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Environmental Performance Indicators for Groundwater

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Signposts for sustainability

Environmental Performance Indicators for Groundwater

REPORT TO MINISTRY FOR THE ENVIRONMENT

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1 INTRODUCTION

The purpose of this report is to strengthen the groundwater section of the proposed set of Environmental Performance Indicators for monitoring air, freshwater, and land. The development of these indicators is described in a discussion document, *Environmental Performance Indicators – Proposals for air, fresh water, and land* (MfE, 1997), and their purpose is for monitoring progress towards achieving the environmental goals specified in the document, *Environment 2010* (MfE, 1995). The review process that followed publication of the proposed indicators concluded that the groundwater section required strengthening.

The Environment 2010 goals for groundwater, as part of freshwaters, can be summarised as managing the quantity and quality of groundwater to meet the current and future needs of the natural ecology and human uses and values. Indicators of the performance of this management task need to be sensitive to the effects of human activity, against a background of natural variability. There are also requirements of feasibility, availability, and cost, which are addressed in this report.

The preceding paragraphs give a succinct summary of the context for developing environmental performance indicators for groundwater. The definition and development of these indicators involves detailed examination of a number of matters. These can be summarised as:

- Why monitor at all?
- Which aquifers should be monitored?
- What should be monitored, and what data should be collected routinely?
- Can environmental performance indicators be implemented?

An understanding of groundwater's role in relation to other parts of the ecosystem – particularly surface water, land characteristics and use, and air – lays the foundation for sound answers to the first three questions. Section 2 provides a simplified overview of how groundwater relates to air, land, and surface water in order to define the scope of the inter-relationships.

The answer to the "Why monitor?" question is presumed to be that society wishes to uphold certain values, with respect to groundwater. Protection of these values requires monitoring the pressures on groundwater, and the associated effects on what is valued, so that appropriate remedial actions can be taken when necessary. Hence it is necessary to identify the values to be protected, as well as to understand groundwater's role with respect to other ecosystem components. Section 3 summarises the main issues to do with groundwater in New Zealand, at present, and attempts to draw from them the values which are central to these issues.

Resources are not available to monitor every aquifer in New Zealand. Neither is it necessary. Section 4 proposes a strategy for developing an answer to the question "Which aquifers should be monitored?" that is applicable at both regional and national levels.

What should be monitored in each aquifer, and therefore which data should be collected routinely, depends on why the aquifer is being monitored. It is also constrained by current knowledge, technology, and resources. Section 5 discusses the selection of indicators in the context of the information and understanding gained through applying the strategy described in Section 4. Comments on the feasibility of implementing environmental performance indicators for groundwater are presented in sections 6 (data availability) and 7 (contributions from current research).

Section 8 summarises the main conclusions of the project

2 HOW GROUNDWATER RELATES TO AIR, LAND, AND SURFACE WATER

2.1 Introduction

Groundwater is not an isolated resource but has specific linkages to land and surface water resources, for which environmental performance indicators are also being developed. Some of the values that society holds for surface water can be adversely affected by how groundwater responds to land-use pressures, for example. This section describes these physical linkages to lay a foundation for the development of environmental performance indicators for groundwater that take account of the interdependency between groundwater and other ecosystem components.

2.2 A Simplified View of Groundwater Hydrology

Groundwater is an important component of the natural environment because it is water in temporary storage which smooth the erratic supply from rainfall and thus provides longer term flow for the ecology of streams as well as being a reservoir of water for human use. The storage medium is the aquifer, a geological formation that is sufficiently porous to store a useful volume of water and which has pores or fractures large enough to allow extraction of water at useable rates.

Typically, aquifers are bounded by impermeable rock through which there is no water flow, and by rivers, lakes, or the sea where water is able to move between the aquifer and these surface waters. Within an aquifer there may be horizontal layers of relatively impermeable material which confine the vertical movement of groundwater, although there may be some slow leakage through this material. Groundwater that is not beneath an impermeable layer is considered to be unconfined and therefore generally subject to the risk of contamination by water infiltrating from the land surface. Confined groundwater, on the other hand, is at risk of contamination from specific areas of the land surface where recharge originates, by leakage through confining layers, by sea-water intrusion, or by water-rock interactions.

The amount of water stored in an aquifer, excluding human intervention, is determined by the difference between recharge through the land surface and flow out to surface water. The water level in a well is an indicator of the amount of water stored, but the quantitative relationship depends on the geological characteristics of the aquifer, well depth, and the location of the well with respect to surface water boundaries. In general, natural variation in groundwater levels increases in amplitude the further the monitoring location is from the relatively constant level of the sea or lakes.

The primary source of water entering an aquifer is any remaining rainfall that infiltrates through the land surface after evaporation has occurred from soil, plants, and other features of the landscape. Therefore, in much of New Zealand, recharge occurs mainly during the cooler period of the year when rainfall exceeds evaporation. This imparts a distinct seasonal component to time series of observations of groundwater level, for example.

Natural variation in groundwater level, for some aquifers, can exhibit characteristic "response times" of a few years, and this background signal needs to be accounted for when monitoring for the effects of water extraction for human use. Pumping of water from wells has two effects on groundwater level. The first is local drawdown that can lower levels in nearby wells, reduce flow in spring-fed streams, and induce seawater intrusion into the aquifer, even when groundwater is plentiful. The second effect is on the longer-term natural variation, caused by consumption of the water resource itself.

The above-mentioned "response times" of up to a few years refer to quantitative fluctuations of the groundwater resource. A similar, and associated, dynamic behaviour also applies to the movement of contaminants through the aquifer. However, owing to the nature of transport and dispersion in aquifers, the "age" of a contaminant since its entry to groundwater may range from a few weeks to many years, depending on the location and depth of the receptor well and the origin of the contaminant.

2.3 Relationship to Air

Air is a source of sodium and chloride ions, from airborne ocean salt particles, and dissolved carbon dioxide, which are important contributions to groundwater chemistry. Evaporation from the land increases the concentration of solutes in infiltrating recharge water relative to the contributing rainfall. While important in some other countries, it is not a significant feature in New Zealand because of the more plentiful rainfall.

There is a considerable amount of research (GNS Ltd) on the movement in groundwaters of naturally occurring isotopes that originate in the atmosphere, as well as contaminants such as halogenated hydrocarbons.

2.4 Relationship to Land

The important role of the land in influencing groundwater is somewhat obvious because all inflowing recharge must pass through the land surface and be influenced by it. Quantitative changes in recharge, for a given rainfall climate, can be caused by changes to evaporation processes resulting from changes in land use. For example, forests evaporate more rainfall than pasture because of the nature of interception and evaporation by tree foliage.

The effect of land use on groundwater quality is rather more complex. The very thin organic layer in the soil near the land surface is highly retentive of many potential contaminants, and below that zone there are relatively fewer chemical or physical processes which can modify the transport of contaminants to groundwater.

The movement of contaminants from the land surface down to the underlying groundwater is determined by the amount of infiltrating water and the pore structure of the unsaturated zone between the two. This transport mechanism is no less erratic than the rainfall and evaporation that drives it, in terms of the time lag between a land-use induced contamination event and the resulting effect on groundwater. This is particularly relevant to risk assessment of groundwater contamination where there is contaminant decay, such as for microorganisms.

2.5 Relationship to Surface Water

Surface water can be a recharge source for groundwater or have groundwater as a source. Both these processes can occur at the same time at different locations on a river, or at the one location at different times. For a river perched on an alluvial fan above an aquifer the recharge flow rate may be relatively insensitive to river flow and yet change unpredictably after flood events as the river bed changes in location and composition.

The chemical quality of a stream during periods of low flow, or that of a wetland, can be no better than the quality of the contributing groundwater, and indicators of groundwater quality are then also determinants of fresh water ecology. Conversely, the quality of surface water is seldom a serious threat to groundwater quality because of filtration and dilution as it enters the aquifer. The one notable exception, for natural waters, is saline intrusion at the coast. This may occur when groundwater levels are abnormally low.

3 ISSUES AND VALUES FOR GROUNDWATER

3.1 Introduction

The protection of values is central to the need to monitor groundwater, and to the justification of which aquifers to monitor. Values tend to be more generic than issues, and are likely to be reasonably consistent across regions. Therefore a strategy for determining which aquifers to monitor that is based around the protection of values should be applicable at both regional and national levels.

Issues concerning groundwater management arise when the use of land or water adversely affects groundwater attributes to the extent that one or more values are threatened. Suppose land application of wastes results in elevated nitrate concentrations in the underlying aquifer. If affordable access to drinking water is the only value and the nitrate concentration doesn't exceed the MAV for drinking water then nitrate contamination is not an issue. However, if the aquifer supplies a spring-fed stream, and there is an additional value of protecting stream-health, then the nitrate contamination is likely to be an issue.

Analysis of issues raised by groundwater users and managers is one approach to identifying the underlying value set. A limited amount of consultation was undertaken during this project, as described below. Full consultation and analysis was beyond the scope of this project, but that which has taken place has most likely identified the main issues. An indicative set of values has been drawn from the issues raised, for use in the sections that follow.

3.2 Nature of the Consultation

Given the limited time available for this study, a request for statements about groundwater issues was E-mailed to 56 members of the Groundwater Studies Group, as listed in the database supplied by Dr Mark Milke, University of Canterbury. Dr Milke has developed and maintained this network of resource managers, researchers, and consultants. A subset of these members are regional council staff who interact through their own network on groundwater issues, called the NZ Regional Council Groundwater Forum.

There have been seven individual replies from the Groundwater Studies Group network, and a set of notes about groundwater research and development needs from a recent meeting of the NZ Regional Council Groundwater Forum. This latter information had not yet been referred back to members for confirmation. The information in these replies is summarised under groundwater quantity and groundwater quality issues.

3.3 Groundwater Quantity

The most common concern reported by regional council staff was management of the groundwater resource in terms of the amount and timing of demand for human use.

The reported issues are:

- Depletion of spring-fed surface water flow
- Sea-water intrusion
- Well interference
- Maintenance of upward pressure gradients (to inhibit contamination of lower aquifers)
- Maintenance of well levels for reliable pumping
- Sustainable yield of aquifers / over-use of the resource
- Bore construction standards
- Lack of knowledge of how much water is being abstracted

This list is not prioritised.

The concept of sustainability of human use of groundwater, within environmental constraints, depends on a management regime that can separate the effects of human use from climate-driven natural variability. It is a reasonable generalisation to say that knowledge about sustainable use of groundwater in New Zealand is not yet developed. This statement is applicable to both national indicators of pressure on groundwater quantity and of the state of the resource.

3.4 Groundwater Quality

The main concerns are primarily related to land-uses that are known to be adversely affecting groundwater quality, or have the potential to. In some areas aquifer development has been limited because of low intrinsic water quality, and development of surface water resources has been seen to be a more viable option.

The reported issues are:

- Contamination of groundwater as a result of applying wastes to land
- Nitrate contamination of groundwater
- Pesticide contamination of groundwater
- Microbial contamination of groundwater

There are a number of concerns about the potential for contamination of groundwater by the disposal onto land of various wastes from municipalities and industry. Most of these are identifiable, localised sources for which there are recognised needs related to monitoring and management of their environmental impact. But, like the water quantity issues, knowledge about the sustainable use of groundwater, as a sink for wastes, is not yet developed. There is very limited understanding of the assimilative capacity of even the most studied New Zealand aquifers.

The most widely reported issue is nitrate contamination of groundwater by agriculture, and it is arguably the most significant and most difficult to manage.

There are growing concerns that currently used indicators of microbial contamination may be inadequate predictors of risks to human health, in both surface water and groundwater, and that the real risks may be more of an issue than is generally believed.

New Zealand has approximately 7800 potentially contaminated sites. The extent to which aquifers are adversely affected is unknown. Procedures are available for identifying, assessing and managing contaminated sites. Where it is established that groundwater is being contaminated, key issues are where is the contamination going, what risks does it pose to downstream uses, and how should the risks be managed. Tools for addressing these issues are not yet well developed. Indicators of remediation performance would normally be site specific and developed as part of risk management planning.

There is a clear understanding among resource managers that the quality of groundwater relates not only to human use for drinking, for example, but can also be a vital factor in the ecology of streams which receive much of their low flow from aquifers. This is an issue in some areas.

3.5 Values Relevant to Groundwater

The following values are proposed as the underlying basis of the issues cited above:

- Affordable access, on all properties, to potable water at the quantity and rate required.

- Affordable access, for all farms and businesses, to water at the quality, quantity and rate required.

- The life supporting capacity of groundwater-fed surface waters.

Additional values may include:

- The life supporting capacity of groundwater

- Land stability

4 A STRATEGY FOR DECIDING WHICH AQUIFERS TO MONITOR

Therefore, key components of any process for developing and implementing indicator systems are the identification of the users and primary audiences for the system and the inclusion of those audiences in the development process.

-Green Mountain Institute (http://www.gmied.org/misstxt.html)

4.1 Context

In developing this strategy, the assumption was made that the principal user would be central Government and that there would be two main audiences. The first audience is primarily internal to New Zealand and comprises those who wish to monitor the effectiveness of the Resource Management Act, and its implementation, as a means of achieving sustainable use of land and water resources. The second audience is primarily external to New Zealand and comprises those who want to verify that New Zealand's exports are being produced in an environmentally sustainable manner. It is anticipated that the needs of both audiences can be met through the same monitoring process, although performance criteria may differ.

Under current arrangements the principal user, represented by the Ministry for the Environment, is dependent on local government for the implementation of environmental performance monitoring. Therefore an environmental performance-monitoring framework for groundwater must be relevant and workable at the regional and district level.

The purpose of monitoring the state of aquifers is to establish whether legislation, policies and plans are leading to the achievement of resource management goals. The Environment 2010 goals for groundwater, as part of freshwaters, can be summarised as managing the quantity and quality of groundwater to meet the current and future needs of the natural ecology and human uses and values.

We suggest that claims that these goals are being met require demonstration that the values outlined in Section 3.5 are being protected.

It is not feasible to monitor in each groundwater system the extent to which these values are being protected, because of constraints on resources for monitoring. Monitoring should concentrate on aquifers for which these values are most at risk. The framework takes a top-down approach to determining which aquifers to monitor and what environmental performance indicators to use. The approach is based on the presumption that the pressures that put the above values at risk are land-use activities and seeks to determine the response of an aquifer to those pressures. Aquifers are then ranked according to the level of risk and monitoring is primarily, but not exclusively, focussed on the most at-risk aquifers.

Incomplete knowledge of groundwater systems and pressures means there is some uncertainty about which aquifers are most at risk. To try and manage this uncertainty aquifers are also classified according to their resilience to the nature and extent of uses of land that is hydraulically connected to them. A minimum of one aquifer in each class should be monitored to provide full coverage of all aquifer types.

In summary, the strategy will result in selective monitoring, concentrating on aquifers most at-risk from the pressure of human activities, but attempting to cover all aquifer types as a means of managing uncertainty and providing an accurate reflection of the condition of New Zealand aquifers.

4.2 The Proposed Strategy

4.2.1 Determine the Value Set

1. Analyse issues raised by groundwater users and managers to identify the underlying value set. See section 3

4.2.2 Characterise the Pressures On Each Aquifer

2. Identify the land-use activities for the area that is hydraulically connected to each aquifer.

   One proven method of doing this is to link relevant parts of two databases commonly held by regional and district councils. These are the Digital Cadastral Database and the Valuation New Zealand database. The first database contains the legal boundaries of all land parcels in the area of interest. The second database contains details of the parcels that make up each property in the area, and the predominant type of land use on that property. This approach has been used successfully for quantitative analyses of potential flood damage costs in several areas (Doull and Bright, 1996).

   The method should be consistent with the land-strand of the Environmental Performance Indicators.

3. Determine the nature of the pressures applied to each aquifer. These can be classified as abstractive or potentially contaminating.

   Once the types of land use are known for an area, an assessment can be made of the type of pressures that may result from each land use. Dairy farming is likely to apply a nitrate leaching pressure in all areas, plus an irrigation abstraction pressure in many areas. Petrol stations may result in hydrocarbon contamination pressures.

   The method used to assess the magnitude of each pressure should be based on the best available information/expertise. It could range from using a standard value for a landuse through to a detailed analysis involving soil type, climate, management practices etc.

4. Assess the likely magnitude of each pressure, and the probability of occurrence.

   For example, mass of nitrogen leached beyond the root zone per year, volume of water abstracted for irrigation per year, mass and type of hydrocarbons from an underground storage tank leakage event, mass and type of contaminants in land-fill leachate per year.

4.2.3 Assess the Risks

5. Predict the likely response of the principal attributes (piezometric head, chemical concentrations, etc) of each aquifer to the relevant applied pressures.

   In very few areas is it possible, at present, to use computer models to predict the response of an aquifer to applied pressures. However, it is not necessary to go to this level of sophistication before determining which aquifers to monitor. What is essential is a good conceptual model of each aquifer. The statistical analysis outlined in the current GNS project "Key indicators of Groundwater Quality" (see 7.4.1) should provide a (simplified) predictive tool that could be used, in conjunction with the conceptual model, to predict the response in semi-quantitative terms. In the absence of mathematical tools, carefully designed and executed "thought experiments", based around the conceptual model, will probably provide sufficient information for the purpose of selecting which aquifers to monitor.

6. For each aquifer, assess the risk to each of the values in the value set.

   For example, predicted changes in piezometric head or nitrate concentration may threaten affordable access to drinking water.

7. Rank the aquifers according to the level of risk to each value, and the relative importance of each value.

4.2.4 Classify the Aquifers

8. Classify aquifers according to their resilience to the applied pressures. An aquifer is resilient to the pressure applied if changes in aquifer attributes are small, relative to natural variability, elastic (return to original state if pressure removed), and dynamic. Resilience can be expected to be primarily a function of the geochemistry and hydrodynamics of an aquifer.

   The purpose of classifying aquifers is to ensure that each main aquifer is monitored and represented in State of the Environment reporting.

4.2.5 Select the Aquifers and the Indicators

9. Allocate up to 70% of the resource available for monitoring the aquifers ranked highest in terms of risk.

   The percent allocated is for illustrative purposes only. The actual balance between monitoring at-risk aquifers and representative aquifers would likely be a matter of consultation and negotiation between central and local government agencies.

10. Uniformly allocate the balance over aquifer classes that would not otherwise be monitored.

    Aquifer(s) in each class could be selected on the basis of highest risk ranking, as an uncertainty management strategy, or lowest risk ranking, as a means of trying to cover both ends of the spectrum of aquifer condition.

11. Select the indicators. The nature of the risks associated with each of monitored aquifer details why the aquifer is being monitored. Indicators can then be chosen with this purpose in mind. The set of indicators must include pressure indicators, as a check on the nature and magnitude of the pressures characterised in 4.2.2, state indicators, to check the predictions that the risk assessment is based on (4.2.3), and response indicators. The selection of indicators is described in Section 5.

4.2.6 Monitor Environmental Performance

12. Every three years evaluate the extent to which values have been protected.

13. Every five years review the effectiveness of land and water management policies and plans, and revise where necessary.

4.2.7 Review the Monitoring Framework

14. Every five years review the ranking and classification, in light of measured response to monitored pressures. Revise allocation of resources accordingly.

5 SELECTION OF INDICATORS

5.1 The Pressure-State-Response Framework

For the Environmental Performance Indicators Programme, MfE use a conceptual framework called Pressure-State-Response as a means of organising relevant information.

Thus for any particular issue (as described in Section 3) the policy questions to be considered are:

- **Pressure:** *What causes this issue?*
- **State:** *What part and characteristic of the environment is affected?*
- **Response:** *What management action is being taken?*

The ability to answer these questions depends on knowledge of the environmental processes as summarised in Section 2.

Indicators of environmental performance are then selected to monitor the presence of and changes to:

- Pressures on the environment.
- The state of the environment.
- Effectiveness of remedial action.

Examples relating to groundwater quantity include:

- Abstraction of groundwater for human use is a pressure on the environment.

- The state of the environment most affected is groundwater level, which then affects flow in surface waters, sea water intrusion, protection of confined aquifers, and land stability.

- A community response is to impose restrictions on pumping when groundwater levels drop below a specified threshold. An individual's response may be to deepen wells or meet demand from an alternative source, such as surface water.

Examples relating to groundwater quality include:

- Application of sewage sludge to land is a pressure on the environment.

- The state of the environment affected is nitrate and heavy metal concentrations in groundwater, along with changes in soil and plant attributes.

- A community response is to impose annual limits on the quantity of sludge that can be applied to land, or to provide a piped supply of drinking water. An individual's response may be to deepen water supply bores, treat water, or shift to an alternative source.

5.2 Requirements for Indicators

The principal requirements for Environmental Performance Indicators, as summarised from MfE (1997), are:

- To convey information in a simple, quantifiable, and credible manner to the desired audience, whether that be resource managers, policy makers, or public.
- Relevance to the issue of interest, within the Pressure-State-Response framework.
- Ability to distinguish human induced change from natural variation.
- Cost effectiveness, especially by utilisation of existing monitoring networks and databases.

5.3 The Indicator Dilemma

The ideal features of environmental performance indicators tend to be polarised between the requirements of relevant simplicity for reporting purposes and the desire for cost effective monitoring. The EPI Programme aims to combine 'bottom up' and 'top down' approaches as a means of bridging the gap between data and information.

The approach taken in the present report is 'top down', in that the purpose of an EPI is to serve the reporting requirements of the particular 'public'. The availability of existing data and monitoring networks may be a deciding factor in selection of an indicator but these data are not indicators by themselves.

The EPI Programme aims to rank indicators according to whether current monitoring can accommodate them now (Stage 1) or later (Stage 2). 'Hurdles to implementation' is considered to be a factor that designates a Stage 2 indicator. We suggest that, for groundwater indicators, this latter factor is the dominant consideration.

5.4 Examples of Groundwater Indicators

The following indicator examples have been developed in relation to the management of groundwater quantity and the dominant quality factor of nitrate contamination. For each indicator, a brief description is given of the analytical processes required for transforming monitored data into information.

5.4.1 A Pressure Indicator for Groundwater Quantity

Indicator (Stage 1)

The current permitted abstraction of groundwater from an aquifer as a percentage of average annual recharge

Analysis

For each aquifer, the current permitted abstraction would be determined from the resource consents database held by the Regional Council.

The average annual recharge for each aquifer can be estimated from at least 20 years record of climatic data and groundwater levels, supported by knowledge of land use and appropriate mathematical modelling techniques.

For collation into a national indicator, the results for each aquifer could be combined as a weighted sum, based on recharge estimates.

5.4.2 A State Indicator for Groundwater Quantity

Indicator (Stage 1)

Current groundwater levels relative to natural variation, expressed in standardised units.

Analysis

Establishment of what are natural groundwater levels requires the same data and knowledge base as for 5.1, with the addition of some more sophisticated modelling and signal processing techniques. Actual departures from estimated natural groundwater levels, caused by human use, could be scaled to a common basis for all aquifers by the use of units of standard deviation, for example.

Collation for a national indicator value may well follow the method suggested in 5.1.

5.4.3 A Pressure Indicator for Nitrate Contamination of Groundwater

Indicator (Stage 2)

The area of land that exceeds a particular value of hazard level for nitrate in groundwater.

Analysis

The risk of aquifer contamination by leaching of nitrate is a complex combination of land use, soil type, geochemistry, and type of aquifer. Synthesis of data on these topics is a proposed outcome of some of the research outlined in Section 6. It is typical of these kinds of study that the results are expressed as a simple numerical score or an alternative grading of the contamination hazard.

Since the nature of the underlying aquifer is incorporated into the hazard score, collation for a national indicator could use land area as a basis.

5.4.4 A State Indicator for Nitrate Contamination of Groundwater

Indicator (Stage 2)

Area of land overlying groundwater that exceeds the drinking water limit for nitrate.

Analysis

Incidence of nitrate contamination, as measured in monitoring wells, would be available from regional council data and WINZ (see section 6.2). However, these data at point locations need to be transformed to information that describes the spatial variation of the contamination in affected aquifers, and hence the land area corresponding to groundwater which exceeds the drinking water limit. This transformation analysis may require statistical filtering of temporal and spatial variations in the water quality data.

6 IMPLEMENTATION OF EPI'S FOR GROUNDWATER

6.1 The Role of Expertise

Implementation of the proposed strategy for selecting aquifers and environmental performance indicators depends on the existence of sound conceptual models of at least the main developed groundwater systems in New Zealand. Refinement of the selection process beyond the "thought experiment" basis to a fully quantitative basis (using computer simulation models) requires a substantial amount of information on aquifer characteristics. It is likely that suitable conceptual models of the main groundwater systems exist. However there are relatively few aquifers for which carefully validated computer models exist. The expertise of water resource specialists is required for any level of implementation of the proposed strategy. Such expertise is available in New Zealand, in both the public and private sectors. Generally it is a lack of financial resources, rather than expertise, that has, and continues to, limit the rate of development of the knowledge and information required for sustainable management of groundwater in New Zealand.

Consideration of groundwater processes (Section 2), the requirements for indicators (Section 5.2), and the nature of database infrastructure (Section 6.2) leads to a conclusion that there will be a continuing need for expert processing of monitored data into indicator information. The reason is the continuing evolution of the scope and quality of data and knowledge about particular groundwater systems.

For example, a simple indicator of pressure on groundwater quantity, for political and public use, might be the current human use of water from each aquifer as a proportion of long term recharge. Regional council estimates of this indicator at the present time would probably have a lower degree of confidence than what is achievable with further refinement of the resource consents database and more sophisticated analysis of existing hydrological data.

There are useful indicators for which databases or monitoring networks exist but there will be a cost for transformation of data into indicator information. Whether this expertise cost resides within organisations such as regional councils, or as contracted services is not relevant. The main issue is that feasible indicator information for use at national level will be associated with significant cost, even when the contributing data already exist.

6.2 Information and Data

It is important to remember that indicators are information, whereas many existing monitoring networks are designed to collect data on specific aquifer attributes, usually for a number of purposes. The technology for transforming data into indicator information is an important link, especially as the receptor audience moves from the scientist and resource manager, with intrinsic expertise, to the policy maker or public who require a more concise and meaningful indicator statement.

In the case of groundwater, natural variation of quantitative and qualitative parameters may exhibit apparent trends and cycles of low frequency character. Detection of human influence on these same parameters may require not only good long-term data records but also the use of sophisticated analytical techniques to filter out indicator information. Indicators of contaminant pressure on an aquifer, for example, may need to incorporate data on land use, soil type, and geological description.

6.3 Data Availability

6.3.1 Regional Councils and Unitary Authorities

Nation-wide there is very little data on actual groundwater abstraction. Existing databases on resource consents for abstraction of groundwater are considered to be poor estimates of actual human pressure on the resource, but some pilot statistical and model studies have been done to improve the estimation process

Most Regional Councils maintain databases on groundwater levels at monitoring wells, groundwater quality data, geological information from well drillers' logs, and information related to resource consents for abstraction of groundwater. The extent of these databases varies considerably between individual councils, probably depending on the significance of the groundwater resource to the particular region. Generally, there are good data on groundwater levels recorded in wells but these show the effect of human use confounded with natural variation.

The groundwater quality data collected by Councils is quite extensive in time and space. The types of chemical and microbiological data collected are usually determined by general requirements such as drinking water standards, or perceived risks in specific areas due to pesticides, hydrocarbons, heavy metals, or sea water intrusion (see Appendix 2).

Recent experience in collating information on nitrate contamination of groundwater indicates that there is considerable variation between Councils in the "maturity" of nitrate (water quality?) monitoring programmes. Councils that have lived with nitrate "problems" for a number of years generally have well-developed strategies and systems for monitoring and data management. Others are relative newcomers to routine monitoring of nitrate contamination. There are differences in the spatial density of the sample sites, which means that different analytical procedures are required to derive information from the data. There is always the difficulty of properly handling anomalous results. Given the issues that must be addressed, it is difficult to see the processing of data into indicators becoming a highly automated process in the short term, even for something as relatively intensively monitored as nitrate concentration.

6.3.2 National Groundwater Monitoring Programme

The National Groundwater Monitoring Programme is based on a subset of the sites monitored by Councils. Samples are collected by Councils from 72 sites on a quarterly basis and sent to GNS for anlaysis. The results are archived by GNS. The principal benefits are due to quality control, the planned representative national coverage and the scope of the analysis undertaken.

6.3.3 Water Information in New Zealand (WINZ)

This is a database established by the Ministry of Health to support a strategy for improving and maintaining the quality of community drinking-water supplies in New Zealand. The national database is co-ordinated for MoH by the Water Group of ESR Ltd, in Christchurch.

The purpose of WINZ is to assist users to fully comply with the *Drinking-Water Standards for New Zealand 1995*. These standards apply to water supplies which serve communities of 25 people or more for at least 60 days per year. Drinking water supply is considered to be defined by the source(s), treatment, and major distribution system. The standard addresses microbiological, chemical, and radiological contaminants.

For those communities supplied wholly or in part by a groundwater source, the WINZ database should be able to provide good indicators of groundwater quality for human use. Other factors arising from water treatment and distribution, in incidents of drinking water pollution, should be available through contributors to the database.

6.3.4 Database Systems

The Councils and WINZ use a variety of database systems for storing information on wells, water quantity and water quality. It is our view that the type of database system used is not important to the implementation of environmental performance indicators for groundwater, because of the amount of interpretation and analysis that is required to achieve consistent and meaningful information. What is important is the exchange of data. Provided all the necessary data is available in digital form, and it is accompanied by an accurate description of content and meaning, it is a simple matter to exchange data as comma delimited ASCII files. Very few database systems are unable to input and output data in this format. Very often data can be exchanged in the native format of commonly used spreadsheets. However the way some email systems treat binary files sometimes upsets exchange of spreadsheet files.

7 POTENTIAL CONTRIBUTIONS FROM EXISTING RESEARCH

7.1 Purpose and Scope of Projects Reviewed

Recent and current groundwater research and environmental data collection projects were reviewed to determine how they may contribute to environmental performance monitoring, in general, and to implementation of the monitoring framework, in particular. The projects reviewed were limited in number by time constraints. No claims are made regarding the completeness of the project set.

The projects reviewed fall into one of the following categories:

- FRST funded research
- MAF funded operational research
- SMF projects
- Regional Council funded operational research, not including contributions to PGSF research
- Environmental data

7.2 FRST Funded Research

The programmes identified in this section are limited to those funded under Outputs 14 (Geology) and 15 (Land and Fresh Water Ecosystems) which are specifically focussed on groundwater issues.

Information about the programmes was sourced from the 1996/97 Parliamentary Report prepared by the Foundation for Research, Science and Technology. The programmes are grouped according to research provider. In general the research programmes cited will be continuing beyond 30 June 1998, under new contracts and with updated objectives.

7.2.1 Environmental Science and Research Ltd (PGSF Contract Total : $566,000)

There are two directly relevant ESR programmes.

The *Contamination of Potable Groundwaters* programme is the most directly relevant programme. It focuses on modelling chemical and microbial attenuation in aquifers, and the leaching of pesticides from soils. The primary outputs are intended to be tools useful to resource managers and planners.

The *Microbiological Contamination of Aquatic Environments* programme will improve understanding of the significance of faecal indicators of microbial contamination. At present the main focus is on identifying reliable indicators of viral contamination, and on discriminating between human and animal faecal pollution.

7.2.2 Geological and Nuclear Sciences Ltd. (PGSF Contract Total : $629,000)

GNS have three directly relevant programmes.

The core of their main programme, *Understanding Groundwater Resources and Processes*, focuses on improving knowledge and modelling of the geological structure of significant NZ aquifers, improving understanding of the processes that formed them, and improving tools for estimating aquifer recharge.

A second programme, *Water Flow Processes in Soil*, is developing tools for identifying water flow processes. The tools are based on the use of conservative tracers, such as isotopes.

The main focus of the programme titled *Sustainable Management of NZ's Groundwater Quality* is the on-going development and maintenance of the National Groundwater Monitoring Programme. Groundwater samples from over 72 sites are received from Regional Councils and Unitary Authorities every three months, are analysed by GNS, and the results archived.

These three programmes have been amalgamated into one programme, commencing 1 July 1998. Also included in this new programme is research previously conducted under a PGSF contract to Thorpe Consultancy. The aim of this latter research is to improve understanding of groundwater recharge processes.

7.2.3 HortResearch (PGSF Contract : $150,000)

The focus of the programme *Rootzone Processes as the Upper Boundary Control on Groundwater* is on improving knowledge of reactive chemical transport through soil. The chemical's of interest are primarily agrichemicals. Mathematical models of reactive chemical transport through soil are planned to be the main outputs.

7.2.4 Landcare Research Ltd. (PGSF Contract : $625,000)

The LCR programme *Pesticide and Nitrate Pollution Management* aims to further understanding of the fate in soils of pesticides and nitrate derived from non-point sources of pollution. The intention is to develop predictive and management strategies to limit potential for pollution of groundwater.

7.2.5 Lincoln Ventures Ltd. (PGSF Contract Total : $720,000)

LVL's *Groundwater Quality Protection* programme is designed to improve understanding of the processes that control the transport and transformation of contaminants in soil and aquifers, leading to methods for predicting the long term effects on groundwater quality of land-use practices, such as land-treatment of effluent. The methods, or tools, are designed to assist resource managers and planners, design engineers, and land-treatment system operators.

7.3 MAF and Green Package Funded Operational Research

7.3.1 Potential Effects on Groundwater of Nitrogen Inputs to Agriculture

This project reviewed knowledge of the effects on groundwater quality of nitrogen inputs at the land surface. It also reviewed policies that are implemented in NZ, and selected other countries, to try and manage the effects of land-use on groundwater. The review was peer reviewed by scientists from Research Institutes and Regional Councils. It identified gaps in current knowledge and, in a follow-up workshop involving research, council, and industry representatives, prioritised issues that need addressing if NZ is to implement an effective nitrate management strategy. Lincoln Ventures, in collaboration with scientists from Lincoln University, Crop & Food, and the private sector, undertook this work. MAF and Canterbury Regional Council jointly funded the project.

7.3.2 Nitrate Flux to Groundwater

The aim of this project is to quantify nitrate flux to groundwater under actual farming conditions, as the monitored farm undergoes the substantial change from dry land sheep farming to intensive, irrigated, dairy farming. The research employs a novel lysimeter that overcomes the limitations of existing drainage lysimeters, which largely limit the use of the later to research plots. Funding to set the project up has come from MAF, Lincoln University and Canterbury Regional Council. On-going funding of operational costs has been budgeted by Canterbury Regional Council. Lincoln Ventures Ltd are undertaking the project.

7.3.3 Extent and Magnitude of Nitrate Contamination of Groundwater

The extent and magnitude of nitrate contamination of groundwater in NZ is being established through collation of readily available data, principally from Regional Councils and Unitary Authorities. This project is a useful test of the feasibility of producing information on the state of groundwater quality, nation-wide, from groundwater quality data obtained at a regional scale. Lincoln Ventures Ltd are undertaking the project

7.3.4 Significance of WHO Nitrate Limit

The purpose of this project, which will commence in August 1998, is to try and establish the significance to NZ agriculture of strict adherence to the WHO nitrate standard. The argument is that there will need to be changes to land management practices in some areas if the standard is strictly enforced. The question is what will the socio-economic effects be. This project will attempt to answer this question, so far as current understanding and information allow. The project is being managed by Ecolink Ltd, and will involve researchers from Crop and Food, Landcare, ESR, Lincoln University, and Lincoln Ventures Ltd.

7.4 SMF projects

7.4.1 Development of Key Indicators to Assess Groundwater Quality (GNS Ltd)

The objectives of this project are to:

1. Provide a national perspective on groundwater quality

2. Identify key non-point source chemical and physical indicators of groundwater quality

3. Statistically relate data on aquifer geology, land-use and recharge areas

4. Implement quality control for regional reporting of groundwater quality.

In our assessment, the project has two main parts.

The first is to expand the coverage of the National Groundwater Monitoring Programme (NGMP), by increasing the number of sites, from 72 to about 100, and the number of analytes. The planned establishment of quality control procedures, along with the increase in sites, will strengthen the NGMP. The NGMP provides a national perspective on groundwater quality, based on a subset of the total Regional Council and Unitary Authority monitoring effort. The more representative this subset is of the total monitoring effort the stronger, and more valuable, the NGMP will be. Funding of the extra sites beyond the term of the SMF project is an important issue.

The other part of this project is to determine sets of aquifer attributes to measure routinely in New Zealand aquifers, and provide guidance on which set to use for a specific aquifer. This work involves identifying major aquifer types, based on aquifer geochemistry and hydrodynamics. An all-encompassing set of chemical and physical attributes will be developed. Statistical analysis will then be used to try to determine, for each aquifer type, which chemical and physical attributes are most affected by typical land-use activities. In this way information will be developed about which attributes (i.e. a subset) to use with each combination of aquifer type and predominant land-use. If successful this approach could provide a semi-quantitative method for predicting response to applied Pressures (see 5.2.2 (4)) and of classifying aquifers based on their resilience to non-point source land-use Pressures (see 5.2.3 (7)), as well as identifying which measurements to make.

7.4.2 Marlborough District Council : Guidelines for Sustainable Surface Application of Agri-chemicals

The aim of this project is to develop guidelines for sustainable surface application of agri-chemicals under different use patterns in several regions of NZ, for the purpose of protecting groundwater quality. It involves conducting an inventory of chemicals used and land use assessments, along with field/pilot studies and site characterisations of chemical mobility. These results will be extrapolated to a wider range of sites. The guidelines, with a decision support system, will have national applicability and provide best practicable options for agri-chemical use and water management to protect groundwater quality.

HortResearch is undertaking much of the project.

7.4.3 Taranaki Regional Council/WestpacTrust : Environmentally Sound Nutrient use for Optimal Dairy Production

Investigations will be conducted into land based effluent disposal and fertiliser application regimes that both minimise nutrient losses to the environment with consequent benefits for water quality, e.g. nitrate contamination, while optimising pasture production. This is a joint WARS-TRC project that is farmer directed. Progress and results will be shared nationally with farmers and councils through written material, workshops and field days. Proven extension techniques will be used. Two dairy pasture management regimes will be compared against environmental and production criteria.

7.4.4 Auckland Regional Council: Development of New Zealand Drilling Standards

This project will develop minimum standards for drilling, construction, testing and maintenance of bores to enhance the protection of New Zealand's groundwater resources. The standards will consolidate scientific knowledge, local industry experience and international experience, and provide a mechanism that brings the benefits of that knowledge into widespread application in New Zealand.

7.5 Regional Council Funded Operational Research

7.5.1 CRC : Vulnerability Mapping and Risk Assessment

Intensification of land-use for food or fibre production often leads to an increased concentration of chemicals in groundwater, particularly nitrate. However differences in soil type, management practices, and climate mean that some areas are more likely to be significant contributors to groundwater contamination than others are. Identification of these hot-spots, or points of vulnerability, is an essential component of cost-effective measures to avoid or remedy nitrate contamination. This project will map groundwater vulnerability zones in the area between the Waimakariri and Rakaia rivers based on an assessment of the risk of contamination by nitrate, and other chemicals, from land use practices. It is based on methodologies adopted for use by authorities in North Carolina and Florida.

The main body of the work will be delivered as an electronic document and map generator that can be accessed on the World Wide Web, or from a local disk or a CD. The document has two main purposes:

- Information dissemination - providing ready access to maps of the vulnerability of groundwater to contamination, plus the supporting data.

- Educational - explaining the processes and factors which are important determinants of vulnerability.

The electronic document will be supported by a written report that describes how to use the electronic document and the technical basis of the vulnerability assessment system.

Lincoln Ventures Ltd is undertaking the project.

7.5.2 Environment Waikato : Nitrate Flux to Groundwater Under Dairy Farm Land-Use on Young Pumice Soils

Significant areas of dairy farming occur, in the southern half of the Waikato region, on predominantly young pumice soils. Previous research on nitrate flux to groundwater under Waikato dairy farming has largely focussed on the Hamilton Basin area. There is limited information on nitrate flux through young pumice soils, and how this is affected by irrigation and effluent application. The aim of this project is to provide this information through measuring the rate and nitrogen concentration of drainage water under four different dairy farming scenarios.

Lincoln Ventures Ltd is undertaking the project.

7.6 Freshwater Microbiological Research Programme

This is a five year research programme (commenced 1997) being conducted by MoH, MAF, and MfE to develop microbiological standards for assessing the health risks to humans from freshwater bathing and drinking, and to animals from drinking water. The programme specifically excludes groundwater, at this stage.

7.7 Groundwater Invertebrates

The following information is summarised primarily from a report that was specially commissioned for this project (Appendix 1). The purpose was to assess the possibility of developing a biological indicator for groundwater, corresponding to the use of the Macro-invertebrate Community Index as an indicator for river ecosystems. Additional material is from Sinton (1985).

7.7.1 The New Zealand Groundwater Invertebrate Fauna

The true groundwater environment, away from the margins or beds of surface waters, tends to be inhabited by invertebrate species that have adapted to habitats lacking primary production by plants. These species, which include worms, molluscs, insects, and crustaceans, obtain their energy by ingesting organic matter imported by groundwater or by grazing microbiological substrate attached to the sand and gravel of the aquifer. The physical limits of their range within an aquifer are probably determined by oxygen availability in the groundwater.

The New Zealand groundwater fauna are poorly known despite having been first reported more than 100 years ago. Subsequent published reports of observations in various parts of the country list a total of at least 29 species of which 16 are crustaceans. Some of these are up to 20-30 mm in length and would require pore spaces of at least 4 mm diameter in groundwater-bearing gravels.

There have been only two quantitative investigations of the abundance of these New Zealand groundwater species. Both studies were in the early 1980's, mostly at sites within a Canterbury aquifer that received organic material transported from surface irrigation of sewage effluent. The reported species were mostly larger crustaceans.

On the basis of overseas research, the biodiversity of New Zealand groundwater fauna is expected to be considerably greater than is indicated by present published accounts. There appears to be a stronger relationship between species inhabiting the gravel aquifers of ancient Gondwanaland than to surface-dwelling species in the same area.

7.7.2 Sensitivity to Human Activity

The two above-mentioned studies (5.5.1) at sites influenced by sewage disposal showed that invertebrate populations could increase in response to an increase in the supply of organic material. However, unusual effluent irrigation events resulted in some massive kills of the fauna. This may have been due to oxygen depletion caused by excessive organic material in the groundwater.

Results from these studies suggest that three of the larger species together assimilate 3-10 tonnes/ha of organic matter per year at this site. These crustaceans clearly play an important role in the removal of organic contaminants and maintenance of groundwater quality. This occurs in at least three ways: conversion of harmful bacteria and fungi into relatively harmless animal tissue; removal of carbon by respiration to carbon dioxide; and maintenance of pore spaces by grazing organic layers from particle surfaces.

There are very few published accounts of the effect of contaminants such as pesticides and heavy metals on groundwater fauna throughout the world, and none for New Zealand species. Groundwater fauna are expected to be more susceptible to pollution than the corresponding surface-dwelling species, because the groundwater communities are less diverse, species have low genetic plasticities, populations are low, food sources are patchy, and geographical distribution is restricted.

7.7.3 Natural Variability of Groundwater Invertebrate Populations

The relevance of population variability to selection of environmental performance indicators is that this must be quantified so that any influence of human activity can be detected as abnormal variation.

In general, fauna of any kind exhibit spatial and temporal variability in abundance and diversity over most scales, often for no apparent reason. Groundwater fauna are no exception, and many investigators regard groundwater environments and the respective fauna to be very heterogeneous, especially so for alluvial aquifers. This leads to considerable variability over relatively short distances and between times at the same site.

Reliable quantitative sampling for detection of human impact on groundwater fauna requires further refinement of methods. Establishing causal relationships between human activity and changes in fauna may be even more demanding than in surface-dwelling aquatic, terrestrial, or marine environments.

7.7.4 Invertebrates as Indicators for Groundwater

Invertebrates have immediate appeal as indicators of the life supporting capacity of the groundwater ecosystem, because they are the only element of this system with the capacity to respond in the short-to-medium term to a broad spectrum of pollutants over a range of concentrations and time distributions. However, their innate natural variability (5.5.3) and the relative inaccessibility poses considerable technological difficulties in sampling and analysis.

The way forward seems to be to establish a Groundwater Invertebrate Index (GII) similar to the Macro-invertebrate Community Index (MCI) for aquatic ecosystems. Some initial work on sampling the fauna is part of a NIWA (Christchurch) research programme to commence in mid-1998. Progress beyond this stage towards the use of a GII will require the commitment of significant resources, mostly in terms of expertise and knowledge development.

8 SUMMARY

Four of the reviewed operational research programmes should contribute directly to the development of indicators. The GNS project (7.5.1) is expected to contribute to the identification of aquifer types and sets of aquifer attributes to measure routinely. The MAF funded project (7.3.3) to establish the extent and magnitude of nitrate contamination of groundwater is indirectly testing the current feasibility of reporting on one important issue, on a nation-wide basis. The Canterbury Regional Council Vulnerability Mapping and Risk Assessment project (7.5.1) is testing some aspects of the aquifer selection strategy. The Auckland Regional Council (7.4.4) will contribute to the indicators programme because it is crucial that monitoring wells are properly designed, installed, developed, and maintained.

The majority of the PGSF investment in research directly related to groundwater is focussed on improving understanding of water and contaminant transport processes. The majority of this investment in process understanding is concentrated on issues to do with transport through soils. Almost without exception the principal deliverables are improved models, or tools, for predicting the effects of land management actions. The ESR programme on microbial indicators appears to be the only PGSF funded research on indicators of relevance to groundwater. However, the value of the tools under development should not be underestimated. They will be essential for helping improve methods for identifying aquifers at-risk from various land management activities.

There is a reasonably high degree of collaboration in the programmes summarised above. Lincoln Ventures researchers are contracted by GNS and Thorpe Consultancy to undertake research on water movement through soil and rainfall recharge estimation methods. Research on contaminant transport and attenuation processes in aquifers is conducted jointly by ESR and LVL researchers at LVL's laboratory. ESR's research on pesticide movement through soil is conducted in partnership with Landcare, as is some of LVL's research on nitrate transport in aquifers and bio-remediation.

Several of the operational research projects are designed to increase understanding of the fate of substances applied to the land surface, and how such applications should be managed to minimise impacts on groundwater quality. These will contribute indirectly to the development of indicators, as do all projects that increase understanding of groundwater systems and processes.

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9 CONCLUSIONS

- At the national level, the most important environmental issues for groundwater are management of groundwater quantity and nitrate contamination.

- Both these issues can have widespread impact on groundwater for human use and maintenance of stream ecology.

- Examples are provided of easily understood Environmental Performance Indicators for both issues, which address the pressure and state aspects of the Pressure-State-Response conceptual framework.

- These indicators can be estimated, in most regions, from existing monitoring networks, but the transformations from data to indicators are usually associated with a cost for expertise.

- There are databases, infrastructure, and current research that are relevant to the development of indicators for other groundwater quality issues that may arise, such as chemical and microbiological requirements for human health.

- The state of knowledge about groundwater invertebrates shows promise for their use as biological indicators of ecological health, but a significant amount of research would be required to realise this potential.

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APPENDIX I:

Groundwater Invertebrates As Potential Indicators

Report prepared for the Ministry for the Environment Groundwater Indicators Project.
Graham Fenwick

APPENDIX II:

Groundwater Monitoring Survey Results