits of remediation could include:

- *costs avoided if remediation takes place*: These include avoiding the risk of litigation (and the considerable costs which may be involved), fines avoided, averting public relations damage which could result in loss of sales revenue, and preventing control orders or shut-downs which may result in lost production and revenue. The elimination of "stigma" value may also be relevant.
- *direct benefits*: These might include increased property value, or direct cost savings through access to clean groundwater.

In situations where the polluter has been identified as a private entity, the costs of implementing remediation will be borne wholly or substantially by that entity.

The costs of groundwater remediation typically may include any or all of the following:

- Site investigation and data collection costs; including the costs of performing non-intrusive surveys, drilling and installing monitoring wells, and sampling and analysis;

- data interpretation and analysis costs; including reporting, predictive fate and transport modelling, and risk assessment;
- decision making costs, including economic analysis costs, negotiations with regulators, public meetings and information costs, public relations costs;
- remedial design fees;
- legal fees;
- permitting fees;
- capital costs of remediation system;
- operation and maintenance costs, including spare parts, power, labour, security, water and waste disposal, and taxes;
- disposal and waste management charges, such as costs for disposing of waste materials and by-products of the treatment system, tipping, and charges for disposal of recovered contaminants;
- remedial system modification costs and contingencies;
- validation costs, including sampling and reporting;
- insurance.

In implementing a remedial solution for contaminated groundwater, there may be situations where a secondary cost has been created, which would not normally be borne by the problem holder. These can be termed *external costs of remediation,* and they are not usually considered in cost-benefit analysis for groundwater remediation projects. In fact, no references to external costs or dis-benefits of groundwater remediation were found in the literature. Dis-benefits would include:

- *Creating a new risk*: In situations where contaminants are removed from groundwater, and introduced into another medium, a new risk which did not previously exist may result. For example, air-stripping of volatile organic compounds (VOC's) from groundwater, without the use of off-gas treatment, puts VOC's directly into the air, where they may affect the health of nearby residents. Moving recovered contaminants to another location (such as a tip) could expose people along the transport route. Exposing remediation workers to risk (health and safety issues) is also an important potential cost of remediation.
- *Contamination of another medium*: Certain remedial approaches may involve redirecting contamination to another medium, such as soil, air or surface water. Examples would include in-situ volatilisation processes which drive volatile contaminants from water into unsaturated zone soils, discharge of pumped contaminated groundwater to the sewer system or to a wetland for treatment, or discharge of volatile compounds to the air.
- *Contributing to air and greenhouse emissions*: Any project which is energy intensive, or produces inordinate levels of greenhouse and other air emissions through the remedial process itself, may also be producing dis-benefits.
- *Permanent elimination of water from the hydrologic cycle*: If we assume that fresh water has some value, then a remedial process which removes it completely from the hydrologic cycle would produce a loss equivalent to the value of the volume of water processed. An example is deep-well disposal of contaminated groundwater, a common practice in many parts of North America.

Protection vs. Remediation

Groundwater protection involves preventing future groundwater contamination, either by direct measures, or through implementation of policy. Groundwater protection costs incurred by the private sector could include a large range of activities, such as:

- implementing environmental management programmes;
- environmental training for employees;
- environmental monitoring plans;
- investment in plant and equipment designed to reduce the probability of leaks and spills that may result in groundwater contamination;
- development of spill response plans;
- remediating soil contamination;
- removing, stabilising or isolating wastes;
- improving waste disposal practices;
- foregoing development to comply with groundwater source protection zone restrictions.

Raucher (1983) comments that in general, the value of avoiding a groundwater contamination incident will be at least as great as the expected cost of damage incurred should it occur. The costs of groundwater remediation, in general, will tend to increase with the complexity and heterogeneity of the subsurface, the depth of groundwater, the mass, longevity, mobility and toxicity of the contaminant, and the time until detection and action. Thus, groundwater contamination can be extremely expensive to remediate once it has occurred, and in some cases is irreversible. In contrast, many of the most effective spill prevention and groundwater protection measures are relatively inexpensive (training programmes, environmental management programmes, improved inventory, storage and handling practices). This suggests that in very many cases, prevention of groundwater contamination will be much more cost-beneficial than remediation. Any framework guidance should include for analysis of the economics of both groundwater protection and remediation objectives.

The wider economic benefits of remediation

In practical terms, the interests of the public and the environment are represented, in most cases, by the government and their representatives within the environmental regulatory bodies. The potential range of benefits of groundwater protection and remediation are discussed at length in Chapter 5, above.

The full range of benefits to society of groundwater remediation and/or protection include use and non-use benefits. For a complete accounting of the real costs and benefits of groundwater contamination, and any remedial action which may be contemplated, the full range of costs and benefits should be considered. These can be defined as (Kulshreshtha, 1994):

- direct use value: uses of groundwater that lead to activities that would not take place if that quantity and quality of water did not exist, including domestic, industrial and commercial water use, and irrigation for the production of crops or animal feed;
- indirect use values: the value of the contribution made by groundwater to tourism, recreation, and support of the natural ecosystem, including contributions to the hydrologic cycle (discharge to lakes, rivers, streams, wetlands, and other important surface water features);

- option values: since all direct and indirect use values are associated with the current use of water, they do not include values stemming from future use of groundwater. Option value represents the premium which certain users may be willing to pay to secure access to and use of groundwater at some time in the future.
- Existence value (non-use): Individuals may derive values simply from the knowledge that uncontaminated pure groundwater, and the ecosystems and hydrological cycle it contributes to, exists, irrespective of whether it will ever be used.
- Bequest value (non-use): Individuals may affix a certain value to groundwater because of their desire to pass on the resource to future generations.

Valuation of benefits

There seems to be some consensus, based on our literature review, that a complete accounting of all of the benefits of groundwater remediation and remediation should be included in some way in the determination of the project objectives. There is, however, tacit acknowledgement that in most cases, full monetisation will not be possible. As discussed in chapter 4, valuation methods fall into four categories:

- direct market value, where the good itself is priced on the open market as a saleable commodity. Groundwater sold as drinking water has a price per unit volume;.
- surrogate market techniques, in which a market good or service is found that is influenced by the non-market good. Hedonic pricing is based on this concept. Where groundwater is not directly sold as a commodity, it might be used to irrigate crops which are sold at market prices - this would be the surrogate market. The travel cost method identifies the expenditures made by travellers who come to experience a particular area of natural beauty (which may depend, in part, on groundwater for its existence) as the surrogate market;
- market creation techniques, in which individuals' WTP for a specific outcome is determined. The contingent valuation method (CVM) is the most common market creation technique;
- dose-response relationships, in which a link is established between a contamination incident or level, and a measurable physical response, such as morbidity. If consumption of contaminated groundwater is linked to morbidity or health effects, these can be valued, and assigned as costs of aquifer pollution.

However, there are a number of obstacles to full valuation of the benefits of groundwater remediation and protection. These obstacles include:

- *The difficulty and expense in monetising site-specific benefits.* The literature review revealed that most workers feel that the economics of groundwater remediation is site-specific. Clearly then valuation of all of the benefits of a project will involve considerable effort, and no small amount of site-specific research. An economic data-worth analysis is probably worthwhile in many situations, to determine the level of data required for appropriate decision making. It is considered unlikely, however, that sufficient time or resources will be available in most cases to develop fully monetised values for all categories. Smaller sites, with less serious contamination problems, will likely not warrant any site-specific valuation studies, and the external benefits of remediation may only be partially monetised. For larger more heavily contaminated problems, involving significant current and potential future risks, a more complete economic assessment may be worthwhile. This "tiered" approach, which is being adopted for the Agency's contaminated land cost-benefit analysis framework, with the level of analysis adjusted to suit the situation, is favoured as a practical way of including economic factors in the decision making, without making it overly onerous.

- *The inherent limitations of many valuation methods, particularly CVM.* The literature review suggested that results of contingent valuation (CV) studies were highly dependent on the design of the survey instruments, and thus were generally not accepted by non-economists. Indeed, currently available data are likely insufficient, in terms of quality and quantity, to be used for a rigorous benefits-transfer valuation of groundwater resources.
- *Some of the most difficult-to-measure values may be among the most significant.* Little research has been conducted in the non-use value of groundwater. Despite this, there seems to be agreement among the work reviewed, that CVM does indicate a strong WTP for non-use benefits of groundwater, and this fact alone may be sufficient to influence groundwater protection or remediation decisions. Some researchers feel that if properly measured, non-use values could be considerable. In practical terms, these views suggest that in many situations where only easily-measured values are considered in a cost-benefit analysis, the benefits of remediating or protecting groundwater could be considerably under-estimated.
- *The lack of basic research into the value of groundwater.* If site-specific valuation studies of the benefits of groundwater remediation cannot be readily conducted, an alternative is to consult published research on similar situations under similar hydrogeological and market conditions. Unfortunately, the amount of information available in general, and on the UK in particular, is extremely limited.

The literature reviewed is consistent in its view that the wider benefits of groundwater protection and remediation can be estimated, at least partly. However, it is clear that monetisation of the benefits is fraught with uncertainty, and requires significant effort and expense in its own right. All of the research reviewed included statements highlighting the need for more research, particularly into non-use benefit valuation (which many felt could be quite significant), valuation techniques themselves (particularly CVM), and the need for more case studies and real data.

Time

The inherently dynamic nature of groundwater contamination has been discussed at length above. It seems clear that the choice of planning horizon will have a significant impact on cost-benefit calculations for groundwater remediation. Over time, growth of a plume would tend to affect a greater number of receptors and thus, result in increased damage costs. Longer planning horizons mean benefits and costs are accrued over a greater number of years, resulting in greater total benefits and costs, all other factors remaining equal. Longer planning horizons may be required in situations involving deep sub-surface sources of contamination, or complex hydrogeological conditions. Irreversible contamination may simply have to be managed in perpetuity. In these situations, long-term operation, maintenance and monitoring costs may be considerable, and the life expectancy of remediation system capital must also be considered (for example, the typical electric submersible pump deployed in a pump-and-treat application will need to be replaced every 5 to 8 years).

Discount Rate

As discussed in the literature review chapter, several workers have found that the choice of discount rate can significantly affect the outcome of cost-benefit analysis for groundwater remediation or protection. The choice of discount rate is open to some debate among economists, and is not straightforward. A concern is that discounting effectively devalues the future, by putting an inordinate emphasis on present value. This is especially the case for natural resources which have long gestation periods (Pearce and Warford, 1993). Deep aquifers which contain relatively old water, and are recharged slowly, are an example. A high discount rate could result in an economic analysis which promotes unsustainable abstraction rates, based on the relatively high value of water in the near term. In the same way, a high discount rate may mean that the benefits of protecting groundwater for the future are too small to warrant expenditure in the near term, resulting in a deferral of action. Indeed, high discount rates are frowned upon in much of the environmental literature (Pearce and Warford, 1993), since they tend to shift the burden of responsibility for environmental protection and remediation onto future generations.

Education

Integration of economic considerations and techniques into remedial decision making for groundwater problems is clearly a relatively new development, even in the US where there has been a long history of concerted action on groundwater contamination. In any new endeavour, success is predicated to some degree on the level of understanding and knowledge of the participants. If guidance on cost-benefit analysis for groundwater remediation is to be put in place and used effectively, those who are to use the methods, and the stakeholder groups who will be asked to accept the conclusions of the analysis, will need a basic understanding of the main issues discussed in this report.

Communication between environmental professionals and economists

The literature on the economics of groundwater protection and restoration was divided into research published by environmental professionals, and work published by economists. The two groups tend to publish in different journals and symposia, use different terminology, and focus on different aspects of the issue. The gulf between these groups can be narrowed in future through support for joint research. In addition, compartmentalisation and specialisation of economic studies in the realm of resource valuation, for example, may mean that economists are limiting their ability to help policy makers integrate information about the value of groundwater and the costs of impacts on the resource. Application of economic techniques to remedial decision making is considered by the authors as necessary and valuable. Rapprochement of the various disciplines and sub-disciplines involved in the issue will help to ensure that appropriate objectives for groundwater remediation are set, and that the most cost-effective approaches and techniques are employed.

7. TOWARDS A GUIDANCE FRAMEWORK

As stated in the Agency's project terms of reference, the following phase of work is to develop a framework guidance for the transparent and consistent assessment of costs and benefits in the remediation of polluted groundwater, on a site-specific basis. Based on the literature review and issues discussion presented above, this chapter provides suggestions for the formulation of such a framework guidance.

7.1 Overall Approach

As mentioned previously, this work is a companion to a parallel study on the costs and benefits of contaminated land remediation on a site-specific basis (Environment Agency, 1999b). This framework is used as a starting point for the discussion, under the assumption that its general structure can be used with modifications, as a template for development of a groundwater remediation guidance cost-benefit framework. The draft framework uses a tiered approach involving the following steps:

- screening step, in which basic questions are asked, and the need to progress further is established;
- qualitative analysis step, involving simple cost-effectiveness analysis;
- semi-quantitative analysis step, using multi-criteria analysis (MCA) and CEA to consider costs and qualitative benefits. The system allows the user to progress into as much detail as is warranted by the particular situation. This provides a high level of site-specificity to the framework. If the analysis provides a clear answer on which direction the project should take at this stage, the analysis stops. If not, the user may proceed to the third and more detailed step;
- quantitative cost-benefit analysis step, in which a more fully monetised and detailed analysis is undertaken, with the costs and benefits of various remedial options being considered.;
- option selection and sensitivity analysis step. A framework for option selection is provided, along with a sensitivity analysis option, which allows the sensitivity of the results to key input parameters to be judged. We consider this a strong and important part of the framework, which can be used to illustrate the limitations of the results. It remains to be seen whether the sensitivity analysis step will help in decision making, or simply cast uncertainty on the conclusion. The question of user and stakeholder education, discussed above, seems particularly relevant for this aspect of the procedure.

It is important to note that the framework does not consider the issue of the level of clean-up required (the remedial objective) but assumes that the decision to remediate has already been taken. As such, it focused on the second of the two goals of this study - "using costs and benefits of different remedial options to determine the most cost-effective remedial strategy". It does deal implicitly with groundwater problems, but only insofar as they are directly related to the major on-site land remediation thrust. No provision is made for many of the key issues discussed above, including:

- major long-term aquifer pollution;
- off-site risks produced by groundwater contamination;
- loss of the productive value of an aquifer (direct-use values);

- the existence of persistent sub-surface sources, which may continue to contaminate groundwater over long periods of time;
- the potential for irreversible aquifer damage;
- accounting for groundwater's role as a contributor to surface water resources and a vital component of some ecosystems (indirect-use values);
- the intrinsic and bequest values that may make up a considerable part of groundwater's total economic value (non-use values);
- the significant uncertainties involved with contaminant migration over long distances;
- or the possibility that remediation could take long periods of time, or indeed may be perpetual (no defined end-point).

Despite these limitations, the contaminated land guidance framework is considered to be a suitable overall model for consideration of groundwater remediation economics. Retaining the basic approach as a common link between the two frameworks will allow for ready integration of the two issues on sites where both are important. At many land contamination sites, groundwater is only a secondary minor issue, and is not expected to be the driving force behind remedial decision making. In these situations, the current contaminated land guidance framework may be sufficient to deal with both problems. However, in situations where groundwater contamination is particularly severe, where off-site migration has the potential to generate significant risks, or where contaminated land is not directly the source of the problem, a separate but parallel groundwater framework may be necessary. It is envisioned that the groundwater remediation framework would be particularly applicable in situations where:

- *contaminated land is not the direct source of the groundwater contamination problem.* This could include situations involving one-off spills where the soil contamination was quickly recovered by emergency response action, but a larger groundwater plume has resulted, or where groundwater contamination has resulted from non-point-sources (such as nitrate or pesticide contamination from agricultural application);
- *multiple point-sources have contributed to an overall groundwater pollution problem, involving several co-mingled plumes.* In such cases, remediation is likely more cost-effectively considered from a whole-problem point of view, rather than as a number of separate site issues;
- *site contamination has resulted in significant off-site migration of contaminants in groundwater*, potentially affecting one or more sensitive groundwater receptors (particularly public water abstraction points, and sensitive surface water bodies which have significant value);

Thus, the basic contaminated land guidance framework should be closely adhered to, wherever possible, when constructing the groundwater guidance. However, it is clear that some aspects of the framework will require substantial modification to make them suitable for many of the very different issues which are relevant to groundwater. In particular, the groundwater framework may require:

- *a procedure for developing the remedial objectives for groundwater clean-up* (the level to which groundwater should be remediated). The framework developed by Raucher (1983) is a good example of a quantitative approach for considering the full costs and benefits of remediation, in order to assist in developing an economically viable remedial objective. Clearly, for many situations, a simpler less data-intensive procedure will be required;

- *the ability to cope with multiple objectives* for a single groundwater contamination problem which generates several very different risks (different SPR linkages);
- *a facility for considering explicitly the mobility of groundwater contamination,* and the fact that risks of exposure to receptors may increase over time;
- *the capacity to include the wider economic benefits of groundwater into the analysis,* even on a semi-quantitative level, perhaps through the use of threshold value concepts ("we know that the value of the groundwater is at least this much, based on readily available market data, even if we have not included the more difficult to measure non-use values");
- *the ability to distinguish between remedial objectives* (the degree to which groundwater should be cleaned-up), *remedial approaches* (the conceptual manner in which the objective is to be reached, for example physical containment, source removal, replacement, natural attenuation and monitoring), *and remedial technologies* (specific tools which form the components of the approach; for example containment can be achieved through use of slurry walls, sheet pile walls, or liners, often in conjunction with groundwater pumping and treatment);
- *some level of probabilistic analysis* of the results of the economic analysis, explicitly recognising the significant level of uncertainty which exists with many groundwater contamination problems;
- *the constraints to remediation which are unique to groundwater,* including the limitations of present technology in dealing with complex and deep-seated contamination, physical restrictions on access to the aquifer because of surface obstructions and property rights issues (off-site), and the potential for exhausting private resources allocated for remediation before objectives are met (a situation which has occurred often in the US, for example);
- *the ability to consider long planning horizons,* particularly in situations where irreversible or widespread contamination exists;
- *the flexibility to incorporate changing remedial objectives* within a long planning horizon.

It may be useful to include a decision point within the contaminated land framework guidance (Environment Agency, 1999b) which directs the user to the parallel, and compatibly structured, groundwater economic guidance, under certain situations. A simple screening matrix, involving questions such as those listed above, could be developed and inserted into the guidance framework. Similarly, the groundwater guidance could refer the user to the contaminated land framework for questions dealing with remediation of contaminated land that is the source of the groundwater problem.

7.2 Setting Remedial Objectives

Overview

The groundwater remediation framework should allow users to use economic arguments in support of remedial goal definition. As discussed previously, this critical decision will in many ways dictate which remedial approaches and technologies will be applicable, and which will not. As such, the selection of remedial objective will have a profound impact on the cost of remediation. The more stringent and aggressive the objective, the higher the likely cost. Thus, objectives set without at least some reference to the costs and benefits of remediation may be unrealistically aggressive, and may not reflect a wider economic optimum.

Conversely, if the wider benefits of remedial actions to remediate and protect groundwater are not considered at an early stage, and only private benefits are included, the remedial objective may not be ambitious enough, and society may unknowingly incur substantial losses in well-being. The cost-benefit framework may thus be seen as a tool for negotiation and consensus-building between the various stakeholders. This is illustrated in Figure 7.1.

Framework elements

The following approaches and techniques are considered to have value, and should be considered, when developing the remedial objective setting part of the framework:

- *Setting a remedial objective will clearly involve MCA.* Several considerations of a non-economic nature will naturally be important parts of the decision making process, including public and private policy, regulations, and stakeholder views. Despite the fact that many of these factors may be expressed in economic terms, it is clear that this will not be practical, nor is it likely to be accepted by many of the involved parties. As such, it may be preferable that the remedial objective is determined by first setting a minimum acceptable range of conceptual objectives, based on the rule of law, environmental regulations, and the results of risk analysis and stakeholder consultation. At this stage, a benefits analysis could be used to set a minimum and maximum range on the benefits of remediation, considering a range of conceptual remedial approaches. This would provide a range of acceptable objectives, from which a final objective can be selected based on the input of all stakeholders, results of a preliminary economic analysis and negotiations between the problem holder and the regulators;
- *Priority analysis.* The Agency has already developed a list of priority for groundwater risk (Environment Agency, 1999), which should be incorporated into the decision making framework at the remedial objective setting stage. The priorities for protection are, in descending order: 1) groundwater currently being used for potable water supply (groundwater protection zones), 2) surface water; 3) unexploited major aquifers, 4) unexploited minor aquifers, and 5) sites located on non-aquifers. These priorities are ideal for inclusion in a screening stage, or for qualitative analysis (MCA);
- *Benefits analysis.* At the remedial objective setting stage, a benefits analysis could be used to set a minimum threshold value for remediation. This would reflect the value of damages which could be expected if no remediation takes place. Based on the severity and complexity of the problem, a partial or full benefits assessment could be used. This value, or threshold value ("groundwater remediation will be worth at least this much ...") could be used to guide the selection of objectives, and to provide a cost-constraint for remedial approach and technology selection (discussed below). In its fully-developed form, such an approach would be similar to the framework developed by Raucher (1983) and discussed in the literature review.
- *Preliminary cost-benefit sensitivity analysis*: For more complex and serious problems, it may be useful to undertake a preliminary CBA, involving a short-list of remedial approaches which are thought to capable of achieving an assumed, reasonable objective. The net benefit of remediation (NB_{rem}) could be estimated by the simple equation: $NB_{rem} = B_{pvt} + B_{soc} - DB_{rem} - C_r$, where B_{pvt} is the private benefit of remediation, B_{soc} is the social (external) benefit of remediation, DB_{rem} are the dis-benefits of remediation, and C_r is the cost of remediation, all subject to a given discount rate over a selected planning horizon. Where complete valuation of some terms is not possible, partial or threshold values could

be used. Comparison of a range of possible approaches, using broad notional costs, could be used in support of selecting a remedial objective.

- *Cost-degradation functions.* Several workers have described the overall relationship between expenditure on remediation and the level of remediation to be achieved. There appears to be a point of diminishing marginal returns, where further expenditure on remediation yields ever-decreasing levels of clean-up (Hardisty, et al, 1998). Setting of remedial objectives could be partly based on such functions, which are presently being used in some jurisdictions, such as the San Fransisco Bay Regional Water Quality Control Board.
- *Groundwater Remediation Cost-Feasibility Function.*. In determining remedial objectives, the technological limitations of remediation must be considered. Clearly, setting a remedial goal which is unattainable is of little value, and may result in over-expenditure. Figure 7.2 shows a conceptual remediation cost-feasibility function, (which could also be presented as an index). Essentially, it alerts the user to the fact that with increasing geologic complexity, increased depth, and the presence of sub-surface sources, that remedial costs will tend to increase. Thus, for problems involving these conditions, it may be worthwhile to consider more fully the wider range of remedial benefits when choosing a remedial objective.
- *Constraints analysis.* As discussed above, key constraints which are relevant to the selection of the remedial objectives should be considered at an early stage in the analysis, to prevent selection of an objective which is unattainable.

7.3 Selection Of Best Remedial Approach And Technologies

Overview

As discussed throughout this document, there is a clear distinction between the remedial objective, and the methods used to achieve that objective. Once a remedial objective is defined, ideally with some reference to the wider economic realities of the situation, then options for achieving that goal in the most cost-effective manner can be explored, costed, and compared. Sometimes, as discussed above, it may be advantageous to include a preliminary economic sensitivity analysis, using a range of conceptual remedial solutions, to help in goal selection.

Different remedial approaches and technologies typically perform different functions, produce different by-products and wastes, have different operation and maintenance requirements, require different amounts of time to achieve their objectives, have different life-expectancies, and have different capital and O&M costs. In addition, the risk of not achieving the set objective will vary - established remedial technologies are likely to present lower risks of failure, while more innovative and experimental methods involve higher risk. As such, selecting the best-practicable solution can be a difficult task. Comparing solutions by considering their costs and benefits is a practical and powerful way of rationalising all of these factors into a common unit of measurement.

In many ways, this part of the framework follows the spirit of the BATNEEC (best available technique not entailing excessive cost) concept. Essentially, BATNEEC promoted a cost-effectiveness approach, and sought to in some way balance the costs of remediation with achievable objectives (implicit in the "best-available" part). However, the BATNEEC approach is overly vague, and highly subjective. It explicitly limits the range of available options to be considered, and in no way considers the wider environmental costs and benefits of remediation.

Framework elements

The following steps and procedures should be considered when developing a framework for selecting the best remedial solution for a groundwater contamination problem:

- *Again, the parallel contaminated land framework is considered to be broadly applicable.* The tiered decision making approach is well-suited to a variety of problems. In many cases, the appropriate solution can be selected without resorting to semi-quantitative or quantitative analysis, through use of a screening step and/or MCA. For more involved situations, qualitative analysis (CEA) can be used. In some situations, as discussed above, CBA could also be used at this stage to compare solutions which actually achieve slightly different results, rather than a pre-set objective.
- *Constraints analysis.* Constraints can play a key role in the selection of the most cost-effective solution to a given problem. Prior to developing a short-list of remedial options that will achieve the objective(s), all relevant constraints should be identified. A key constraint to remediation is often time: there may be real urgency in implementing remediation in order to protect vital water supplies or ecosystems. In that case, for example an initial objective of plume containment may be set, and a constraint applied that containment must be achieved within a set (short) period of time. Accordingly, options which require long periods to achieve containment, or which require considerable periods of time for design and installation, will not be considered, even if their overall cost is lowest. Other constraints may include physical access restrictions (which might prevent certain solutions from being adopted), and the presence nearby of sensitive features, such as residences, playgrounds, schools, or valuable ecosystems, which would curtail or prevent the use of certain techniques (for reasons of noise, vibration, traffic, nuisance, odour, or other factors). Identifying the constraints at the beginning of the process allows solutions to be eliminated from further consideration, or modified so that they are feasible and realistic. An accurate comparison can then be made. Constraints analysis is suitable for inclusion in qualitative decision making steps.
- *Screening analysis.* A simple first-tier screening analysis, of the type used in the contaminated land guidance, might include the following questions: 1) does the solution (approach / technologies) achieve the remedial objective(s)? (Y/N/partially/maybe); 2) does the solution violate any constraints? (Y/N/M); 3) what is the risk of the solution not reaching the objective(s)? and 4) are data available to conduct a benefits assessment? (Y/N/partially).
- *Cost-time analysis.* Cost and time are perhaps the two most important factors when deciding between remedial solutions which will achieve the same objective. Life-cycle cost functions can be developed for each remedial option being considered. All of the various components of each solution can be costed, and the costs assigned to various stages in the remedial programme. Thus, the potentially significant differences between various solutions can be rationalised into a single function, assuming that they all will achieve the set objective. Comparing these cost-time functions allows solutions to be compared rationally, and the differences between them assessed. The advantages of this method are: 1) it ensures that alternatives which are designed to achieve the same objective

are compared. As discussed in the literature review section, in many cases, solutions are inappropriately compared; 2) uncertainty envelopes on cost and time can be included in the analysis, reflecting the different degrees of certainty; 3) the wider costs (dis-benefits) of remediation can and should be included in the analysis; 4) the temporal nature of many groundwater remediation solutions can be explicitly accommodated in the analysis, allowing for staged capital investment, intermittent operation, O&M and capital replacement schedules to be included; and 5) cost and time constraints can be fitted to reveal a range of feasible acceptable solutions.

- *The framework may include the capacity to provide analysis at the remedial approach level, or the remedial technology selection level.* This explicitly recognises that many technologies might be involved in executing a given remedial approach (for example, plume containment (objective) might be achieved by hydraulic containment using pump-and-treat (approach), which in turn could involve different numbers of wells of different design, equipped with different types of pumping and control systems, using one or more of a number different water treatment options, and a number of available options for final water disposal technology. A cost-effectiveness analysis for the use of different technologies which fulfils one part of the overall approach can also be very valuable. However, this level of detail is probably of most benefit to the problem holder, and less valuable to regulators and other stakeholders, who are more interested in the external costs and benefits. Regulators would probably be satisfied with an analysis to the remedial approach level, allowing the problem holder relatively free reign in selecting the component technologies which make up the approach.

7.4 Summary

Clearly, there is considerable connection and overlap between the two main elements of this study: setting the remedial objective, and determining the best way in which to achieve the objective. As we have discussed, each can be used in the development and selection of the other, depending on the circumstances. In many situation, it will be easiest and most useful to define the remedial objective first, based on current regulations, policy, and an analysis of the benefits of remediation. Then the most cost-effective way of achieving that objective can be determined. In some situations, the costs and benefits of a number of remedial approaches can be used to help identify a feasible and economic objective. The constraints of the problem will be relevant to both steps. A conceptual example of this type of integrated and flexible framework model is presented in Figure 7.3.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

1. Relatively little research has been conducted into the subject of applying cost-benefit techniques to problems of groundwater remediation and protection. This supports earlier findings by Martin et al (1997) that the use of economic analysis in support of contaminated land decision making (including groundwater) in the UK was in its infancy.

2. The available literature has been produced by economists or technical (scientific and engineering) disciplines, and shares little common ground. Not unexpectedly the economic literature deals mainly with valuation of groundwater and the external economic benefits of groundwater protection. Some work deals directly with groundwater remediation. The technical-scientific literature focuses on the application of specific techniques and technologies to groundwater problems, and deals almost entirely with remedial costs, cost-comparisons, and cost-effectiveness. The wider benefits of remediation are rarely discussed. Much of this work is of primary interest to problem holders, but even so, very little is available which discusses the private benefits of remediation.

3. Groundwater has significant economic value in the UK, and its contamination will result in direct impacts on society's well-being.

4. The contaminated land literature is only partially applicable to the groundwater problem. Fundamental differences exist between the two situations, on many levels.

5. The risks associated with groundwater contamination can be classified into three categories: 1) risks of damage to groundwater resources themselves (aquifers), and thus to the users of that groundwater (humans, crops, animals); 2) risks of impact to surface water resources, as a result of groundwater's contribution to the resource (via baseflow discharge), and thus to the users of the surface water (humans, crops, animals, ecosystems); and 3) risks of impact to receptors as a result of contaminant migration via groundwater (as a risk pathway), including ecosystems, property, natural amenity features, and possibly humans and animals).

6. The benefits of remediation or protection can be expressed as the total value of damages that would occur if the contamination were not remediated, or protection measures were not implemented. This should include use and non-use values of groundwater. Implicit in any such analysis is that situations will arise where it is economically preferable to do nothing, and a policy decision would then need to be taken to finalise a course of action.

7. The literature reviewed is consistent in its view that the wider benefits of groundwater protection and remediation can be estimated, at least partly. However, it is clear that monetisation of the benefits is fraught with uncertainty, and requires significant effort and expense in its own right. All of the research reviewed included statements highlighting the need for more research, particularly into non-use benefit valuation (which many felt

could be quite significant), valuation techniques themselves (particularly CVM), and the need for more case studies and real data.

8. The value of avoiding a groundwater contamination incident (protection) will be at least as great as the expected cost of damage incurred should it occur. In very many cases, prevention of groundwater contamination will be much more cost-beneficial than remediation.

9. Economic analysis of groundwater contamination issues is inherently site-specific.

10. Groundwater contamination issues must be seen in the context of time and space, and are inherently dynamic in nature.

11. In many situations, the quantity of available groundwater is just as important as its quality. Groundwater contamination may result in decreased availability of water. Measures or actions designed to protect or remediate groundwater quality may also affect the quantity of groundwater available for use or as contribution to the hydrologic cycle.

12. The *scale* of a groundwater problem is not necessarily fixed. A spill which is initially concentrated in a small area, may over time affect a considerably larger area, as groundwater carries the contaminants along, and brings them into contact with other media and receptors. The scale of a contamination problem may have significant impact on how it is valued by society.

13. In the worst case, groundwater contamination may be irreversible, for all practical purposes. In most such cases, the remedial objective is to isolate the damaged area, contain the contaminants, and prevent them from affecting a greater volume of the aquifer. These may be termed conditions of "perpetual maintenance", where for the foreseeable future, an isolation or containment system will have to operated, maintained and monitored. What is implicit in the term "irreversible" is an upper limit on society's WTP for a solution.

14. The private benefits of remediation include:

- *costs avoided if remediation takes place*: These include avoiding the risk of litigation (and the considerable costs which may be involved), fines avoided, averting public relations damage which could result in loss of sales revenue, and preventing control orders or shut-downs which may result in lost production and revenue. The elimination of "stigma" value may also be relevant.
- *direct benefits*: These might include increased property value, or direct cost savings through access to clean groundwater. In situations where the polluter has been identified as a private entity, the costs of implementing remediation will be borne wholly or substantially by that entity.

15. In implementing a remedial solution for contaminated groundwater, there may be situations where a secondary cost has been created, which would not normally be borne by the problem holder. These *external costs of remediation* are not usually considered in cost-benefit analysis for groundwater remediation projects, but should be.

16. There are a number of obstacles to full valuation of the benefits of groundwater remediation and protection. These obstacles include: 1) the difficulty and expense in monetising site-specific benefits; 2) the inherent limitations of many valuation methods, particularly CVM; 3) the fact that some of the most difficult-to-measure (non-use) values may be among the most significant, and 4) the lack of basic research into the value of groundwater.

17. The choice of discount rate can significantly affect the outcome of cost-benefit analysis for groundwater remediation or protection. A concern is that discounting effectively devalues the future, by putting an inordinate emphasis on present value. This is especially the case for natural resources which have long gestation periods. Deep aquifers which contain relatively old water, and are recharged slowly, are an example. A high discount rate could result in an economic analysis which promotes unsustainable abstraction rates, based on the relatively high value of water in the short term. In the same way, a high discount rate may mean that the benefits of protecting groundwater for the future are too small to warrant expenditure in the near term, resulting in a deferral of action.

8.2 Recommendations

1. Any framework for incorporating cost-benefit analysis into remedial decision making must, in our opinion, include the ability to account for:

- incorporation of the results of risk assessment, on which current remedial guidance is based;
- the existence of multiple SPR linkages on a given site;
- the co-mingling of contaminant plumes, possibly involving several sources, and several responsible parties;
- the three fundamental modes by which groundwater-related risks may be generated;
- situations where remedial objectives are set first, and then approach and technology options evaluated to determine which reaches the objective most economically, or situations in which the costs and benefits of a range of remedial approach options are assessed to determine what the remedial objective should be;
- the inherent uncertainties associated with predicting groundwater contaminant behaviour and the associated risk;
- the significant temporal and scale issues associated with groundwater contamination and remediation.

2. The contaminated land guidance framework (Environment Agency, 1999b) is considered to be a suitable overall model for consideration of groundwater remediation economics. Retaining the basic approach as a common link between the two frameworks will allow for ready integration of the two issues on sites where both are important. At many contaminated land sites, groundwater may not be the driving force behind remedial decision making. In these situations, the current guidance framework may be sufficient to deal with both problems. It is envisioned that the groundwater remediation framework would be particularly applicable in situations where: 1) contaminated land is not the direct source of the groundwater contamination problem; 2) multiple point-sources have contributed to an overall groundwater pollution problem, involving several co-mingled plumes; and 3) site contamination has resulted in significant off-site migration of

contaminants in groundwater. 4) Groundwater resources (particularly source protection zones or major aquifers) are potentially at risk.

3. Some aspects of the contaminated land framework will require substantial modification to make them suitable for the issues which are relevant to groundwater. In particular, the following should be considered as part of the groundwater framework: 1) a procedure for developing the remedial objectives for groundwater clean-up (the level to which groundwater should be remediated); 2) the ability to cope with multiple objectives for a single groundwater contamination problem; 3) a facility for considering explicitly the mobility of groundwater contamination, and the fact that risks of exposure to receptors may increase over time; 4) the capacity to include the wider economic benefits of groundwater in the analysis; 5) the ability to distinguish between remedial objectives, remedial approaches, and remedial technologies; 6) some level of probabilistic analysis of the results of the economic analysis; 7) provision for coping with the constraints to remediation which are unique to groundwater; 8) the ability to consider long planning horizons; and 9) the flexibility to incorporate changing remedial objectives within a long planning horizon.

4. In development of the framework step(s) for setting remedial objectives, consideration should be given to including the following: 1) the use of MCA or similar qualitative and semi-quantitative methods; 2) the EA priorities for protection; 3) benefits analysis, including all use and non-use benefits. If all benefits cannot be monetised, they should at least be considered in qualitative manner, or through partial threshold benefit estimates; 4) cost to clean-up-level relationships; 5) groundwater remediation cost-feasibility relationships (perhaps in the form of an index); 6) constraints analysis, and 7) a preliminary cost-benefit sensitivity analysis, involving comparison of a range of possible remedial approaches, using broad notional costs, in support of selecting a remedial objective.

5. The following steps and procedures should be considered when developing a framework for selecting the best remedial solution (approach/and/or technology) for a groundwater contamination problem:

- the parallel contaminated land framework is considered to be broadly applicable. The tiered decision making approach is well suited to a variety of problems. In many cases, the appropriate solution can be selected without resorting to semi-quantitative or quantitative analysis, through use of a screening step and/or MCA. For more involved situations, qualitative analysis (CEA) can be used. In some situations, as discussed above, CBA could also be used at this stage to compare solutions which actually achieve slightly different results, rather than a pre-set objective.
- constraints analysis: Constraints can play a key role in the selection of the most cost-effective solution to a given problem. Prior to developing a short-list of remedial options which will achieve the objective(s), all relevant constraints should be identified.
- cost-time analysis. Life-cycle functions can be developed for each remedial option being considered assuming that they all will achieve the same objective. All of the various components of each solution can be costed, and the costs assigned to various stages in the remedial programme. Comparing these cost-time functions allows them to compared rationally, and the differences between them assessed. Cost and time constraints can then be applied to the analysis to find a range of acceptable solutions.

- The framework may include the capacity to provide analysis at the remedial approach level, or the remedial technology selection level. A cost-effectiveness analysis for the use of different technologies which fulfil one part of the overall approach can also be very valuable. However, this level of detail is probably of most benefit to the problem holder, and less valuable to other stakeholders, who are more interested in the external costs and benefits. Regulators would probably be satisfied with an analysis to the remedial approach level, allowing the problem holder relatively free reign in selecting the component technologies which make up the approach.

6. It may be useful to include a decision point within the contaminated land framework guidance (Environment Agency, 1999b) which directs the user to the parallel, and compatibly structured, groundwater economic guidance, under certain situations. Similarly, the groundwater guidance could refer the user to the contaminated land framework if contaminated land is the source of the groundwater problem.

7. Data worth analysis should be considered as part of the guidance. This could apply for both the technical and economic portions of the analysis.

8. The guidance should include the ability to study both groundwater remediation and groundwater protection measures.

9. It is clear that more research into the subject of the economics of groundwater protection and remediation is required. In particular, research into site-specific case studies involving contaminated sites, valuation of the wider benefits of remediation; and the selection of appropriate discount rates for long-term groundwater projects, are particularly needed (particularly in the UK context). CV studies assessing WTP in situations where actual contamination is affecting people should be considered. Joint integrated technical and economic research programmes should be developed and promoted.

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Figures

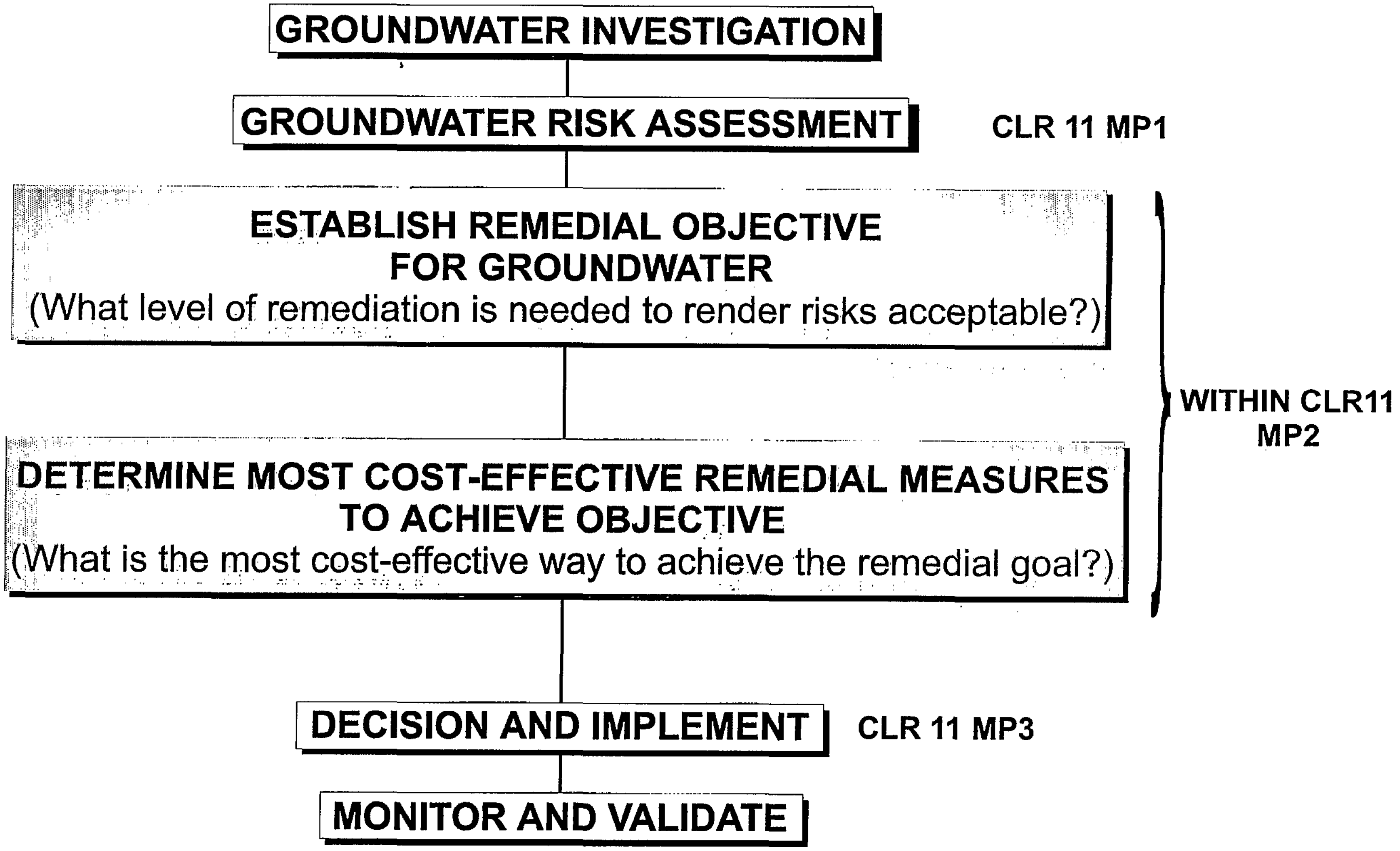
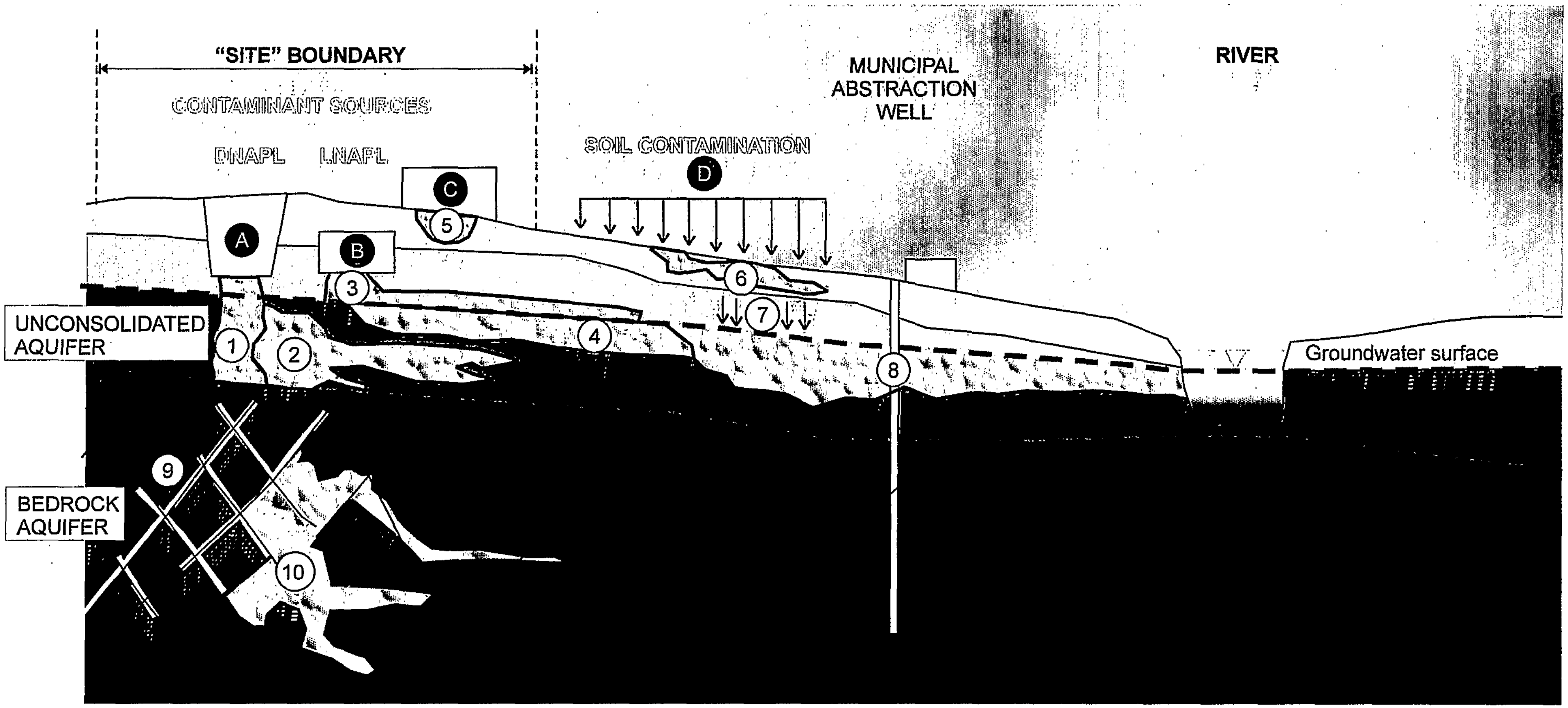


FIGURE 1.1
COST BENEFIT ANALYSIS FOR REMEDIATION OF CONTAMINATED LAND: PROJECT CONTEXT



SOURCES	SUB-SURFACE SOURCES	PLUMES
Ⓐ Buried wastes (landfill, orphan sites)	① Dense NAPL	⑨ Deep NAPL
Ⓑ Underground tanks	③ Light NAPL	② Dissolved phase organics
Ⓒ Above ground facilities	⑤ Soil contamination (point source)	④ Dissolved phase organics
Ⓓ Non-point source sources (agricultural application)	⑥ Non-point source soil contamination	⑦ Leached contaminants
		⑧ Dissolved phase (various) (co-mingled plumes)

FIGURE 4.1
SCHEMATIC OF TYPES OF GROUNDWATER CONTAMINATION

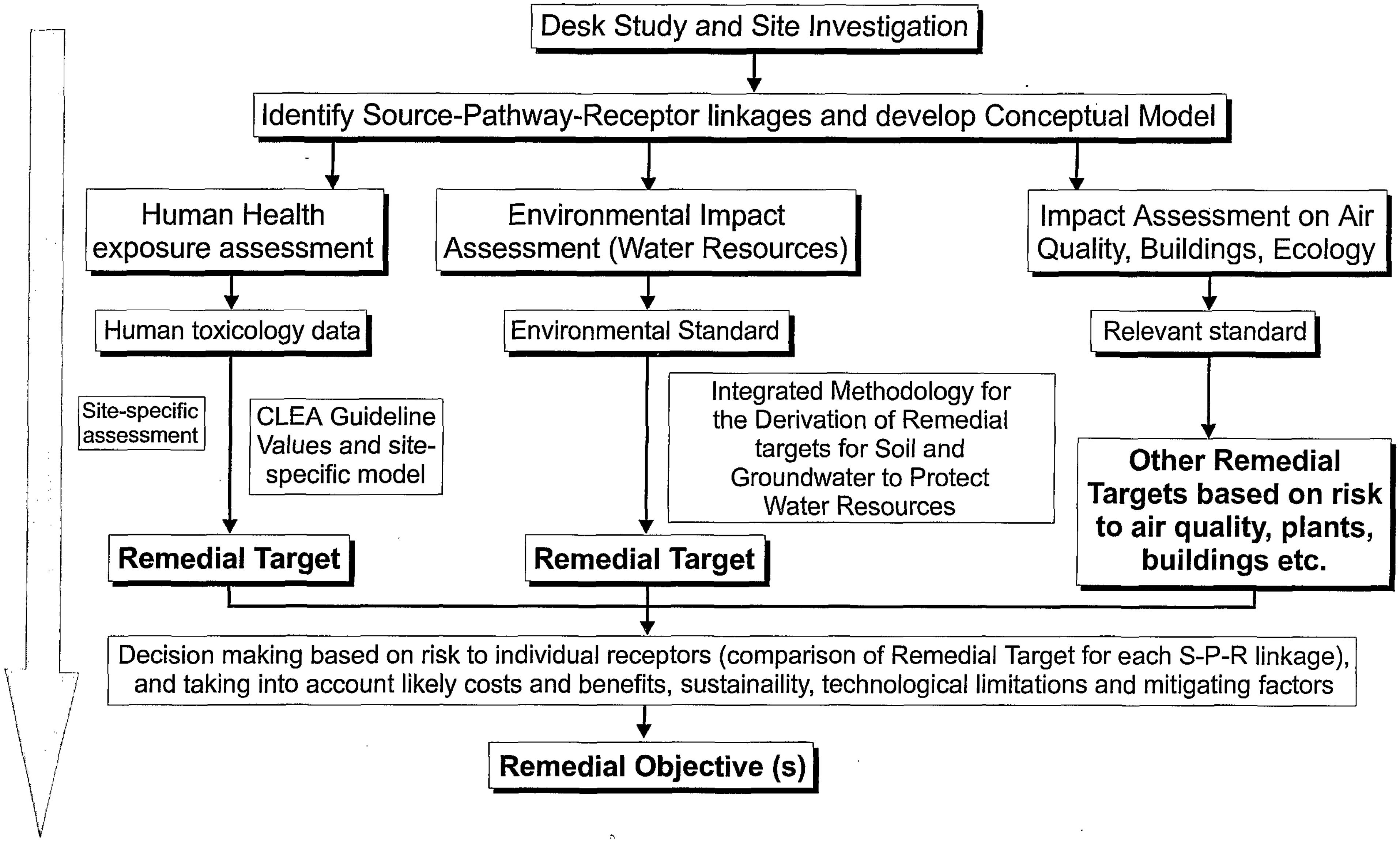
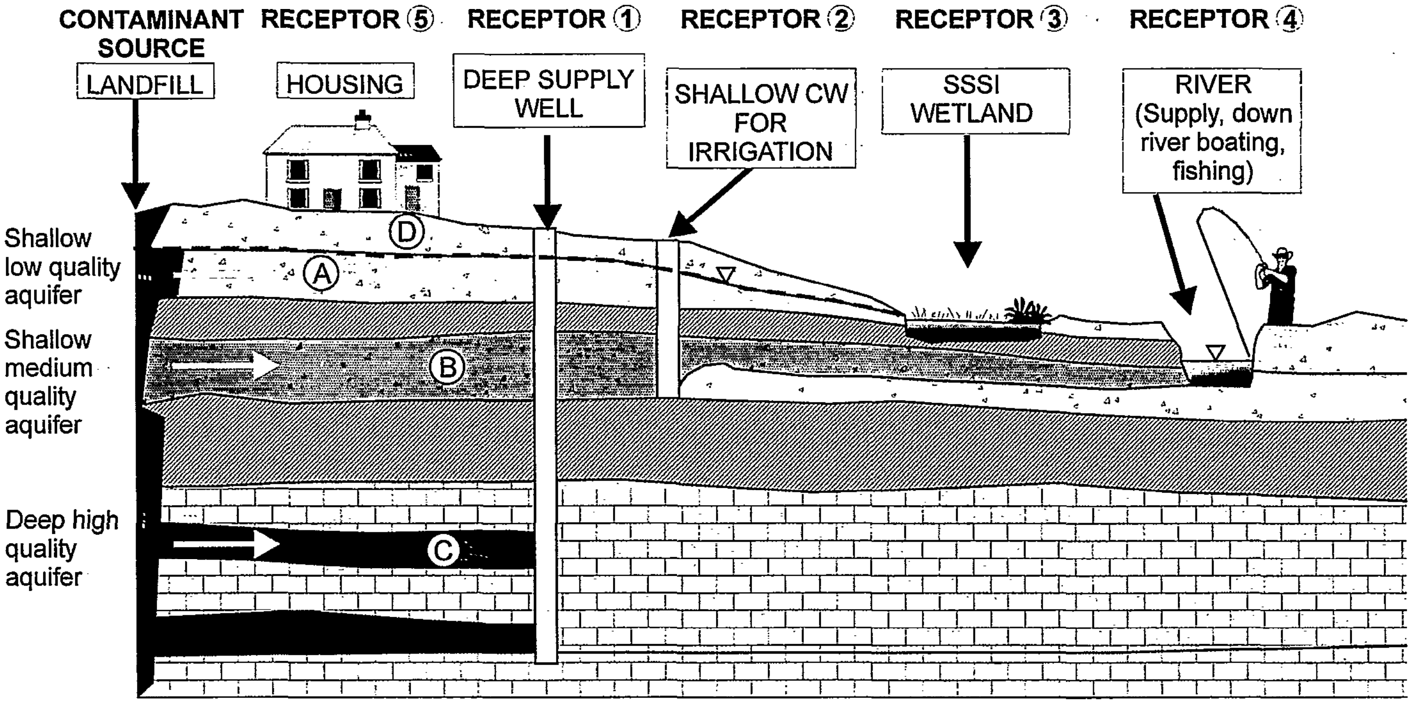


FIGURE 4.2
DERIVING SITE-SPECIFIC REMEDIAL OBJECTIVES
(From EA, 1998)



SOURCE	PATHWAY	RECEPTOR
LANDFILL	Ⓐ Shallow low quality aquifer.	③ SSSI Wetland → protected ecosystem
LANDFILL	Ⓑ Shallow medium quality aquifer.	Ⓑ Aquifer ② Irrigation wells → crops ↗ humans ↘ animals ↘ soil quality
LANDFILL	Ⓒ Deep high quality aquifer.	Ⓒ Aquifer ↗ humans (supply) ④ River → ecosystem ↘ amenity
LANDFILL	Ⓓ Soil overlying shallow groundwater plume.	① High quality aquifer ↗ humans → property values ↘ infrastructure

FIGURE 4.3
SCHEMATIC OF MULTIPLE RISK SPR LINKAGES ASSOCIATED WITH GROUNDWATER MIGRATION

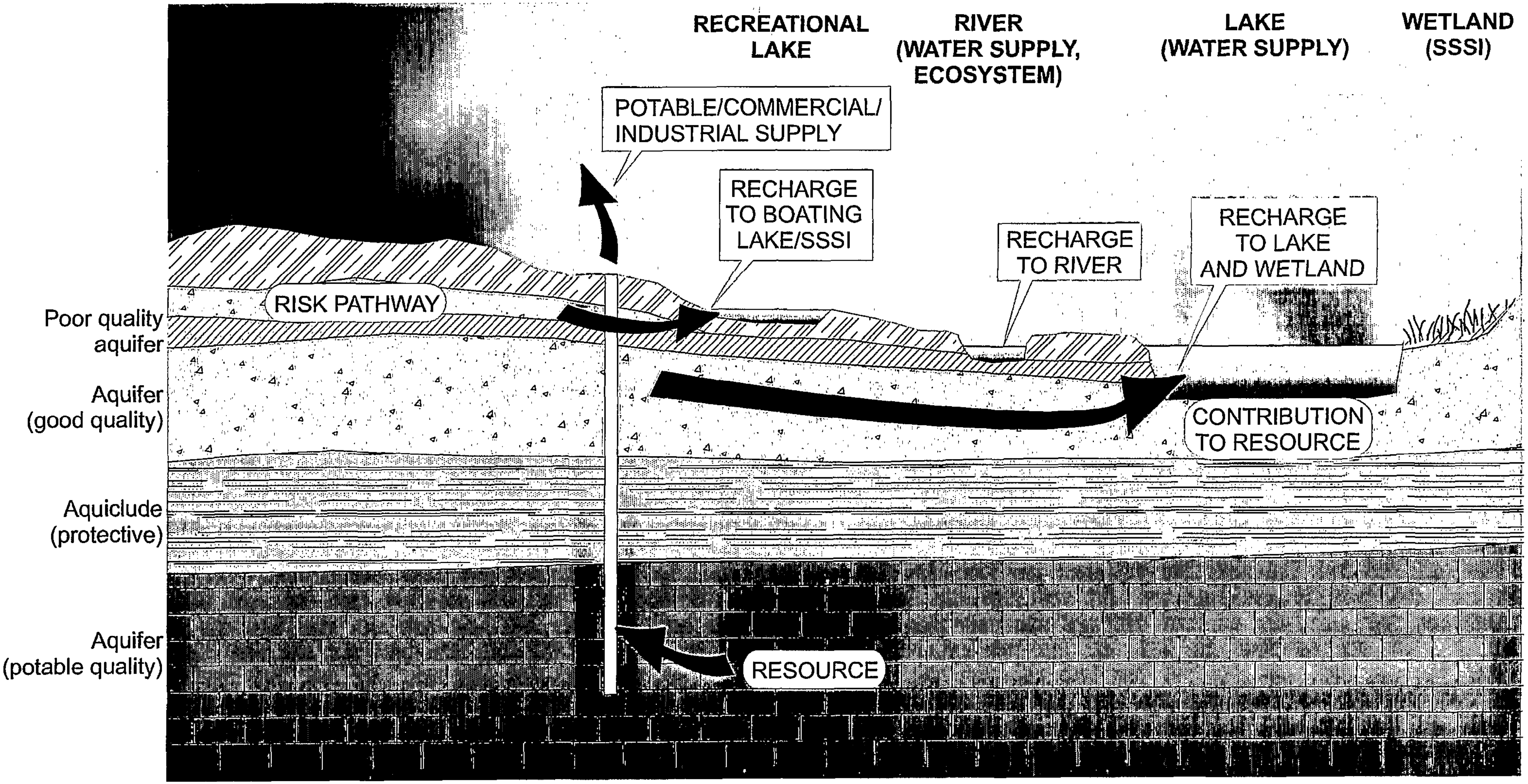


FIGURE 4.4
SCHEMATIC OF WAYS IN WHICH GROUNDWATER CONTRIBUTES TO ECONOMIC VALUE

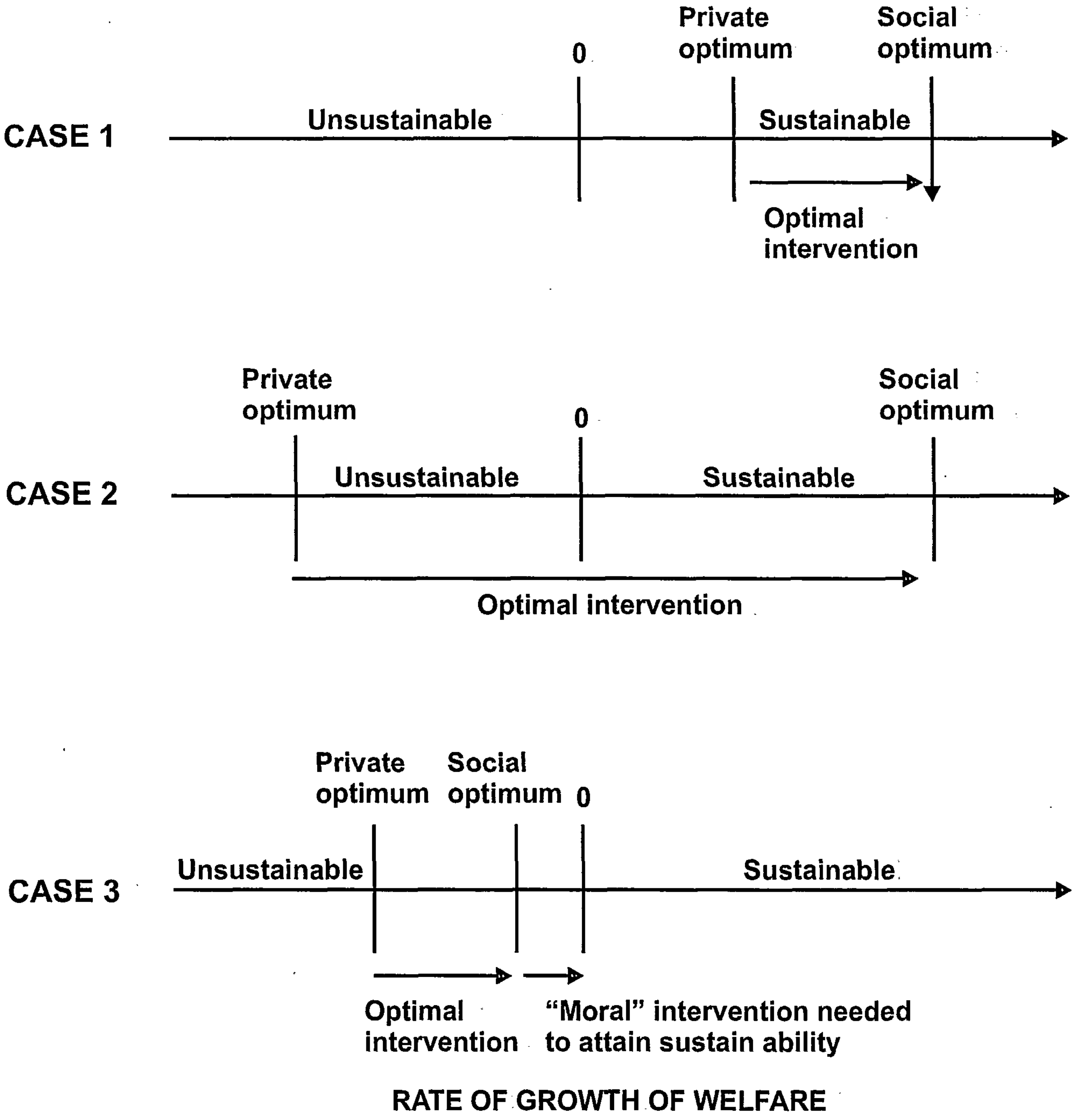


FIGURE 4.5
SUSTAINABILITY, OPTIMALITY, AND GOVERNMENT INTERVENTION (From Pearce and Warford, 1993)

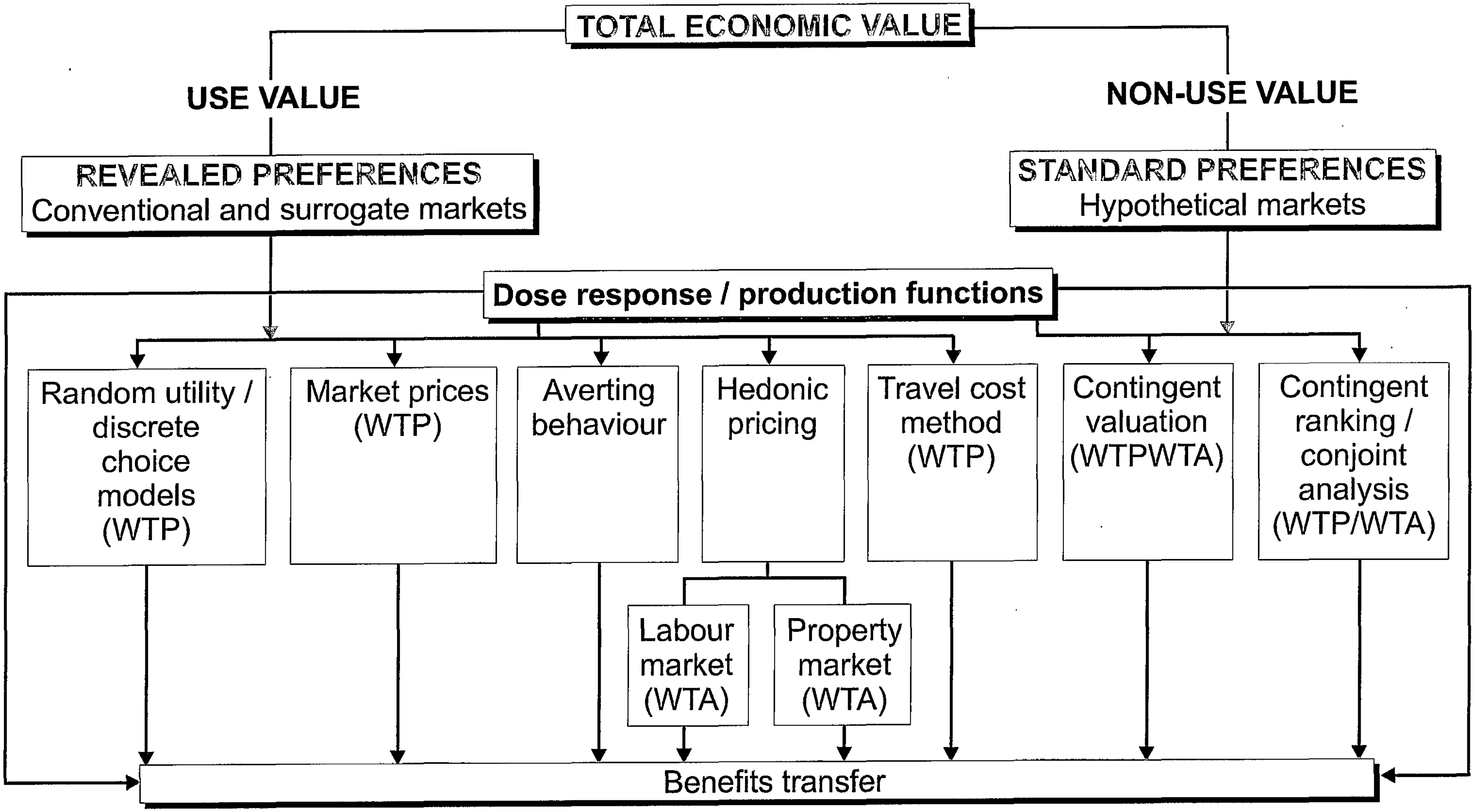
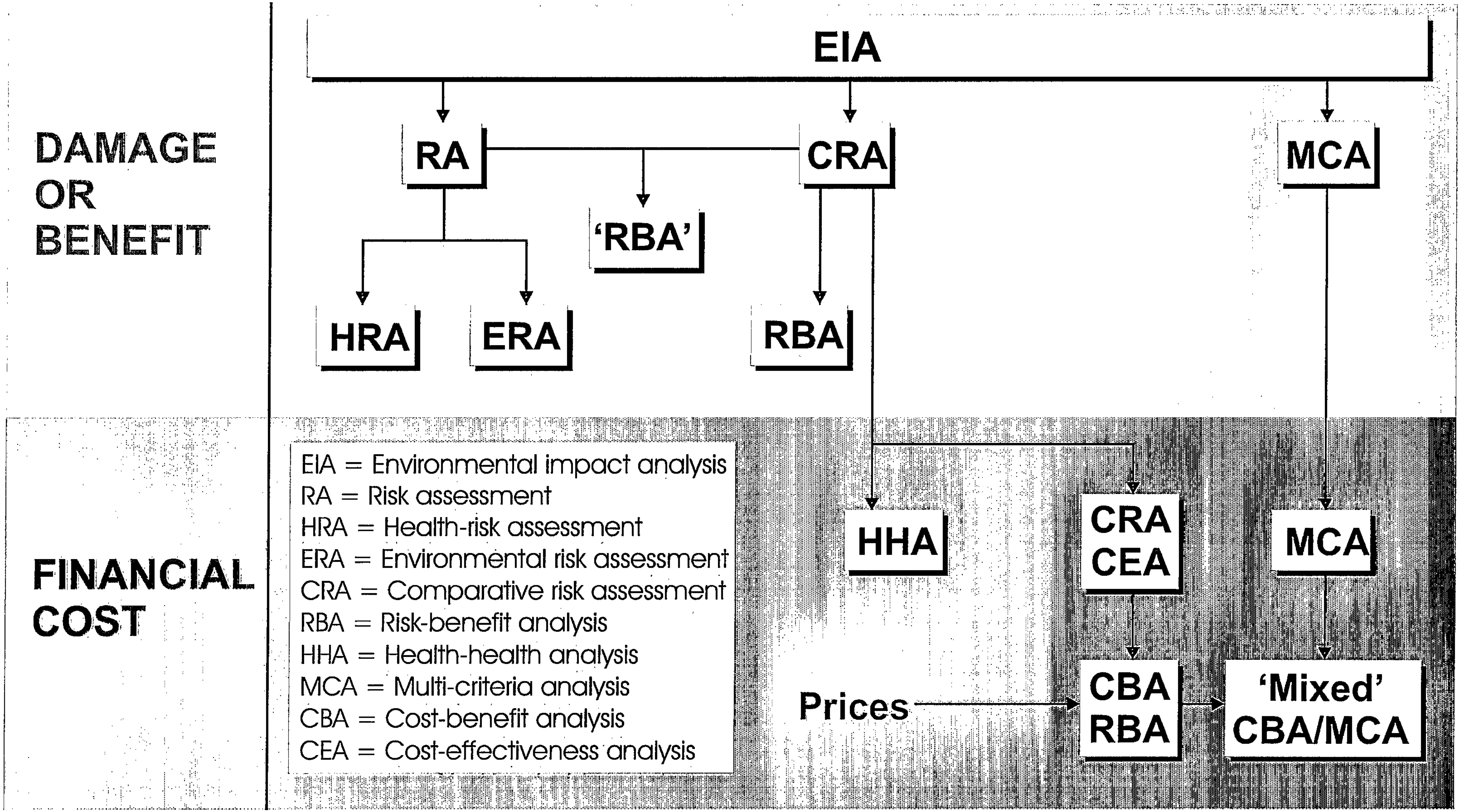


FIGURE 4.6
TECHNIQUES FOR MONETARY VALUATION AND HOW THEY ARE RELATED
(From EFTEC, 1998)



EIA = Environmental impact analysis
RA = Risk assessment
HRA = Health-risk assessment
ERA = Environmental risk assessment
CRA = Comparative risk assessment
RBA = Risk-benefit analysis
HHA = Health-health analysis
MCA = Multi-criteria analysis
CBA = Cost-benefit analysis
CEA = Cost-effectiveness analysis

FIGURE 4.7
LINKAGES BETWEEN ECONOMIC ASSESSMENT TECHNIQUES (From EFTEC, 1998)

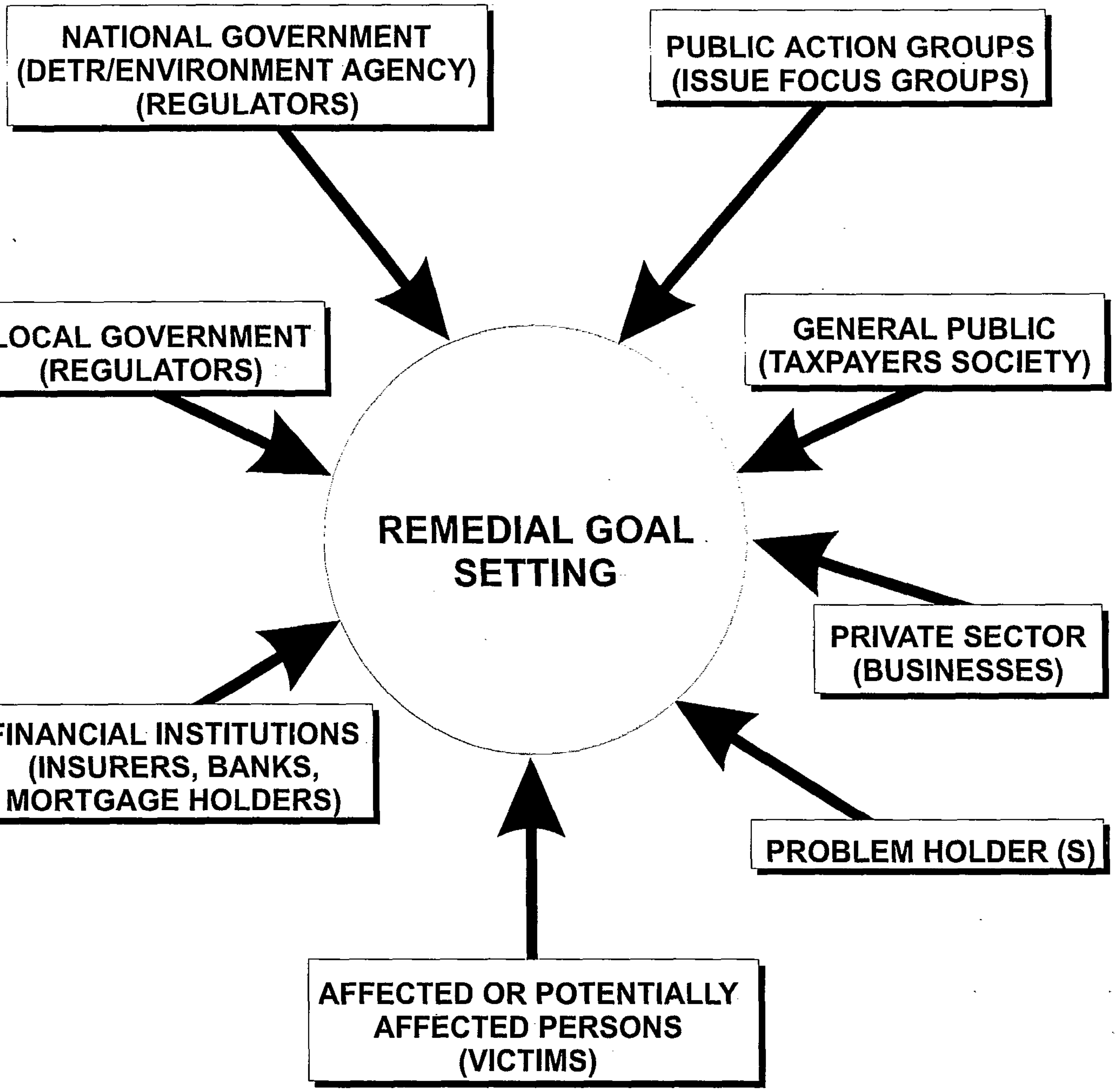


FIGURE 6.1
REMEDIAL GOAL SETTING DECISION:
POTENTIALLY INVOLVED STAKEHOLDERS

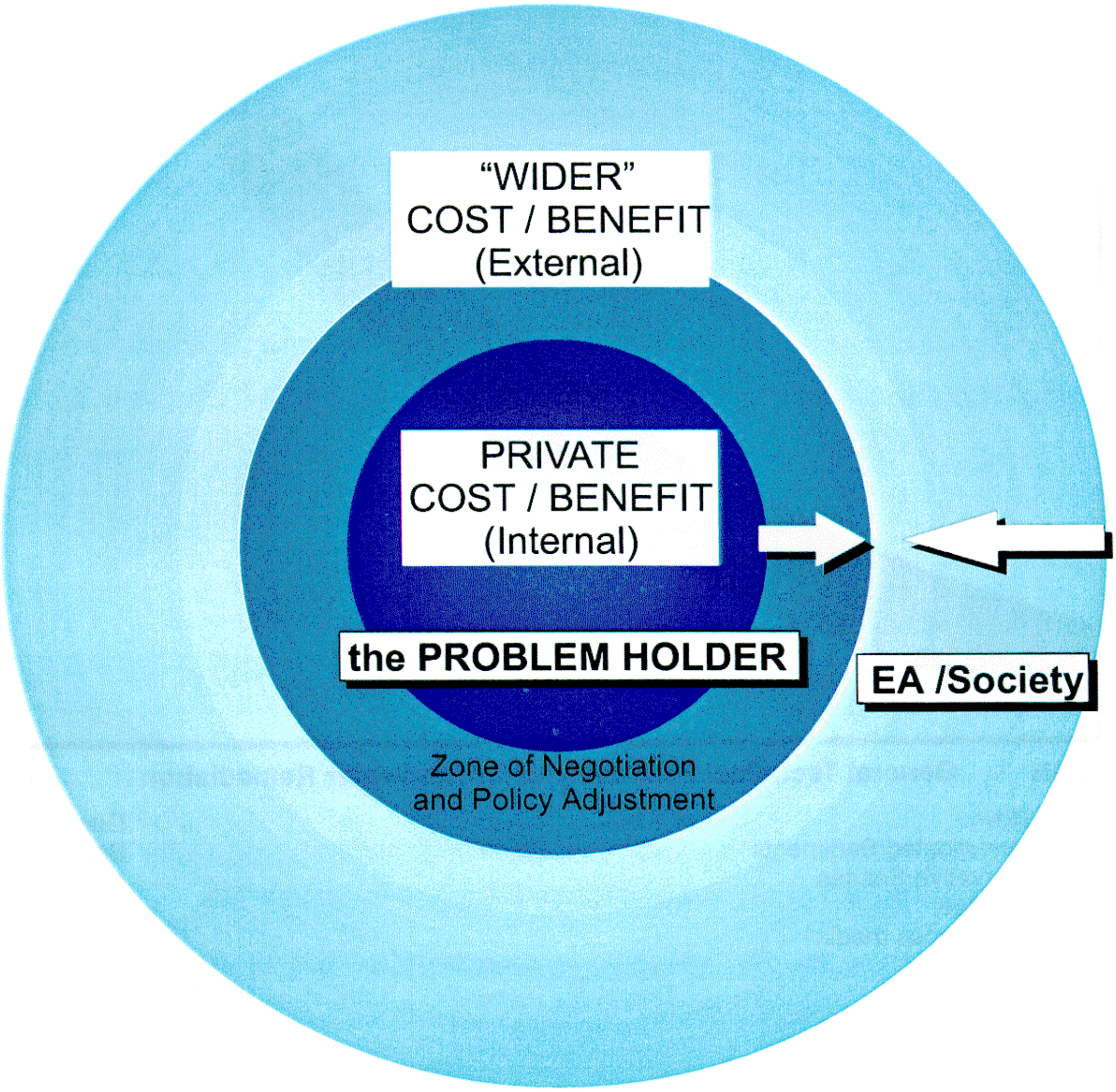


**FIGURE 7.1
USING THE COST-BENEFIT FRAMEWORK
AS A TOOL FOR NEGOTIATION**

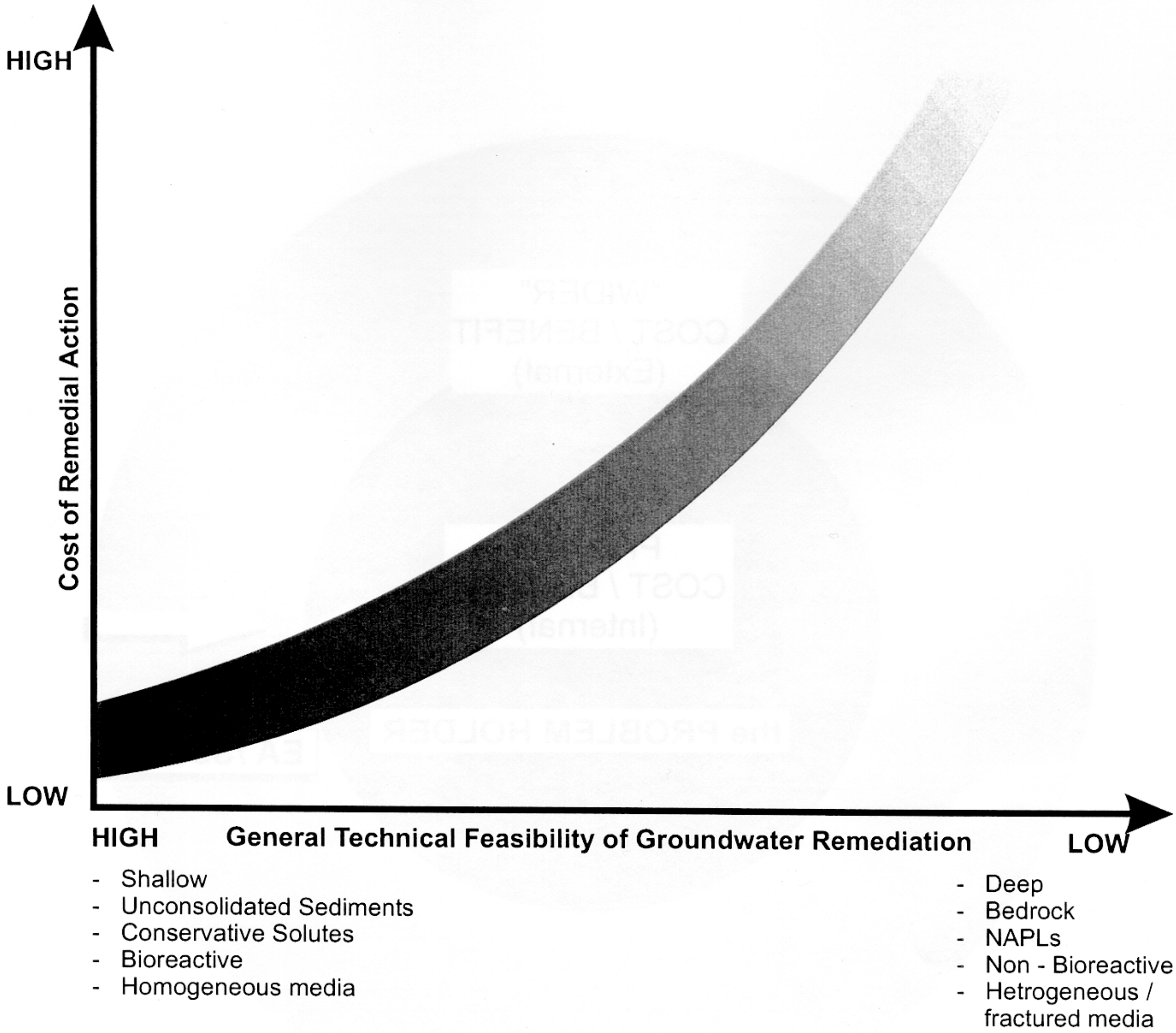


FIGURE 7.2
CONCEPTUAL COST - FEASIBILITY CURVE
FOR GROUNDWATER REMEDIATION

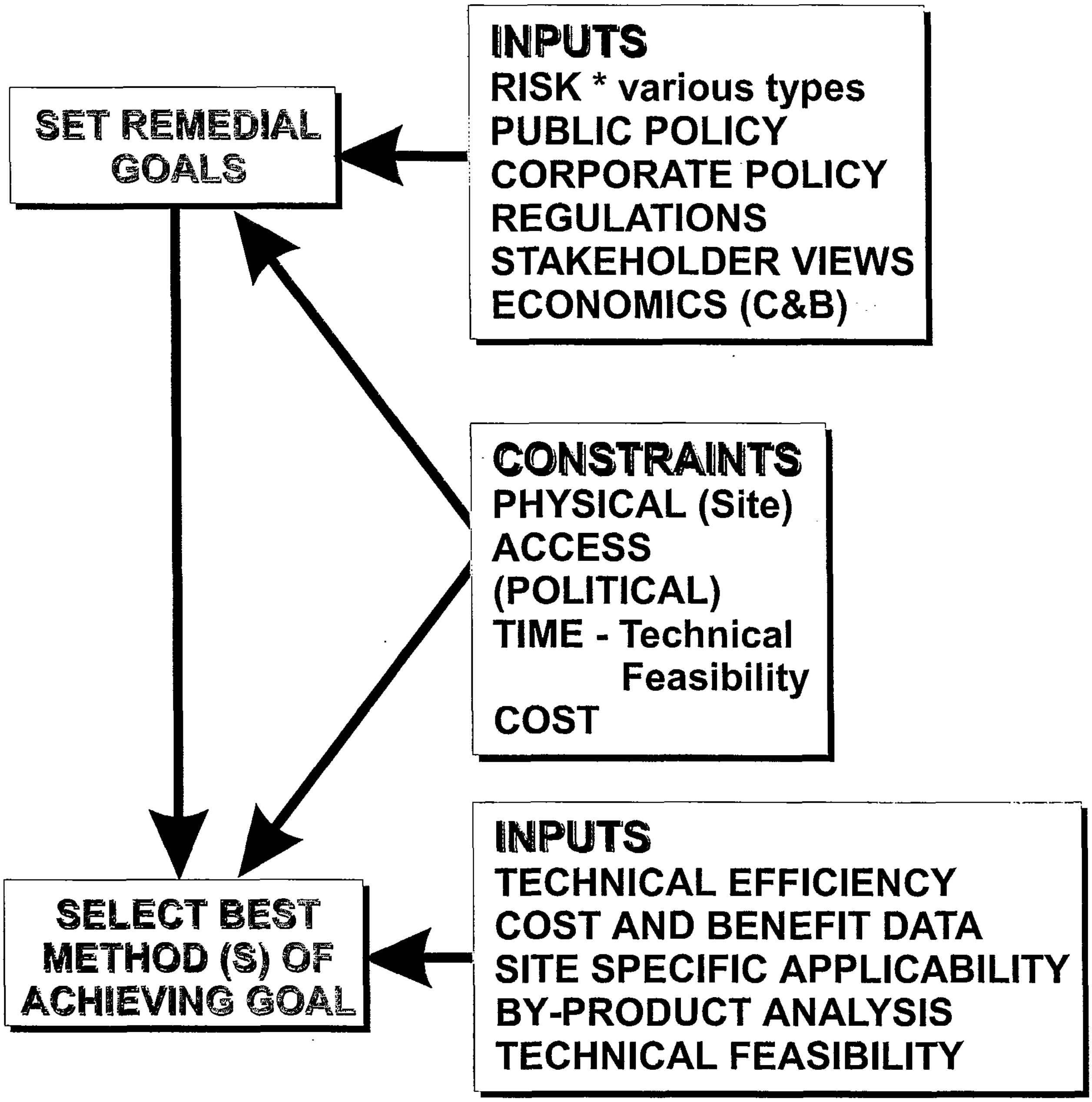


FIGURE 7.3
CONCEPTUAL SCHEMATIC OF INPUTS TO THE DIFFERENT STAGES OF REMEDIAL DECISION MAKING