Ministry for the Environment
Manatū Mō Te Taiao

Sustainable Management Fund

Client Report 2001/05

Section 1 of 4
Executive summary
Recommendations
Introduction
International context
New Zealand context
Chemical parameters considered
Methods

CONFIDENTIAL

Determination of non-point source chemical groundwater quality indicators for New Zealand aquifers

M R Rosen
S G Cameron
R R Reeves

April 2001

Determination of non-point source chemical groundwater quality indicators for New Zealand aquifers

Prepared for

MINISTRY FOR THE ENVIRONMENT

M R Rosen
S G Cameron
R R Reeves

CONFIDENTIAL

Client Report 2001/05
Job Number 53053C.10

April 2001

CONTENTS

Page

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF APPENDICES

EXECUTIVE SUMMARY

The New Zealand Ministry for the Environment commissioned the Institute of Geological & Nuclear Sciences Ltd. to develop indicators of groundwater quality through a grant from the Sustainable Management Fund. The development of groundwater indicators is part of the overall Environmental Performance Indicators programme administered by the Ministry for the Environment. This report summarises the testing and selection of groundwater quality indicators for non-point source (diffuse) chemical contamination of groundwater using the "pressure-state-response" framework. "Pressure" indicators were chosen qualitatively based on the most important national pressures effecting groundwater quality. The "state" indicators that were chosen are based on statistical principal component analysis of chemical data taken from the National Groundwater Monitoring Programme. In addition, descriptive evaluation of "state" indicators was included for those parameters where significant temporal data were not available (pesticides and metals). Land use information and geological knowledge of the aquifers included in the survey were used to test the significance of the "state" indicators chosen.

Eight primary "pressure" and "state" indicators and five secondary "state" indicators have been chosen to assess changes in groundwater quality with time. The recommendation section of this report lists the indicators chosen. The indicators selected will be valuable in assessing changes in groundwater quality from non-point source contamination caused by fertiliser applications, impacts of human and animal wastes applied to land, leaching of animal wastes from pastoral farming, pesticide application, contaminants from sheep dips, and corrosion of metals from urban settings. "Response" indicators were not evaluated in this study. It will be beneficial for the regional authorities and the Ministry for the Environment to evaluate and choose "response" indicators based on the "pressure" and "state" indicators developed in this report.

RECOMMENDATIONS

The recommendation of this report is that the following non-point source "pressure" and "state" indicators for groundwater quality be implemented:

Pressure Indicators

1. Percentage change of each land use in an aquifer area (both recharge areas and confined areas)
2. Measurement of stocking rates on pastoral land uses
3. Amount and type of fertiliser applied to land (e.g. NPK or urea) or produced and imported
4. Amount of triazine pesticides applied to land (or produced and imported)
5. Number of well with appropriate wellhead protection per unit area
6. Number of sites with contaminated soils detected
7. Percent change in chemical indicators of recharge water quality from streams, lakes and rivers
8. Abstraction volume of groundwater per aquifer

"State" Indictors

Major ions:

Primary indicators	Potassium, sulphate, chloride
Secondary indicators	Alkalinity, sodium, bromide, magnesium (in Tasman district)

Nutrients:

Primary indicators	Nitrogen as total nitrogen, or nitrate and/or ammonium depending on aquifer conditions and expected contaminants.

Metals:

Primary indicators	Total arsenic and total lead (total dissolved arsenic and lead may also be used)
Secondary indicators	Total copper (total dissolved copper may also be used)

Pesticides:

Primary indicator	Atrazine: High sensitivity atrazine test kits with detection limits of at least 0.015 mg m^{-3} have been shown to be a cost effective method of testing for atrazine.

These "state" indicators should be used in the following context related to the "pressure" indicators:

Pressure indicator	**Related state indicator**
Percentage change of each land use in an aquifer area (both recharge areas and confined areas)	Percent average change in indicator chemical (nitrogen, chloride, sulphate) concentrations relating to land use in an aquifer
Measurement of stocking rates on pastoral land uses	Percent average increase in indicator chemical (nitrogen, chloride, sulphate) concentrations relating to stocking numbers in an aquifer
Amount and type of fertiliser applied to land (e.g. NPK or urea) or produced and imported	Percent average change in indicator chemical (nitrogen, potassium, chloride, sulphate, magnesium) concentrations relating to fertiliser use in an aquifer
Amount of triazine pesticides applied to land (or produced and imported)	Percent detection of atrazine in wells, percent change in copper concentrations relating to a given land use.
Number of well with appropriate wellhead protection per unit area	Percent average change in indicator chemical (nitrogen, potassium, chloride, sulphate, magnesium) concentrations. *(microbiological indicators may be more appropriate for this state indicator)*.
Number of sites with contaminated soils detected	Number of detections of arsenic and lead in groundwater
Percent change in chemical indicators of recharge water quality from streams, lakes and rivers	Percent average change in indicator chemical (nitrogen, potassium, sodium, chloride, sulphate, magnesium) concentrations in wells in the recharge area of an aquifer
Abstraction volume of groundwater per aquifer	Percent average change in indicator chemical (nitrogen, potassium, sodium, chloride, bromide, sulphate, magnesium) concentrations per land use in an aquifer

This list of both the "pressure" and "state" indicators is intended to cover as many major issues for non-point source groundwater contamination as possible. It is not intended that all of these possible indicators be monitored in all areas of the country. Two major constraints will be the data and resources available in each region to monitor some of the "pressure" indicators. However, to insure that a national indicator programme for groundwater contamination is useful, some common "pressure" and "state" indicators should be chosen that are monitored throughout the country.

Details of how and when these indicators should be applied are detailed in this report.

1.0 INTRODUCTION

After the publication of the document *The State of New Zealand's Environment* in 1997, The New Zealand Ministry for the Environment (MfE) realised that a database of accurate and reliable information was needed to enable good decisions to be made about the environment. In addition, consistent measures were needed to ensure that improvements or degradation to the environment could be assessed on a national scale. MfE decided to launch a significant programme to identify key indicators of the environment for air, fresh water, and land. These indicators complement indicators developed for determining changes in air, land, freshwater, Maori health, terrestrial and freshwater biodiversity, transport, energy, amenity, waste, toxics and contaminated sites, pests weeds and diseases, ozone, and climate.

The MfE approach to environmental performance indicators uses the conceptual framework called Pressure-State-Response, also known as Pressure-Condition-Response (Fairweather and Napier, 1998). This framework allows indicators to be developed that incorporate each of these conditions into a policy framework. Bright et al (1998) illustrated an example of this approach for groundwater quality as follows:

Pressure:
Application of sewage sludge to land

State:
Groundwater effected by increases in nitrate and metal concentrations

Response:
Limitations on the quantity of sludge that can be applied to land on a yearly basis, provision of a piped water supply, deepening of wells, or treatment of water.

As part of the indicators programme, MfE commissioned the Institute of Geological & Nuclear Sciences Ltd. (GNS) to develop separate indicators for groundwater quality and quantity through the Sustainable Management Fund. Provision of resources and additional funding from all of the regional and unitary authorities in New Zealand were essential to carry out these projects. The rationale behind the development of the water quality indicators programme was to focus on non-point source rural chemical contaminants in order to develop quantitative "state" indicators of groundwater quality. Because the contaminants derived from point sources are highly variable and are generally well known or easily determined, the indicators for point source groundwater contamination would be locally derived from the known contaminant source. In addition, microbial indicators are relatively well developed for groundwater settings (both point and non-point source). In general, faecal coliforms and *E. Coli* are used as indicators of microbial contamination in groundwater. Although there is further research being conducted on other microbial indicators, this study didn't focus on further refining these basic microbial indicators.

This report documents chemical indicators of groundwater quality developed for non-point source pollution of groundwater. Although the focus of the report is on providing quantitative "state" indicators, the report also provides some guidance for quantifying "pressure" indicators for non-point source groundwater pollution. Response indicators are generally based on community initiatives and are not addressed in this report. The report documents the indicators chosen and provides the basis for their derivation. The development of groundwater quantity indicators is on-going and will be reported separately.

1.1 What is an indicator?

MfE defined an indicator as a "quantitative measure (i.e. distance from a goal, target, threshold, benchmark) against which some aspects of policy performance can be assessed" (Ministry for the Environment, 1997). The United States of America Environmental Protection Agency (US EPA) defines environmental indicators as:

"*A measured or observed property or some value derived from properties which provides managerially significant information about patterns or trends in the state of the environment or about relationships among such variables.*"

Another definition that places indicators in the context of watershed assessment is:

"*An indicator is a measurable feature that provides evidence of the magnitude of stress, or the degree of exposure to stress, or the degree of ecological response to the exposure, or habitat characteristics.*" (Dates et al., 1996)

Taken together, the last two definitions describe indicators as measurable features that help assess environmental or human health conditions and trends. These definitions are indicators of the environment, whereas the MfE indicators are measures of the effectiveness of environmental policy. The "state" indicators established for groundwater in this study can be used in conjunction with the guidelines provided for "pressure" indicators to assess the effectiveness of environmental policy in the long-term. For example, increasing concentrations of certain indicator chemicals may be related back to general pressures such as intensification of land use or increases in chemical spraying that can be used to initiate responses from the community that can reverse these trends.

There are three types of environmental indicators (Dates et al., 1996):

1. Early warning: Indicators that can detect early signs of environmental change.
2. Compliance: Indicators that tell us whether ecosystem objectives have been achieved.
3. Diagnostic: Indicators that provide insight into the causes of problems.

The groundwater chemical indicators proposed in this study are designed to fulfil the different aspects of all three of these types of indicators.

1.2 Need for groundwater indicators

The need for a reliable set of groundwater pollution indicators is illustrated by the importance that New Zealand places on its groundwater resources to maintain its agricultural production, drinking water supplies and industrial output. Approximately 50% of New Zealand's population is totally or partially dependant on the use of groundwater as a source for drinking purposes (Ministry of Health, 2000), and although no quantitative assessment of groundwater use for irrigation and industry has been made, groundwater supplies are essential to the economy of the east coast regions of New Zealand (Thorpe, 1992).

Bright et al. (1998) in a report written for MfE highlighted a small set of groundwater pollution indicators. They determined two groundwater performance indictors one for groundwater quantity (groundwater level) and one for groundwater quality (nitrate contamination). However, these indicators were not based on any significant study of potential water quality contamination. In fact, the water quality indicator chosen (nitrate) is essentially a direct measure of contamination rather than an indication of contamination. Regardless of this, it is understandable that nitrate was chosen as an indicator on a policy level (as indicators are defined by MfE) because it is such a ubiquitous rural contaminant in New Zealand (The State of New Zealand's Environment, 1997).

In order to supplement this small set of indicators and to test their validity, this project uses statistical analyses to relate groundwater chemistry to land use and the lithology of aquifers to determine a set of reliable indicators of non-point source groundwater contamination. The current study encompasses all major non-point source contaminants (see Section 4.0) and as a consequence provides a more robust set of potential indicators for New Zealand.

2.0 INTERNATIONAL CONTEXT

Environmental performance indicators for groundwater have been established in few countries, and it is difficult to assess if the indictors have been implemented or are effective. For example, the only direct hit when searching for the string of words "groundwater AND chemical AND indictors" is the New Zealand Institute of Geological & Nuclear Sciences Ltd web page, which highlights the current project. The Australian effort on groundwater indicators is very different to New Zealand because their potential contamination and resource use problems are different to New Zealand's. Key indicators for groundwater in the Australian programme are (Fairweather and Napier, 1998):

1) Depth to groundwater (state/condition)
2) Groundwater salinity (state/condition)
3) Borehole capping (response)

4) Estimated resources (state/condition)
5) Net amount abstracted/discharged (pressure)
6) People, stock and crops supported (pressure).

Groundwater salinity and borehole capping (capping of artesian flowing wells) are not currently major issues in New Zealand and may not be useful indicators on a national scale. However, flowing artesian losses can be an issue in Canterbury. Environment Canterbury has had to cap a number wells to stop them flowing (V. Smith, written Comm., 2001). The issue may be more important if there are many flowing wells in an area, or in water short areas. It may also be important in the future given the age of some wells with many of them being "lost" when land changes ownership. Although capping of wells to prevent artesian flows may not be as important a problem in New Zealand as in Australia, capping of wells for wellhead protection purposes may be a useful indicator in New Zealand. Similarly, groundwater saltwater intrusion (salinity) problems are important locally in New Zealand and management of this issue will be the focus of a workshop in April 2001. Therefore, it may be important to provide indicators of saltwater intrusion for New Zealand aquifers. Saltwater intrusion is different type of salinity problem than the problems that occur in Australia. Salinisation in Australia is mainly related to irrigation and deforestation practices in the interior of the country (particularly the Murray-Darling Basin), which leaches salts out of the soil in the arid regions and contaminates the shallow groundwater table (Macumber, 1991)

The other four indictors have some relevance to New Zealand but will require further investigation to be utilised fully. Chemical indicators were considered by the Australian investigators, but were rejected due to perceived technical difficulties in establishing the indicators, although no explanation was given of what the specific technical difficulties were (Fairweather and Napier, 1998).

The commission on Geological Sciences for Environmental Planning, which is part of the International Union of Geological Sciences, has produced a monograph on geoindicators (Berger and Iams, 1996) that includes chemical indicators for groundwater. These indicators are global in nature and are designed to assess both natural and human induced changes to groundwater systems (Edmunds, 1995; 1996).

Table 2.1 highlights the recommended primary and secondary chemical indicators of change in association with a number of processes and problems that occur in groundwater systems in a generic way (Edmunds, 1996). The indicators were designed to assess rapid environmental change in groundwater systems. The basis for choosing the individual indicators is not clearly defined in a quantitative way, and it would appear that the indicators were chosen by a qualitative assessment of their ability to detect changes. It is interesting to note, however, that many of the indicators chosen for this project are similar to the recommendations made in this report. However, the indicators chosen for New Zealand aquifers are more specific to agricultural systems encountered here.

Table 2.1 Recommended chemical indicators of environmental change in groundwater systems (modified from Edmunds, 1996).

Process	*Primary indicator(s)*	*Secondary indicator(s)*
Natural hydrogeochemical processes:		
Mineral dissolution	HCO_3	Si, $SI_{calcite}$*, major ions
Redox reactions	O_2	Eh, Fe_T
Salinity	Cl, SEC (specific electrical conductance)	Mg/Ca, SO_4, Br, trace elements $\delta^{18}O$, $\delta^{2}H$, ^{3}H, ^{14}C
Residence time		^{3}H (tritium), ^{14}C, trace elements
Anthropogenic pollution (diffuse):		
Environmental radioactivity	^{3}H	^{36}Cl, ^{14}C
Agrichemicals	NO_3, DOC, HCO_3	K, Na, SO_4, pesticides
Industrial, urban	Cl, DOC, HCO_3	B, SO_4, metals, hydrocarbons, organic solvents
Mining	pH, SO_4	metals

*SI = Saturation Index

In an international context, the manner by which indicators are chosen is generally qualitative. Possible sources of contamination are identified (i.e. from agriculture, mining or urban areas) and indicators are chosen based on a knowledge of what the contaminants may be. This method of determining indicators is consistent throughout the state environmental protection agencies in the United States of America, Australia and in Europe. This means that indicators are specific to regions and land uses. However, the indicators chosen are not designed to monitor for changes in land use in an area, so that possible environmental effects could go unnoticed until such monitoring is put in place. This could leave the population and ecosystems at risk from contamination resulting from activities that are not properly monitored.

3.0 NEW ZEALAND CONTEXT

The desire to create a standard set of indicators for the New Zealand environment from which the Ministry for the Environment could reliably assess progress on environmental policy goals has lead to the development of a number of methods for developing indictors. Several options were available for determining chemical indicators for groundwater in New Zealand. The most viable options included: 1) determining indicators qualitatively as is done elsewhere and attempted by Bright et al. (1998), 2) developing indicators statistically (quantitatively) from regional and unitary authority databases, and/or 3) using the National Groundwater Monitoring Programme (NGMP) database that is run by GNS to develop the indicators. The use of regional and unitary authority databases was too difficult to manage because quality control criteria for each component of the database is different, and the same parameters may not be collected (in equal quantities) from each area. In addition, the resources available for the study would not allow the assessment of such a large database in a timely manner. The sheer problem of collecting the data and performing quality control tests on all of this data made it impossible to use these data reliably for indicator purposes given the resources allocated. Further qualitative assessment of groundwater quality data has been included in this study for specific indicators such as pesticides and heavy metals, but the main contribution of this project has been to statistically determine groundwater chemical indicators from a high quality set of consistent data using the NGMP. This enabled the development of a quantitative assessment of potential "state" indictors that could be enhanced by indicators that were chosen using scientific judgements of New Zealand land use and geological contexts.

The NGMP currently monitors approximately 100 groundwater wells throughout the country that are located in areas of aquifers that can act as early warning sites for potential non-point source contamination. A description of the basic formulation of the NGMP can be found in Rosen (1997) and (1999). The programme started in 1990 with 22 wells from 4 regional authorities of the country. The NGMP now includes 15 of the 16 regional and unitary authorities (Figure 1.1). The Nelson City Council, which is not included in the NGMP, has relatively little groundwater use in its area and does not have a groundwater quality monitoring programme. There are only two water permits to take groundwater (total of 1.1 L/s) within the Nelson City boundary and all the city's water supplies are from surface water sources (Thomas, in press). The NGMP is considered a nationally significant database by the New Zealand Foundation for Research Science and Technology.

The NGMP allows for a comparison of aquifer water compositions and conditions on a national basis because the samples are all analysed at one laboratory in a consistent manner and all samples undergo stringent quality control checks. Poor quality data are thus minimised. In addition, samples are collected quarterly so that long-term seasonal trends in water quality can be analysed and an assessment of changes in land use and aquifer vulnerability to contaminants leaching with recharge can be made.

4.0 CHEMICAL PARAMETERS CONSIDERED

Table 4.1 lists the chemical parameters assessed in the study and the likely environmental causes of change (including anthropogenic pressures). Over 25,000 chemical analyses, some collected from wells over a period of 10 years, were used in this study (see Appendix I). Most analyses that were routinely measured were of major components and properties in the water (sodium, calcium, potassium, magnesium, chloride, alkalinity, sulphate, silica), nutrients (phosphate, nitrate, ammonium) and trace elements (bromide, fluoride, dissolved iron, dissolved manganese). Single "snap-shot" surveys of trace elements (lead, copper, chromium, arsenic) and pesticides were undertaken to help assess their importance as potential indicators.

The reason that these chemical parameters were chosen for this is study is because:

1. They are relatively inexpensive to analyse compared to other sets of determinands
2. They are routinely measured in groundwater monitoring programmes run by regional and unitary authority staff
3. They are found in many different types of non-point source pollutants found in New Zealand

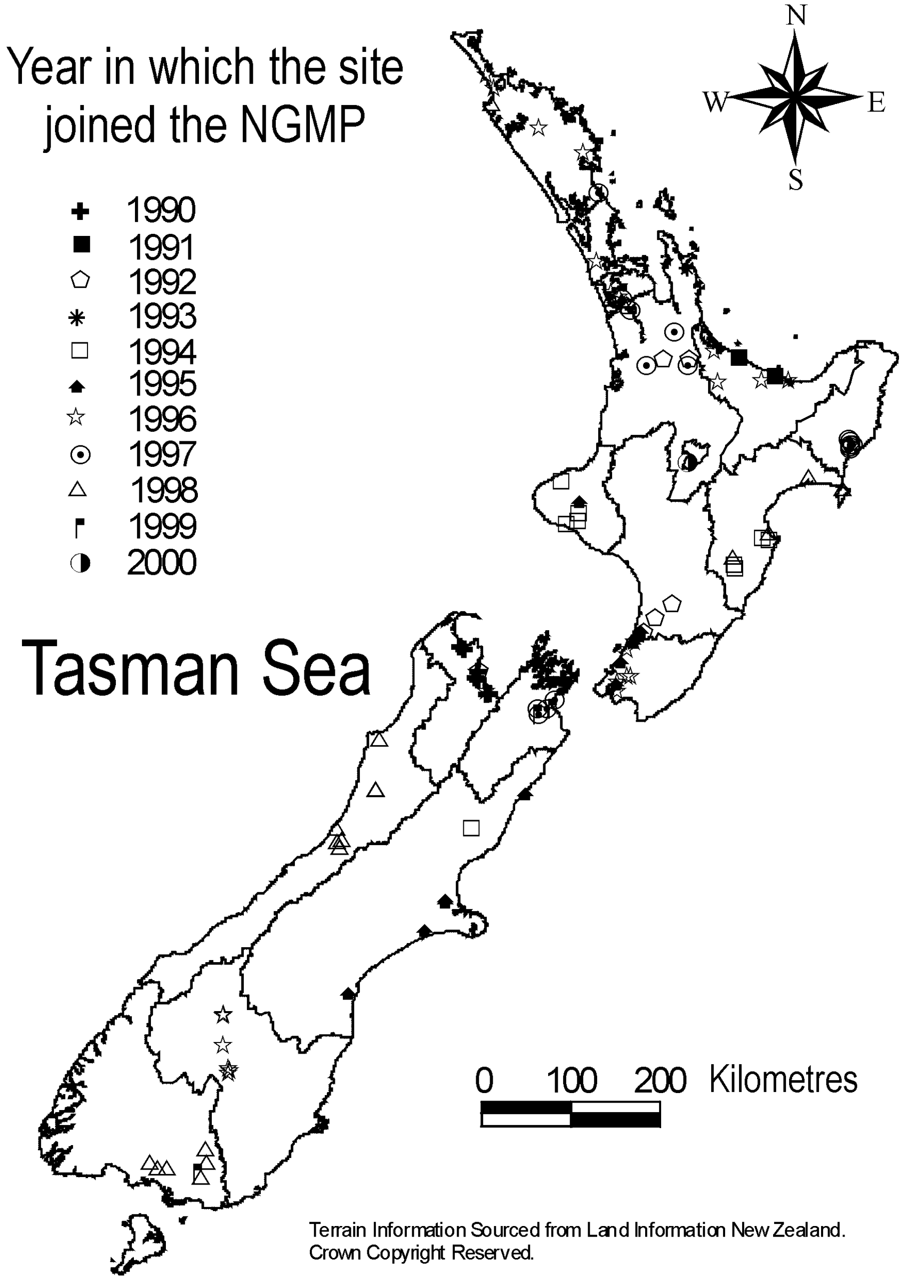


Figure 1.1 Map of New Zealand showing NGMP well sites. Boundaries shown are regional and unitary authority boundaries.

4. A large quantity of data for these chemical parameters is readily available from the NGMP

The use of microbes and organic chemicals (other than pesticides, e.g.. hydrocarbons) as indicators were not considered in this study. As discussed in Section 1.0, there are already microbial indictors in use, so it was not considered necessary to further define these indicators at this stage. Organic chemicals such as hydrocarbons are likely to be related to point source discharges from leaking underground storage tanks, industrial spills landfills or other accumulations of petroleum products and were not considered to be good indicators of the health of an entire aquifer or region of an aquifer.

Isotopic parameters (as shown in Table 2.1) were not considered as potential indicators in this first assessment of groundwater indicators because: 1) they are not routinely measured by regional or unitary authority staff, 2) they are relatively expensive to analyse and potentially complex to sample for (i.e. ^{14}C), and 3) they may need highly trained specialists to interpret the results. However, as technology improves and isotopic measurements become routine their use as environmental indicators will be assessed.

5.0 METHODS

The main purpose of this study was to develop "state" indicators within the Pressure-State-Response framework. Therefore, most of the methodology revolves around this aspect of the study. However, a qualitative attempt has been made to develop "pressure" indictors to provide a context for the "state" indicators developed. The "pressure" indictors are developed in Section 6.0.

Information on land use, geology and lithology of the aquifer, hydrogeology of the aquifers (unconfined, confined, semi-confined) and chemical composition for each aquifer water included in the NGMP was used in the statistical analysis to determine the "state" indicators. A brief summary of these parameters and their relationships is given in this chapter as well as the methodology of the principal component analysis and other statistical tests used.

Table 4.1 Chemical parameters used to assess indicators in groundwater

Chemical	Symbol	Natural reasons for environmental change	Anthropogenic reasons for environmental change
pH	- - -	Seasonal variations from recharge inputs	Acid mine drainage, land use changes
sodium	Na	Seasonal variations from recharge inputs	Fertilisers, animal or human waste, seawater intrusion/over exploitation
calcium	Ca	Weathering of rocks and soils, climate change	Fertiliser (liming), acidification
magnesium	Mg	Weathering of rocks and soils	Fertilisers, acidification
potassium	K	Weathering of rocks and soils, climate change	Fertilisers, animal or human waste, acidification
chloride	Cl	Seasonal variations from recharge inputs	Fertilisers, animal or human waste, seawater intrusion
sulphate	SO_4	Weathering of pyrite	Fertilisers, acid rain
alkalinity	HCO_3	Weathering of calcite and feldspars	Dairy shed runoff, liming
nitrate	NO_3-N	Seasonal variations from recharge inputs	Fertilisers, animal or human waste, cropping
ammonium	NH_4-N	Reducing-oxidising conditions (Redox conditions)	Fertilisers, dairy shed runoff, cropping
phosphate	PO_4-P	Seasonal variations from recharge inputs	Fertilisers, animal or human waste
silica	SiO_2	Geothermal inputs, weathering of silicate rocks	Dairy shed runoff
bromide	Br	Seawater inputs	Over pumping in coastal regions, some fertilisers
fluoride	F	Seawater inputs, geothermal input	Waste water from fluoridated water supplies
iron	Fe	Redox conditions	Industry, mining
manganese	Mn	Redox conditions	Industry, mining
arsenic	As	Redox conditions, geothermal	Industry, fertilisers, fungicides, mining
lead	Pb	Redox conditions	Industry, mining
chromium	Cr	Redox conditions	Industry, mining
copper	Cu	Redox conditions	Industry, fertilisers, fungicides, mining
pesticides	Many	- - -	Pesticide use for agriculture or industry

5.1 Relationship between groundwater composition, land use and aquifer geology

5.1.1 Summary of geological information

The regional councils supplied well construction details and driller's bore log data. The aquifer geology category at each well was established based on these data. The aquifer lithology was standardised into the following 11 categories (Table 5.1, Appendix 2): silt, sand, gravel, sandstone, siltstone, limestone, shell, volcanic sediment, basalt, rhyolite, and ignimbrite. These categories were based on a combination of lithology (e.g. siltstone, sandstone, limestone, basalt, rhyolite, or ignimbrite, presence of marine shell material or volcanic sediment) or grain size (e.g. silt, sand or gravel).

Table 5.1. Summary of aquifer geology information

Aquifer lithology	Number of wells with specified aquifer lithology	Percentage of wells with specified aquifer lithology
Silt	4	2.5
Sand	50	32
Gravel	68	44
Sandstone	4	2.5
Siltstone	4	2.5
Limestone	3	2
Shell	7	4.5
Volcanic sediment	8	5
Basalt	5	3
Rhyolite	1	0.5
Ignimbrite	1	0.5
TOTAL	155	

The most common aquifer lithology categories associated with the NGMP wells are sand and gravel. Wells that draw water from aquifers that contain these sediments make up 76% of the total aquifer lithology categories. Wells that draw water from aquifers that contain shell or volcanic sediment make up 10% of the total aquifer lithology categories. Aquifer lithology categories that are less than 5% of the total aquifer lithology categories are silt, sandstone, siltstone, limestone, basalt, rhyolite, and ignimbrite.

5.1.2 Summary of land use information

The regional councils supplied land use information for each well. The land use information detailed land use within 10 m and 200 m of the well for those wells in unconfined or semi-confined aquifers. The land use information detailed the significant land use activities in the aquifer recharge area for those wells in confined aquifers. These land use data were standardised into the following 16 land use categories (Table 5.2, Appendix 3): dairy, drystock, cattle, sheep, deer, horse, cropping, fallow, horticulture, orchard, rural residential, lifestyle, urban, golf course, native, and forestry. A general land use category was created for each well that summarised the land use activities at 10 m, 200 m in the unconfined or semi-confined aquifers, or in the recharge area of the confined aquifers. Therefore, there were 64 separate land use categories established (i.e., 16 x 4).

The dates for which the land use information pertains is given in Table 5.3. Land use data were obtained by council staff from field observations or from land use or consent databases. The data relates to land use activities between January 1980 to May 2000, although the majority of the information relates to land use occurring in January or February 1998. Additional wells from Environment Southland and West Coast Regional Council were added to the NGMP in September 1998 so land use information for these councils is at September 1998.

The most common land use activities associated with the NGMP wells are dairy farming, dry stock farming, sheep farming, horticulture, orcharding, and urban. Wells with these land use activities make up 85% of the total general land use activities. Wells with land use activities that comprise less than 5% of the total land use activities are cattle farming, deer farming, horse grazing, cropping, fallow ground, rural residential, lifestyle blocks, golf course, native bush, and forestry.

Table 5.2. Summary of land use information. Note some wells have multiple land use.

Land use	Number of wells with the specified general land use	Percentage of wells with the specified general land use	Number of wells in unconfined aquifers with the specified 10 m land use	Percentage of wells in unconfined aquifers with the specified 10 m land use	Number of wells in unconfined aquifers with the specified 200 m land use	Percentage of wells in unconfined aquifers with the specified 200 m land use	Number of wells in confined aquifers with the specified recharge area land use	Percentage of wells in confined aquifers with the specified recharge area land use
Dairy	24	19	24	17	25	16	6	13
Drystock	25	20	28	19	36	24	15	32
Cattle	4	3	4	3	4	3	2	4
Sheep	16	13	17	12	17	11	3	6
Deer	1	1	1	1	1	1	0	0
Horse	3	2	3	2	3	2	0	0
Cropping	3	2	3	2	3	2	1	2
Fallow	1	1	1	1	1	1	0	0
Horticulture	10	8	10	7	13	9	4	9
Orchard	19	15	19	13	21	14	4	9
Rural residential	0	0	16	11	4	3	0	0
Lifestyle	0	0	2	1	2	1	0	0
Urban	13	10	11	8	15	10	1	2
Golf course	4	3	4	3	4	3	0	0
Native	2	2	2	1	2	1	5	11
Forestry	0	0	0	0	1	1	6	13
TOTAL	125		145		152		47	

5.1.3 Summary of hydrogeological information

The aquifers from which the wells draw water were classified as either unconfined, semi-confined or confined. The classification was based on information supplied by council staff or on interpretation of bore log data. Fifty-seven of the 108 NGMP wells draw water from unconfined aquifers (Table 5.4). Fourteen wells draw water from semi-confined aquifers and 37 wells draw water from confined aquifers.

Table 5.3 Summary of land use information dates

Council	Date for which land use data pertains	Comment
Auckland Regional Council	January 1998 and January 2000	Data pertains to land use at monitoring sites one of these dates
Environment Canterbury	February 1998	Data pertains to land use observed at monitoring sites on this date
Environment Bay of Plenty	June 1992 to March 1996	Data pertains to land use at monitoring sites during this period
Environment Waikato	February 1998	Data pertains to land use at monitoring site on this date
Environment Southland	September 1998 and May 2000	Data pertains to land use at monitoring sites on one of these dates
Horizons (Manawatu – Wanganui)	January 2000	Data pertains to land use at monitoring sites on this date
Hawke's Bay Regional Council	February 1998	Data pertains to land use at monitoring sites on this date
Marlborough District Council	February 1998 and October 1999	Data pertains to land use at monitoring sites on one of these dates
Northland Regional Council	February 1998	Data pertains to land use at monitoring sites on this date
Otago Regional Council	January 1980 to February 1998	Data pertains to land use at monitoring sites during this period
Tasman District Council	January 1980 to February 1998	Data pertains to land use at monitoring sites during this period
West Coast Regional Council	September 1998	Data pertains to land use at monitoring sites on this date
Wellington Regional Council	February 1998	Data pertains to land use at monitoring sites on this date

Table 5.4 Summary of aquifer condition

Aquifer condition	Number of wells
Unconfined	57
Semi-confined	14
Confined	37

The distance that the confined aquifer wells are located from the aquifer recharge area and confined-unconfined aquifer boundary will have an important influence on the potential for groundwater contamination from land use activities in the unconfined aquifer area. NGMP wells that are in confined aquifers in Hawke's Bay (well 3697), Wellington (Mahoest), Tasman (WWD6601), and Marlborough (P28W/1873, P28W/1879), are located sufficiently close to the unconfined-confined aquifer boundary for there to be potential effect on groundwater quality from land use in the unconfined aquifer recharge area. The level of confined aquifer vulnerability to contamination also depends on hydraulic properties such as aquifer transmissivity, hydraulic gradient, volume of groundwater through flow, and nature of the aquifer materials.

Hydrogeological information that was supplied by regional council included aquifer transmissivity, storativity and permeability data, for those wells for which these data existed. The depth from ground surface to the aquifer and aquifer thickness at each well was determined based on driller's log information, including the depth at which the well screen was installed and depth of water bearing lithology. The aquifer depth below ground surface has an important influence on potential effects on groundwater quality from land use activity. In general, the deeper the aquifer is located below ground surface the less vulnerable the aquifer is to surface contamination. The permeability of the sediment overlying the aquifer is one of the important variables controlling the rate at which water infiltrates from the surface to recharge the aquifer.

5.2 Statistical analysis

The objective of the statistical analysis of the groundwater composition, land use and aquifer lithology data was to identify which groundwater components are elevated as a consequence of a particular land use or aquifer lithology. P-value calculations were performed on the data

Table 5.5 Mean measurements of concentrations for all wells except those columns marked with "*", which are individual analyses from a one-off sampling round. DRP = Dissolved reactive phosphorus. NA = Not analysed.

Well ID	pH	Elec. Cond.	Na	Ca	Mg	K	Cl	SO_4	Alk	SiO_2	NO_3-N	NH_4-N	DRP	Br	F	Fe	Mn	Pb*	Cu*	Cr*	As*
6475015	7.09	0.26	22.7	19.1	9.6	2.3	22.8	0.04	128	46	<0.01	0.14	<0.01	0.08	0.05	6.27	0.28	0.0002	0.0008	0.0007	0.015
6485070	7.69	0.61	37.9	74.3	29.5	1.8	74.7	<0.04	312	22	0.04	0.30	<0.01	0.24	0.08	1.00	0.06	0.0002	<0.0005	<0.0005	<0.001
7417023	8.72	0.43	96.2	2.3	0.9	4.0	32.8	1.23	213	9	0.05	0.31	<0.01	0.10	0.09	0.01	<0.01	NA	<0.0005	<0.0005	<0.001
7418027	7.86	0.29	21.8	30.5	7.3	3.3	21.0	0.03	149	37	<0.01	0.16	0.07	0.06	0.03	0.11	0.05	0.0006	0.0007	<0.0005	<0.001
7428103	8.37	0.26	27.6	17.4	6.0	4.6	22.9	2.84	120	22	<0.01	0.10	0.14	0.10	0.08	0.03	0.02	0.0007	0.0006	<0.0005	0.002
7428105	7.07	0.19	16.0	10.6	7.6	0.9	17.5	2.52	58	47	4.77	<0.01	<0.01	0.10	0.04	0.05	<0.01	NA	NA	NA	NA
AHIPARA	6.59	0.17	25.6	4.3	3.4	1.6	30.3	6.98	37	38	0.33	0.10	<0.01	0.11	NA	1.36	0.04	0.0003	0.0007	<0.0005	<0.001
ALLEN	6.43	0.25	22.5	13.3	5.8	9.3	34.6	5.86	69	81	1.27	<0.01	0.02	0.07	0.07	0.03	<0.01	0.0004	0.0026	<0.0005	<0.001
BAYLY	8.09	0.29	21.4	30.2	9.9	1.8	9.5	0.19	183	20	0.04	0.47	<0.01	0.03	0.13	0.19	<0.01	0.0004	<0.0005	<0.0005	<0.001
BEEK	7.48	0.40	47.0	29.6	12.3	4.7	22.7	18.52	224	69	0.08	1.00	0.08	0.03	0.23	2.01	0.26	0.0003	0.0015	<0.0005	0.002
BETTYS	6.47	0.15	12.8	7.5	3.9	2.3	15.1	10.82	22	14	4.06	<0.01	<0.01	0.05	0.08	0.01	<0.01	0.0002	0.0012	<0.0005	<0.001
BOFFA	6.93	0.26	31.5	11.8	7.6	1.7	27.6	10.76	83	20	3.30	0.02	<0.01	0.16	0.19	0.27	0.02	0.0003	0.0065	<0.0005	<0.001
COCACOLA	6.43	0.10	9.5	5.8	2.1	1.4	11.3	4.10	27	15	0.74	NA	NA	NA	NA	0.02	NA	NA	NA	NA	NA
COLVILLE	6.88	0.20	29.4	5.8	3.7	1.4	29.2	9.22	54	41	0.04	<0.01	<0.01	0.35	0.06	1.24	0.06	0.0009	0.0016	0.0009	0.001
COROMANDEL	7.97	0.22	8.2	34.5	2.2	1.7	9.8	3.33	115	14	0.47	<0.01	0.06	<0.01	0.03	0.03	0.04	0.0002	0.0007	<0.0005	0.006
CORRIGAN	8.14	0.33	23.5	31.4	12.2	2.8	24.9	5.36	169	27	0.33	0.12	0.03	0.10	0.07	0.05	<0.01	0.0015	0.004	<0.0005	<0.001
EDHOUSE	7.00	0.35	34.4	20.8	9.8	2.5	31.8	7.42	82	56	13.43	<0.01	0.02	0.18	0.05	0.01	<0.01	0.0003	0.0018	0.006	<0.001
ELTHAMDAIRY	7.77	0.75	102.1	52.9	16.8	7.3	16.5	0.53	506	32	0.01	6.51	0.05	0.14	0.17	0.29	0.98	NA	0.001	<0.0005	<0.001
FARNORTH	7.92	0.41	42.9	36.0	5.9	2.8	53.0	8.63	150	42	0.06	0.02	<0.01	0.19	0.05	0.05	0.09	0.0004	0.005	<0.0005	<0.001
FERNLANDSPA	7.55	0.84	151.9	10.2	7.4	7.1	198.6	0.05	135	83	0.01	0.02	0.07	0.65	0.38	0.56	0.54	0.0008	0.001	<0.0005	0.007
G400120	7.53	0.16	3.1	27.1	2.9	0.8	0.6	4.78	94	9	0.43	<0.01	<0.01	<0.01	0.25	0.01	<0.01	0.0005	0.0013	<0.0005	<0.001
G400129	7.43	0.10	2.2	16.3	2.1	0.5	0.4	4.72	58	9	0.17	<0.01	<0.01	<0.01	0.14	0.02	<0.01	0.0004	<0.0005	<0.0005	<0.001
G410103	7.44	0.23	9.9	33.3	5.2	1.3	2.6	5.88	137	13	0.75	<0.01	<0.01	<0.01	0.09	0.01	<0.01	0.0026	0.0059	<0.0005	<0.001
G420119	7.04	0.19	3.0	33.6	2.3	1.0	1.5	2.91	112	8	0.80	<0.01	<0.01	<0.01	<0.01	0.10	<0.01	0.0062	0.0017	<0.0005	<0.001
G420150	7.21	0.20	7.0	27.9	6.0	1.4	2.8	6.36	116	12	0.60	<0.01	<0.01	<0.01	0.07	0.03	<0.01	0.0004	0.0005	<0.0005	<0.001
G420160	7.30	0.22	9.5	30.0	4.9	1.0	3.6	5.55	123	15	0.66	<0.01	<0.01	<0.01	0.14	0.07	<0.01	0.0011	0.0011	<0.0005	<0.001
G420190	6.95	0.13	5.5	13.1	3.0	0.8	3.1	7.82	54	8	0.16	<0.01	<0.01	<0.01	0.07	0.21	<0.01	0.0003	0.0014	<0.0005	<0.001
GPB102	7.88	1.03	92.0	116.3	23.0	8.0	46.6	0.54	647	21	<0.01	5.95	<0.01	0.20	NA	0.28	0.13	NA	NA	NA	NA
GPC031	7.68	0.88	37.6	140.0	16.3	5.0	35.1	74.50	450	37	0.04	0.53	<0.01	0.13	0.16	3.22	0.89	NA	NA	NA	NA
GPC062	7.57	1.64	107.6	209.6	28.8	15.4	287.6	26.34	565	39	<0.01	0.35	<0.01	0.90	NA	9.87	1.11	NA	NA	NA	NA
GPD130	7.44	1.31	108.9	162.2	25.9	10.2	123.6	<0.04	708	36	0.02	3.89	<0.01	0.46	NA	0.58	0.43	NA	NA	NA	NA
GPE006	7.58	0.66	31.0	102.4	9.6	5.3	33.3	4.23	382	37	<0.01	0.52	<0.01	0.16	0.33	1.34	0.66	NA	NA	NA	NA
GPF090	7.52	0.89	80.9	118.0	13.6	5.8	56.3	1.04	528	29	<0.01	0.56	<0.01	0.26	0.03	0.27	0.87	NA	NA	NA	NA
GRAHAM	6.76	0.23	23.8	8.2	8.3	1.4	31.3	3.01	32	32	8.87	<0.01	<0.01	0.12	<0.01	0.02	<0.01	0.0002	0.0006	<0.0005	<0.001
GREEN	7.36	0.29	17.9	40.4	6.0	1.4	14.9	9.82	142	26	1.27	<0.01	<0.01	0.05	0.07	0.05	<0.01	0.0003	0.0006	<0.0005	<0.001
HAMBASIN	6.97	0.22	21.1	11.7	5.9	3.9	11.2	20.91	58	35	5.32	<0.01	0.02	0.06	0.06	0.01	<0.01	0.0004	0.0019	<0.0005	<0.001
HANDCOCK	6.75	0.56	25.0	32.6	30.5	2.5	77.9	1.71	38	38	32.57	<0.01	<0.01	NA	NA	0.02	<0.01	0.0006	0.0011	<0.0005	<0.001
HANN	7.62	0.21	16.8	16.0	3.6	4.6	13.5	2.70	104	30	0.88	0.46	NA	NA	NA	0.90	NA	NA	NA	NA	NA
HAURAKIGRABEN	6.64	0.17	14.0	9.2	4.5	6.2	9.7	9.90	40	74	6.50	<0.01	0.02	0.05	0.04	0.02	<0.01	0.0002	0.0031	0.0006	<0.001
HINDE	8.09	0.30	13.9	38.8	7.0	2.8	20.2	11.27	144	45	0.01	0.30	0.06	0.07	0.08	0.09	0.05	0.0007	0.0023	<0.0005	<0.001
J39/0109	7.32	0.44	22.6	65.3	6.8	1.9	30.5	19.92	191	12	2.72	<0.01	<0.01	0.12	0.14	0.32	<0.01	NA	NA	NA	NA
KAIKOHEHILL	6.91	0.16	13.7	10.1	4.9	1.6	12.1	2.17	53	56	3.57	<0.01	0.12	0.04	<0.01	<0.01	<0.01	0.0004	0.0013	0.0005	<0.001
LAING	6.79	0.09	11.6	3.0	1.6	2.9	6.6	3.44	35	86	0.19	<0.01	0.03	<0.01	0.16	0.01	<0.01	0.0002	<0.0005	<0.0005	0.008
LIDDLENNURSERIES	6.38	0.13	12.7	7.4	2.8	1.4	17.4	7.53	29	13	0.92	NA	NA	NA	NA	0.01	NA	NA	NA	NA	NA
M35/1382	7.02	0.10	4.3	12.5	1.4	0.8	3.7	4.56	43	11	0.44	<0.01	<0.01	<0.01	0.04	0.06	<0.01	0.0005	0.0027	<0.0005	<0.001
M35/6791	7.62	0.13	8.8	14.6	3.1	1.0	5.2	3.06	70	19	0.22	<0.01	<0.01	<0.01	0.10	<0.01	<0.01	0.0002	0.0016	0.0005	<0.001
MAHOEST	6.52	0.13	12.1	8.0	3.0	1.1	14.8	6.68	36	15	0.87	<0.01	<0.01	0.06	0.09	0.02	<0.01	0.0006	0.004	<0.0005	<0.001
MANGAROA	7.05	0.17	20.3	8.4	5.4	0.8	13.1	2.41	81	24	0.22	<0.01	<0.01	0.07	0.16	0.64	0.53	0.0004	0.0013	<0.0005	<0.001
MCALOON	7.47	0.32	23.7	25.4	9.4	8.1	16.3	0.77	172	52	0.01	2.94	0.42	0.08	0.20	1.09	0.39	0.0003	0.0006	<0.0005	0.013
MCCALLUM-2	7.69	0.30	31.0	18.5	7.6	7.8	28.1	0.50	140	56	0.09	1.21	0.15	0.11	0.30	1.82	0.78	0.0007	0.0042	<0.0005	<0.001
MCCALLUM-WELL	6.78	0.49	57.7	19.4	12.4	6.0	101.4	28.21	51	53	3.07	<0.01	0.03	0.39	0.09	0.03	<0.01	0.0003	0.0018	<0.0005	0.001
N32/0054	8.57	1.67	364.4	5.4	0.1	5.2	451.4	19.64	121	47	NA	4.05	<0.01	NA	5.16	0.16	NA	NA	NA	NA	NA
N33/205	7.65	1.12	8.9	25.3	2.4	1.2	3.6	6.32	79	15	4.28	<0.01	<0.01	<0.01	0.10	0.01	<0.01	0.0007	0.0008	<0.0005	<0.001
O31/0156	7.44	0.32	26.7	33.7	9.0	1.2	5.0	1.25	208	34	0.21	0.25	0.34	0.02	0.26	0.97	0.59	0.0001	0.0007	<0.0005	0.054
OHOPEGC	8.37	0.35	32.2	19.9	12.6	3.9	48.4	12.46	98	36	3.17	<0.01	0.11	0.14	0.10	0.03	<0.01	0.0002	<0.0005	<0.0005	0.012
P28W/0371	6.97	0.08	5.4	9.1	2.4	0.8	3.1	3.03	41	13	0.70	0.03	<0.01	<0.01	0.06	0.03	<0.01	0.0003	0.0006	<0.0005	<0.001
P28W/0426	6.57	0.07	4.3	7.9	1.7	0.6	3.4	3.00	31	11	0.64	<0.01	<0.01	<0.01	0.06	0.01	<0.01	0.0003	0.0026	<0.0005	<0.001
P28W/0612	6.71	0.12	7.2	12.8	3.1	0.9	3.7	7.12	46	15	2.20	<0.01	<0.01	<0.01	0.08	0.05	0.06	0.0005	0.0037	<0.0005	<0.001
P28W/1634	6.96	0.24	13.8	32.9	5.9	1.1	14.5	12.63	112	17	1.04	<0.01	<0.01	<0.01	0.06	0.03	<0.01	0.0003	0.003	0.0008	0.001
P28W/1873	7.24	0.25	27.2	18.7	6.4	1.1	4.5	7.20	126	25	4.42	<0.01	<0.01	<0.01	NA	0.06	0.37	NA	NA	NA	NA

Well ID	pH	Elec. Cond.	Na	Ca	Mg	K	Cl	SO_4	Alk	SiO_2	NO_3-N	NH_4-N	DRP	Br	F	Fe	Mn	Pb*	Cu*	Cr*	As*
P28W/1879	7.80	0.30	45.7	23.3	4.5	0.6	17.3	6.42	166	21	0.10	<0.01	0.12	0.08	0.16	<0.01	0.03	0.0002	0.0015	<0.0005	0.002
P28W/1945	7.53	0.20	28.0	17.3	9.1	1.2	5.5	4.70	151	25	<0.01	<0.01	NA	NA	NA	0.06	0.19	NA	NA	NA	NA
PEMBERTON	6.57	0.08	10.2	3.2	1.9	1.6	5.5	1.38	31	67	1.33	<0.01	0.02	0.03	0.32	<0.01	<0.01	0.0003	0.0006	<0.0005	<0.001
PENRAY	6.39	0.26	24.9	12.2	7.3	1.8	24.5	11.48	27	22	13.18	<0.01	<0.01	0.12	0.17	0.08	<0.01	0.0007	0.0049	<0.0005	<0.001
PUKEKOHE	7.47	0.24	16.4	13.9	10.5	3.8	21.0	5.33	87	53	2.99	<0.01	0.22	0.08	0.04	0.02	<0.01	NA	<0.0005	<0.0005	<0.001
PUPU	7.71	0.64	58.1	63.5	7.9	4.6	93.2	16.39	205	7	0.32	<0.01	<0.01	0.26	0.02	0.01	<0.01	0.0003	0.0146	<0.0005	<0.001
QEPARK	6.85	0.25	24.8	16.2	6.0	2.5	35.9	25.17	53	20	0.03	0.04	<0.01	0.13	0.13	0.95	0.09	0.0005	0.0023	<0.0005	0.004
REESBY	6.89	0.65	39.5	43.1	30.1	2.9	45.5	74.67	54	34	35.41	<0.01	<0.01	1.16	0.07	<0.01	<0.01	0.0003	0.0309	0.0031	<0.001
REIDS	6.78	0.13	8.9	7.0	5.1	2.6	9.0	9.36	24	33	4.94	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	0.0002	0.0006	<0.0005	<0.001
SPRINGDALE.SCH	6.15	0.22	18.3	8.0	5.0	7.1	28.4	22.93	21	78	2.69	0.04	NA	<0.01	<0.01	4.34	0.47	0.0003	0.0036	<0.0005	<0.001
SPTYRES	6.59	0.10	10.0	6.1	2.2	1.0	11.7	4.59	27	13	0.98	<0.01	<0.01	0.05	0.04	0.03	<0.01	0.0005	0.0085	<0.0005	<0.001
SRC-EDENDALE	6.60	0.18	22.0	8.9	5.8	0.7	26.0	4.20	55	34	1.27	<0.01	<0.01	0.10	NA	<0.01	<0.01	NA	NA	NA	NA
SRC-HARGEST	6.29	0.21	15.8	18.4	6.1	2.2	18.5	24.27	31	14	7.23	<0.01	<0.01	0.08	NA	<0.01	<0.01	NA	NA	NA	NA
SRC-RYAN	6.85	0.20	16.2	24.0	9.9	0.7	14.3	11.90	102	29	4.40	<0.01	NA	NA	NA	<0.01	<0.01	NA	NA	NA	NA
SRC-THOMPSON	6.53	0.21	19.1	14.4	8.2	0.7	19.1	17.20	77	29	0.04	0.02	<0.01	0.08	NA	1.26	1.17	NA	NA	NA	NA
SRC-WALLACE	6.42	0.17	13.8	15.3	4.9	2.5	16.0	9.43	46	15	4.17	<0.01	<0.01	0.08	NA	0.01	0.12	NA	NA	NA	NA
TARA.MANGAWHAI	6.72	0.20	15.3	7.6	5.2	1.6	20.0	3.00	42	37	3.11	<0.01	<0.01	0.08	0.05	0.42	<0.01	0.0002	0.0019	0.005	<0.001
TUTUKAKA.MARINA	6.88	0.71	142.0	4.3	7.7	9.3	68.4	168.56	106	32	0.11	<0.01	0.15	0.21	0.23	0.27	0.54	0.0006	0.0018	0.0007	<0.001
WAINUIOMATAGC	6.29	0.17	18.7	6.7	4.4	2.6	25.5	7.44	29	17	2.81	<0.01	<0.01	0.13	0.05	0.01	<0.01	0.0006	0.0014	<0.0005	<0.001
WAIPUKURAU	7.77	0.26	35.8	16.1	4.7	2.1	10.2	1.55	151	20	0.05	0.19	0.12	0.03	0.22	0.07	0.16	NA	<0.0005	<0.0005	<0.001
WATSON.AVE.1	7.04	0.25	22.2	11.5	6.1	5.6	17.5	17.27	61	18	4.34	<0.01	0.12	0.10	0.11	<0.01	<0.01	0.0015	0.0019	0.001	<0.001
WCRC-AGNEW	6.48	0.07	3.2	10.0	1.0	2.3	3.0	3.77	33	9	0.72	<0.01	<0.01	NA	NA	0.34	<0.01	NA	NA	NA	NA
WCRC-ANDERSON	6.39	0.06	3.3	8.4	1.1	2.8	2.0	2.87	32	14	0.93	<0.01	<0.01	NA	NA	0.01	<0.01	NA	NA	NA	NA
WCRC-BERTACCO	6.70	0.10	8.1	9.2	2.3	0.7	5.2	6.77	36	22	1.45	<0.01	<0.01	NA	NA	0.03	<0.01	NA	NA	NA	NA
WCRC-HUNTER	6.54	0.09	8.8	7.9	1.9	1.2	6.2	2.60	39	15	0.78	0.04	<0.01	NA	NA	0.42	0.07	NA	NA	NA	NA
WCRC-HUNTER	6.54	0.09	8.8	7.9	1.9	1.2	6.2	2.60	39	15	0.78	0.04	<0.01	NA	NA	0.42	0.07	NA	NA	NA	NA
WCRC-LYNDALE	6.53	0.09	2.9	13.6	1.5	2.4	2.2	4.10	47	10	0.53	<0.01	<0.01	NA	NA	0.05	<0.01	NA	NA	NA	NA
WCRC-MILNE	7.01	0.08	5.4	6.7	1.2	1.0	6.7	3.57	34	9	<0.01	0.08	<0.01	NA	NA	0.89	2.60	NA	NA	NA	NA
WCRC-WALLACE	6.52	0.10	10.2	6.1	3.0	1.9	10.7	5.63	33	18	1.04	<0.01	<0.01	NA	NA	<0.01	<0.01	NA	NA	NA	NA
WELL#1450	7.79	0.17	9.3	21.0	3.5	1.6	6.3	9.91	82	17	0.05	<0.01	<0.01	<0.01	0.13	0.16	<0.01	NA	NA	NA	NA
WELL#1558	6.85	0.19	13.3	11.5	7.0	1.5	11.0	5.10	63	24	4.38	<0.01	<0.01	<0.01	0.22	<0.01	0.51	0.0003	0.0047	<0.0005	<0.001
WELL#1940	7.15	0.51	40.4	52.3	10.8	3.5	44.5	38.91	197	30	0.11	0.44	0.02	0.18	0.20	3.48	0.43	0.0005	0.0008	<0.0005	0.001
WELL#3697	7.78	0.29	16.0	36.1	6.4	1.9	20.8	12.07	119	18	3.11	<0.01	<0.01	0.10	0.08	0.18	0.03	0.0009	0.0009	<0.0005	<0.001
WELL#3699	7.98	0.37	24.0	44.9	8.9	5.1	12.7	<0.04	235	15	<0.01	2.24	<0.01	0.08	0.11	2.75	0.26	0.0004	0.0211	<0.0005	0.002
WILCOX	6.82	0.16	11.3	10.8	4.0	4.8	12.2	8.84	31	78	5.57	0.02	<0.01	0.05	<0.01	<0.01	<0.01	0.0002	0.0094	<0.0005	<0.001
WWD3108	6.20	0.24	5.9	15.0	14.8	1.2	11.0	39.50	61	21	2.10	NA	2.00	NA	NA	0.70	0.95	NA	NA	NA	NA
WWD3115	6.58	0.21	5.8	14.1	12.3	1.1	7.2	26.22	83	24	0.16	0.07	<0.01	<0.01	0.06	1.53	2.58	0.0002	0.0008	<0.0005	<0.001
WWD32	7.70	0.35	9.9	18.9	25.7	0.7	16.1	20.86	102	28	12.51	0.03	0.02	0.10	0.02	0.07	<0.01	0.0005	0.0019	0.0055	<0.001
WWD3216	6.94	0.20	4.9	23.9	7.3	1.0	5.9	14.49	84	14	2.12	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.0004	0.0018	<0.0005	<0.001
WWD3314	6.37	0.27	7.3	22.3	12.3	4.4	10.3	64.10	48	16	1.97	<0.01	<0.01	0.04	0.02	0.97	0.11	0.0008	0.0125	<0.0005	<0.001
WWD37	7.49	0.53	11.0	11.1	55.1	0.9	18.6	33.85	168	36	21.04	<0.01	0.04	0.08	0.04	0.02	<0.01	0.0003	0.0154	0.0058	<0.001
WWD6601	7.52	0.25	4.9	43.7	2.8	0.8	6.3	3.85	133	10	2.17	<0.01	<0.01	0.02	0.03	0.31	<0.01	0.0002	0.0015	<0.0005	<0.001
WWD802	7.06	0.19	7.5	15.4	10.1	0.5	12.3	7.24	78	16	1.67	<0.01	<0.01	<0.01	0.05	0.01	<0.01	0.0012	0.0029	0.001	<0.001
WWD8404	6.98	0.21	20.2	16.4	6.3	1.2	5.0	3.19	128	64	0.01	0.02	<0.01	<0.01	0.35	2.94	0.30	0.0006	0.015	<0.0005	<0.001
WWD8407	8.06	0.29	25.2	29.9	6.6	0.6	5.7	1.88	178	23	<0.01	<0.01	<0.01	<0.01	0.18	0.26	<0.01	0.0004	0.0013	<0.0005	<0.001
YULE	7.13	0.44	11.2	4.6	3.0	1.0	10.0	2.94	39	29	0.31	<0.01	0.03	0.03	0.07	0.25	<0.01	0.0004	0.0129	0.0012	<0.001

Table 5.5 continued …

sets to determine if the observed differences in means were statistically significant. The methodology for the statistical analysis of the data is displayed in a flow diagram in Figure 5.1.

The mean concentrations for 20 chemical variables (pH, calcium, alkalinity, sulphate, potassium, nitrate, ammonia, phosphate, manganese, magnesium, iron, chloride, sodium, silica, bromide, fluoride, arsenic, lead, chromium, copper) were calculated for all groundwater samples from NGMP wells (Table 5.5) on S-PLUS for Unix software (Math Software Inc. 1998) (Step1, Figure 5.1). The mean was chosen as the measure of sample average as it is generally more representative of the sample and more sensitive with respect to the tails of the distribution than the median (Davis 1986). Also the statistical tests (F-test and P-value) that were performed on the data refer to the mean.

The aquifer lithology and land use data were coded so statistical analysis could be performed on the data set (Step 2, Figure 5.1). The coding was a simple "zero" or "one" format. If a well was in an area with a particular aquifer lithology or land use then a "one " was entered in that field for that well. If an aquifer lithology or land use did not occur at a particular well then a "zero" was entered. The coding was automated using a Microsoft Excel macro.

A constant was applied to all chemical data so "zero" values could be displayed and analysed in log format. The constant was applied in the following format:

$$Z_i = \log(C + X_i)$$

where Z_i = new log variable
C = minimum positive value of observation variable
X_i = observation

Box and whisker plots were used to display the data so the distribution of conditions for each aquifer lithology or land use category could be visually compared with the distribution for the rest of the database (Step 3, Figure 5.1). Log format box and whisker plots were used as these are less affected by outliers. Box and whisker plots were produced for all combinations of chemical variables, aquifer lithology and land use categories. In total 13,200 (20 x 11 x 16 x

4) box and whisker plots were constructed. The groundwater chemistry, land use, and aquifer lithology data were combined and stored in a Microsoft Excel spreadsheet. Microsoft Access queries were used to extract the well reference numbers and mean chemical concentrations of groundwater quality from all wells with a particular land use and/or aquifer lithology that was higher than the database mean concentration, as identified in the box and whisker plots. This allowed the influence of land use on groundwater chemistry to be separated from the influence of aquifer lithology on groundwater chemistry (Step 4, Figure 5.1).

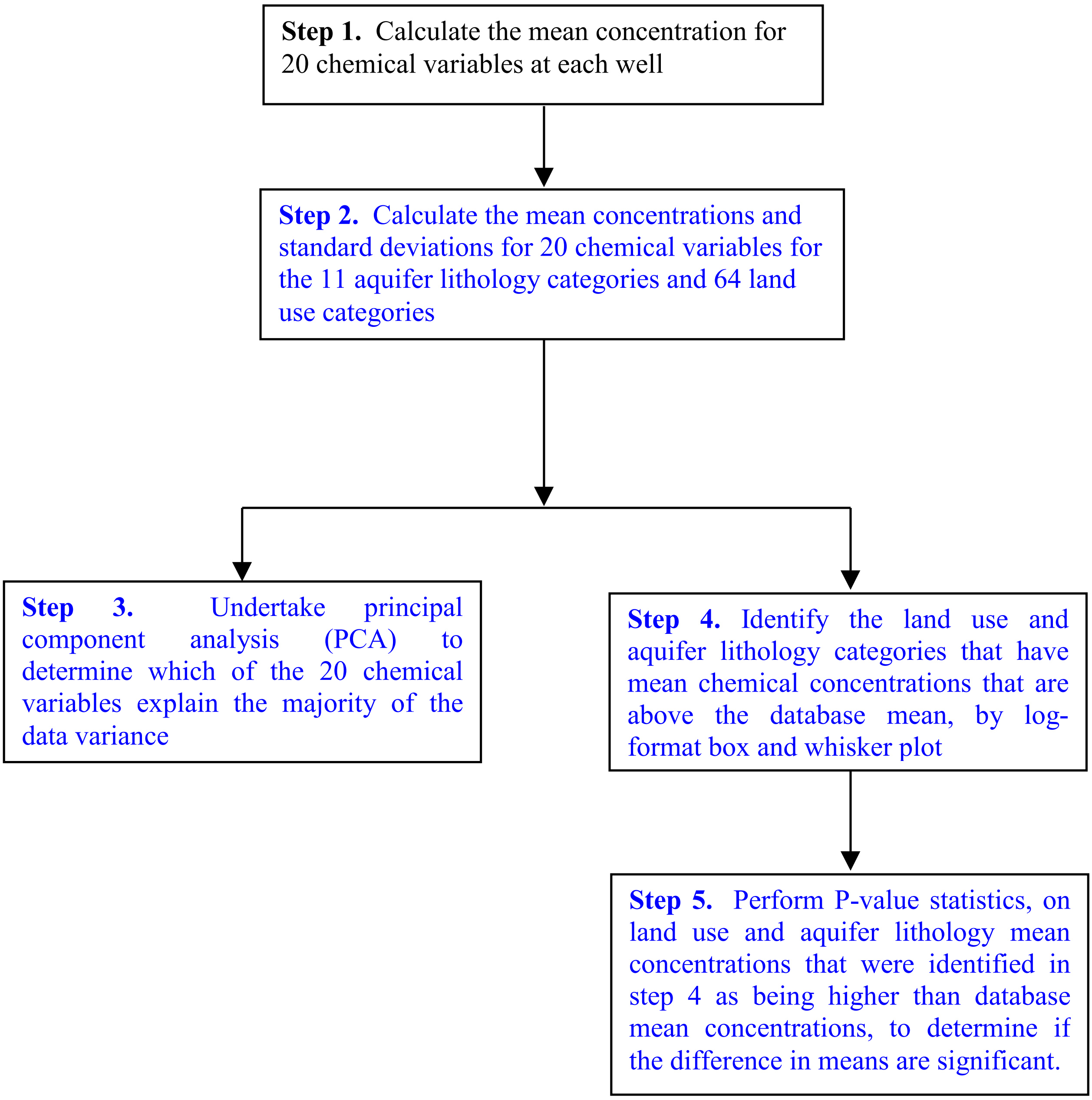


Figure 5.1 Flow diagram of methodology of statistical analysis.

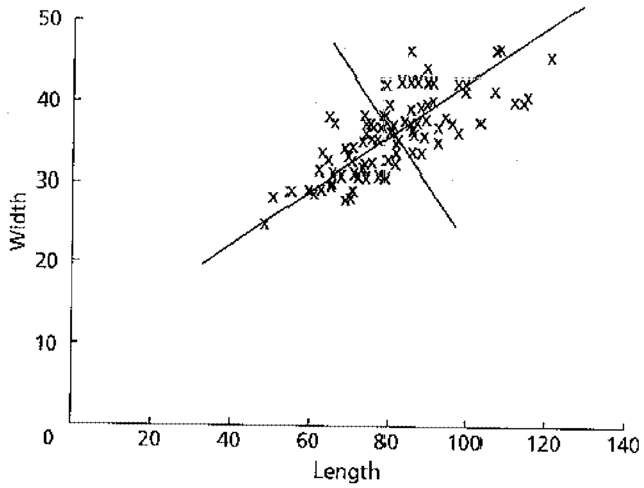
Statistical significance testing P-value were then undertaken to determine if the difference in mean concentrations were significant. The mean concentrations of those wells with aquifer lithology or land use categories that were higher than the database mean for a particular chemical parameter were compared to the mean concentration for the rest of the database (Step 5, Figure 5.1).

5.2.1 Principal component analysis

Principal component analysis (PCA) was used to identify the chemical parameters that may be potential groundwater quality indicators based on sensitivity of the chemical parameter to natural (aquifer lithology) and artificial (land use) influences (Step 6, Figure 5.1). PCA is a technique for finding linear combination of correlated variables (Swan and Sandilands 1995). For example, suppose there is bivariate data scatter that have the maximum variance along two perpendicular axes representing variables with strong linear correlation (Figure 5.2a). If a vector (eigenvector) is passed along the "long axis" of the data scatter and another vector perpendicular to the first, it produces a new pair of perpendicular axes that provide an alternative reference frame for the data scatter (Figure 5.2b). The new axes are different in that the amount of variance in the direction of the first axis is maximised and variance along the second axis is minimised. The useful property of the result is that it reduces the dimensionality of the data scatter in an optimal way by using the first axis only. The method can be applied to n-dimensional data (e.g. the 20 groundwater chemical parameters presented in Table 5.5) to rank the parameters in terms of contributing variance in the data scatter. The linear combination of variables that explains most of the variance in the data scatter is termed the first principal component, the linear combination that explains the next most variance is termed the second principal component, and so on. The results of the PCA are presented as loadings, which represent the contribution of each variable to that particular principal component. The loadings are coefficients of the linear combination that defines the principal component.

PCA is extremely useful for viewing high-dimensional data scatters. Applying PCA to the groundwater quality data identifies the chemical parameters that contribute most of the variance in the data and as such may be the most useful groundwater quality indicators in terms of sensitivity to environmental (e.g. land use) or natural (aquifer lithology) factors.

a)



b)

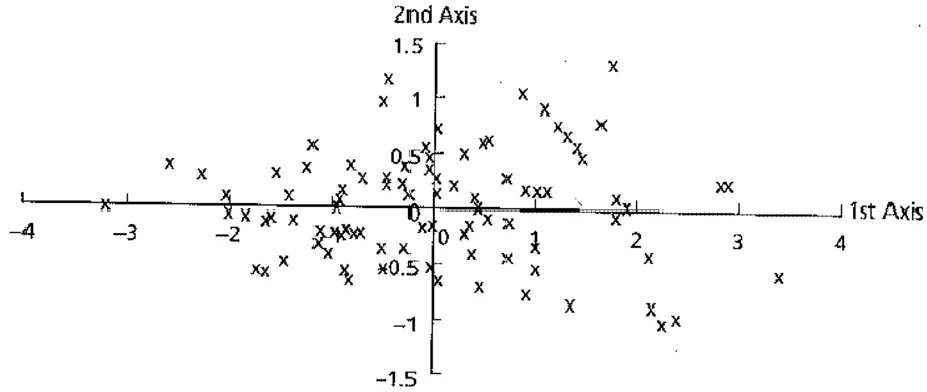


Figure 5.2.. Bivariate scatter of data shown in (a) can be re-plotted against the new axis (b) (from Swan and Sandilands 1995).

The PCA statistical analysis used for this study indicates that ten chemicals (see Section 6.0) can explain most of the variation in the data. However, the variation that these data explain is variation between sites, not variation of parameters over time for on particular site. This means for example that the variation in alkalinity is large across the nation (i.e. areas such as Gisborne have alkalinity concentrations of over 700 g m^{-3}, but areas such as the West Coast are less than 50 g m^{-3}), but it may not vary over time. Because of this, factors that explain the significant variation in the data set using means may not show changes over time or be relevant to any land uses. In order to address this problem, twelve sites were selected from the NGMP and subjected to PCA to determine if the proposed indicators explain the data in a temporal sense as well. The sites were selected from wells that showed some variation in the potential indicators: K, NO_3-N, SO_4, and Cl. Temporal statistics could not be performed on metal and pesticide data because temporal information is not available for these parameters.

5.3 Descriptive analysis

Descriptive (non-statistical) analyses were undertaken when there was insufficient data to obtain meaningful statistical analysis or when statistical results did not appear to have meaning in a geological or land-use context. Descriptive analyses were undertaken for the pesticide results and for some of the heavy metal results. In addition, some chemical indicators that appeared to have merit based on statistical results were not chosen as indicators due to their unsuitability in a geological or land-use context. For example, sodium was shown to be statistically important as an indictor of certain land uses and lithology, but because the chemical factors controlling sodium concentrations are complex (i.e. adsorption desorption, cation exchange etc), it was not chosen as an indictor. It should be noted however, that the descriptive analysis is based on data collected for the specific purpose of assessing the ability of a parameter to be used as an indicator.