National Water Quality Management Strategy

Guidelines for Groundwater Protection in Australia

September 1995

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Australian Water and Wastewater Association
PO Box 388
ARTARMON NSW 2064
Telephone (02) 9413 1288 Facsimile (02) 9413 1047

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For further information, contact:

The Secretary
Agriculture and Resource Management Council of Australia and New Zealand
Department of Primary Industries and Energy
GPO Box 858
CANBERRA ACT 2600

Tel: (06) 272 5216 Fax: (06) 272 4772

or:

The Secretary
Australian and New Zealand Environment and Conservation Council
GPO Box 787
CANBERRA ACT 2600
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SUMMARY

These guidelines are part of the National Water Quality Management Strategy. The objective of these guidelines is to provide a framework for protecting groundwater from contamination in Australia. This framework will enable each State, Territory and the Commonwealth to develop policies and strategies which are tailored to their specific legislative and resource management situations.

One million people in 600 communities around Australia enjoy great benefits from their groundwater resources. Groundwater is an important source of water for major cities, industries and rural towns. For many isolated communities and rural properties, their very existence relies on the availability of good groundwater. Many features on our landscape, such as wetlands and lakes, are directly linked to the groundwater beneath.

A benchmark report. The Status of Groundwater Contamination and Regulation in Australia, was published in 1990. The report showed that for most of the States and Territories there was adequate legislation available to protect groundwater, even if it was fragmented across several areas of government in some States and Territories. However, little protective action was actually taking place.

The protection framework outlined in these guidelines involves the identification of specific beneficial uses and values for every major aquifer, i.e. the classification of groundwater bodies. Depending upon specific circumstances, there are a number of protection strategies which can emerge to protect each aquifer, but all involve monitoring. A public planning process is required in order to examine possible options and select the best set of strategies. The protection strategies which emerge will mainly be pro-active in nature but some current problems will also require remedial action.

The major types of protection strategies are classified into three 'legislative' groups. First, there is a whole range of traditional groundwater management measures available, such as vulnerability maps, aquifer classification systems and wellhead protection plans. Secondly, there is a range of land-use planning measures which can help prevent contamination occurring at inappropriate locations. Finally, there is a variety of environmental protection measures emerging which tackle modern waste management problems in progressive ways. Nearly all protection strategies will rely on government intervention backed by community support.

Protection planning processes are at an early stage of evolution in Australia. These guidelines assist by providing a case example of the steps involved in developing a regional protection plan for groundwater. This case study aims to assist and guide managers and the community towards a successful outcome from their planning.

Finally, a national goal is set for all groundwater managers in Australia. The goal is for all States Territories and the Commonwealth to have a beneficial use classification in place for all significant aquifers by the end of the decade. Consequently, this goal will help ensure that the first step is talon towards adequately planning for the protection of Australia's groundwater resource.

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[* For technical reasons, Figures 1 and 2 have not been reproduced in this downloadable web version]

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The preparation of these guidelines was undertaken by the Water Resources Management Committee of ARMCANZ. Appreciation is extended to the numerous contributions to the various versions of these guidelines since the first draft appeared in 1958. Editing and writing was carried out by Jim Keary. Harry Ventriss wrote the original version of Chapter 5.

I INTRODUCTION

1.1 Background

Contamination of Australia's groundwater resources and the resultant undesirable effects on the environment and humans has been a growing concern among water managers in all States and Territories of Australia for some years. In the first comprehensive publication on groundwater in Australia published by the Australian Water Resources Council (AWRC) in 1975, the threat of contamination from 'waste chemicals…percolating from the surface…' was clearly recognised[1]. In 1979 a conference in Perth sponsored by AWRC documented numerous cases of groundwater contamination and showed the general level of concern about these matters in the water sector[2].

Work on these guidelines was initiated by the AWRC Water Resources Management Committee following a recommendation from the former AWRC Groundwater Technical Committee. This committee had earlier commissioned an inventory study of incidents of groundwater contamination in Australia. It was recognised that while that study gathered a substantial database and illustrated that the issue of groundwater contamination is of concern across Australia, the study needed to be supplemented by further work which assessed the significance of this contamination since groundwater and its environment vary widely across Australia. It was also evident that a number of significant incidents and types of contamination were not reported thus giving a distorted view of the distribution of contamination across Australia.

Since there were general concerns among Australian groundwater managers regarding contamination which needed to be addressed, the primary purpose of further work was to be directed towards development of groundwater protection guidelines. These guidelines could then be used to assist State, Territory and Commonwealth Governments in the formulation of policies to protect groundwater from pollution.

These national guidelines were developed to address this common need. They provide the common national framework under which each State, Territory and the Commonwealth can create appropriate management arrangements to protect this continent's groundwater resource from undesirable degradation.

These guidelines focus on a specific part of groundwater management, viz. the protection of the quality of groundwater from contamination, and also focus on land-based management of the groundwater resource. Whilst the scope of any guidelines is limited, it is important to recognise the boundaries of guidelines from the outset and realise that these guidelines need to be viewed as a small but important step towards better management of this nation's water resource.

1.2 Objectives of Guidelines

The objective of these guidelines is **to provide a national framework for the protection of groundwater from contamination**. This framework will enable each State, Territory and the Commonwealth to develop policies and strategies which are tailored to their specific needs. They are written primarily for managers and specialists working in this field. They also provide a valuable information source for many other interested individuals and groups.

The guidelines were written to provide this broad framework since there is great variation in actions being taken and in the legislation available in each State, Territory and the Commonwealth . The aim of these guidelines is to provide an overall vision for groundwater protection and strategies. Individual States, Territories and the Commonwealth would then fill in the strategic details which are pertinent to their institutional, legislative and physical situations.

Many States are currently preparing a second generation of strategies for groundwater protection in critical areas. These guidelines will provide a timely focus for coordinating this new set of strategies within an Australian context.

1.3 Scope of Guidelines

The starting point for these guidelines is the current set of actions which are occurring throughout Australia to protect groundwater. The background *report The Status of Groundwater Contamination and Regulation in Australia*[3] provides a description of this starting point.

The desired end point is a situation where general protection strategies cover all major Australian groundwater bodies and detailed protection strategies are in place for localities with high potential for groundwater pollution. These guidelines provide the framework in which government groundwater and environmental managers can develop strategies to achieve this desired end-point.

Chapter 2 makes use of local and overseas experience to describe the benefits of groundwater, the ways contamination can occur and identifies the need for groundwater protection. This chapter sets the scene for the non-specialist.

Chapter 3 initially outlines the difficulties associated with managing and protecting groundwater. Principles are then described which are the basis for the framework of these guidelines.

Many types of protection measures are used throughout the world. Chapter 4 classifies and describes the prominent measures and presents a planning framework which will allow relevant groundwater management and protection plans to be drawn up in each Australian State, Territory and the Commonwealth.

Groundwater protection plans and strategies can be developed in a multitude of ways. A practical approach to the development of a regional protection plan using conventional regulatory provisions is outlined, step by step, in Chapter 5. This chapter demonstrates to the practitioner how the principles and components of protection strategies can be brought together into a workable plan and draws upon the details of several practical approaches from the United States.

The appendices provide a ready reference for detailed technical information which is required in the development of protection strategies. The appendices and an accompanying document, *A Preliminary Guide to the Standard Operating Procedures for Groundwater Sampling*[4], provide technical guidance for the specialist who will be required to document various technical processes and' procedures for protection plans.

1.4 National Water Quality Management Strategy

The Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ). which incorporates the activities of the former AWRC, and the Australian and New Zealand Environment and Conservation Council (ANZECC) are developing a National Water Quality Management Strategy. The Strategy consists of a series of policy and guideline documents which will help water authorities, environment protection agencies, catchment managers and the community manage the quality of the nation's water resources in a sustainable way. The documents cover topics including:

- *Policies and Principles*
- *Implementation Guidelines*
- *Wetter Qualitv Guidelines for Fresh and Marine Waters*
- *Drinking Water Guidelines*
- *Guidelines for Sewerage Systems*
  -Acceptance of Trade Waste (Industrial Waste)
  -Effluent Management
  -Sludge (Bio-solids) Management
  -Use of Reclaimed Water
  -Sewerage System Overflows'
- *Rural Land Uses and Water Quality*
- *Guidelines for Urban Stormwater Systems*
- *Effluent Management Guidelines for Farm Dairies and Dairy Processing Plants*
- *Effluent Management Guidelines for Piggeries*
- *Effluent Management Guidelines for Wool Scouring*
- *Effluent Management Guidelines for Tanning arid Related Industries*
- *Effluent Management Guidelines for Wineries and Distilleries*
- *Monitoring and Reporting Water Quality*

These guidelines on groundwater protection were written to be generally consistent with other documents in the series. However, every document has its own particular points of emphasis or use of special terminology depending on the topic. There are also some areas of overlap between the documents, which is to be expected. The groundwater guidelines do not attempt to cover all topics in detail and they specifically refer to other guidelines and documents where this is appropriate.

1.5 Terminology

For those who are unfamiliar with groundwater terminology, a glossary is included which defines many terms. However, it is also important that some terms are clearly defined at the outset so as to avoid any misunderstanding by the variety of people from different disciplines who will read and use this document.

First, a distinction between the terms 'contamination' and 'pollution' is useful when discussing some particular facets of groundwater protection. The terms are often referred to in a colloquial manner, and their meanings can depend upon the audience. For this reason a brief explanation is required of the usage of these terms in these guidelines.

These guidelines refer mainly to groundwater contamination. **Contamination** is defined in these guidelines to mean a change in water quality that produces a noticeable or detectable change in its characteristics. Contamination occurs when substances are introduced into an aquifer, whereas pollution occurs when the contamination reaches a level that restricts the beneficial use of groundwater.

The term pollution may have various meanings and may be confined by definitions found in legislation. It has not been uncommon in Australia for several definitions to be found in legislation within one State which offer different refinements of meaning.

The term **pollution** is used in these guidelines to refer to a state of contamination for which the water quality has deteriorated to a point where the ability of the water to support or maintain the existing or potential identified beneficial uses is diminished.

The distinction between contamination and pollution is consistently applied throughout the guidelines except for the term 'polluter pays'. This term really should be referred to for the sake of consistency in these guidelines as 'contaminator pays'. However, the term 'polluter pays' is adopted because of its broad use in international literature.

Second, the term **beneficial use** is adopted throughout this text. The benefits of water use or non-use cover a range of exploitative benefits as well as an emerging set of environmental and conservation benefits and values. An analogous term is **environmental values**. Environmental values are defined as values or uses of the environment which are conducive to public benefit. welfare. safety or health and which require protection from the effects of pollution, waste discharge and deposits.

The terms 'beneficial use' or 'beneficial uses and values’ are used throughout this text for reasons of internal consistency and readability of the document. These terms are also commonly used by groundwater managers.

Finally, the term, **well** and **wellfield** are adopted throughout the guidelines as generic terms which include **bore** and **borefield** respectively. The term 'well' is now internationally accepted as meaning both small and large diameter holes, and is independent of the means of construction.

2. THE NEED FOR GROUNDWATER PROTECTION

2.1 The Benefits of Groundwater

Groundwater in the broad sense is all water which occurs within the 'hydrologic cycle' below the land surface. It is a pervasive resource, interacting with the land surface, streams and lakes, but because it occurs below the Earth's surface, its occurrence and movement are generally poorly understood.

Groundwater plays a significant role as a resource which is necessary to sustain life, either as a source of water for human use or as water which helps sustain life in surface waters such as streams and wetlands in dry periods. In the broader context, it also forms a major component of many water supply systems where aquifers are used as sole water supply sources or to balance surface water surpluses and deficiencies. Underlying each of these uses is the economic value of groundwater, particularly where it forms a resource which would need to be replaced, at some cost, should that groundwater become polluted.

Groundwater as a Water Source

Groundwater is commonly used as a source of domestic, recreational, rural and industrial water both in Australia and overseas, although in the experience of many Australians living in the Eastern State capital cities, its relative importance is poorly perceived.

Major urban centres in Australia benefit from groundwater. Figure 1* shows the amount of water derived from groundwater sources[1] for some of Australia's major cities.

The figure highlights the importance of groundwater sources to the greater Perth metropolitan area where groundwater accounts for two-thirds of all the water used.

In addition to major urban centres, many smaller centres rely on groundwater as their sole source of reliable water. Figure 2* shows the number of communities and the estimated populations relying upon groundwater for their drinking water supply in Australia[2]. Groundwater is the principal source of domestic water for about 600 communities, with a total population of almost one million people across Australia.

The use of groundwater in urban areas has been quantified in Figures 1* and 2* to show its importance and economic benefit to Australians. It is harder to present a comparable quantitative impression for groundwater use by agricultural and rural industries. Yet, groundwater availability is for many rural people the reason for their existence in their current location and enterprise.

For example, many agricultural industries have developed in isolated areas due to the availability of good groundwater sources. These industries vary from pastoral activities in western Queensland to grape growing in South Australia. The development of these parts of the Australian landscape is directly linked to groundwater. In fact, about 18% of Australia's total water use is derived from groundwater sources.

[* For technical reasons, Figures 1 and 2 have not been reproduced in this downloadable web version]

Overseas, the reliance on groundwater for public water supply is even greater than in Australia. Groundwater accounts for 38% of the total water supply for 34 of the 100 largest cities in the United States[3] and 50% of the total population rely partially or completely on groundwater[4].

Most European countries derive over 50% of their total water supply from groundwater[5]. Groundwater provides approximately 30% of all public water supplies in Britain[6]. For example, in the Severn-Trent Water Authority area of the English Midlands, groundwater provides 40% of all public water supply in a region of 8 million people[7]. These groundwater resources, which are a significant part of the total water supply for many European communities, are directly linked to public health and community prosperity. Therefore, great importance is given to their protection and maintenance.

There are indirect pathways for human exposure to groundwater contaminants apart from drinking water. For example, the consumption of vegetable crops irrigated with contaminated groundwater or products from animals which drank contaminated water, can constitute a public health risk. Consequently, groundwater can be a 'silent messenger', capable of insidiously communicating contamination in ways not intuitively connected with the contamination source.

Water for the Environment

In Australia, the role of groundwater as a significant component in the physical environment has only recently been realised. Strangely, this realisation has come about from two extreme but opposing effects; rising water levels and falling water levels. A consequence of rising water levels is the flow of contaminated or poor quality groundwater into streams and wetlands. Falling water levels have resulted in the drying of some wetlands. The ubiquitous nature of groundwater and its interaction with most streams and wetlands indicates the dependence of surface water quality on groundwater quality. The protection of surface water can, therefore, be often closely linked to the protection of groundwater.

In many situations, the poor natural quality of a groundwater resource lessens the perceived need for protection unless the environmental significance of the groundwater is taken into account. Contamination of brackish aquifers, particularly where aquifers are highly permeable, can lead to serious degradation of interconnected surface waters and the ecosystems which depend upon them. Consequently, ecological issues can in some cases be the critical factor which determines protection measures, for groundwaters.

The Aquifer Structure as a Resource

Groundwater bodies not only provide an important source of public water supply and environmental water in Australia, but aquifers with favourable hydraulic properties play other valuable roles in water supply systems. Aquifers are used as conduits for the distribution of water and as places to store water, which may be from surplus surface water. The usefulness of aquifers in such situations results from the flow transmission and storage properties of the aquifer structure. These properties are themselves resources which deserve protection from degradation.

2.2 Groundwater Contamination Sources

Contamination of groundwater has been observed world-wide, and it is becoming self-evident that concentrated human activity will lead to groundwater contamination . In general, it has been shown to occur wherever three main components exist; a potential source of contamination, an underlying aquifer, and a pathway for transfer between the two. This pathway can be either indirectly through the soil or directly through man-made structures which intersect the watertable such as pits, wells, trenches and quarries.

Sources of contamination are most often referred to as either **point sourc**es or **diffuse sources**. Point sources refer to cases where contamination is localised and often is centred on one or more identifiable structures or surface facilities. Alternatively, diffuse sources are broad scale and cannot be ascribed to a sole source, but are caused by either a widespread land-use practice (e.g. use of agricultural pesticides) or by a widespread collection of small point sources (e.g. septic tanks in an unsewered area).

Both point and diffuse sources of contamination are of comparable significance and concern, and the nature and extent of groundwater contamination can often be indicated by the distribution and nature of land uses in an area. For example, areas of concentrated manufacturing industry are often associated with contamination by heavy metals and organic compounds. Areas of intensive horticulture have been related to excessive pesticide and fertiliser contamination, and landfills generate leachate which can result in groundwater contamination from a range of contaminants. Thus, the expected chemical character of groundwater contamination can initially be gauged by knowledge of the chemical profile of the potential sources of contamination. From this information, the environmental and public health significance of any such contamination can be assessed. Appendix I outlines the types and sources of contaminants found in groundwater around the world.

The assessment of groundwater contamination has been the subject of investigations by State and Commonwealth Governments for many years. Contamination has been recorded in most industrialised areas of Australia, however the extent and severity of the problem is highly variable.

Incidents which have led to groundwater contamination have recently been summarised by the AWRC. The sources of these incidents and the associated contaminant types are:

- industrial effluent and manufacturing wastes;
- leaking underground storage tanks and pipelines;
- landfill stockpiles or contaminated soil producing leachate;
- intensive agricultural fertiliser and pesticide use or waste generation;
- contamination from septic tanks and from sewage and wastewater lagoons;
- mining industry processes and wastes;
- contamination from wells;

- urban stormwater;

- atmospheric fallout;

- interaquifer contamination by alteration of flow;

- firefighting accidents;

- emergency response wastes during and after chemical fires;

and

- energy generation and town gas sites.

In addition, contamination incidents due to accidental spillage are a concern throughout Australia.

2.3 Groundwater Protection in Australia

Overseas, there is a history behind the development of groundwater protection strategies in recent decades. This development of strategies is continuing. The Netherlands and the United Kingdom have adopted 'wellhead protection areas' to protect drinking water wells from contamination. These measures are supported by broader policy directives from the European Community[9].

A wide variety of protection strategies have been adopted in the United States. The Federal Environment Protection Agency (EPA) has issued a broad set of groundwater protection guidelines. Individual States have, however, often developed their own measures which rely on a mixture of technical solutions for clean-up, hazardous waste control, hazardous materials controls, land-use controls and financial arrangements.

In contrast, relatively little work has been carried out to develop groundwater protection strategies in Australia.

Control of water resources and water quality in Australia is a State and Territory responsibility with coordination and some funding of national programs being provided through the Commonwealth Government. Protection of groundwater has been catered for in State water legislation since the beginning of this century and more recently by State environmental protection legislation. However, much of this legislation was generally reactive and simply prohibited wilful or negligent acts of pollution. The regulations deriving from this legislation have now been adapted to some extent to provide pro-active protection mechanisms.

Victoria released a draft State Environment Protection Policy for Groundwaters of Victoria in October 1994. Provision is made in the *Environmental Protection Act 1986* of Western Australia for the development of statutory policies, with one finalised and several more under development. Policy development is also starting in some of the other States. However, there is no systematic framework for policy development and implementation across Australia. The main purpose of these guidelines is to provide guidance through specifying a systematic framework for protection.

2.4 The Need for Protection

Groundwater remains an important domestic resource for at least one million people in 600 communities around Australia. It makes a substantial contribution as a source of water to maintain aquatic environments and is an integral component in the long-term management of water resources on a regional and national scale. Groundwater is an important commodity and a vital input to both urban and rural industries, and our economy.

Consequently, the need to protect groundwater resources is directly related to the value of these resources and the risk of devaluation or destruction of this resource due to human activities.

3. UNDERLYING PRINCIPLES FOR GUIDELINES

3.1 Groundwater: A Pervasive Resource

There are many pervasive features of groundwater which were considered when adopting a framework for the national guidelines. The major features are discussed in this section to provide a background for policy makers.

First, the extent of the groundwater resource is difficult to specify with precision in many places. Geologic features can make assessment of the physical boundaries of aquifers costly to explore and difficult to map precisely. There can also be great uncertainty in the determination of parameters related to the flow and storage properties of aquifer materials. Uncertainty in resource boundaries and parameters makes groundwater assessment and management a complex and costly task.

Next, the maintenance of groundwater quality can be directly affected by an overdraw of the stock of water stored in an aquifer. Overuse will lead to a lowering of the watertable. This can induce polluted water or poorer quality water to enter and contaminate the good quality water. Consequently, resource allocation and protection are interdependent management task.

Protection of groundwater is generally easier when the source of contamination is concentrated at a point rather than spread over a broad area. Yet even for problems which involve point-source contamination, the flow of contaminants to an aquifer may take years or decades before being noticed. By the time contamination or pollution is observed in the aquifer, the offender may have abandoned the site and left. Subsequently, the cost of cleaning up pollution may be left with the general community if the offender cannot be found or has no money.

Fortunately, water bodies generally have some ability to undergo a self-cleansing process as contaminants are deposited. But the effectiveness of such cleansing processes depends upon the nature of the contaminants and on the rate at which they are deposited. For groundwater, the rate of cleansing is often very low and contaminants can accumulate quickly. Self-cleansing of large contaminated bodies of groundwater then is only a prospect aver a geological time-scale.

These foregoing points show that groundwater is a resource which is often difficult to define, requires skilled management, can be polluted by contaminants which were released many years ago, and may not have the ability to assimilate contaminants at significant levels. In addition, the cost of cleaning up groundwater, once it is polluted, is often extremely high, if indeed it is technically possible.

This goal aims for development that improves the total quality of life, both now and in the future in a way that maintains the ecological processes on which life depends[1].

Australia's groundwater resource provides benefits to a wide range of people through its use to support the current standard of living. The task confronting us is to manage this resource on a sustainable basis to ensure that the needs of tomorrow's generations are incorporated into today's decisions.

The pervasive nature of the groundwater resource and its susceptibility to contamination means that deliberate decisions need to be taken now to protect groundwater bodies for the benefit of future generations. In many instances, no decision or action will have the same long-term effect as making a deliberate decision to allow contamination to occur. Therefore, these guidelines aim to promote the development of groundwater protection strategies for every major groundwater body in Australia, and to place the cost of contamination firmly with potential polluters

In order to focus on the development of broad-scale protection strategies across Australia in the next decade, a specific goal for groundwater protection was formulated.

> *The goal of groundwater protection is to protect the groundwater resources of the nation so that these resources can support their identified beneficial uses and values in an economically, socially, and environmentally sustainable and acceptable manner.*

The goal recognises that not all groundwater is of the same value and that the focus for action in the coming years across Australia is to get strategies in place for protecting all major aquifers.

At the end of the decade it will be appropriate to review groundwater contamination incidents and the coverage of Australia by various protection strategies. This review will hopefully find that there is a diverse group of strategies in place across Australia and lead to a more sophisticated set of guidelines for following decades.

3.2 Beneficial Use Framework and Polluter Pays Principle

The guidelines for groundwater protection rely on a framework in which there is the identification of existing or potential beneficial uses for each groundwater resource. These classifications of beneficial use assist in determining the level of protection afforded to each groundwater body.

The choice of a beneficial use classification for a groundwater body will depend upon the quality of water present and the potential values of the groundwater in the long term. Generally, the designated beneficial use of a groundwater body should aim to protect water quality to the greatest extent. Complexities which arise in the implementation of this principle are described in Section 5.4.

Once a beneficial use determination has been made, the developer of an industry or activity which has the potential to contaminate the groundwater body should bear the full costs of protection of the aquifer against any threats which the development may pose. In these instances, the developer would be required to show on a continuous basis that the activity did not pollute the groundwater body.

This approach is consistent with the 'polluter pays principle'. The 'polluter pays principle' is a concept where the costs of preventing or abating pollution are borne by those who could potentially place contaminants in a situation where they will ultimately degrade environmental values. The principle can be applied to many situations. For example a groundwater user who deliberately overdraws an aquifer which leads to deterioration should expect penalties commensurate with the damage caused. It must be clearly understood by all members and organisations in society that no-one has the right to pollute groundwater in a way that creates a significant risk to the public health, ecosystems or other valued uses of water.

Beneficial Uses and Values

There are numerous ways of categorising beneficial uses and values. The classification system adopted in these guidelines follows the five broad categories of environmental values outlined by the Australian and New Zealand Environment and Conservation Council (ANZECC) in *Australian Water Quality Guidelines for Fresh and Marine Waters*[2]. The five categories are:

- ecosystem protection;
- recreation and aesthetics;
- raw water for drinking water supply;
- agricultural water; and
- industrial water.

Groundwater may be extracted to provide these values directly or may need protection because of indirect effects on surface waters and their values.

A description of each of these categories is provided in Appendix II. This is not a comprehensive list since aquifers can have other values. For example, the water in some aquifers can vary in age both in an aquifer and through an aquifer ie, it is fossilised. The waters in these aquifers can have significant value to both research and education. In other cases, special beneficial uses may be created to cover specialised uses of groundwater, such as mineral water.

Also some confined aquifers, particularly in the sparsely settled areas of Australia, contain groundwater of extremely poor quality. The water body is confined and far from the surface and there is no presently foreseen commercial use nor ecological link with the water body. In this instance, where there is no identified beneficial use or value, developments which affect the water quality in the aquifer would have to be carefully evaluated and justified in a way that meets the precautionary principle. These are likely to be rare developments but they still need to be fully evaluated by all government agencies and the community on a case by case basis.

The ANZECC water quality guidelines provide a useful reference document for identifying water quality criteria associated with each beneficial use.

Some issues associated with applying water quality criteria for protecting groundwater are:

- The beneficial use classes chosen are necessarily wide and therefore more than one set of criteria may apply to each class.

- Water quality criteria, especially for environmental purposes, are often specified broadly and local research findings may allow for more specific criteria to be chosen.

- For groundwater, the point of application of criteria involves some special considerations and these are discussed further in Section 5.7.

3.3 Achieving Equity

When strategies for protecting groundwater are being developed, difficult situations can often arise in dealing with past, current and future contamination problems. There are numerous legal and technical aspects involved and fundamental issues arise, such as:

- the extent of financial liability far contamination;

- the responsibilities and liabilities of authorities, owners, operators and lenders;

- applying liabilities retrospectively; and

- the impact of future changes in standards on current liabilities.

All of these issues involve major judgments on social equity. Some of these issues will be dealt with by government legislation and edicts, and others under common law.

Managers can improve the equity of their decision making by becoming aware of social theories which deal with the issue of developing procedures and with the concept of distributive justice There is one theory that says if the process of decision making is seen to be fair, the decisions arising from that process will be more likely to be accepted by those parties affected. There are also methodologies which assess the rules that are applied to people when making judgments about the fairness of particular decisions[6,7]. Finally, fairness in some societies is often assessed against a 'yardstick'[8,9].

It is important that groundwater planners and protectors do not become overly distracted in trying to achieve social justice over pollution incidents which have occurred in the past. These will always be difficult issues to deal with and there will not always be quick or equitable outcomes.

Rather, protection is about the future. The main objective is to create a 'benchmark' position so that new strategies are put in place to protect the groundwater resource from further undesirable contamination. Once the benchmark is in place, the polluter pays. The conflict and the difficulty of dealing with pollution incidents can consequently be reduced significantly in the future.

4. APPROACHES TO GROUNDWATER PROTECTION

4.1 Forms of Intervention

Intervention by government to improve the activities of companies and individuals can take place in three main ways, viz. by direct command or fiat over activities, by the introduction of market approaches, and by raising social awareness through community participation and education. The effective use of each type of intervention relies on the circumstances present but there is now available a basic understanding of when each form of intervention is effective.

First, intervention can be by command or fiat over specified activities or practices. The most common example would be the many government regulations which directly control actions and activities. Government regulations are a forthright way of achieving a stated objective. They are the quickest way of stopping contamination when it can be easily identified. A specific threat is identified and a protective regulation is appropriately formulated. Problems are met by a response which offers an assured outcome. For example, an edict can be written and enforced which stops contaminants from a point-source entering into a highly valued aquifer.

However, in many circumstances, the link between a contamination source and the long-term vulnerability of an aquifer to contamination can be hard to define or the source of contamination can be widespread. These problems may not justify a blunt form of intervention over long periods since the monitoring, enforcement and political costs to government can be very high. Regulations, by their nature, also tend to be rigid and unresponsive to legitimate differences in local circumstances.

Three specific disadvantages are associated with this relative inflexibility of regulatory approaches:

- Regulations generally provide no incentive to achieve better than a prescribed standard.
- Regulations do not consider the distributional aspects of reducing environmental damage, either in terms of equity or efficiency.
- Regulations often do not allow individuals to choose the lowest cost response to meet environmental objectives.

The second type of intervention can be by market approaches which provide financial incentives for proper behaviour and provide more efficient and equitable distribution of the costs of contamination or, for the purposes of these guidelines, the cost of protection measures. Market approaches in other fields rely on regulations which set limits on contamination and/or have the real costs of contamination met by dischargers. Dischargers then have a financial incentive to optimise the marginal costs and benefits of their contamination and to look at least-cost ways of reducing the release of contaminants. Market incentives harness the initiative, knowledge and judgement of individual dischargers to create a set of efficient behaviour rather than force all dischargers to behave alike, regardless of the damage they do or the contamination-control costs they face.

The efficient and equitable implementation of one or a mix of market approaches to groundwater requires a thorough economic analysis to be made of each situation. A good understanding of the aquifer's vulnerability, dimensions, and flow and storage parameters is also required. A range of market instruments can then be suggested which have different efficiencies, distributional consequences and administrative costs for improving the situation. The instruments might include taxes, optional insurance covers and bond arrangements.

For groundwater protection strategies, application of the 'polluter pays principle[1] would lead to potential polluters paying for the monitoring and reporting of contaminant levels in aquifers. Financial instruments, such as insurance bonds, can provide added incentive for potential polluters not to pollute groundwater.

The third form of intervention covers a range of social actions and processes which involve community participation and education. In the development of strategies, public participation processes can greatly improve the general understanding of the need for groundwater protection and lead to the ready adoption and implementation of strategies. A community participation process informs the community of the problems and their options, improves decision making by getting community input, and creates a sense of ownership of a strategy by the community. When these processes involve a social learning process, they can lead to a wide variety of people voluntarily changing their actions or create community pressure for potential polluters to stop bad practices.

Long-term protection of groundwater from dispersed pollution is an example which requires the development of protection strategies through a community participation process. Awareness and appropriate action needs to be developed by all levels of government as well as by community groups. Often the result will be in the form of a plan of coordinated and cooperative action. This form of intervention is strongly recommended as part of the development of any and all broad-scale strategies for groundwater protection.

The three types of intervention discussed all have a part to play in groundwater protection. Most strategies will involve action derived from utilising more than one of these intervention methods.

4.2 Types of Protection Strategies

The three major types of government intervention have just been outlined. A protection strategy is in part a plan for intervention. It is made up from a detailed set of policies, plans and actions which together aim to achieve certain objectives. Consequently, the purpose of strategy development is to plan ways in which the government and the community at large can adopt a coordinated and comprehensive approach to the protection and management of a State's or Territory's groundwater resources.

There are various types of groundwater protection measures which are used in different part of the world. Each measure has its strengths and weaknesses. Consequently, there is not one measure which can be universally adopted to protect Australia's groundwater. Each State and Territory will need to examine the range of, measures available and adapt one or more of these measures to their particular circumstances and local needs. The choice of suitable measures will not only depend on the physical properties of the groundwater body and the nature and type of contamination, but also can legislative, financial, social, environmental and political considerations.

If groundwater is to be protected in the long term then a viewpoint must be adopted on the desired outcome. For groundwater, determination of a beneficial use will provide an initial focus for this desired outcome. A plan can then be drawn up to manage and protect the resource so that this outcome can be achieved in the long term. This planning activity will also determine the protection measures which are pertinent to the situation being examined.

There are a variety of State, regional and local government legislative powers which can be utilised to develop and implement groundwater protection plans. This legislation can be grouped under three broad headings:

- -Groundwater Management;
- -Land-use Planning; and
- -Environment Protection.

Groundwater management legislation is weighted towards management issues related to the allocation and utilisation of the resource. Groundwater may be integrated with surface water management on a catchment or regional basis, and may, or may not, involve other specialised bodies such as State departments of mines or geological survey. Legislation typically includes controls on groundwater extraction rates, the gathering of hydrogeological information, and monitoring of critical over-draw situations. Controls can cover aquifer contamination issues through the reservation of special areas, well construction and abandonment measures, and driller licensing. Disposal of waste liquids via wells may be included.

In some cases, groundwater management legislation will also specifically include powers to protect groundwater quality particularly in stressed areas or public water supply areas. These powers can take the form of by-laws to control activities, regulate the disposal of materials, control the storage of materials underground, and intervene in risky activities.

Land-use planning legislation places controls over the broad uses to which land is put. Inevitably, long-term effects result from land uses which are detrimental to groundwater or social reasons, significant use has not been made of planning legislation to control slo degradation of groundwater over large regions of Australia. One exception is the *Planning Act* (1982) in South Australia which prohibits or restricts certain land-use activities which can degrade groundwater. However, land-use controls are likely to be more widely adopted as contamination problems become more critical over broad areas in future. Land-use planning is a critical factor in implementing effective groundwater management strategies at a regional scale.

Environment protection legislation varies in its coverage, though it tends to be generally built on pollution control concepts. As such, it can protect aquifers by directly applying controls to point-source contamination and indirectly applying controls to diffuse-source contamination through regulations on contaminants such as agricultural chemicals. Such legislation would also be expected to cover the remediation of contaminated sites and polluted groundwater bodies.

A protection plan will need to take into account the available legislative tools, which in most States and Territories will involve the above three elements. If current legislation is deficient it will be necessary to recommend new legislation or changes to existing legislation to ensure that an adequate legislative base exists for groundwater protection.

These guidelines favour measures which derive their intervention power from existing groundwater management legislation. This bias is present because the main audience for these guidelines will be groundwater managers in the water sector and they can readily intervene under this type of legislation.

Protection of groundwater in the long-term will not only rely on traditional groundwater management measures but will also rely more and more on land-use planning and environmental protection measures. In all States and Territories, groundwater managers over the next decade need to be the leaders in the creation of awareness and the development of co-ordination mechanisms between groundwater managers, planners and environmental protection managers so that these alternative measures can be implemented.

An example of the need for this leadership role is the growing trend to discharge sewage effluent to land rather than discharging the effluent to inland rivers or the ocean.
The implications of replacing one pollution sink (an inland stream or ocean) with another sink (the land and its groundwater) are not readily recognised. Those most familiar with groundwater, i.e. groundwater specialists and managers, need to contribute their expertise to those debates so that more informed decisions are made about the options available. This knowledge must be integrated into planning at a strategic level so that the management of groundwater becomes part of the whole water cycle.

4.3 Groundwater Management Measures

4.3.1 Groundwater management plans

Groundwater policies and regulations have traditionally been developed within a planning framework. This approach aims to integrate the many issues involved with resource management and provide an efficient plan for allocation and development of the resource by users.

The objectives and components of this traditional approach to groundwater management will be discussed initially. The discussion will then turn to how the objectives and issues of groundwater protection and the principles of beneficial uses can be incorporated into this planning approach.

Once a groundwater body reaches a stage of being used by many competing users, the net benefits of resource use will be maximised if a common plan exists for regulating individual behaviour. The formation of this common plan has traditionally involved setting some common objectives. The planning process involves component studies which take into account, inter alia:

- an assessment of the resource base;
- water demands and their location;
- appropriate methods of extraction;
- recharge and discharge characteristics;
- water quality variation;
- environmental and land subsidence issues;
- controls of application rates of contaminants;
- monitoring needs; and
- regulations and charges.

Traditionally, the focus of many groundwater management plans was on resource utilisation and the aim was to maximise the net benefits to users of groundwater. Consequently, these users were the main beneficiaries of the plan.

Logically, this traditional approach to planning for allocation of a resource can be adapted so that the initial allocation decisions are improved in view of current data and knowledge, and also extended so that the beneficiaries of planning are a broader community of interests. In some circumstances, the planning will need to cover both surface water and groundwater issues if there is a high level of interaction between these resources.

Integration of allocation and protection issues starts with the identification of the benefits or values of groundwater. Groundwater values are most often defined in terms of some classification system which, for the purpose of groundwater resource mapping in Australia, usually combines water quality criteria with a measure of aquifer productivity. In the United States, the system of classification is much simpler, the main criterion being the use of groundwater for drinking water (or sustenance of a unique ecosystem). In Europe, all groundwaters are taken to be highly valued or closely linked to the human environment, and are thereby uniformly protected.

A significant impediment to the definition of a simple groundwater classification system is the multi-dimensional nature of groundwater systems. Even where the time dimension is ignored for the purposes of simplicity, a three dimensional problem remains within which 'protection areas' need to be defined. The boundaries of these areas are defined by natural hydrogeological entities such as 'aquifers', 'aquifer Systems', 'groundwater flow systems' or 'groundwater basins'. Once these areas are identified, each area requires a 'beneficial use' classification.

The designation of a beneficial use is approached with care for the unknown. The degree of natural variation within hydrogeological systems does always not lend itself to simple definitions of protection areas. The classification of groundwater is also limited by the knowledge and cost of investigating the resource. However, a degree of conservatism can be brought to bear on these decisions to allow for the uncertainties in decision making. The categories for beneficial use which have been adopted for these guidelines were discussed in Section 3.2. More information and references for linking water quality criteria to these categories is contained in Appendix 11 and Section 5.3 also discusses this issue.

Protection of groundwater can be improved in the planning processes for allocating water if protection issues are integrally linked into the analysis. Allocation of groundwater has traditionally been aimed at maximising the net benefits to groups in society who extract groundwater. This does not necessarily maximise the net benefits to society of a range of conservation and environmental values which do not rely on the extraction of groundwater. A public education and consultation process needs to be part of the process if these broader values are to be incorporated into an overall allocation and protection plan to manage the resource.

Groundwater management plans have traditionally relied on government regulation for implementation. Market incentives can assist in this management task. Once there are many competing demands on aquifers, proper prices and transfer mechanisms will achieve efficient allocation of the resource. Protection of the resource can be improved by taxes and charges on contaminant releases or activities that lead to contamination and by performance bonds and non-compliance fees on industries which produce contaminants. Complex problems involving multiple sources of major contamination can be dealt with by tradeable pollution permits. The use of these economic instruments is in an early stage of development and greater adoption of these instruments will occur as Australia's contamination problems gain greater recognition as the economic environment matures.

Groundwater managers can facilitate the move toward the introduction of market mechanisms for protection of aquifers in the long-term by introducing market mechanisms for other purposes first, such as user pays pricing and trading in water rights. A familiarity with market mechanisms on the quantity side will promote their introduction on the quality side in the longer term to both users, and managers.

The Council of Australian Governments (COAG) Water Reform Policy framework agreed in February 1994 recommended that management arrangements relating to groundwater be considered by ARMCANZ by early 1995 and advice from such considerations be provided to individual jurisdictions and the report be provided to COAG.

The COAG reform framework embraces pricing reform based on the principles of consumption based pricing and full cost recovery, the clarification of property rights, the allocation of water to the environment, the adoption of trading arrangements in water, institutional reform and public consultation and participation.

In the final analysis, the effectiveness of a groundwater management and protection plan will depend on its enforcement. This requires a good monitoring program and adequate enforcement procedures with the backing of financial and human resources.

The planning approach is an excellent way to integrate many issues and the classification of beneficial uses will provide an initial basis for protecting Australia's groundwaters from contamination. However, there are several other groundwater management techniques which usually need to be considered in the formulation of resource use and protection plans. These techniques are particularly pertinent to the more intensively developed parts of the continent.

4.3.2 Vulnerability and vulnerability mapping

One technique for assisting the development of groundwater protection strategies is based on determining a groundwater body's vulnerability to contamination. The vulnerability of groundwater to contamination varies both within and between natural hydrogeological systems. Vulnerability may be defined as a relative evaluation of the potential exposure of a groundwater resource (and consequently, its beneficial use) to contamination from planned and unplanned sources. It provides a means of assessing the need for groundwater protection mechanisms according to the loss of a beneficial use of that groundwater resource. Ranking of vulnerability needs to incorporate a number of hydrogeological variables such as:

- thickness of the unsaturated zone;
- nature of the overlying soils;
- degree of confinement and nature of porosity;
- geochemistry of the aquifer;
- sedimentary architecture, e.g. shoestring sands;
- hydraulic properties of the aquifer;
- topography and groundwater flow system;
- impact on surface waters; and
- land and water (i.e. catchment) management.

A number of different schemes for mapping vulnerability, using these types of parameters, have been devised. These maps provide a good guide to groundwater resource vulnerability on a regional to subregional basis, but have only limited potential for classifying the true vulnerability at specific sites. Interpretation of such maps therefore requires some caution as the subtle variations in natural hydrogeological systems geometry can be misleading. For example, a groundwater basin which contains an unconfined aquifer that is close to the surface and of high quality water may be considered to be more vulnerable to contamination than deep confined aquifers in the basin which are covered by dense and impermeable sediment. Vulnerability mapping and ranking schemes commonly in use include the 'Drastic'[2] and 'Le Grand'[3] systems. Simplified ranking systems have also been used in regional studies around Melbourne for determining suitable sites for industrial waste disposal.

In Australia, the Le Grand method of site assessment was proposed by the EPA in Victoria in a Draft Landfill Policy[4,5] as a means of assessing sites for suitability for landfills, but the method was not adopted in the final policy *'State Environment Protection Policy - Landfills'*.[7] The Le Grand methodology is considered to be fundamentally different to most vulnerability mapping methods. Although it is based on a specific methodology, it is site specific and has been used to assign a rank score to enable a comparison of different sites. It should not be confused with vulnerability mapping methods which can be applied over broad areas.

Vulnerability mapping schemes generally assume that the source of contamination is at or just under the land surface. Sources such as spills, landfills, storage tanks or industrial plants fall into this category. However, another group of contaminant sources are the man-made conduits which reach deep into the sub-surface. These include water supply wells, mineral exploration wells, oil wells, gas wells, and most importantly waste injection wells. Contamination from inadequately designed and constructed deep wells produces a significant increase in the risk of contamination vulnerability in what would otherwise be low vulnerability groundwater systems, and must be classified accordingly.

The vulnerability of a groundwater system (aquifer, flow system car basin) to contamination can therefore be assessed on a regional basis using an appropriate analysis by a skilled hydrogeologist or groundwater engineer. This vulnerability may be mapped on a flow system scale to illustrate conditions at the surface. Once a vulnerability map has been produced, it may then be used by any professional to assess the relative priorities for groundwater protection and be incorporated into the groundwater management planning process. An example is now given of a groundwater vulnerability assessment exercise.

The assessment system in this example combines the five beneficial use classes with two arbitrary vulnerability classes, high and low, which correspond to the two end members of a spectrum of aquifer types. High vulnerability aquifers are shallow (usually unconfined), highly permeable aquifers with little attenuation character, whereas low vulnerability aquifers are, taken to be deep, usually confined systems or have properties that slow and attenuate contaminant transport. Given the number of variables needed to define vulnerability the potential number of vulnerability classes could be very large. However, in this example, two categories were adopted. The resultant groundwater beneficial use and vulnerability categories are presented in Table 1.

Idle categories (E1, E2, R1, R2, ... I1, and I2) would be related to various allowable and prohibited activities. A map which adopted these categories could then be used to provide this information to the public in an easily understood format.

TABLE 1
GROUNDWATER USE AND VULNERABILITY CATEGORIES

Use	Vulnerability	
	High	Low
Ecosystem Protection	E1	E2
Recreation and Aesthetics	R1	R2
Raw Water for Drinking	D1	D2
Agricultural Water	A1	A2
Industrial Water	I1	I2

4.3.3 Aquifer classification systems

Aquifer classification systems allow development of protection strategies that take account of the specific attributes of the resources to be protected. These attributes may include:

- designated beneficial use;
- water quality (usually in terms of Total Dissolved Solids);
- social value;
- economic value;
- ecosystem values:
- vulnerability to contamination;
- current and planned land tenure and use;
- availability of alternative sources;
- current extent of contamination and potential for successful clean-up; and
- hydraulic relationship with other resources (surface and groundwater).

A working example of a comprehensive aquifer classification system is that developed and adopted by the State of Connecticut in the United States. The System is a four-class groundwater classification system based on water use rather than discharge criteria. The most protected class applies to water utility and municipal drinking water supplies. The next two classes apply to private drinking water supplies, and water supplies that may require treatment to make them potable because of past impacts upon water quality. The final class designates areas where there are no plans to use groundwater and in which certain treated industrial wastes and major residential waste disposal practices are allowed. For each class, the compatible discharges that may be permitted is prescribed. This approach is generally narrative, and relates to the protection goals determined for each aquifer class. The system has been effectively used to direct the priorities of the State's enforcement program[8,9,10].

The Connecticut example illustrates the successful integration of water quality standards, landuse policies and discharge permits. However, its final class which allows for waste disposal differs significantly from 'no identified beneficial use' in these guidelines under which waste disposal may be permitted if it can be shown to benefit society.

The development of the 'sole source aquifer' concept by the USEPA[11] for principal drinking water sources is another example of a form of aquifer classification that allows the setting of clear goal-oriented protection programs for high priority sources.

4.3.4 Setting levels of action

Conventional approaches to groundwater protection have relied heavily on technology and designing containment systems for waste disposal facilities. In the USA, hazardous waste disposal sites have been the focus, while in Australia municipal landfills have been a focus in some States.

The approach which has evolved to manage the level of groundwater contamination in these hazardous situations involves a hierarchy of increasing intervention. 'Levels of action' are designated for particular protection areas dependent upon the perceived threat from contamination in that area.

This type of approach is generally reactive rather than proactive. However, there may be situations in Australia where contamination is already present and this type of strategy needs to be adopted. For many protection plans, the details of this type of approach will also be pertinent to contingency plans (Section 4.6).

Action levels need to be chosen to match the long-term beneficial use of groundwater in view of the source of contamination present. Sources include operational waste sites, abandoned sites, new operations, point sources and diffuse sources.

In the following example six levels of action are adopted. The guiding principles underpinning these action levels are:

- protection must relate to risk;
- containment of hazardous waste cannot be assured;

- prevention of pollution is far less costly than clean-up;
- wellhead protection may be needed;
- some specification of hydrogeological assessments is required; and
- the rigidity of water quality criteria may not be helpful.

The six levels of action are as follows:

LEVEL I NO ACTION

In areas which have low groundwater value, where groundwater discharge to surface waters is not significant and where no obvious source of contaminant occurs, no action is required. In order to make this judgement on 'no action', significant amounts of information are required. This information is unlikely to exist for low-valued groundwater and so this classification level would be rarely, if ever, adopted.

LEVEL II GROUNDWATER CONTAMINATION ASSESSMENT REPORT

In areas where one or more of the variables might indicate a potential risk to groundwater or the environment, a desk study to identify the concerns and the need for further action is required. A standard format hydrogeological report would result. This could also be the only measure applied in cases where controlled degradation was occurring.

LEVEL III SITE INVESTIGATION WITH MONITORING

In areas where the level II assessment indicates a potential risk or where it is otherwise known to exist, a site investigation and groundwater monitoring is required. The extent of work should involve a limited amount of site investigation, soil and water sampling and testing, definition of flow systems and reporting.

LEVEL IV DEMONSTRATED GROUNDWATER PROTECTION SYSTEM

In areas where the risk to groundwater is demonstrated by Level II and III assessment or is otherwise known and where these effects cannot be tolerated, a demonstrated groundwater protection system should be implemented. The work should include level II and III assessments plus implementation of an on-going monitoring program. In addition the protection design (considering natural attenuation, hydraulic: barriers, physical barriers etc.) need to be shown (by modelling for example) to be effective.

LEVEL V DEMONSTRATED REMEDIAL ACTION PLAN

In cases where the potential risk is so great or where the impact of contamination in a high ranking aquifer is evident but not sufficient to warrant clean-up a demonstrated remedial action plan is advised. The work should include level II, III and IV assessments and monitoring plus a feasibility plan for clean-up which analyses the effectiveness of the remediation approach in achieving designated water quality criteria (by bench tests, models, protocols etc).The financial capacity of the responsible party to enact the plan should also be evaluated.

LEVEL VI PROHIBITION/CLEAN-UP

In the event that the risk to groundwater is unacceptable an activity may be banned by the responsible authority. This might not be feasible in many cases without substantial financial damage to the affected parties and thus would need to be phased-in so that lower levels of protection could be broadly applied. If the current state of contamination is unacceptable then a clean-up order could be issued. In this event a Demonstrated Remedial Action Plan should be required prior to clean-up to ensure its effectiveness.

Appendix III provides considerable detail of the reports, monitoring, protection schemes and action plans which are necessary for this type of approach.

4.3.5 Wellhead protection plans

Protection of public water supply wells (wellfields, bores or borefields) is a high priority in some countries where the main source of drinking water is from unconfined and very vulnerable aquifers. A similar type of protection is provided in parts of Australia, for example the Underground Water Pollution Control Areas around the public water supply wellfields near Perth in Western Australia.

- Water supply wells can become contaminated in a number of ways including:
- incompatible land-use practices within well recharge areas, eg. septic tanks;
- leakage of contaminants into the well or around the outside of the casing, if not properly sealed or poorly operated and maintained;
- aquifer contamination by leakage of poor quality or contaminated groundwater from one aquifer to another via improperly constructed or corroded wells;
- interaquifer leakage in wellholes drilled for mineral or oil and gas exploration which are not properly abandoned; and
- drill stems not properly cleaned, thus transferring bacteria or contaminants.

Measures to prevent occurrences identified in the latter three mechanisms are included in groundwater control laws in most States which require driller licensing and the adoption of proper well construction methods. However, the control of non-water boring activities is generally less stringent. Attention is required in groundwater strategies to remedy this weakness in current groundwater protection.

The contamination prevention measures provided in present groundwater legislation do not provide adequate protection for water supply wells. Some better assurance of protection and definition of the response to a contamination incident is required. This could be provided by a plan which specifies technical details including the construction of the collar of the well, integrity of the casing, operation and maintenance procedure, safe storage of hazardous and tainting substances, monitoring pumped water and nearby aquifers for pollution indicators, or an appropriate response plan in the event of contamination from any source.

Consequently, all public water supply wells should be subject to a Wellhead Protection Plan, whether they are in shallow unconfined, vulnerable systems or deep confined aquifers of low vulnerability. This is based on the rationale that shallow systems will need protection because of their high vulnerability to contamination by surface sources whereas deep aquifers are potentially at risk from interaquifer contamination or well failure. Adoption of a Wellhead Protection Plan will also heighten the awareness of water supply operators and the public about groundwater protection. Based on previous experience of the lack of care in the operation of some town supply wellfields, such protection is overdue.

The Wellhead Protection Plan is a system of groundwater protection which involves the following components:

- **Well Integrity Assurance**: A set of actions to assure that the well is properly designed and constructed to achieve protection objectives. This includes provision of adequate protection of the well collar against physical damage and seepage of contaminants.

- **Wellhead Protection Zones**: The delineation of protection zones around the wellhead aims at protecting that part of the groundwater flow system which contributes to the discharge of the well. This will include the nearby cone of influence defined by drawdown of the watertable and the flow field up gradient not affected by drawdown. The size and location of these zones needs to be defined on a site specific basis to allow for effective designs of the monitoring system. These may need to account for non-advective particle motion since density, dispersion and diffusion effects can predominate in many circumstances.

- **Monitoring System**: Water quality within the aquifer and in the pumping well needs to be monitored to protect against contamination. Monitoring the pumping well alone is inadequate as no warning of an imminent contamination incident is provided. Monitoring is needed within the aquifer at positions at sufficient distance up-gradient to allow time for preventative and if necessary, remedial action to be implemented in the event of contamination being detected. Groundwater near the contamination sources within the zone also needs to be monitored.

- **Contamination Sources/Land-use Control**: The location and nature of existing contamination sources within the protection zones needs to be documented and controls placed upon these or potential land-uses within the zones.

Given the degree of complexity of the Wellhead Protection Plan design and implementation process, it follows that a degree of technical guidance documentation is needed, to enable the responsible parties (water boards, councils etc.) to implement such plans.

Table 2 presents an example of one approach to a Wellhead Protection Plan.

TABLE 2
EXAMPLE OF A WELLHEAD PROTECTION ZONE FOR PUBLIC WATER SUPPLIES

Zone	Boundaries	Restrictions
I	50 m radius (or within the wellfield)	No storage of hazardous or tainting material, implementation of an integrity assurance plan.
II	10 years residence time	No waste dumps, implementation of a monitoring system, including monitoring for response to a contaminated plume within the boundary.
III	Greater than 10 years residence time	No restrictions beyond those imposed by a regional protection plan and monitoring system to provide warning of deterioration in water quality.

The approach is based on the definition of concentric protection zones around the wellhead. The nearest zone (Zone 1) would commonly encompass the water authority compound around the wellhead but could also include adjacent properties. The most stringent controls on land use and materials handling would apply in this zone. The second zone (Zone II) is arbitrarily defined as the maximum distance a contaminant particle would have travelled if it took 10 years to reach the well. The controls on land use in this zone would require a monitoring system for all potentially polluting activities within the area. Monitoring of groundwater within this area, particularly up-gradient or within the capture zone of a well would give early warning of contamination.

The third zone (Zone III) would correspond with the regional protection area where greater than 10 years residence time is available. This is usually the 'catchment area' of the contributing aquifer. Definition of the size in outer protection zone(s) would require adoption of a standardised methodology for estimation of the area within the specified residence time zone(s). The approach to management within this area would be largely affected by the nature of the aquifer being protected, particularly its degree of confinement.

When wellhead protection zones are declared for existing bores supplying towns and cities, careful thought needs to be given to the implementation strategy. The zoning will only protect against future contamination threats and so the strategy must look at all existing threats and take remedial action.

4.4 Land-use Planning Measures

The planning process for land and resource utilisation is complex, and usually has many tiers of authority, delegation and appeal. In many parts of Australia, surface water supply catchments have long been afforded special status and protection. Groundwater protection in the planning process has usually been implemented in the form of conservation areas, i.e.

an area or zone to be protected from over extraction, or reserved specifically for public water supply.

There are only a few examples in Australia of specific catchment protection measures for the protection of groundwater recharge zones. In Western Australia, by-laws are promulgated for designated areas. These are termed either 'water reserves' under *the Country Areas Water Supply Act 1947* (WA) or 'pollution control areas' under the *Metropolitan Water Supply, Sewerage and Drainage Act 1909* (WA).

Land-use planning controls are a powerful instrument in situations, such as:

(a) Mining and quarrying (especially in recharge areas)

Competition for resources by mining and quarrying can impact on the quality of groundwater, by firstly mining the aquifer material and secondly replacing it with incompatible low permeability material. This reduces recharge and diminishes the yield of the water resource. The competition for the resource should be recognised in the land-use planning stage and appropriate controls recommended.

(b) Reclamation and regulation of waste disposal

Sources of contamination such as waste disposal sites are normally regulated by authorities that are independent of the water sector. Land-use or catchment management plans should include provision for the exclusion of some types of waste disposal operation in areas where groundwater is vulnerable to contamination.

(c) Land clearing and development

The clearing of native growth and land development for industrial or rural activities can induce changes in water quality and recharge rates to aquifers or directly contaminate groundwater. This should be recognised in the land-planning process. Land planning can ensure that land development activities take place in areas appropriate to each type of development. Urban and rural runoff may also have to be addressed in a whole-of-catchment approach to groundwater quality protection.

These are just three possibilities where land-use planning can greatly assist groundwater protection. The power of this regulatory instrument should not be underestimated in the development of groundwater protection strategies. Land-use planning controls should be the subject of much public discussion in the strategy development process and this will involve coordination between groundwater managers and local/regional government planners.

The implementation of land-use controls can often be most effectively achieved through the existing local government planning process. The challenge for groundwater managers associated with State Government departments and agencies is to educate and convince local governments and their communities of the need for groundwater protection. They must then provide hydrogeological expertise and maps so that groundwater protection needs can be easily analysed by local government planners.

4.5 Environment Protection Measures

During the 1970s, Environment Protection Agencies (EPAs) were incorporated into governments overseas and in various Australian States. In more recent time, the Commonwealth has formed an Environment Protection Agency. It has focused on the chronic waste disposal problems that have emerged in cities and across the countryside.

A joint State, Territory and Commonwealth Ministerial Council, known as the National Environment Protection Council will have responsibility for developing National Environment Protection Measures. These measures may include standards, guidelines, goals and protocols in any combination that the Council considers appropriate.

Waste management measures were developed to deal with not only protecting the environment from waste pollution but also minimising the production of waste. These strategies rely on a hierarchy of actions which are approached in the following order according to a decreasing desirability:

- waste avoidance;
- waste re-use;
- recycling or waste reclamation;
- waste treatment to reduce potential degrading impacts; and
- waste disposal.

If there is more of the first then consequently there will be less need for the last. A range of action can be taken on each of these measures through regulation, market incentives or consumer education. The action of EPAs in these areas can have significant flow-on effects for groundwater protection. It is likely that for many urban problems, environment protection measures will be more effective in the long-term than many of the traditional groundwater protection measures.

An example of direct action on groundwater protection by an EPA is Victoria. The EPA in Victoria produces State Environment Protection Policies (Sepp) on special subjects and has developed a draft State Environment Protection Policy for Groundwaters of Victoria. The policy goal is to maintain groundwater quality sufficient to protect existing and potential beneficial uses of aquifers throughout Victoria, by the prevention of pollution. It identifies beneficial uses to be protected for groundwater of different quality and provides water quality objectives based on the *Australian Water Quality Guidelines for Fresh and Marine Waters* (ANZECC, 1992). The policy also includes a program for the attainment of these objectives. The draft policy is due to be finalised and become State legislation in 1995.

Western Australia's water resource and environmental protection agencies have recently established an Environmental Protection Policy (EPP) for groundwater, wetlands and native vegetation of a groundwater resource north of Perth. This policy establishes beneficial uses and quality objectives, for that groundwater, prohibits certain activities, and has the force of law as though part of the *Environmental Protection Act* 1986.

Some basic steps in environmental discharge management can achieve a significant level of protection with only a little effort. Most of the potential sources of contamination are small point sources or collections of small point sources. Under current environmental law in most States these would be regulated by waste discharge licensing, septic tank regulations etc., although groundwater protection in general has only recently become a concern requiring address as part of this process. Exceptions to this are underground storage tanks, some mining activities and most abandoned waste disposal sites, all of which are high on the priority lists of groundwater protection authorities.

By using this approach to protection, it is believed that the majority of new potential contamination sources can be designed to minimise contaminant impact potential and protect groundwater (or alternatively prohibited on the grounds of potential impact to groundwater). Consequently, the appropriate level of protection in the case of point-sources, may be defined by an impact assessment based on the relevant classification of beneficial use for groundwater in the area. This may then be implemented as part of the existing environmental management or waste discharge licence system.

The protection of groundwater at specific sites, such as landfills, can be achieved in a number of ways. One potential protection scheme is the multi-barrier concept which applies in Germany to landfills located over groundwater bodies. The owner of the landfill must show the regulatory authority that it has barriers in place to handle a variety of risks. These barriers cover:

- the stability and characteristics of the site (a geological barrier);
- the sealing system (a technical barrier);
- controls over the waste (a material barrier); and
- subsequent safeguarding of the landfill after closure.

The application of a protection scheme to new proposals for potentially contaminating activities is straight forward. These schemes can also be applied in cases which involve diffuse sources, such as fertiliser and pesticide contamination. For example, the use of pesticides in some agricultural systems requires compliance with chemical handling regulations, and the relevant Department of Agriculture would normally have some regulatory or advisory role. If pesticide use in a certain area becomes a concern to the water sector or the environment agency, then the agriculture authorities or a group of land owners might be required to comply with a groundwater protection order and undertake work to ensure an appropriate protection level.

There is a large variety of actions that can be taken under emerging environmental legislation. Some specific examples of possible actions, including the use of market incentives, are provided in Section 5.7.

4.6 Other Measures

The development of protection strategies should also include suitable arrangements for monitoring and reviewing the performance of protection measures. An example is given in Section 5.8 of the development of suitable monitoring and review arrangements.

A strategy should also allow for the worst and have a contingency plan. Section 5.9 provides an example of this component of a protection strategy. In addition, significant technical guidance is provided in Appendix III to various facets of investigation, monitoring, reporting and remedial action which could comprise a contingency plan.

Strategies can be implemented under various legislative powers of State and local Government. Examples of some protection measures which can be implemented under State and local government powers are given in Table 3. A comprehensive tabulation of all available measures for each Australian State and Territory along the lines of this tabulation would be a useful starting point for identifying the list of potential players in groundwater protection.

For each State, Territory and the Commonwealth, a possible initial step in development of a plan would be to examine all legislation and organisations which have groundwater protection responsibilities associated with them. The strengths, weaknesses and aspects not covered or inadequately controlled by legislation or organisations should be found. This could be followed by a survey of the adequacy of groundwater contamination information and monitoring. Once this Statewide position is known, and deficiencies remedied if necessary, development of protection plans can proceed for each aquifer or groundwater province.

TABLE 3
EXAMPLES OF SOME PROTECTION MEASURES

	State Government	**Local Government**
Water Management Measures	-provision of vulnerability maps -driller licensing -prioritising protection areas	-assist in the implementation of Wellhead Protection Plans
Land-use Planning Measures	-requirement for groundwater assessment for prescribed activities in protection areas -provision of referral advice on groundwater protection areas	-amendments to planning controls over land clearing and development to protect groundwater -enforcing conditions placed on development and land clearing
Environmental Management Measures	-requirements for impact assessment and monitoring at landfill sites -compliance policies for all new projects -underground storage tank monitoring	-developing and implementing waste management strategies -improved garbage collection and recycling to minimise waste disposal -preparing and amending local environmental plans to protect groundwater -providing professional advice on local issues -information dissemination to the community -co-operative measures to police environmental legislation

5. DEVELOPMENT OF A PROTECTION PLAN

5.1. Background

Strategies can be applied to a specific groundwater resource under an overall protection plan. Groundwater protection plans and their component measures may take many forms. They may vary from policy statements outlining broad management objectives to prescriptive regulatory programs, including statutory controls and specific regulations on contaminating activities. Their intent may be limited to influencing decision making regarding approval of potentially contaminating activities, or it may be to closely control these activities. Protection plans may apply to specific geographic localities of various sizes from Statewide to a small aquifer. They may cover part or whole of an aquifer, or groups of aquifers. Groundwater protection plans may be directed to minimising future contamination of groundwater, or to detecting and managing contamination associated with past or existing activities.

The scope of protection plans and the range of measures which may be incorporated in these plans is endless. One practical approach to development of a groundwater protection plan has been selected for description in this chapter. This approach has the flexibility to be adapted to a large variety of political, institutional, legislative and physical circumstances. It is a case study of plan development at a regional level using mostly conventional regulatory provisions. The text is written with detailed examples from good overseas practice so as to illustrate major points in plan development. The steps in the overall development of this plan are illustrated in Figure 3. The Implementation Guidelines of the National Water Quality Management Strategy provide further information.

Development of a protection plan for a specific region will need to address several issues. The involvement of the public in the planning process will be an important initial decision.

The physical characteristics of the resources which are to be protected need to be understood. Once there is an understanding of the resource in terms of its quantity, quality and extent, the objectives of protection need to be identified in terms of their existing and potential beneficial uses. For each category of beneficial use, appropriate criteria then need to be selected. A separate set of processes and decisions will apply if there are no identified beneficial uses or values.

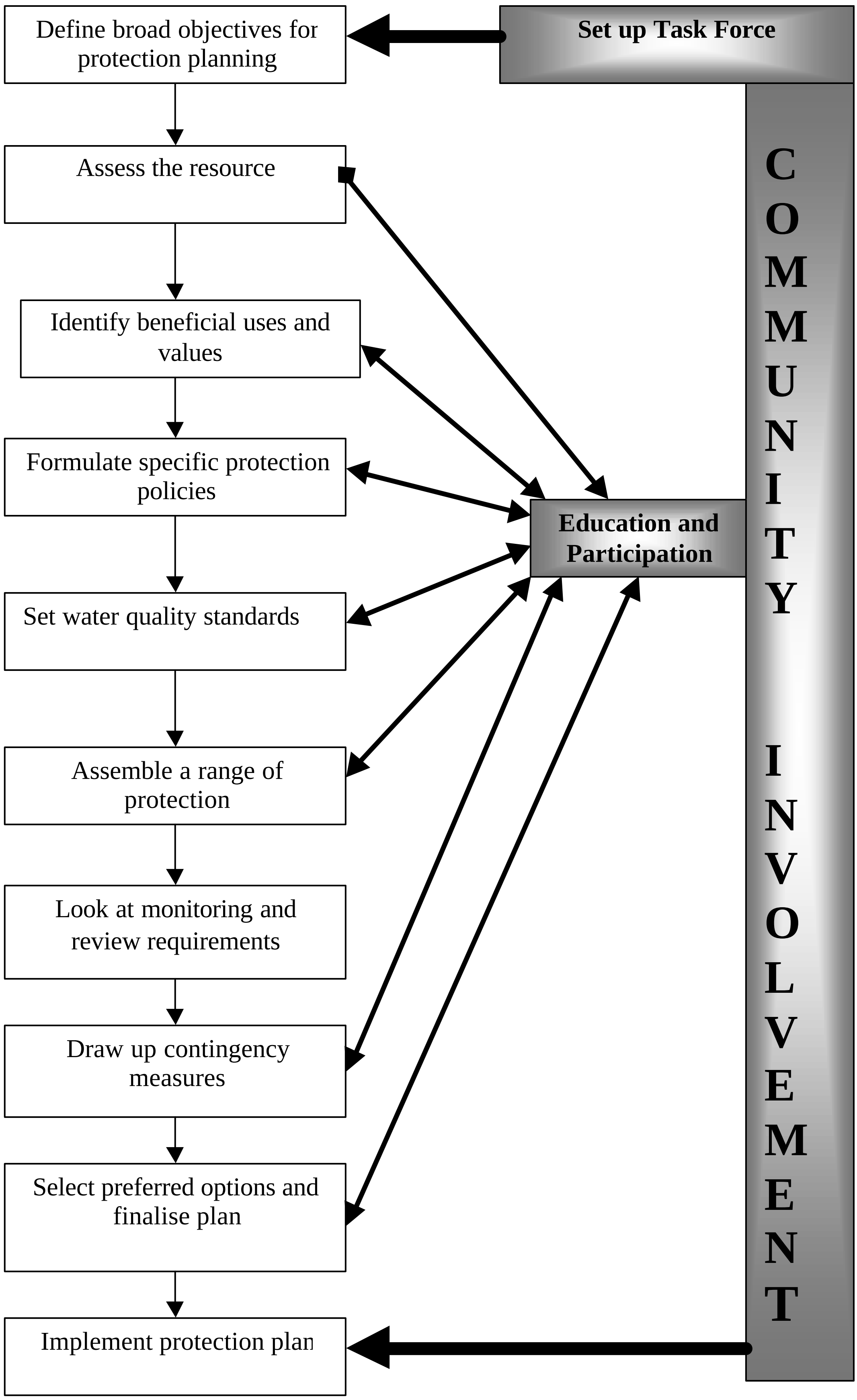

FIGURE 3: EXAMPLE OF STEPS IN DEVELOPING A REGIONAL PROTECTION PLAN FOR GROUNDWATER

Various components of the protection plan need to be considered at this stage. Aquifer classification systems, the assessment of vulnerability, land-use controls, and considerations of the risk and consequences of contamination by different activities and substances are some of the measures which can be evaluated. These components need to be packaged as part of an overall plan of action under legislation from the groundwater management, land-use planning and environment protection areas of government.

Other issues such as contingency actions and monitoring requirements also need careful consideration. Implementation will also require definition of the roles of the various agencies, and co-ordination of their efforts. It is important that there be unambiguous lines of responsibility for decision making and management. Part of any groundwater protection plan will require identification of these responsibilities, proposed outcomes and timetables for action, followed by regular reporting to government and the community on the success or otherwise of the protection plan and agency responsibilities.

A groundwater protection plan is not a static event. It must evolve with improvements in the information base and changes in society and land use. This requires an adaptive management approach. This will require regular review of strategies, their priorities, effectiveness, direction and focus and the evolution of adapted or different strategies in order to continually meet protection objectives. This cycle of events is simply illustrated in Figure 4.

These issues are discussed in further detail through the remainder of this chapter.

5.2 Public Involvement

In today's society, the management of natural resources must have public involvement.

There is a clear trend of increasing expectation within the community for high standards of protection of the environment and the quality of drinking water sources. The public therefore must be involved in the development of a groundwater protection plan as it will be both affected by the plan, and will have a desire to support, amend or oppose components of the plan. An informed public is a valuable asset in achieving the implementation of a plan.

Statutes and policies are limited in their ability to provide effective protection of groundwater resources. Development and implementation of these require community support and cooperation in the long term. This is best achieved through an aware and informed public who can debate the issues and give support to initiatives that, in a less informed community, may be politically unacceptable.

The value of public involvement is not restricted to adequately addressing public concerns. There is a potential for greater public identification and ownership of strategies fostering mutual trust and understanding, particularly where trade-offs may need to be made. After all, if people have the same information as the decision makers then they are likely to come to the same conclusions.

Adaptive Management Cycle

Develop Initial Plan
Implement Protection Plan
Develop Appropriate measures to correct deficiencies
Monitor and review performance of plan against objectives
Identify deficiencies

FIGURE 4: ADAPTIVE MANAGEMENT APPROACH TO PROTECTION

Public involvement has two related components: public education and public participation. Public education is the comprehensive provision of information to the public to improve awareness of the nature, value and sensitivity of groundwater resources. Public participation is the involvement of various sectors of the community in the development and implementationof programs to protect, conserve, use and monitor groundwater resources.

It is probably fair to say that, in Australia, the level of understanding of groundwater by the lay public is poor. This is in terms of understanding how and where groundwater occurs, the processes affecting its recharge, movement and discharge, and how it is affected by interaction with human activities. The traditional 'mythology' associated with groundwater plays an important role in preserving the status quo in respect of the public's understanding. It should be a priority of any Statewide strategy to include a program of public information to raise the level of public understanding of groundwater and its associated management issues. The myths need to be explained, and where appropriate, dispelled. The level of debate on groundwater issues involving an informed public can then be more useful than the hindrance often presented by uninformed debate.

The experiences of resource management agencies in New York State clearly show how public education and participation have been an integral part of successful resource management on Long Island. There have been major achievements in development and implementation of groundwater protection programs for the resources underlying the island. These achievements were made within a society that resists State Government regulatory activity that affects the freedom or rights of an individual. The New York programs are so restrictive that they could be considered to even exceed the reasonable expectations of programs that could be put in place within a more compliant Australian society.

The New York agencies overtly recognise the important role that public education plays in the successful development of groundwater protection programs and regulations. Typical agency efforts at public education and participation include:

- public hearings and/or information meetings on new regulations or programs;

- public hearings and/or information meetings on controversial regulatory decisions, permits, enforcement cases, etc.;

- routine publication of agency public information magazines, bulletins, pamphlets and reports;

- speeches, press interviews, magazine articles by agency representatives on elements of government programs;

- responses to citizen questions and/or complaints; and

- public information 'hot lines'[1].

A first step in developing a groundwater protection plan may be to form task forces that both inform the community and obtain its view through several initiatives. These initiatives could include public seminars and hearings, meeting with local public officials and interest groups, and publishing handbooks and brochures explaining groundwater issues.

An important ingredient of successful public involvement is development of an extensive, professionally competent press coverage of issues. This should consciously form a component of any major planning process.

It should be recognised, that as important as public involvement is, there should not be an expectation of universal participation, nor of achieving an outcome entirely satisfactory to all parties. The reality is that somewhat small numbers of the community participate, and there are often conflicting concerns that cannot be reconciled to everyone's complete satisfaction. What is important, is that the public are involved to the extent that they are satisfied their concerns receive consideration in determining an outcome.

5.3 Strategic Assessment of Groundwater Resources

The choices related to development of a specific protection plan require a strategic assessment of the groundwater resource. This assessment involves an appreciation of the magnitude and quality of the resource, its recharge and discharge zones, its interaction with surface water and other groundwater resources, environmental links and demands, and consumptive demands on the resource by all consumer groups. Most assessments will be limited by the amount of good data available.

A precursor to development of a protection plan is knowledge of the resource to be protected. This requires an understanding of water quantity in terms of the water balance of the resource, including -anthropogenic and ecosystem water demands and the availability of water to meet these demands. The water demands and potential resource yields will form the basis for designation of beneficial uses and values to the resources through an allocation process that is discussed further in Section 5.4. The designated beneficial uses and values then provide a rational basis for development of detailed protection goals.

An understanding of the water quality regime is necessary for the development of water quality protection goals. Some aquifers are of pristine quality and their protection program could be different to that of an aquifer whose quality is so poor (naturally or through contamination) that it may be unusable.

The location of aquifers is also important. Fresh water aquifers are of high value regardless of where they occur. In arid areas aquifers could require a particularly high level of protection activity because of their extremely high value to communities. Some fresh groundwater at great depths may have limited economic or environmental value. These resources may not warrant as high a level of protection activity at this stage.

This assessment of resources should not be limited to waters of potable quality. Brackish and saline resources are often valuable sources of water for industry, or as feed water to desalination plants in areas where fresh resources are or may become scarce. They also require decisions on their potential use.

Finally, an understanding of the physical characteristics of the groundwater resource requiring protection is necessary so that the protection area boundaries can be determined.

5.4 Protection Objectives and Beneficial Uses

The general policy approach on the objectives of protection needs to be clearly defined and articulated in formulating any strategy. This policy approach is the basis for determining water quality objectives.

The objective of a regional protection plan should be consistent with the national water quality policy objective. The national objective aims to *"achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development"*.

Within this broad policy objective, there is the normal process of defining beneficial uses and values in which the policy of protection or, if possible, enhancement of the resource is to be pursued. The most straight-forward protection decisions for aquifers are when non-degradation policies are strictly applied in sensitive zones. These situations occur when an aquifer is identified as requiring maintenance of quality at its current level for conservation reasons. A broad range of exclusion policies can be applied to keep the aquifer in a pristine state. However, these pristine situations are becoming rarer with time.

For some large aquifers which are subject to development it may be desirable to identify different beneficial uses and values for different parts of these larger scale systems. Some reasons for adopting a variety of beneficial uses and values are:

- differing vulnerability to contamination may require different levels of protection to be provided;
- certain contaminants may either be fixed within an aquifer or be subject to chemical or biological degradation prior to impact on a beneficial use;
- the types of uses of the resource may vary and each use requires a different level of quality to be maintained, e.g. beneficial uses;
- there may be variations in the expected degree of treatment of different resources before use;
- there may be variability in the existing quality of different resources that suggests different levels of protection should apply;
- the importance of some aquifers over others in terms of their value and consequence of loss ;
- an assessment of the economic and social values of land and other resources within some catchments may require absolute protection via total exclusion from risky contamination activities.

A protection plan flowing from these objectives can incorporate one or a variety of the groundwater management measures outlined in Section 4.3. Vulnerability assessment and mapping, various aquifer classification systems, systems based on levels of protection and wellhead protection provisions are available. Adoption of these measures will depend on factors such as regional groundwater conditions, aquifer vulnerability and the type of contaminant which poses a threat.

There are also instances when protection policies are written to preserve groundwater quality above certain specified criteria. Such policies should be developed recognising the need to sustain beneficial uses. The standards specifying degradation limits can be expressed in either prescriptive or narrative forms. The prescriptive forms can be qualified by the requirement for application of best management practices.

There will be rare circumstances where aquifers have no identifiable beneficial uses and values. An example is where there is a deep confined aquifer in stable geological structure which contains extremely poor quality water because of high salt or radioactivity levels. This confined aquifer may be sought to be developed as a long term depository for wastes.

There will also be complex decisions which involve requests for further degradation of polluted aquifers where there is no foreseeable opportunity on technical and economic grounds for rejuvenation. There needs to be a careful case-by-case assessment carried out of these situations to ensure that there are no remnant beneficial uses and values that require protection. The costs of investigating and developing these aquifers can fairly lay with the proponent. The proponent also needs to show that there are long-term benefits to society by taking this course of action.

In making these assessments of the use of underground sites for waste deposition, there needs to be a strong recognition given to the precautionary principle. This principle implies that we should not put wastes into an aquifer if there is even a minor chance of this leading to significant future problems or militating against possible future beneficial uses. It must be remembered that the injection of liquid or gaseous pollutants will increase the potential for groundwaters to migrate and the option of clean-up is unlikely to exist.

5.5 Identifying Beneficial Uses and Appropriate Criteria

A regional groundwater protection strategy should include a program for the assignment of designated beneficial uses to water bodies. This program will usually involve the following sub-programs:

- an assessment of the total water resource in the region in terms of both quantity and quality;
- an assessment of the existing and planned developments in the region in terms of their potential demands for water and the type of water use;
- an assessment of the important environmental features that are reliant on the region's water resources; and
- specification of the policies for water allocation which should identify any existing commitments to the environment and a conservative estimates of general environmental requirements.

This information provides the basis for the designation of beneficial uses for the region's water resources.

In some instances, it will be necessary to examine the ecological and consumptive management objectives associated with a water body in more detail as a single beneficial use category may not be adequate for protection purposes.

For example, if a resource has the two perceived priorities for protection of ecological value; and drinking water, the beneficial use of ecological protection would be most likely chosen as aquatic ecosystems generally have more stringent water quality criteria. However, some specific parameters such as fluoride are not critical in ecological systems but constitute a health concern in drinking water. The converse applies to phosphate which is neither of health nor aesthetic: concern in drinking water but is critical in wetlands. It is therefore appropriate to form protection criteria that are a combination of those from the two normal beneficial use categories in order to protect the two primary objectives. These criteria will normally be the most restrictive value from the two sets of criteria.

It is obvious, but should be stated nonetheless, that existing uses should be designated for protection unless other beneficial uses requiring more stringent objectives are defined.

5.6 Narrative and Prescriptive Criteria

Water quality criteria are a vital part of any groundwater protection plan. These may be narrative or prescriptive. They will relate closely to the designated beneficial uses for which the water is being protected.

Narrative criteria allow maintenance of flexibility in determining the acceptability of potentially polluting activity. However, there is a risk of inconsistency of approach, and difficulties can be created by establishing undesirable precedents in such decision making. Decisions under narrative criteria can often be challenged as arbitrary or capricious. Consequently, narrative criteria are less informative than prescriptive criteria and are harder to enforce.

On the other hand, prescriptive criteria provide a basis for consistent decision making. They provide clear goals for proponents of potentially polluting activities to meet. Prescriptive criteria suffer from a lack of flexibility, and are difficult to develop in terms of covering all the potentially polluting substances or activities.

In developing prescriptive criteria, maximum water quality criteria for the designated beneficial use should not always be directly adopted. A non-degradation objective may override these criteria in circumstances where the existing levels of contaminants are lower than the criteria.

For example, the ARMCANZ/National Health and Medical Research Council (NH&MRC) drinking water guideline values may not be directly applicable as water quality protection objectives for a groundwater resource with a designated beneficial use of drinking water. If the guideline values are used directly, there is a potential for them to be used as 'target' levels for contamination. The ultimate result could be that a resource becomes contaminated to levels just below or at the guideline values. While this may mean that a resource still satisfies the drinking water guidelines, such high levels of contamination may not be publicly acceptable. There is also the strong risk that any review of drinking water guideline values may result in development of more stringent guidelines. In such a case, the previously contaminated but unpolluted resource may become technically polluted.

A combination of prescriptive and narrative criteria provides another possible solution. The narrative will allow some flexibility. It also ensures interpretation of the prescriptive criteria towards achievement of a well-defined protection goal. For example, the State of Wisconsin has legislation in its Groundwater Standards Law (1984)[2] which provides a possible approach. Under this law, a two-tiered system of water duality standards is established for every substance already detected in groundwater or with the potential to reach groundwater. The two standards are an 'enforcement standard (ES)' and a 'preventive action limit (PAL)'.These represent concentrations of the substances in groundwater.

The ES is set at the level necessary to sustain the beneficial use of the resource. For example, the ES for drinking water is the equivalent of the drinking water quality guideline values. The PAL is either 10, 20 or 50% of the ES, based on potential health effects of the substance: 10% applies to carcinogenic substances, 20% to substances with potential health effects (non carcinogenic), and 50% to substances without health concerns but with aesthetic implications.

The PAL is used for several purposes:

- to stabilise the criteria for design of facilities (e.g. a landfill);
- to set up rules for use of certain products (e.g. agricultural chemicals) to prevent contamination from the outset;
- to serve as an early warning and trigger to a remedial response;
- to provide a buffer against the accidental exceeding of design criteria; and
- to provide a buffer against future review of use related water quality criteria.

The ES is a level beyond which the regulatory agency must act to prevent continuation of the contaminating activity. When substances are detected entering the groundwater at concentrations equal to or above the ES, a violation occurs and the activity is subject to immediate enforcement action. Unlike the PAL, where technical and economic feasibility of remedial actions are considered, a regulatory agency must prohibit continuation of the activity unless an alternative response will achieve compliance with the ES.

5.7 Point of Application of Criteria

Policy decisions must be made on the point of application of adopted water quality criteria. Three options are usually available for this location:

- at the boundary of a zone of discharge sufficient to allow for dilution and possible subsurface degradation of contaminants;

- at the boundary of the property upon which the effluent is discharged; and
- at the point of discharge of effluent.

The 'zone of discharge' approach allows more flexible approaches to be taken to contaminating activities. It does require a detailed knowledge of the hydrogeology and hydrochemistry of the receiving aquifer, and may require the installation of extensive monitoring networks to ensure compliance. The zone of discharge may be within or extend beyond the boundaries of the property containing the discharge point. If the zone extends beyond the boundaries, there must be careful consideration of the impact of contaminated water underlying adjoining properties.

The main disadvantage of the zone of discharge or 'property boundary' approach is the potential for a large concentrated plume of contaminated water to exist within the system boundaries. The future movement of this plume may result in criteria being exceeded at the designated boundaries. Remediation or contingency action may be either difficult or expensive.

The 'point of discharge' approach is a preventive approach and ensures much tighter control of the discharge process, before significant contamination aggregates in the aquifer. Water quality standards for point of discharge policies can be developed based on the expected natural dilution and degradation within the aquifer, and on its expected assimilative capacity.

The most effective policy is a combination of the point of discharge with either of the other approaches. This allows monitoring and management of the discharge at source since the flow of contaminants to the aquifer may be slow, and provides for monitoring and management in terms of the effect of the discharge within the aquifer.

The adoption of this combined approach should not rule out other options. For example, in some circumstances the water table or a particular confining layer or strata boundary may be more appropriate locations for monitoring. In future, the vadose zone (the intermediate zone between surface recharge areas and aquifer receptors) may become a better location and provide an early warning of contamination. Significant improvements in monitoring should not be ruled out.

Water quality objectives could form part of an Environmental Protection Policy for an aquifer if opportunities are available to use such policies to implement a groundwater protection plan (see Section 4.5).

5.8 Land-use Planning Options

Land-use controls are a principal means of providing protection for groundwater resources. Section 4.4 has already indicated some possible situations where they would assist with groundwater protection.

Land zoning creates expectations among landholders about activities that can be carried out on their land. This creates considerable difficulty if those activities conflict with protection of an underlying aquifer. An extreme example is an industrial zoning overlying a drinking water source with high protection priority. In these circumstances, the type and extent of industrial activity that could be carried out would be extremely limited. The ability of landholders to make reasonable use of their land commensurate with its zoning would be curtailed accordingly. On the other hand, appropriate land zoning can ensure that landholder expectations are aligned to land uses commensurate with required levels of protection of underlying groundwater resources.

A completely prescriptive approach to the compatibility of land-use options with specific levels of groundwater protection is usually not practical. Most land uses can be managed to reduce the risk of contamination. For example, residential land can be subject to requirements for reticulated sewerage that provide a significant reduction in potential contamination compared to unsewered developments. However, it is not possible to comprehensively prescribe the management requirements for all land-use options. In particular, it is difficult to protect unconfined aquifers in urban environments.

An approach to this problem is to develop a land-use risk matrix to help decision making on the compatibility of land uses. The land-use alternatives can be few or many depending on specific needs, and the risks of each can be assessed in terms of particular water quality parameters.

The differences between risk and consequence of contamination make rigorous unequivocal assessment of land-use compatibility difficult. While the risk of a particular type of contamination resulting from a land-use activity may be low, the consequences may be considerable. The converse also may apply. The specific hazard resulting from any particular contamination source will depend on how much is released, when it is released, and where it is released[3].

There is a degree of subjectivity in developing risk matrices, and there could be considerable argument about the specific assessments of matrix components. However, they can provide a useful guide to the relative levels of compatibility of different activities. For example, managed residential development can be of lower risk than poorly managed rural or industrial land uses.

Groundwater management options for protection of a resource under the various land uses can be developed from inspection of detailed risk matrices. For example, residential areas with reticulated sewerage, high integrity protection of underground storage tanks, and limited commercial areas provide a relatively low risk of groundwater pollution.

Land zoning and groundwater management options to provide required levels of groundwater protection must account for the existing situation in terms of land tenure and existing land planning. There needs to be a balance between groundwater protection objectives and broader community expectations and considerations for land use.

The trend towards the utilisation of sewage effluent on land has significant implications for groundwater. The decision over the siting, type and level of sewerage treatment and the disposal of effluent require recognition of the role of groundwater as a transporter of wastes and also as the sink for wastes in the long term. These decisions require a broad scale planning approach.

The difficulties that may arise if groundwater allocation policies or protection plans become **de facto** land plans should also be recognised. Land planners require advice on the criteria they need to consider to ensure land-use plans are compatible with groundwater protection objectives. To this end, land planning strategies and processes need to complement groundwater protection plans, and allow the land-use component of protection plans to be implemented. Water resource and environmental agencies can be given one of a range of legal rights to deal with these interrelated issues such as reservation rights over certain lands and veto or referral or appeal rights over development and land use change proposals.

5.9 Environment Protection Options

There is a body of environment protection legislation emerging from State and Federal Governments in Australia. This legislation not only aims to protect the environment from waste pollution but also protect the environment by minimising the production of waste. Consequently, groundwater protection decisions can be improved not just by considering contamination controls but also by minimising the amount of waste produced by the recycling and reuse of waste products.

The conventional regulatory approach to protection concentrates on permissible activities. In future, community action and market mechanisms may considerably improve the mix of options available. The introduction of market mechanisms, such as tradeable permits, will require explicit and exclusive definition of rights to produce or dispose of waste, and the administrative and monitoring skills to enforce these permits at a reasonable cost.

5.9.1 Permissible activities

One regulatory approach to groundwater protection which has emerged from environmental legislation is the prescription of activities or types of discharges that will be allowed over a specified aquifer or class of aquifers. Definition of activities that will not be permitted can also help in clarifying prescriptive or narrative standards. This approach may be applied with a formal aquifer classification system as discussed in Section 4.3.3.

Strategies should provide specific guidance on how to deal with potentially contaminating activities within designated protection areas. This applies to activities such as waste disposal sites, underground and above around storage tanks, surface impoundments and material stockpiles.

For example, waste disposal sites need to be considered from several different aspects including:

- whether they will be completely excluded from particular areas;
- whether they will be permitted subject to application of certain construction technologies to enhance containment (e.g. lining);
- whether they will require underdrainage for leachate recovery;
- whether they will be controlled in terms of the materials allowed to be deposited;

- the extent to which monitoring will be required; and

- the nature of contingency action that may be required

similar considerations need to be applied to all other potentially contaminating activities involving the handling, storage or disposal of hazardous or toxic materials.

5.9:2 Market incentives

Market incentives can be introduced in many forms. If pesticides are contaminating groundwater across broad areas then a tax on pesticides would reduce their use and consequently reduce contamination. However, there are inefficiencies in doing this, since many users of pesticides may be located in areas not overlying important groundwater bodies.

Market incentives are more likely to be introduced to improve the efficiency of existing regulatory arrangements. For instance, it is common for States to require a permit for any discharge of waste or contamination. In future, there may be a locality where these discharges go directly into an already degraded groundwater body. When there are a large number of discharge permits, market arrangements can be set up to improve the allocation of the available number of permits across multiple dischargers.

Under a normal market arrangement, the groundwater or environmental manager is required to determine the total amount of contamination which can be tolerated over a set time within the groundwater and subsequently the effect on beneficial uses. This is a difficult task which requires a significant amount of information and analysis.

The application of this type of market situation to groundwater is likely to be extremely limited since the focus. for all, highly valued aquifers for many years to come will be on protection from contaminants rather than introducing them. However, a case might evolve for market permits in the long term at some specific site.

5.10 Monitoring and Review

A program of monitoring and review should be an integral component of any protection plan. Two distinct sub-programs are required. One sub-program should monitor the effectiveness (if a developed groundwater strategy, in the broader sense. The second sub-program should involve technical groundwater resource monitoring and review.

It is important that the plan is monitored to evaluate its effectiveness. Effectiveness needs to be considered from two broad viewpoints:

- the extent to which the plan has been implemented; and
- the extent to which the plan has succeeded in meeting the desired goals for protection.

Attention should be given to the difficulties experienced in implementation, including an assessment of the extent of implementation. An issue to be considered in measuring the success of a plan is the extent to which compliance with requirements is enforced.

Groundwater resource monitoring and review are important elements of protection program to determine whether, when and how groundwater contamination is controlled. In practice, such monitoring is neither cheap nor simple. The parties responsible for any potential contamination should be responsible for the costs of monitoring and review of the data. Agreement on the implementation of a monitoring and review program should be reached before any potential contaminating activity is approved. This is an efficient approach since it internalises the full costs of potential contamination with the potential polluter.

The monitoring program should be consistent with adopted policy on the point of application of water quality standards (see Section 5.5). For example, if the policy applies standards at the point of discharge, then obviously monitoring should at least include that point. Monitoring programs also should attempt to define the impact of the discharge on the aquifer, and monitoring of the resource also should be included where practical. This particularly applies where 'zone of discharge' or 'property boundary' water quality standards apply.

The monitoring program should include a commitment for regular professional review and reporting of the data to the regulating agency.

Provisions also should be made for contingency action on detection of adverse impacts on the receiving aquifer. This is discussed further in the next section.

5.11 Contingency Measures

Approvals for potentially contaminating activities should include provisions for contingency measures. They should specify the contingency action that will be implemented. They also should prescribe as closely as possible, when an action should be implemented. Appendix III outlines technical details which will assist documenting actions which should be undertaken.

Contingency measures may vary from simply doing nothing, to ceasing the contaminating activity, through containing the area of contamination, to clean-up action.

In deciding the level of action to be taken, it is useful to assess the costs of proposed action against the benefits likely to be achieved. This will require several assessments including:

- the extent to which any existing or future beneficial uses may be compromised by the contamination incident;
- the alternative water sources available to those affected by the contamination incident;
- the range of potential remedial actions that may be implemented; and
- the likely outcome of any proposed remedial action in terms of meeting water quality standards, and the time expected to achieve the outcome.

Clean-up actions may be in situ and these usually involve a combination of techniques, including containment techniques. In-situ techniques are difficult, often expensive and often not totally successfully unless conditions are extremely favourable. They have yet to prove substantial cost savings. New in-situ remediation techniques, such as bioremediation for organics and nitrates, show promise although they are largely untried. Alternatively, clean-up may require abstraction of the contaminated groundwater followed by several combinations of options including treatment and re-injection, discharge to other receiving waters with or without treatment, or 'point of use' treatment. These techniques are also expensive and often not totally successful.

Use of an alternative source of water may be less expensive than clean-up. This option should generally be avoided where possible as it can create a precedent and expectation that it is acceptable to pollute a resource provided an alternative is available. The long-term consequences of this approach could be extremely undesirable, particularly where there is a strong demand for limited water resources such as cities and industrial areas.

The ability to achieve clean-up action is largely dependent upon the legislative support to the groundwater protection strategy. In some States (eg. Victoria and Western Australia), environmental protection legislation provides considerable power to enforce clean-up. These provisions include a retrospective capability. A practical consideration is the cost and viability of clean-up for the polluting industry. In Western Australia to date, the mining industry, the oil industry and some land developers have attempted to clean-up sources of groundwater contamination often on a voluntary basis. Development of a groundwater plan should therefore consider the legislative requirements to allow it to be effective.

5.12 Selection and Implementation of Preferred Options

From the discussion in this chapter it is evident that there are several alternative approaches to be taken and issues to be considered in formulating a protection plan. A broad approach for Statewide application should be selected from the alternatives and clearly defined. Within this, more detailed local measures can be developed that conform with the general approach selected.

One important aspect of implementation relates to co-ordination between interested agencies. The following agency types usually have an interest and need to be considered:

- water resources management agencies;
- water resources assessment agencies;
- environmental protection agencies;
- land management agencies;
- land planning agencies;
- health agencies;
- local government; and
- other agencies with responsibilities for related activities such as storage of explosives and dangerous goods, transport regulation, and public safety.

A high level of cooperation is required to effectively implement strategies with a multiplicity of agencies involved. The opportunity for more integration of agency functions may exist in some States.

It will be necessary to define the functions for which each agency will be responsible, and to decide the legislation most appropriate to each program within a protection plan. There should be consistency and co-ordination in the development and implementation of protection programs at various levels, and in various localities. There also needs to be a consistency of approach with similar or complementary plans that may be developed for surface water protection.

A rigorous economic evaluation of options will greatly assist policy makers when groundwater protection involves issues of degradation or diffuse-source contamination. Nitrate contamination of groundwater is an example of this type of problem.

In the latter case, extensive areas are often affected by contamination, and there are potentially long residence times within sails and groundwater systems. Very careful consideration of social, economic and environmental effects, such as land-use changes to reduce groundwater pollution, over the lifetime of a strategy need to be made. This requires a multi-disciplinary approach to planning. Another requirement of success is that the chosen set of options should be communicated, understood and accepted by the community.

6. CONCLUSION

The groundwater protection guidelines proposed in this report are intended to provide assistance to States, Territories and the Commonwealth in implementing or extending their groundwater protection policies. The guidelines are intended to address a broader range of basin/catchment management issues than are currently considered in groundwater protection strategies elsewhere, and allow for the integration of groundwater planning with surface water planning.

The guidelines are based on a planning approach. They adopt the principle of 'beneficial use' for groundwater classification and risk assessment to derive appropriate protection measures. The concept of 'polluter pays' is also adopted to ensure that parties responsible for potentially polluting activities share the responsibility for protection.

The guidelines have been framed so that they can be readily adapted to the different regulatory situations in each State, Territory and the Commonwealth. However, implementation of such a groundwater protection policy will require co-ordination between a number of government agencies with jurisdictions in areas such as water management, public health, environmental protection, land-use planning and waste management.

The protection of groundwater from contamination will always be dominated by regulatory measures. This is because of the long term and often irreversible nature of the damage imposed. However, there is considerable room for more community involvement in protection planning and also for the gradual introduction of market mechanisms where these are appropriate.

When States, Territories and the Commonwealth are developing groundwater protection plans for the first time, the initial effort should be focused where contamination will cause the greatest harm. The highest priority should be to protect resources which are used for drinking-water and that support important ecosystems. In view of attaining the objectives of these guidelines, it is concluded that a national goal should be set which is to at least provide a beneficial use classification for all significant aquifers in each State and Territory over the coming decade.

APPENDIX I

TYPES AND SOURCES OF CONTAMINANTS

TABLE I.1
CONTAMINANTS AND SOURCES

Industry	Activity	Contaminants
Water and Waste Water	Treatment plant floc Sewerage sludge landfill Waste water land spreading Septic tank effluent Lagoons	Heavy metals, high organics, nutrients (P,K,N), faecal bacteria, viruses, protozoa
Solid Waste Disposal	Municipal landfill Industrial landfill	sulphate, chloride, ammonia, TOC, high TDS, Biological contaminants, fatty acids, leachates.
Waste Treatment Disposal Industry	Storage of hazardous waste Waste handling	A range of mainly hazardous contaminants. See the 'priority contaminant" list.
Transport Industry	Storage of hazardous materials Fuel storage Oil and grease discharge Accidental spills	Hazardous materials on the 'priority contaminant' list. Petroleum hydrocarbons, benzene, ethylbenzene
Fire Fighting	Disposal/seepage of contaminated fire fighting water	Hazardous contaminants derived from industrial fire and fire fighting water
Agriculture and Agribusiness	Cropping practices Dairies and feedlots	Pesticides, herbicides, nitrates, TDS, heavy metals. High nitrogen and phosphorus loads, biological contaminants
Electricity Generation	Fly ash ponds and landfill Waste briquettes, tars	Sulphate, heavy metals, TDS, Se, Ge, petroleum hydrocarbons, PAH
Town Gas Production	Coal Tar disposal Gas scrubber waste disposal	Petroleum hydrocarbons, PAH, BTX, phenols, sulphur compounds, cyanide, ammonia, heavy metals
Chemical and Petroleum	Hydrocarbon storage hazardous material process Wastewater lagoons and storage Solid waste landfills Accidental spills	Petroleum hydrocarbons, PAH, BTX Vanadium Pentoxide

Table I-1 CONT

Industry	**Activity**	**Contaminants**
Mining and Mineral Industries	Mine water disposal Storage of fuel and hazardous chemicals Tailings dams Heap leaching	High TDS, iron, sulphate, heavy metals, organic flocculants, mercury cyanide, vanadium pentoxide, acidic water, Petroleum hydrocarbons and hazardous materials.
Manufacturing industry	Food processing Pulp and paper manufacturing Automotive industry Paint and printing Metal foundries, machinery plating and fabrication Timber mills and preserving Tanneries Coke and steel manufacture	Nutrients, Nitrogen, K, P, TDS, Organics such as lignins, organo-chlorines, sulphites, organosulphur Organic solvents, petroleum hydrocarbons Organic solvents, resin making compounds, heavy metals. Petroleum hydrocarbons, phenols, BTX, heavy metals, cyanide, furans, organic solvents. Tannins, arsenic, chromium, cresols, phenols, pesticide compounds, nutrients, Sulphides, TDS, chromium Metals, petroleum hydrocarbons.

Source: Adapted from Young (1981)[1]

TABLE I.2
PRIORITY CONTAMINANTS IN INDUSTRIAL WASTE STREAMS

Metals and inorganics:	**Pesticides and metabolites:**	**Aromatics:**
antimony	aldrin	benzene -
arsenic	a-BHC	1,2-dichlorobenzene
asbestos	lindane	1,4-dichlorobenzene
beryllium	dieldrin	ethylbenzene
cadmium	DDT	toluene
chromium	chlordane	xylene
copper	4,4'-DDE	
metal cyanide complexes	4,4'-DDD	**Phenols and cresols:**
lead	a-endosulfan	2-chlorophenol
manganese	b-endosulfan	2,4-dichlorophenol
mercury	endosulphan sulphate	2,4-dinitrophenol
nickel	heptachlor	2,4-dimethylphenol
selenium	heptachlor expoxide	phenol
silver	isophorone	4,6-dinitro-o-cresol
thallium	2,4 .- D	Parachlorometa cresol
zinc	2,4,5 - T	
Halogenated aliphatics:	**Polycyclic aromatic hydrocarbons (PAH):**	**Polychlorinated biphenyls and related compounds (PCB):**
carbon tetrachloride	acenaphthylene	aroclor 1242
chloroform	acenaphtene	aroclor 1248
dichlorobromomethane	anthracene	aroclor 1254
1,2-dichloroethane	benzo (a) pyrene	aroclor 1260
1,2-trans- dichloroe thylene	chrysene	
methylene chloride	fluoranthene	**Biological:**
1,1,2,2-tetrachloroethylene	fluorene naphthalene	*Escherichia coli*
1,1,1-trichloroethane	phenanthrene	**Others:**
trichloroethylene	pyrene	nitrates
		cyanide
Phthalates:	**Radionuclides:**	dioxins (chlorinated)
bis (2-ethylhexyl) phthalate	radon	
di-n-butyl phthalate	radium	
diethyl phthalate	uranium	
dimethyl phthalate		

Source: Adapted from US EPA (1985)[2]

APPENDIX II

WATER QUALITY CRITERIA

WATER QUALITY CRITERIA

Specific water quality criteria are often ascribed by water resource managers to individual beneficial use classes to assist in the implementation process.

A range of documents are available which list water quality criteria according to beneficial use (or protected environmental values) and provide methodologies for assessment (National Health and Medical Research Council 1987[1], World Health Organisation 1984 a & b[2], and Environmental Protection Authority of Victoria 1983[3]).

Recently, the Australian and New Zealand Environment and Conservation Council (ANZECC) carried out a study to provide national water quality reference values for specific environmental values (beneficial uses) of water. The ANZECC guidelines[4] focus on surface waters but are substantial and a useful starting point for setting water quality criteria for groundwaters around Australia. Other factors to be considered in establishing suitable criteria are local conditions, risks, economics and state policies.

The following provides a brief description of the five environmental values for which reference values are provided by ANZECC:

Protection of Aquatic Ecosystems

This category covers the protection of freshwater and marine aquatic ecosystems. The guidelines cover biological and physico-chemical factors, toxicants, and additional guidelines for protecting fish and water-associated wildlife.

Recreational Water Quality and Aesthetic

This category covers values for primary body contact, secondary body contact (less frequent) and visual use (no body contact) recreational sporting activities for water bodies.

Raw Water for Drinking Water Supply

The guideline values presented are taken from the document 'Guidelines for Drinking Water Quality in Australia', produced jointly by NH&MRC and AWRC in 1987. A new set of drinking water guidelines will be produced as part of the National Water Quality Management Strategy and these will supersede the values presented in the ANZECC document. A separate document from NH&MRC is likely to be produced covering algal toxins.

Agricultural Water Uses

Values are provided for the purposes of irrigation and livestock water use. A brief description is provided on farmstead water use which in normal times should be up to the standards of drinking water.

Industrial Water Quality

Guidelines values are provided for various industrial uses covering a range of generic processes (heating, steam generation and cooling); hydro-electric power generation, textile, chemical, food and beverage, iron and steel, tanning and leather, pulp and paper and petroleum industries.

APPENDIX III

TECHNICAL GUIDANCE DOCUMENTATION

TECHNICAL GUIDANCE DOCUMENTATION

Significant technical detail is required to establish the "Levels of Protection' approach described in Section 4.3.3 or contingency plans for groundwater protection. These technical details for assessing, reporting, investigating and monitoring contamination or pollution require technical guidance documents. In addition, details are also provided for documenting demonstrated groundwater protection systems and remedial action plans.

Many textbooks are available to assist with this task of documentation. However, much of the current state-of-the-art with respect to geotechnical practice for waste disposal is summarised in the proceedings of an American Society of Civil Engineers conference in 1987[1].

1. GROUNDWATER CONTAMINATION IMPACT ASSESSMENT

An impact assessment methodology for groundwater contamination assessment will need be designed, based on:

(a) Definition of criteria for unacceptable impact. These criteria should include:

- aquifer value;
- aquifer vulnerability;
- nature, type and source of hazard posed by proposed activity;
- technological safeguards for contaminant containment;
- operational advantages and disadvantages of contaminant manage systems;
- proposed monitoring system;
- clean-up mobilisation lag time; and
- impact of loss of amenity.

(b) Design of the analytical process to combine the inputs and arrive at a measure of impact.

Further technical guidance needs may be defined by analysing the inputs required in the implementation of the protection levels. This has been proposed in Section 3.3 of this report.

2. GROUNDWATER CONTAMINATION REPORT

The requirement for preparation of an assessment report would be ineffective some guidance as to the content of such a report is provided, much the same as for an Environment Impact Statement. It is proposed that specifications for the format and the level of detail in such reports be prepared for adoption by the States. Preparation of such reports will be largely dependent upon the availability of information on groundwater quality and characterisation of the potential sources using an industrial chemistry database. Formalisation of access to this information for groundwater professionals will also be required.

The contents of a groundwater contamination report should encompass that normally expected in a hydrogeological report. This would include:

a. **Geographic Setting:** This should provide a concise explanation of the physical setting of the site in terms of climatic regime; the topographic position of the site in the landscape and its relationship to the surface water drainage system; additional information on land use and vegetation can be relevant.

   This section should also present information on climatic averages, at least monthly and annually and preferably an adequate number of parameters to enable estimation of potential evapotranspiration. In particular it would be relevant to identify the periods of the year when recharge of groundwater is most likely.

b. **Geology, Aquifers and Vulnerability:** This section should describe the geology of the area in such a way that it enhances the readers understanding of the occurrence of groundwater rather than the geological history of the area, for example, the geological sequence should be described noting the lithologic units and structure. A typical stratigraphic column or cross section should be presented. The groundwater bearing and transmission properties of each major geological unit should be discussed and data on hydraulic properties presented where possible. The hydraulic relationships between each unit should be explained and potentiometric levels discussed if possible.

   The vulnerability of each aquifer should also be addressed in terms of the thickness of the unsaturated zone, the mineralogy of the formations, and other geochemical properties of the aquifer.

c. **Groundwater Flow Systems**: This section is presented separately to emphasise the need to appreciate the groundwater flow system as an important aspect of describing and investigating groundwater conditions. The flow systems should be described or interpreted on the basis of geological and topographic information, both at local and regional scale.

   Areas of recharge should be identified for confined aquifers and discharge areas should be indicated or at least postulated. It is important to identify or postulate areas with significant vertical flow components in the flow system as this can have significant consequences for the interpretation of field data.

   In addition it is important to explain any relevant interrelationships between surface waterbodies and the groundwater flow system; for example, where groundwater might discharge to wetlands or as stream baseflow.

d. **Groundwater quality, Beneficial Uses and Contamination:** This section should present information on the water quality of the main aquifers, the background levels of contamination and any evidence of elevated levels of contamination. The relationship between observed and expected water chemistry should be discussed.

A statement of the designated or potential beneficial uses of groundwater is the area that should be provided by reference to extant policy documents, the ambient water quality and available water quality criteria.

A statement of the potential fate of these contaminants and their impact in terms of the flow system, the aquifer vulnerability and beneficial use should also be provided.

e. **Groundwater Resources and Current Usage:** This section describes significance of groundwater as a resource and its current level and type of usage.

Estimates of replenishable and permanent resource volume in the basin or the local segment of the basin should be provided if available. This can be compared with current level of usage.

The types of current groundwater usage should be discussed in order to reinforce or contrast the discussion on potential beneficial uses of the groundwater.

f. **Potential Impact of Proposal:** This section discusses the potential impact of the existing proposed project or land use on groundwater quality. The potential contamination threats to groundwater quality should be identified and the chemical names and characteristics of the potential contaminants should be presented if possible. The significance of this impact in time and space should be assessed and discussed. The appropriate level of action should be identified and recommended.

g: **Summary and Conclusions:** A concluding section should be provided to succinctly describe the groundwater regime and make conclusions about the rank of the resource, the flow system and interrelationship to surface water and the vulnerability or contamination status of the groundwater systems in question.

3. SITE INVESTIGATION AND MONITORING

The level of activity at a particular site requires a substantial amount of documentation of procedures, in order to provide an adequate level of Quality Assurance and Quality Control such that variation in results between sites or at different times as a result of technical procedures, is minimised. The validity of a sample or test can therefore be established to the extent that it conforms to a defined standard.

The specific areas of procedures which need to be documented include:

- monitor well design and construction;

- groundwater sampling
- soil sampling
- chain of custody procedures
- field testing of groundwater
- laboratory test methods
- Quality Assurance/Quality Control (QA/QC) for laboratory testing; and
- Occupational Health and Safety (OH&S) procedures for workers.

Some of these issues are more significant than others and those areas of immediate interest to the water sector are discussed in more detail below. A preliminary guide to the standard operating procedures for groundwater sampling has been prepared by the Water Resources Management committee of AWRC[2]. A number of reference documents containing such standard operating procedures are included in this document.

3.1 Groundwater Monitoring Systems

Groundwater monitoring systems of various types are implemented for a number of purposes, but in general they can be one of two basic types:

- Groundwater Quality Monitor Systems
  These are designed for long-term monitoring of ambient conditions and to characterise the hydrogeology and background status of aquifers.

- Groundwater Contamination Site Investigation/Validation Systems
  These are designed to evaluate the contamination arising at specific sites and as a secondary function to monitor groundwater at least until there is no statutory need for the expense. This period of time could be long term.

Groundwater monitoring systems consist of a number of components which could be loos classified as either 'hardware' or 'software' components having associated capital or operational costs. The hardware usually consists of wells and measurement instruments while the software consists of manpower inputs to visiting and maintaining the system and data processing.

These systems generally function in the following manner and sequence:

1. Design of the monitoring system.

2. Installation of monitoring wells and equipment.

2. Characterisation of the baseline groundwater conditions.

3. Periodic measurement of water levels and water quality parameters.

4. Analysis and reporting of monitoring data.

6 Decision making on the future actions needed in response to the monitoring reports.

System Design: It is critical that monitoring systems are properly designed. This may first involve the establishment of the objectives of monitoring and consideration of the of the system in the management decision making process.

The design process will also determine the location of wells with respect to the groundwater flow system and sources of contaminants. Other specific aspects to be defined in the design stage
include the well design, the program of monitoring, resources needed, and the management and
reporting system.

Well Location: The location of monitoring wells depends on the purpose for which they installed.
In the case of site investigations, wells are constructed to evaluate contamination in groundwater:

-entering the site boundary;
-leaving the site boundary; '
-deriving from specific point sources within the site, and if possible; and
-evaluate ambient uncontaminated background quality.

The number of monitoring wells required near a suspected point source of groundwater contamination
will depend to a large extent on the size of the contamination source, and its perceived impact on groundwater quality.

In general the investigation of a point source will require the construction of at least wells
to characterise conditions and evaluate the groundwater flow direction. However in isolated rural
conditions there may be only the need for one or two wells for cases such as small landfill sites with non-toxic materials.

In the case of a groundwater quality monitor system, wells would generally be located within principal aquifers across a region to enable evaluation of the time and spatial variation in quality.
Components of this system could also be located within or downgradient of areas of suspected or
know contamination to monitor the long term effects on groundwater broad scale.

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Well Design and Construction: In terms of the hardware (the wells and fitments) all systems are basically similar, however the selection of materials and well design in a short term monitoring system will often be different from that needed for a long term monitoring system. For example, long term monitoring for organic contaminants may justify the use of stainless stell well casing, whereas for short term assessments PVC casing materials may be adequate. Further details on material selection are available in reference books.

The selection of drilling methods used to construct a monitoring well also needs to take account of the potential for contamination of the aquifer, however the geological condition will often dictate the choice of methods available. Standard methods sometimes need to be modified to reduce contamination or to prevent personnel coming into contact with hazardous contaminants.

An important feature of monitor wells is the selection of a discrete interval in the aquifer to be sampled. This is achieved by constructing the well using a short (1-3 m) length of screen isolated by a bentonite seal above the screen. An artificial filter pack is generally places around the screen. This also enables the installation of two or three piezometer tube (50 mm diameter) in one well with screens isolated at different intervals to sample different aquifers or zones within an aquifer.

Monitor well construction differs from conventional well construction in the level of precision and attention to detail, much in the same way as practised in geotechnical drilling and testing.

The use of monitoring devices to measure and log water level and water quality parameter would tend to be justified where monitoring is intensive or where the monitor wells are widely dispersed. This is mainly because the software (monitoring) component soon becomes the most costly component of the system, for longer term monitoring.

Characterisation of Hydrogeology: The characterisation of the hydrogeological condition of a site is a key component of the establishment of a monitoring system, particularly for the evaluation of contaminated sites. The work should involve the recording of geological information derived from drilling, measurement of water levels, definition of the groundwater glow system, and measurement of aquifer hydraulic properties.

These data and interpretations can then form the basis for the analysis of future monitoring data and for the establishment of computer models of groundwater flow and contaminant transport.

Monitoring Program: The monitoring program should be defined in the design phase as the desired program might not be feasible if the well depth, construction or materials are inappropriate.

Generally the monitoring program consists of a series of field measurements of water level and
some water quality perameters; groundwater samples are taken and tested in the laboratory.
The selection of test perameters is often determined on the basis of the characterisation phase when
a wide range of perameters would be tested. The monitoring program in the case of a site investigation
monitoring system need only monitor for a set of indicator contaminants as the frequency of sampling
is often quite high (weekly or monthly). In the case of regional groundwater monitoring network
it is more likely that the program would require a comprehensive set of chemical tests but the sampling
frequency is typically monthly, quarterly or even annually.

The standard operating procedures for sample collection, sample preservation and handling
chain-of-custody documentation and quality control/quality assurance are an integral part a
monitoring program. These must be available in written form for personnel involved monitoring
to use as a guide to the performance of the work. A preliminary guide to the standard operating
procedures for groundwater sampling has been published by the AWRC. This document will help the
States prepare their own guidelines if they do not already exist.

Data Management: Another component of a monitoring system is data management a trend analysis,
which should lead to decision making. While the emphasis may initially be on data acquisition,
the decision to continue or change the program is also important because the system is justified
on the basis of its use as a resource environment management tool.

The minimum requirement is for the data to be verified to assure that the reported result
relates to a specific sample and the laboratory results have been accurately input into database,
preferably of a computer compatible form.

The data needs to be reported in a format which indicate sample location and number, the limit
of detection and the units of measure.

The determination of trend or the significance of a value or group of values which exceed the
water quality criteria used for the program, needs to be performed in a systematic manner using
appropriate statistical techniques.

3.2 Quality Assurance/Quality Control

A Quality Assurance/Quality Control (QA/QC) system is required in the investigation of serious
groundwater contamination incidents to assure the integrity and reproducibility tests and provides a check on the contaminating potential of the sampling process.
QA/QC system for site investigations should include the use of:
Work Plan: A written Work Plan is required to be used as a guide to all personnel work on the investigation. It should contain information on the sample locations and number system, the standard operating procedures, the laboratory testing program and
Occupational Health and Safety Plan.

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Qualified Personnel: Another aspect of QA/QC is the deployment of trained personnel familiar with
the operating procedure and other aspects of quality assurance.

Chain of Custody: chain of custody procedures and documentation are used to ensure identification
of the sample, non interference with samples and request for correct laboratory tests.

Equipment Blanks: A water sample derived by washing the sampling equiptment in deioninsed water.

Background Samples: Samples taken from background wellholes during site assessment to determine
background groundwater quality data.

Duplicate Samples: Two sub-samples of the same groundwater sample sent to separate laboratories.

Spike Samples: Samples spiked with a known quantity of contaminant to test for recovery rate by
laboratory method.

Detailed technical guidance documents of this type have been prepared in the United States and
adopted and modified for use in Australia by local consultants. Further reference material on well construction can be found in the Johnson Water Well Handbook.

3.3 Occupational Health and Safety

Occupational Health and Safety (OH&S) is a matter of growing concern to authorities, site owners and particularly consulting companies whose workers are regularly exposed to hazardous
materials when investigating contaminated sites. In order to protect the health and safety of their workers, companies implement ongoing OH&S monitoring programs.

These programs need to address the following:

- OH&S training;
- the hazards present on site;

• personal protection equipment requirements;
• on-site monitoring;
• site control;

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•decontamination
•emergency response
•medical surveillance program

A number of extant American OH&S guidance documents for use on contaminated sites have been adapted
by consultatnts for use in Australia.

3.4 Industrial Chemistry and Hazardous Materials Databases

Databases currently exist in Australia which may be used to quickly characterise the likely contaminants present on a site and define the toxicity of specific contaminants or the chemical constituents in a proprietary product. These databases which are currently derived from overseas provide a comprehensive guide to the properties of compounds, the effects of exposure and
their recommended handling procedures. They may be essential for an investigator in assessing
either the risk of contamination or the significance of known contamination. For example, the Kirk-Othmer database on industrial chemistry will ally the user to identify the chemicals used in any manufacture process.

A selection of these databases is as follows:

'ADCHEM' - Material Safety Data Sheet Service;
'KIRK OTHMER' - Encyclopaedia of Chemical Technology;
'NIOSHTIC' - Toxicological Database; and
'IRIS' - Integrated Risk Information Services;
'CHEMINFO' - a Canadian database with 40 000 compounds listed; and
'INFOSAFE' - a database marketed in Victoria.

Access to these systems is available through commercial information services or libraries. The
ADCHEM service is located in Melbourne while some others are US based. Obvious these databases
do not detail the locations of industries using compounds of environmental significance, and there is a need for such locally-derived information.

4. DEMONSTRATED GROUNDWATER PROTECTION SYSTEM

This level of protection requires the provision of information which can demonstrate that monitoring and protection system implemented will be effective in preventing acceptable contamination of groundwater.

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These systems can have active or passive components and the approach differs from a remediation plan only to the extent that the focus is prevention and not clean up.

The types of systems which can be considered within this category include:

- physical liner and barrier wall systems;
- hydraulic barriers and other groundwater movement control systems;
- numerical models of groundwater flow and contaminant transport; and
- a groundwater monitoring system.

This level of protection requires that the effectiveness of the system needs to be demonstrated. Such demonstration can be achieved in at least two ways:

- by conformance with an accepted standard in the design and construction of the system, for example, by adhering to a specification for a liner system; and
- by using the best available technology to demonstrate the space and time scale of the range of contamination outcomes both with and without the protection system. This could be achieved by numerical modelling using an accredited method.

It follows that an amount of technical guidance documentation will be needed in order to provide quality assurance at each stage of the design and demonstration of groundwater protection systems.

5. DEMONSTRATED REMEDIAL ACTION PLANS

The purpose of this level of protection is to devise a plan to restore a degraded groundwater body to a higher quality to satisfy a designated beneficial use. This could be required in the case of contamination having already occurred or where it may potentially occur in the future.

While remediation of contaminated groundwater is a common occurrence in the USA and Europe mainly associated with hazardous waste and petroleum facilities, the specification of remediation plans for as yet uncontaminated aquifer is less common. The remedial action plan proposed herein requires the proponent to demonstrate the technical feasibility of a clean-up in achieving the desired water quality objectives. The cost of remediation also needs to be estimated in order to evaluate the practicability of achievement. In addition the financial resources need to be assured to implement the clean-up, if necessary by the use of statutory financial assurance devices. Such demonstration could be achieved by a combination of reference to precedent, bench and pilot tests, numerical and physical models and adoption of a QA/QC system.

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The complex nature of the requirements of a remedial action plan necessitate the provision of some separate guidelines for the level of technical analysis acceptable. For example, it would be desirable for proponents to know the ground rules prior to making formal proposals for a project such that pre-feasibility studies can include an assessment of the cost of remediation.

Remediation Methods: Groundwater contamination clean up is performed in a number of ways, however
most methods incorporate some combination of physical controls and bio- hemical treatments either in situ or at the surface. The most common method of groundwater remediation practised in
the USA and Europe is pumping and treating. Table III-1 summarises the major methods for controlling, recovering and treating groundwater.
Methods using in situ biological treatments are becoming more attractive for large scale remediation where time is available to progressively achieve clean-up. These methods are ultimately much less costly than those involving rapid recovery of contaminated groundwater with disposal or conventional treatment by carbon filters and air stripping.

The most common approach to in situ bioremediation involves some form of groundwater recovery
combined with reinjection or land spreading in which the selected micro-organism which can consume
the contaminant compound is cultivated. The system can progressively improve the groundwater
quality by recirculating between the spreading area and the recovery system, until acceptable levels are reached.

Table III-2 summarises the main methods of groundwater remediation response to acute and chronic
contamination problems. This emphasises the importance of the time constraints it the choice of
method.

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A. Recycling v
are to reduce the volume of waste to be handled, or reduce the

B. Resource recovery
threat a certain waste possesses by altering its physical or

C. Centrifugation
chemical make-up.

D. Filtration
'

E. Sand drying beds

II.
Physical/chemical alteration

measures

A. Chemical fixation

B. Detoxification

C. Degradation

D. Encapsulation

E. Waste segregation

F. Co-disposal

G. Leachate recirculation

Well Systems
Well systems for groundwater pollution control are based on

manipulation of the subsurface hydraulic gradient through
I.
Well point systems
injection, and/or withdrawal of water. Well systems are
II.
Deep well systems
designed to control the movement of the water phase directly
III.
Pressure ridge systems
and the subsurface contaminants indirectly. This approach is
IV.
Combined systems
referred to as plume management. Well systems are also used
V.
Immiscible (hydrocarbon)
for recovery of immiscible contaminants, usually hydrocarbons,

contaminant recovery systems
that float on the watertable.
Interceptor Systems
Interceptor systems involve excavation .of a trench below the

watertable, and possible the placement of a pipe in the trench.
I.
Collector drains
The trench can be left open (interceptor trench) or backfill can

A. Leachate collection systems

be placed on a pipe in the trench (collector drain). Interceptor

B. Interceptor drains
trenches can be either active (pumped) or passive (gravity

C. Relief drains
flow). These systems function similarly to an infinite line of

extraction wells by effecting a continuous zone of depression
II.
Interceptor trenches
running the length of the trench.

A. Actively pumped systems

B. Gravity flow, skimmer

pump systems

Wastewater Treatment
Wastewater treatment technologies are utilised at the surface to

treat contaminated ground water. The technologies most
I.
Air/steam stripping
widely applied to organic contaminants are air stripping, carbon
II.
Carbon adsorption
absorption and biological treatment. Chemical precipitation is
III.
Biological treatment
used for inorganics and metals removal.
IV.
Chemical precipitation

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purpose. Surface water control measures reduce potential
I. Natural attenuation (no liner, no

infiltration by minimising the amount of surface water flowing
cap)
onto a site. Capping is designed to minimise the infiltration of
II. Engineered liner
any surface water or direct precipitation that does come onto a
III. Engineered cover
site. Impermeable liners provide ground water protection by
IV. Engineered cover and liner
inhibiting downward flow of low-quality leachate and/or

attenuating pollutants by adsorption processes.
Impermeable Barriers
Barriers are measures designed to influence the subsurface

hydraulic gradient by placing a low permeability material into
I. Steel sheet-piles
the subsurface. Barriers typically are constructed with driven
II. Grout curtains or cutoffs
sheet piles, injected grouts, or dug slurry walls. Sheet-piles
III. Slurry walls
provide immediate impermeability, while grouts and slurries

both are emulsions that require a hardening period to achieve

impermeability.
Ill situ Treatment
The in situ treatment methods involve adding materials to the

subsurface so as to cause or increase the rate of a reaction that
I. In-site chemical
will render a contaminant immobile or remove the contaminant.
II. In situ biological
The in situ chemical technologies attempt to immobilise

contaminants through some chemical reaction, while the in situ

biological techniques are designed to provide an environment

suitable for microorganisms to utilise the contaminant as food

source.
Innovative Technologies
Three of the innovative technologies that have yet to find wide

applicability are the block displacement method envirowall
I. Block displacement
concept, and fly ash stabilisation. The block displacement
II. Envirowall
method is similar to grouting except the emulsion is injected
III. Fly ash stabilisation
laterally with the effect of raising or isolating a whole block of

contaminated soil. The Envirowall concept involves vertical placement of a synthetic liner material within a slurry wall. Fly ash stabilisation involves injection of fly ash into an existing impoundment to solidity the contained liquid or slurry. It is the calcium oxide content of materials such as fly ash which are the active stabilisers, and the right sort of fly ash, usually 'Class C', needs to be specified. Other materials such as Portland cement and pulverised quicklime are commonly used in stabilisation work.

Source: Canter et. al. (1987)8

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Pollution problem	Goal	Methodologies
Acute	Abatement	In situ chemical fixation
		Excavation of contaminated soil with subsequent backfilling with 'clean' soil
	Restoration	Removal wells, treatment of contaminated groundwater, and recharge
		Removal wells, treatment of contaminated groundwater, and discharge to surface drainage
Chronic		

Restoration
Removalb wells, treatment of contaminated groundwater, and recharge Removal wells, treatment of contaminated ground water, and discharge to surface drainage Removal wells and discharge to surface drainage
In situ chemical fixation Excavation of contaminated soil with subsequent backfilling with 'clean' soil Interceptor trenches to collect polluted water as it moves laterally away from site Surface capping with impermeable material to inhibit infiltration of leach ate-producing rainfall Subsurface barriers of impermeable materials to restrict hydraulic flow from sources Modify pumping patterns at existing wells Inject fresh water in a series of wells placed around source or contaminated plume to develop pressure ridge to restrict movement of pollutants
Removal wells, treatment of contaminated ground water, and recharge Removal wells, treatment of contaminated ground water, and discharge to surface drainage Removal wells and discharge to surface drainage In situ chemical treatment In situ biological treatment
Chronic
Abatement

Restoration
Source: Canter et. al (1987)$
Notes
Acute refers to one-off occurrences such as spillages and accidental discharges. Chronic refers to long-to continuous discharges. The differentiation is made here to help with the preparation of contingency measures but the abatement/restoration schemes mentioned will often apply equally to both.
b Could also be referred to as interceptor wells.

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Glossary

Aquifer: Rock or sediment in a geological formation, group of formations or part of a formation which is capable of being
permeated permanently or intermittently and can thereby transmit water.

Aquifer, confined: A completely saturated aquifer that is overlaid and underlaid by confining bed. The confining beds have a significantly lower hydraulic conductivities than
the aquifer. The groundwater is contained under sufficient pressure to allow it to rise above the
aquifer if the overlying confining bed is penetrated. The level to which the water would rise is the potentiometric surface. Synonyms are pressure or artesian aquifer.

Aquifer, unconfined: A permeable soil or rock layer which is either partly filled with water or has no impermeable or semi
impermeable layer restricting a rise in the water table. It contains groundwater which is not subjected to any pressure other than its own weight. Watertable aquifer is a synonym.

Attenuation: the removal of contaminants from a solution passing though a porous medium by natural mechanisms such as ion exchange, chemical precipitation, absorption and filtration.

Confining bed or layer: A layer of low permeability material adjacent to one or more aquifers. Its hydraulic conductivity may vary from near zero to some value much lower than that of the aquifer.

Contamination: A change in water quality that produces a noticeable or detectable change in its characteristics

Diffuse Sources: Source(s) of contamination which is spread across a large area or region.

Discharge area: An area in which there are upward movements of hydraulic head in the aquifer.
Groundwater flowing toward the land surface in a discharge area may escape as a spring, leading to a discharge, seep or baseflow, or by evaporation and transpiration.

Drainage Basin: The land from which runoff drains into a stream system.

Drawdown: The difference between the observed water level during pumping and the non-pumping water level.

Ecosystem: An environment containing a community of adapted organisms interacting in such
a manner that there is a transfer of energy through the system and recycling of material resources within the system.

Groundwater: All waters occurring below the land surface.

Groundwater flow: The movement of water through an aquifer.

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Groundwater Basin: The area pertaining to a groundwater flow system, which is more or less separate from neighbouring groundwater flow systems. A groundwater basin may be separated
from adjacent basins by geologic or hydrologic boundaries.

Hazardous Waste: Means any waste present in sufficient quantities to present a danger.
(i) to life or health of living organisms when released in the environment;
(ii) to the safety of humans; and
(iii) to the safety or operation of equiptment in disposal plants if incorrectly handled

Hazardous substances may possess toxic, carcinogenic, mutagenic, or teratogenic characteristics
as well as flamability, chemical reactivity, infectious or other biologically damaging properties
(including radioactivity).

Hydrogeology: Brance of science dealing with groundwater, and the geological controls on its occurrence and movements,
its availability and chemistry.

Indicator: Any physical, chemical or biological characteristic used as a measure of environmental
quality.

Infiltration: The flow of water downward from the land surface into the sub surface.

Leachate: A liquid which has percolated through and/or drained from waste material and which
contains soluable components of the waste, including products of decomposition.

Municipal landfill: A site for the disposl of municipal waste to land.

Piezometer: A nonpumping well, generally of small diameter, which is used to measure the elevation
of the watertable or potentiometric surface. A piezometer generally has a short well screen through
which water can enter.

Point Source: A source of contamination which comes from a single point.

Pollution: A state of contamination for which the water quality has deteriorated to a point where the ability
of the water to support or maintain the existing or potential uses is diminished.

Potable Water: Water which is fit for human consumption.

Travel time: The time that it takes a contaminant to travel from the source of contamination to the
point of interest in the aquifer.

Recharge area; a geographical area in which water infiltrates then percolates to reach an aquifer.

Unsaturated zone: The zone between the land surface and the watertable. it includes the root zone, intermediate zone,
and capillary fringe. The pre spaces contain water at less than atmospheric pressure, as well as air and other gases.

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Vulnerability: A relative evaluation of the potential exposure of a groundwater resource to contamination.

Watertable: The surface of the saturated zone in an unconfined aquifer.

Well: A hole drilled into an aquifer for the purpose of monitoring or extracting groundwater. This generic term includes bores, water wells and tube wells.

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CHAPTER NOTES

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