

*An analysis of groundwater quality
in the Morven, Glenavy and Ikawai area,
South Canterbury, New Zealand.*

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Frontispiece



A representation of the study area:

Greener pastures - greater production.

Does this affect the groundwater quality?

Abstract

The quality of groundwater beneath land surfaces can be influenced by activities carried out on the land. The combination of these activities and effects of the physical environment can cause groundwater contamination, being the threshold at which human or animal health is at risk. The physical environment can induce unacceptable levels of chemicals to groundwater and these may be measured by indicators such as pH and hardness. Particular activities leading to contamination in rural environments include farming activities utilising irrigation and chemicals to enhance production. An outcome of these activities may include the disposal of animal wastes which is a direct contaminant input having the potential to reach groundwater. Settlement patterns, in particular small settlements which are unsewered, can also contribute to groundwater contamination through sewage disposal from septic tanks. This thesis explores how these activities may influence groundwater quality of the Morven, Glenavy and Ikawai area in South Canterbury, New Zealand. In doing so it utilises groundwater measurements taken by the Canterbury Regional Council from 90 wells in February and May 1996. The results from these measurements are related using a Geographic Information System to various human activities, namely farm type, irrigation, waste disposal and settlement patterns and two physical parameters, soil permeability and groundwater depth or piezometric surface. Patterns emerge which indicate contamination from settlement patterns and activities such as waste disposal, but not so much from dairying or irrigation. Levels of hardness are highest near the Waikakahi Downs, coinciding with the pattern of less permeable soils near the Downs. It is important that other factors, such as temporal changes, are not overlooked or neglected.

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Chapter One

Introduction

1.1 Preface.

Often geographic research involves looking at the effects of phenomena and processes which are "out of sight, out of mind." The very nature of these phenomena and processes means that the way in which they affect humans is often unexpected. Any solution may be inappropriate and implemented too late to remedy the problem. This is because it is not known what factors and to what extent these factors contribute to it. A particular example of such a problem, the concern of this thesis, is groundwater contamination. A contaminant can be defined as "A substance or organism in the water which can cause undesirable public health or aesthetic effects." (Ministry of Health, 1995). A groundwater contamination problem is often identified only when it directly affects humans. Thus groundwater quality investigations can often begin too late and act as a means of clarifying a contamination problem which is already occurring.

A wide body of opinion suggests that changing agricultural landuse activities can increase the chances of groundwater contamination. The Canterbury Regional Council (CRC) (1995 a) addressed this issue for the Morven, Glenavy and Ikawai area in South Canterbury, New Zealand. Groundwater quality of this area was measured by myself and the Canterbury Regional Council (CRC) in February and May 1996. The thesis utilises results obtained from these measurements to describe the groundwater quality and identify groundwater contamination. It then seeks to explain these results by linking them to possible causative factors using a Geographic Information System (GIS).

The rural study area lies in the south eastern portion of South Canterbury, between 44° 46' 00" and 44° 56' 15" latitude and 170° 48' 00" and 171° 10' 20" longitude. Figure 1.1 shows its location in New Zealand and also provides a precis of the region.

It is an area of approximately 22000 hectares, gently sloping to the Pacific Ocean. The gentle gradient is due to it being part of the outwash fans of the Waitaki and Waihao Rivers. Lowland downs and hills border the area to the north and west and the two forementioned rivers bound it to the north and south. Chapter Four deals with aspects of the study area relevant to groundwater investigations.



Figure 1.1: The Study Area.

Source: Author, 1996 and Department of Survey and Land Information, 1984(a).

1.2 Research of groundwater quality in rural areas.

Links to factors causing groundwater contamination are made by various studies from overseas and New Zealand. Adriano *et al.*, (1972) focus on crop fertilisation in California in the United States and its effects on groundwater chemistry. A review of five United States studies by Hamilton and Helsel (1995) identify several landuse practices which contribute to groundwater contamination, in particular the effect of agricultural activities.

Connell (1974) provides a general review of groundwater contamination causes and effects using Australian examples. Brown (1991) begins to identify New Zealand groundwater contamination from agricultural and urban landuses in key areas, such as the Hawkes Bay, Hutt Valley, Nelson and Canterbury. Burden (1982 and 1979) also explains some of the studies carried out in New Zealand in the 1970s which began to link nitrate contamination of groundwater to agricultural activities. He also stresses that future landuse activities, in particular farming, may increase nitrate contamination of groundwater. Tillman (1995) investigates how dairying contributes to high nitrate levels in groundwater in the Manawatu region in the North Island of New Zealand. Scott's (1979) work in the Heretaunga Plains of the North Island, New Zealand, sought to explain groundwater quality in terms that would assist with land management. Inferences can be made for this study based on outcomes which suggest nitrate contamination from urban areas. Bathurst *et al* (1979) reflect the interests of this and other studies, saying "By 1977 the need for better information on the quality of underground water [groundwater] and factors likely to influence this was generally recognised..." By 1996 it is hoped that the groundwater quality of the Morven, Glenavy and Ikawai area will be well known and will be able to be explained in terms of what factors may be influencing it.

Groundwater quality studies carried out in Canterbury tend to be quite focussed on a few contaminants and landuses. The rural area around Christchurch city has received considerable attention. A recent thesis by Wilkinson (1995) touched on groundwater contamination problems to the north of Christchurch and also discussed the factors contributing to such problems. Sinton (1982) looks at the effects of household septic tanks on groundwater quality at Yaldhurst near Christchurch, New Zealand. Bathurst, *et al* (1979) identify groundwater contaminants and contamination areas around Christchurch and recognise that certain landuses are contributing to the contamination. Because these studies are carried out at the urban rural boundary, they identify a wide range of landuses and contaminants resulting from these. Research has also taken place (Burden, 1984; Quin and Burden, 1979) in the area known as the Canterbury Plains to

the south and west of Christchurch. These focus on more rural landuses and resulting contamination. Detailed work by Smith (1993 a), 1993 b) for the CRC show that agricultural and urban landuses can contribute to groundwater contamination.

1.3 Rationale.

Figure 1.2 illustrates the utilisation of groundwater in the study area where groundwater is an important resource. It supplies the Lower Waihao Water Scheme operated by the Waimate District Council, which serves residents within and outside the study area. Private households not served by the water scheme draw groundwater from wells for their own uses. Farms, in particular dairy farms, require groundwater for stock drinking water and for cleaning purposes, mainly in milking sheds on dairy farms. Although groundwater contamination can affect these users of groundwater, the thesis is concerned with how the environment (or users) influence groundwater quality. It is well established that various landuses and activities can contribute to groundwater contamination. The study being undertaken by the CRC will monitor and examine the nature of this interaction.

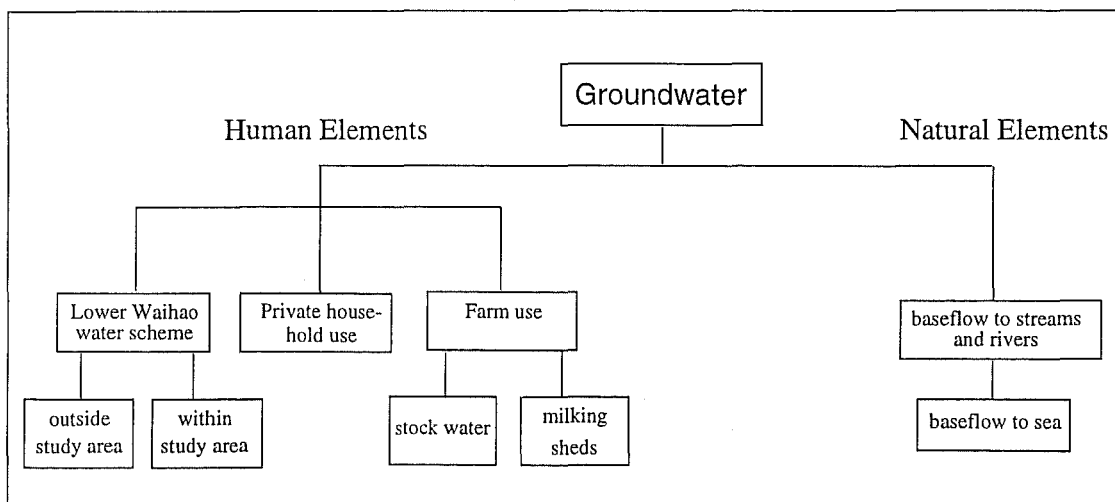


Figure 1.2: Linking groundwater to the study environment.

Source: Author, 1996.

In order to explain groundwater quality it is necessary to collect measurements from wells. Secondly it is necessary to identify the possible causative factors through research of the literature. These need to be linked spatially to groundwater quality

results, which can be done using a GIS. Once this is achieved it is possible to analyse the results to explain the influence of causative factors. The research is focused around the following objectives:

- 1) to identify any patterns of groundwater quality;
- 2) to identify the independent factors which may influence any such patterns;
- 3) to establish a database linking groundwater quality measurements to the independent factors;
- 4) to determine if the independent factors influence the spatial pattern of groundwater quality.

1.4 Interest in groundwater quality and the environment.

Recent interest in the state of groundwater quality in the study area can overshadow past beliefs and values. Maori view groundwater as being Te-Muri-Wai-Hau (Ultimate Purifying Waters) and believe it needs to be preserved (Tomoana, 1993). Local Maori have a particular interest in the Morven, Glenavy and Ikawai groundwater. Mr. Kelly Davis from the Waihao Marae feels that this groundwater has been degraded over the last 18-24 months and links the degradation to septic tank and dairy farm effluent disposal. He also stated that the groundwater was known to Maori to be the best available in the wider Canterbury and Otago regions in pre-European times and even until recently.

The main administrative body which investigates and monitors groundwater quality in the study area is the Canterbury Regional Council (CRC). Their main concern is that water is not degraded for future use, which follows closely the focus of Section 5 (2, a-c) (Appendix One) of the Resource Management Act (RMA) 1991 (CRC, 1993). More direct concern is stated by the CRC (1995 a):

The increase in dairying in Mid and South Canterbury increases the chances of contamination of streams and groundwater, especially where it is combined with border dike irrigation.

Such problems are addressed in the Proposed Regional Policy Statement:

Issue 3, Policy 12.

Promote landuse practices which maintain and where possible enhance water quality and which minimise discharge of contaminants onto land where they adversely affect water quality. (CRC, 1993)

Although this sounds convincing, it does not actually state any specific landuses or how landuse can affect water quality. Potential threats to groundwater quality are listed under Issue 9.3 Water Quality, under the sub-heading Groundwater Quality. These are:

- Timber treatment plant discharges.
- Previously contaminated sites which continue to pollute.
- Location of industry or settlement in areas vulnerable to contamination.
- Underground storage tanks, fittings and pipelines.
- Storage and handling of hazardous substances.
- Stormwater disposal.
- Agricultural solid and effluent waste disposal.
- Pesticide and chemical storage and application.
- Sewerage disposal.
- Location and discharge from landfills and waste disposal sites. (CRC, 1993)

These threats can be exacerbated "...where an aquifer is unconfined, i.e. there is no impermeable surface sediment which would prevent or minimise the downward flow of contaminants." (CRC, 1993). Obviously the CRC are concerned with groundwater contamination in Canterbury and in keeping with the RMA (1991) to not allow any contamination to occur.

The Waimate District Council (WDC) also takes an interest in groundwater and the environment. Section 4 of the Proposed District Plan (April 1996) identifies key areas of interest. Under Issue 3, Protecting Rural Amenity, concern is given to effluent disposal which is seen to affect groundwater quality, especially "...where the groundwater table is close to the land surface." (WDC, 1996 b) This issue is then addressed under Objective 5, a general objective which seeks to protect the quality of the rural environment. Policy 5A, however, is more specific and looks at Factory Farming and Dairying. It is up to the Council to decide, via consent whether these operations will not harm the amenity of rural areas and the quality of the physical environment. Further explanation is given, in which dairying is assumed to have adverse effects on the environment. In particular, "...for contamination of waterways and groundwater by dairy effluent and fertiliser application particularly in areas with border dike irrigation or in areas with high water tables." (WDC, 1996 b) Policy 5F, Pattern of Subdivision is concerned with the "cumulative adverse impacts of septic tank disposal systems on the quality of groundwater." (WDC, 1996 b) Thus two distinct activities have been identified as being harmful to groundwater quality, farming

practices and septic tank disposals.

Objective 6, Water bodies and their margins, also addresses the problem of water quality degradation. Policy 6B, Factory Farming and Dairying is concerned with the effects these activities may have if located too close to waterways. Explanation of the policy is given and identifies a problem with high water tables which are at risk from effluent disposal, flood irrigation and fertiliser application, all of which can contaminate groundwater.

Under Section 10, Subdivision, another objective is given which reiterates Policy 5F. It is concerned with septic tanks and their possible effect on groundwater quality, through seepage. These objectives and policies are part of the District Plan, being important considerations under the resource consent process.

Local interest in the issue is also growing with an environmental quality group being formed this year. As water quality directly affects local residents, it is important for them to show interest in what is happening to the groundwater resource. Although councils can represent locals, often this representation is not at an appropriate level or with the required support.

1.5 Methodology.

Quantitative methods were used to gain a better understanding and full knowledge of processes occurring in the study area. Data were collected on and off site and included personal contact with the Ministry of Agriculture (MAF) Invermay office near Dunedin to obtain past records of the irrigation schemes and some theoretical background material. A full list of the data sets collected is shown in Table 1.1.

Data set	Format	Source	Date	Location
groundwater quality	excel spreadsheet	CRC	1996	Christchurch
well locations	GIS coverage	CRC	1996	Christchurch
groundwater samples	field notes	fieldwork with CRC	1996	study area
groundwater levels	field notes	fieldwork with CRC	1996	study area
farmtype	map	fieldwork	1996	study area
soils	map	DOSLI map	1984	Christchurch
topographic features	map	DOSLI map	1984	Christchurch
resource consents	GIS coverage	CRC	1996	Christchurch
piezometric surface	GIS coverage	CRC	1979	Christchurch
irrigation schemes	map	DOSLI map	1984	Christchurch
	scheme reports	MAF	1983	Invermay
Maori values	personal comments	Kelly Davis	1996	Waihao Marae

Table 1.1: Data sources.

1.6 Thesis Structure.

The thesis is dedicated to answering the four research questions developed earlier. To achieve this goal the thesis is divided into six chapters.

Chapter 2 examines the physical environment and focuses on hydrology. This chapter provides information on the processes involved with infiltration and soil moisture recharge and the implications for groundwater recharge. It also introduces irrigation and its effect on hydrology of the soil and groundwater.

Chapter 3 focuses on groundwater contamination. Initially this chapter examines natural groundwater chemistry, types of contaminants and sources of contamination. It then focuses on the groundwater quality field survey and explains how it was conducted, describing the sampling locations, variables and methods. The results are also discussed before being put into use in Chapter 5.

Chapter 4 describes the study area in order to provide the necessary data for the analysis in Chapter 5. The physical aspects of the study area relevant to the thesis are described, which include permeability and the piezometric surface. Human influences are then described, including farming activity and the spatial distribution of population.

Finally the chapter revisits the groundwater sampling points, wells, to expand further on them.

The key Chapter, 5, compiles and analyses the data using GIS and statistical methods. The methodologies are discussed once the analysis has been carried out a discussion of the results is made.

Finally Chapter 6 concludes the thesis, bringing together the ideas and linking them with the earlier chapters. The use of GIS in this type of analysis is assessed. An assessment will also be made regarding the usefulness of this type of work for further research.

1.7 Summary.

A groundwater quality problem at Morven, Glenavy and Ikawai is to be investigated and explained. It is hoped that links can be made between groundwater quality results and causative factors utilising measurements collected in February and May 1996 along with a variety of other data. Research suggests that activities carried out at or near the land surface influence groundwater quality, often leading to the contamination of it. Examples from the Canterbury Plains, which are of similar nature to the study area, indicate that agricultural and urban landuses and activities can be linked to groundwater contamination. Under national legislation, namely the RMA (1991), the regional and district councils must monitor and control both the groundwater quality and landuse practices to ensure compliance with the Act. In carrying out thesis research in conjunction with the CRC and WDC, it is hoped to provide a better understanding of local groundwater problems, while also contributing to the wider body of research concerned with groundwater quality and contamination.

Chapter Two.

The Physical Environment - Hydrology.

2.1 Introduction: The Hydrologic Cycle.

The hydrologic cycle of the earth is a "...global pattern of continuously circulating water between the ocean, the atmosphere and land. It is powered by the energy of the sun." (Watson and Burnett, 1993). At the global scale the sun controls the amount of moisture available to the earth by heating the earth's atmosphere, biosphere and oceans. Moisture is distributed through a complex assortment of circulation processes, mainly influenced by the sun's energy and the earth's rotation. Atmospheric moisture evaporated from the earth and ocean is distributed around the globe and will come back into contact with the earth and ocean via precipitation. Water moves continuously through the hydrologic cycle as shown below:

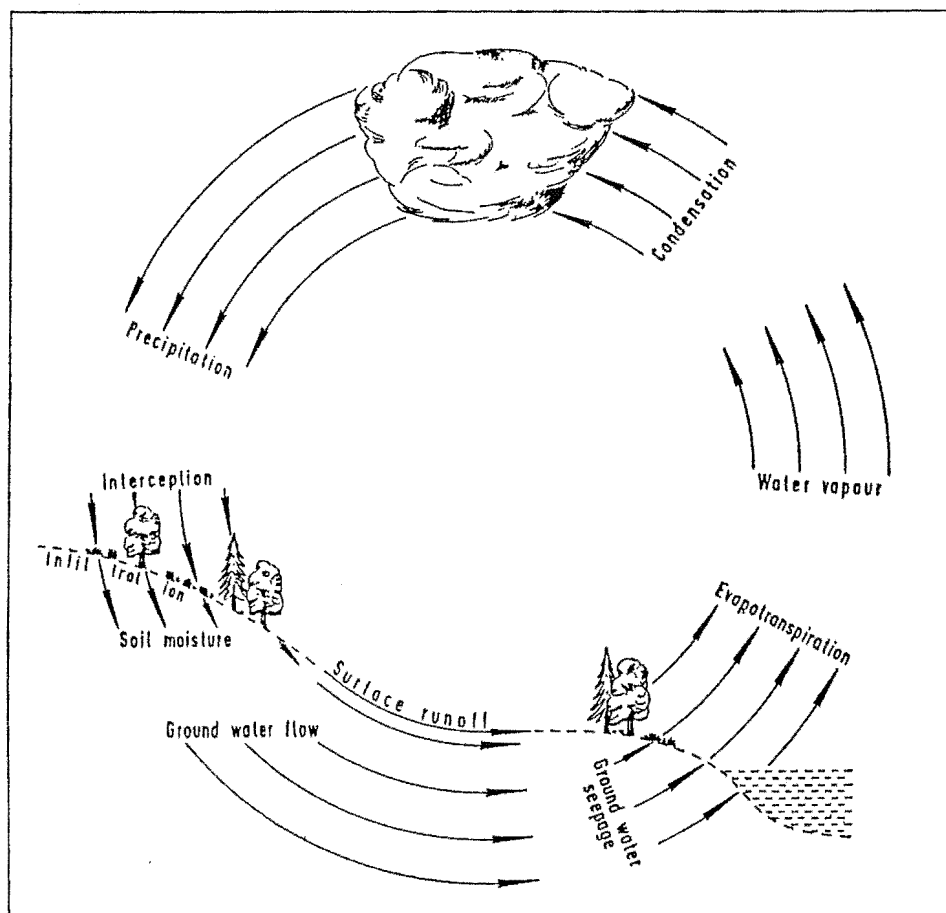


Figure 2.1 : Hydrologic cycle.

Source: Ward, 1967, p 17, Figure 1.1.

Of particular relevance to this thesis are the lower parts of the cycle. Precipitation supplies water to soil moisture, which in turn may contribute to groundwater. Water inputs may be lost to evaporation and runoff before reaching groundwater. Human actions can affect these fluxes in a manner which can either increase or decrease the groundwater in an area. The following sections will examine more closely the processes involved in groundwater hydrology and groundwater and irrigation.

2.2. Groundwater Hydrology.

It is clear that groundwater can be both a store and a transfer in the hydrological cascade. Figure 2.2 draws attention to the other elements of the cascade which affect groundwater. As can be seen, various transfers can interrupt water flow to groundwater and in some cases groundwater may not even be recharged if these are more dominant. Evaporative losses may transfer moisture from any of the storages shown, though normally not from groundwater. Groundwater recharge relies on water infiltrating through a medium. As water is applied to it the ability of soil to store further moisture declines as pore space is filled, thus inhibiting further water storage in the soil. This is because water held in the soil (S_t) is filling the storage capacity (S_c). The ability of soil to store further moisture declines as $S_c - S_t$ tends towards zero. Overland flow occurs when water is delivered to the surface at a rate which exceeds surface absorption (Freeze and Cherry, 1979). This may occur because the rainfall intensity or water input is greater than the infiltration capacity of the soil, or because the water table has risen to the surface.

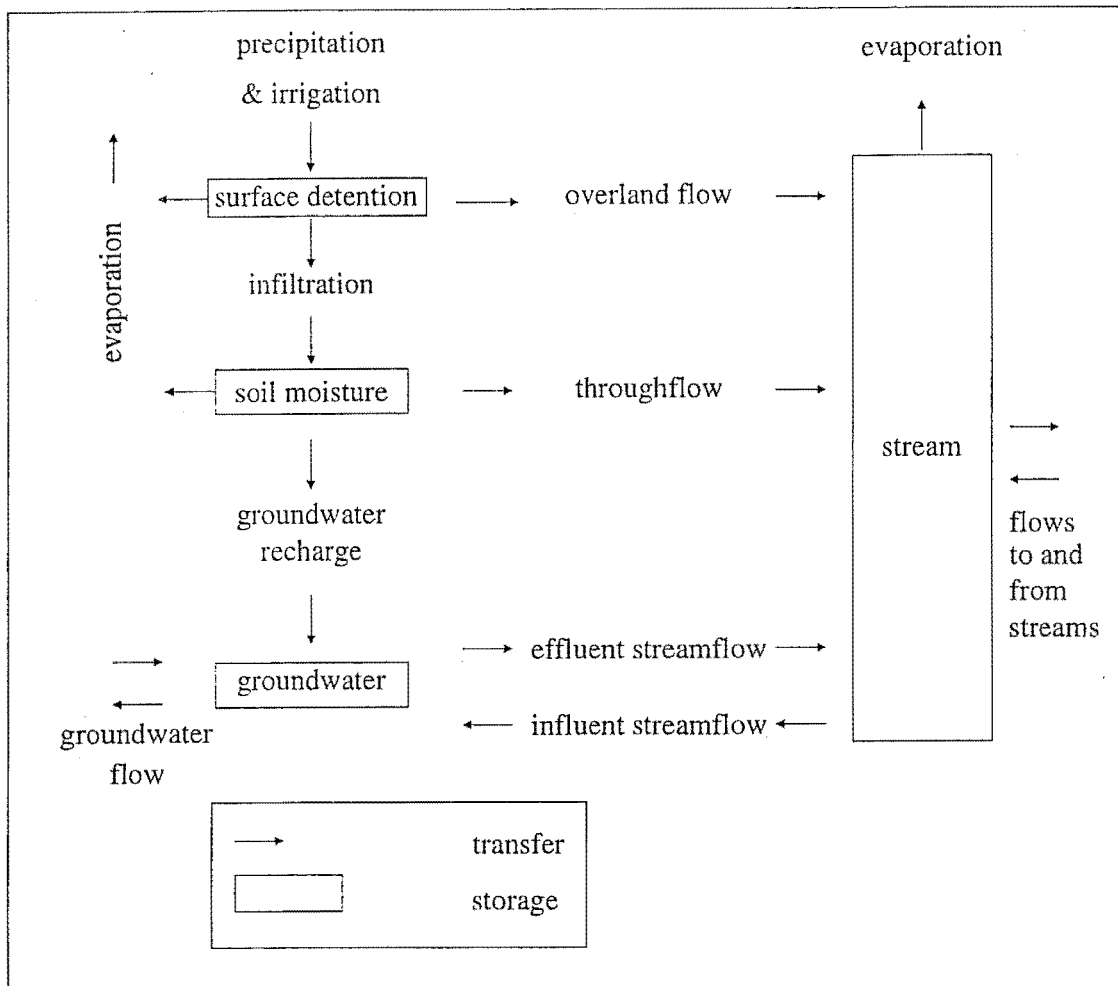


Figure 2.2: A simplified lumped cascade showing stores and transfers relevant to groundwater.

Source: Author, 1996 and Domenico and Schwartz, 1990, p11, Figure 1.3.

The amount of water able to enter soil is determined by the infiltration capacity and rate of water supply to the surface. Infiltration capacity can be defined as the "...maximum rate at which water can penetrate into soil," (Kirkby, 1969) and can be given by equation 2.1:

$$f = A + B \cdot t^{0.5} \quad (2.1)$$

where f is the instantaneous rate of infiltration, t is the time elapsed since the beginning of rainfall, A is the transmission constant of the soil and B is the diffusion constant of the soil (Kirkby, 1969). The transmission constant is a measure of a steady flow through soil, while the diffusion constant relates to the initial rapid infilling of air-filled pore spaces which slows down over time. Typically the rate of infiltration falls between 0 and 60mm per hour and is dependent on the soil grain size, soil structure, initial moisture content and the vegetation cover.

The physical characteristics of a medium are significant for both infiltration and groundwater recharge. Porosity refers to presence of voids in the material, which allows storage of water and air. The connectivity of pores through a medium influences the permeability or hydraulic conductivity of material which is "...the ease with which a fluid will pass through it and indicates its capacity to transmit water." (Wilkinson, 1995).

Directional and spatial variations of permeability commonly occur. The term anisotropic describes "...materials where the permeability or conductivity is different in different directions. When permeability is the same in all directions, the material is isotropic." (Domenico and Schwartz, 1990). In bedded sediments "...permeability is often greatest in the direction of the stratification and smallest perpendicular to the stratification." (Domenico and Schwartz, 1990). If permeability is the same from point to point in the material then it is known as homogenous, otherwise it is heterogeneous. It is important to collect samples when drilling wells to help describe the geology and to ascertain a level of permeability for the medium of interest. Information such as this was not readily available for the study area.

A groundwater body, supplied as shown in Figure 2.2, may occupy an aquifer. An aquifer can be described as being "A rock unit that is sufficiently permeable so as to supply water to wells..." (Domenico & Schwartz, 1990). Watson and Burnett (1993) identify three key characteristics of an aquifer as:

- dynamic storage systems for groundwater supply;
- conduits for groundwater flow; and
- 'filters' for reclaiming groundwater quality.

The supply of water to wells from an aquifer may not be reliable, but the aquifer is still considered to be a water bearing unit. There are two main types of aquifers which are described as:

- 1.) Confined Aquifer. This is an aquifer which is overlain by a confining layer (i.e. an overlying geologic unit of relatively low permeability).
- 2.) Unconfined or Water Table Aquifer. This, by contrast, is an aquifer which has no confining layer at the top of its saturated zone (its water table) and the earth's surface. (Watson and Burnett, 1993)

Unconfined aquifers are of relevance to this study and are recharged as shown in Figure 2.2. Because there is no confining layer, water movement to the aquifer is relatively unhindered, but is constrained by the factors such as porosity and conductivity.

Groundwater Movement.

The rate of groundwater flow is described by Darcy's Law:

$$v = Ki \quad (2.2)$$

where v is the groundwater flow velocity, i is the hydraulic gradient causing flow and K is the constant describing the ability of a geologic material to transmit water (hydraulic conductivity or permeability) (Watson and Burnett, 1993). Groundwater flows commonly range from two metres per day to two metres per year (Waltz, 1969) depending on the two controlling factors from Darcy's law.

The permeability of aquifer material will be a significant determinant of groundwater flow. The influence of hydraulic conductivity can vary depending on the materials involved. Table 2.1 shows the range of hydraulic conductivity values expected from various sediments.

Material	Hydraulic conductivity (m/sec)
SEDIMENTARY	
Gravel	3×10^{-4} – 3×10^{-2}
Coarse sand	9×10^{-7} – 6×10^{-3}
Medium sand	9×10^{-7} – 5×10^{-4}
Fine sand	2×10^{-7} – 2×10^{-4}
Silt, loess	1×10^{-9} – 2×10^{-5}
Till	1×10^{-12} – 2×10^{-6}
Clay	1×10^{-11} – 4.7×10^{-9}
Unweathered marine clay	8×10^{-13} – 2×10^{-9}

Table 2.1: Values of hydraulic conductivity for various sediments.

Source: Domenico and Schwartz, 1990, Table 3.2, p 65.

2.3 Irrigation and Groundwater.

Irrigation artificially recharges the soil moisture of the area under irrigation. The quantity of groundwater recharge depends on the quantity and the method of application by the user, soil conditions at the time of irrigation and subsequent weather. As Bouwer (1989) says: "The rate of downward water movement or deep percolation flow is determined by the water balance of the root zone (infiltration minus evapotranspiration)."

Irrigation has been a common practice in areas where rainfall is unreliable and/or insufficient to meet the demands of producers. Heerman et al (1989) provides an excellent definition of irrigation: "Irrigation is the application of water to meet crop evaporation (ET) demands when rainfall and stored soil water are insufficient." Groundwater can be used as a source of irrigation water, but it is not used in the study area.

Irrigation will alter the soil moisture levels at both the spatial and temporal scales. Although irrigation is frequently used to provide moisture when a moisture deficit exists, an outcome can be a short term moisture surplus. At the temporal scale a sudden

moisture input can be generated with each irrigation (or rainfall) event which can be illustrated in Figure 2.3.

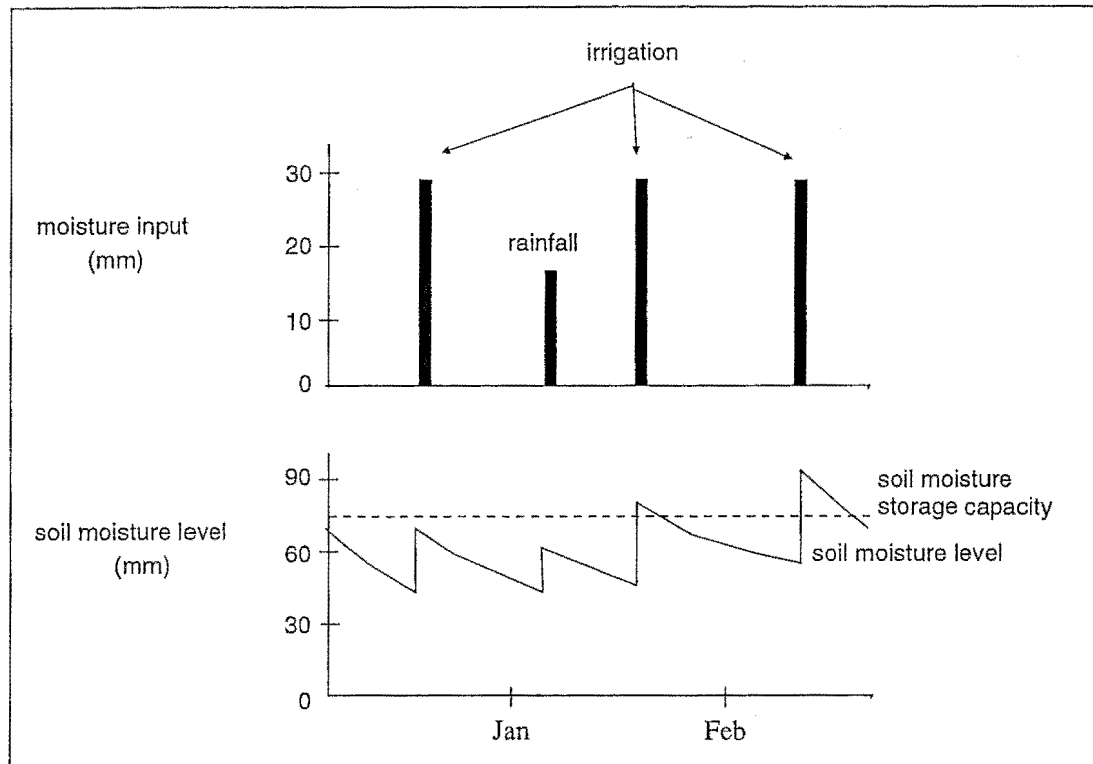


Figure 2.3: Moisture input and its affect on soil moisture levels.

Source: Adapted from Maidment et al, 1983, p 413, Figure 4.

In this example, although each moisture input event does not result in a soil moisture surplus, the gradual build up of soil moisture levels over time leads to a surplus in the final two irrigation events when groundwater recharge could be more likely to occur. Overland flow can also occur during the soil moisture recharge event. The soil moisture level declines between events as it is lost to percolation and evaporation.

The spatial effects of irrigation on soil moisture and any subsequent groundwater recharge are related to the techniques used. Common techniques include flooding and spraying the land. The latter tend to rely on greater technology involving pumping and spraying water above the surface to simulate a rainfall event. This is carried out by machinery of which several types exist. For example spray irrigators can be moved across the land in various ways. The amount of water applied is influenced by the

length of time the irrigator is used in one place. During a spray irrigation episode, water distribution to the surface and sub-surface may be uneven. Such an outcome can result in a pattern of water deficiency or surplus as shown in Figure 2.4.

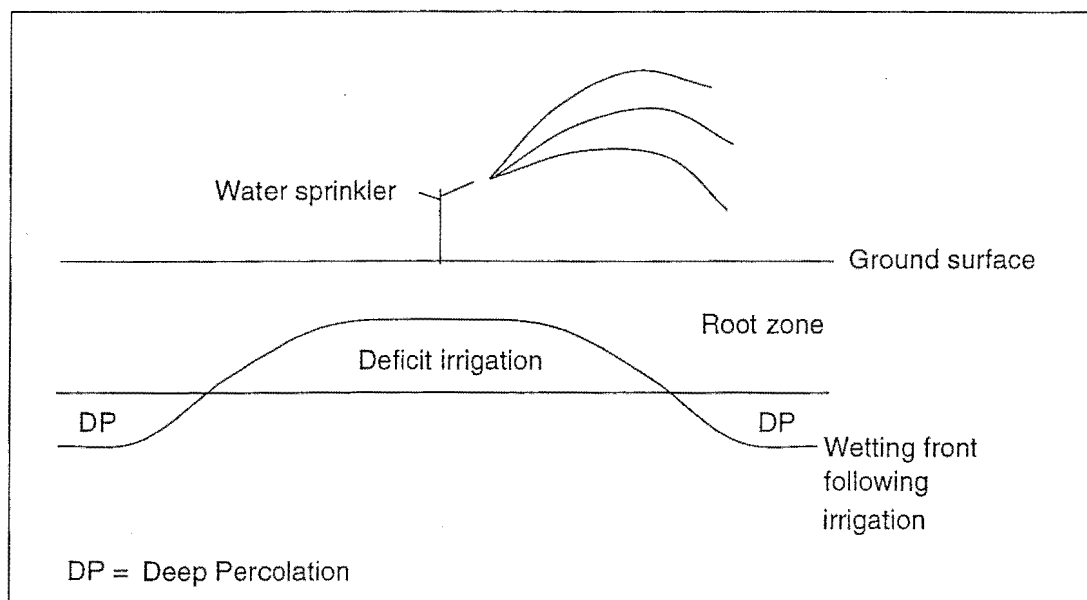


Figure 2.4: Spray irrigation water losses and gains from a stationary source.

Source: Adapted from Carran, 1979, p 48, Figure 1.

This pattern can affect the subsequent distribution of water to groundwater. The processes affecting percolation following a spray irrigation event will very much depend on the stratigraphy of the soil profile and how this affects the permeability. Despite the fact that water in the soil may be unevenly distributed as a result of irrigation, its pattern further down the profile may be evened out and possibly redistributed because of the organisation of the strata. A good method to detect spray and other irrigation efficiency or losses is to remotely sense the area of interest. In this way patterns of water surplus and deficit can be identified by the patterns of vegetation growth or stress. Generally a pasture will turn yellow in the visible wave bands as it comes under more stress.

Flood irrigation is the main technique used in the study area and is accomplished by the border dike method, described by Heerman et al (1989):

A border irrigated field is divided into graded (sloping) strips by constructing parallel dikes or border ridges. Water is turned on at the upper end of the strip and flows down slope in sheets to the lower end. The lower end may either be

diked to prevent surface runoff or opened to remove excess water if desired.

Spatial patterns of water distribution also occur with border dike irrigation. Heerman et al (1989) explains how timing affects these patterns:

Typically the water is turned on for the time required to infiltrate the desired depth at the head end of the field. After inflow is stopped, the water continues to advance onto the lower end and infiltrates as the water recedes from the top. Uniform irrigations result when the advancing front moves at the same rate as the recession after cutoff, over the entire length of the border. If water recedes down field more rapidly after irrigation ceases than it advances across dry soil [Figure 2.5 (a)], then the upper end of the field has a longer time for infiltration to occur (longer infiltration opportunity time). If advance and recession rates can be made nearly equal [Figure 2.5 (b)] then uniform infiltration can be expected from one end of the field to the other.

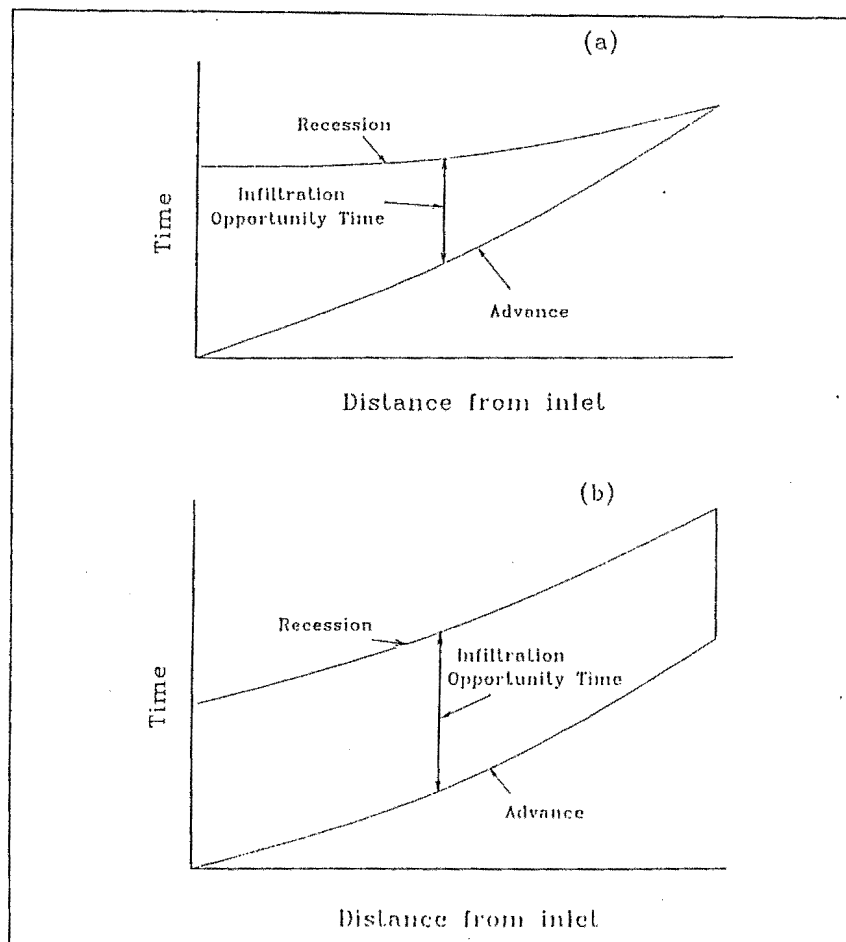


Figure 2.5: Hypothetical advance - recession curves when (a) advance is slower than recession and (b) advance and recession rates are about equal.

Source: Heerman et al, 1989, p 322, Figure 2.

Figure 2.6 gives two examples of irrigation variations as a result of two outcomes being

sought.

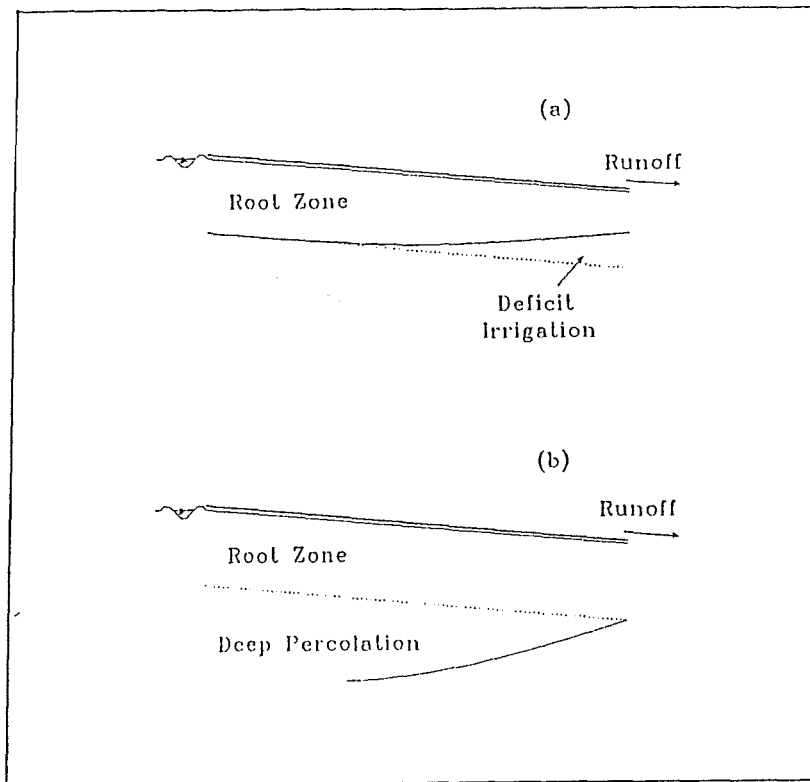


Figure 2.6: Hypothetical water distribution under surface irrigation when (a) sufficient water is applied to meet irrigation requirements at the upper end of the field and (b) irrigation requirement is met at the lower end of the field. Source: Heerman et al, 1989, p 334, Figure 4.

Essentially the first scenario (a) is less costly as it involves using less water than the second (b) which requires a lot more water to fully provide the root zone requirements down the entire length of the field. The second practice is not strongly recommended as it does not allow for natural (rainfall) recharge as the ability of soil to store further moisture will be nil (zero) or negligible, promoting surface runoff or ponding.

To overcome the deficit problem it may be necessary to trap the irrigation water at the end of the field to allow it to fulfil the deficit shown in Figure 2.6 (a). Whatever methods are used will result in some degree of deep percolation to layers below the root zone. The sheer volume of water involved may also vary considerably, as illustrated in the above example. Irrigation will increase the amount of water moving into sub-surface storages. It is also important to note that the spatial pattern of this recharge may be quite unique and will be affected by the spatial variations in the water supply rate.

The use of irrigation can promote the movement of contaminants to soil or

groundwater. Any such movement of contaminants will be influenced to some degree by the spatial and temporal patterns resulting from irrigation. Irrigation is seen to promote contaminant movement, but it can dilute contaminants as well.

2.4 Contaminant Movement.

Some contaminants are transported in water in a dissolved form while others are transported in a particulate form. A contaminant moves when it is exposed to a surface which is interacting with groundwater transfers and/or storages. Movement through material can be slowed or stopped as soil and/or organic materials attract the contaminant. For example nitrate can be taken up by plants for growth. Dentrification may also occur to nitrate, converting it to a gaseous form of nitrogen which can be lost to the atmosphere (Tillman, 1995; Jury and Nielson, 1989). Reference is made to Chapter Three where this is discussed at greater length. It is important to note however that the movement of contaminants to groundwater may be slower than the transporting agent, water. Once in a groundwater body the processes affecting contaminant transport are as follows:

- * Advection: transport by motion of the flowing groundwater.
- * Diffusion: movement of molecules from areas of high to low concentration .
- * Dispersion: mixing caused by microscopic differences in flow rate through porous media. (Lowrance and Pionke, 1989)

These transport processes apply for an homogenous aquifer. Dilution of a contaminant in an heterogeneous aquifer can be affected by:

- Heterogeneities in aquifer flow patterns;
- Heterogeneities in aquifer storage;
- Heterogeneities in aquifer recharge;
- Heterogeneities in aquifer discharge. (Lowrance and Pionke, 1989)

Contaminant transport processes can be represented in two dimensions by looking at an ideal contamination plume. This example is of a point source contamination and the subsequent transportation of the contaminant.

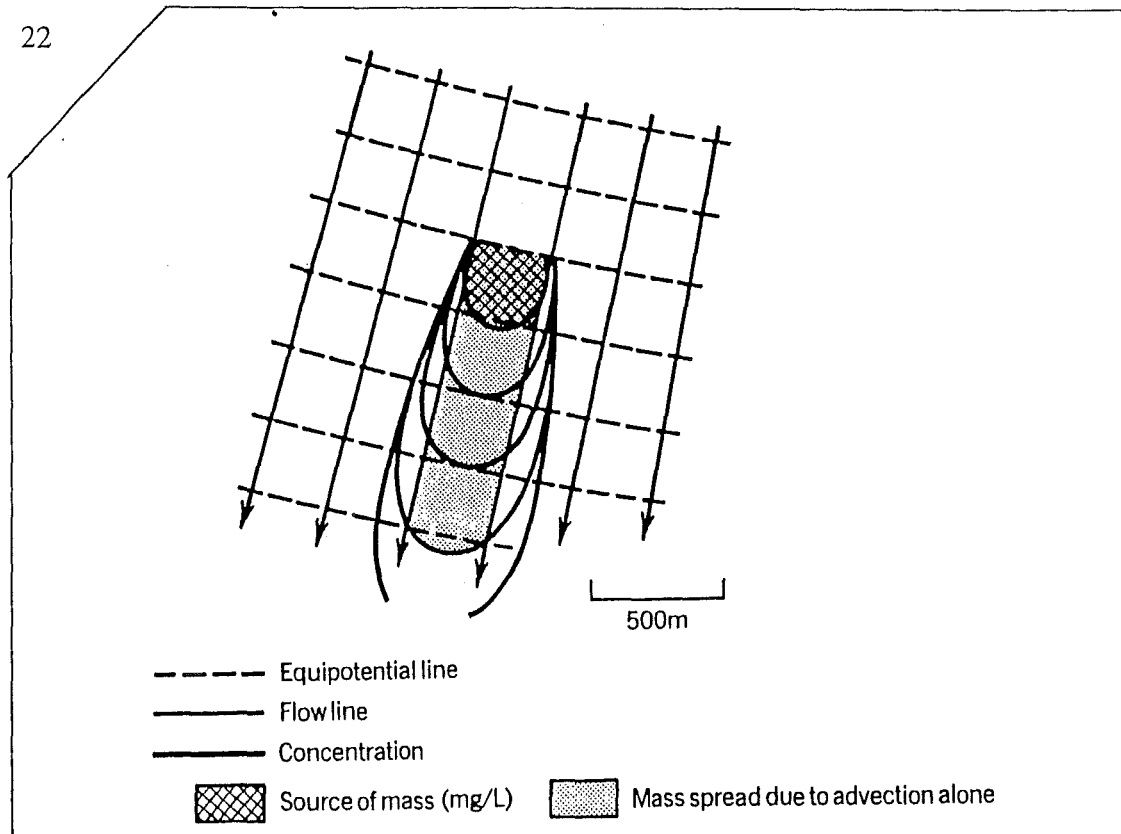


Figure 2.7: Spread of contaminant (mass) in a shallow unconfined aquifer by advection alone and advection dispersion.

Source: Domenico and Schwartz, 1990, p 364, Figure 10.6.

2.5 Summary.

The hydrologic cycle is a global system which distributes water in time and in space. Recharge of water to groundwater can be variable in time and in space. After the water input to recharge, the next major factor is the permeability of the medium the water passes through. This will affect the rate at which water reaches groundwater, and the subsequent flow of groundwater. Because water on and beneath the land surface is unevenly distributed, its distribution is often modified to suit the demands of its users. Irrigation may be used to satisfy a soil moisture deficit but it may in fact over supply water, resulting in inadvertent recharge of groundwater. Following an irrigation event or season, a surplus of water can result which will affect the hydrology of the area. Contaminant movement to groundwater, being similar to that of water movement, can be affected by various factors, such as the water it is moving with and the material it encounters along the way. Spatial techniques are used in this study because the available data lends itself to spatial analysis rather than process modelling or remote sensing.

Chapter 3

Contamination of groundwater.

3.1 Introduction.

Groundwater quality can be influenced by a variety of factors, to such an extent that contamination of it may result. The physical environment plays an important role in determining the groundwater quality. Groundwater catchment characteristics can influence the groundwater quality to some extent, with geology, soils and biological activity contributing to the 'signature' of the water which can be described in chemical terms. It has already been established that human activity can influence groundwater quality and even contaminate it.

The first part of this chapter describes groundwater quality and contamination and the contributing factors. This is achieved by discussing natural groundwater quality and influences on it, followed by sections looking at types of contaminants and sources of contamination from human activities. The bulk of the chapter focuses on groundwater quality in the study area, identifying sampling locations, methods and the results obtained.

3.2 Groundwater Quality and Contamination.

3.2.1 Influences on Groundwater Chemistry.

Water is a chemical compound, made up of two Hydrogen (H) atoms and one Oxygen (O) atom. The two H atoms each have a positive charge while the O has two negative charges (Watson and Burnett, 1993). Given that each atom is positively or negatively charged, they will be attracted to atoms with the opposite charge. An example of such an attraction is a salt molecule:

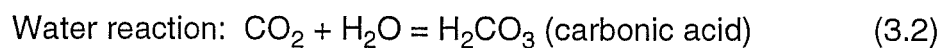
Na^+Cl^- will be attracted to water H_2O in the following way:



The end result is a reaction in which water dissolves or absorbs the salt. The concentration of H ions in water, or pH, measures its acidity and alkalinity. Values for groundwater in Canterbury usually fall between 6.5 and 8.5 (CRC, 1995 c). Low values indicate acidity and high values alkalinity.

Water reacting with a ground surface may have been altered by chemicals it has previously come into contact with, such as those found in the atmosphere. Once on the surface, water molecules will also react with chemicals at the surface. Because most human activities occur at the land surface, they contribute directly to surface water contamination. This is usually where the chemical quality of water moving to groundwater is significantly altered (Nightingale and Bianchi, 1974).

Once water infiltrates the ground surface, it becomes exposed to another range of chemical elements and molecules in the soil which can significantly alter the water's characteristics. For example water moving through soil with a high lime content "...will contain high concentrations of calcium (Ca), magnesium (Mg) and bicarbonate." (CRC, 1995 c). Total Hardness (HDT) measures this property of water. Another example involves a plant reaction with water:



(Freeze and Cherry, 1979.)

The potential for further changes to water can be influenced by the depth of groundwater in conjunction with surface and sub-surface reactions. The CRC (1995 c) explain:

...shallow unconfined groundwater (usually from wells less than 30m deep) can be slightly acidic - down to 6.0. This is because rain water (slightly acidic itself) carries carbon dioxide (produced by plant roots and microbiological organisms) into the underlying groundwater where carbonic acid is produced.

Watson and Burnett (1993) identify four factors which can change the balance and make-up of groundwater chemistry below the soil zone:

1. The mineral composition of aquifer rocks.
2. The general hydrogeologic framework of the area.
3. The potential for groundwater mixing and for the occurrence of interactive geochemical reactions.
4. The activities of man relative to the recycling capability of the aquifer.

The last factor (4) is of less concern at this stage, but the third factor identifies an interesting concept that relates to the plant reaction described earlier. It is evident that groundwater can be altered significantly by a whole host of physical factors which can interact with water at any of the stages shown in Figure 2.2. Human factors can also interact with water at any of these stages particularly at or near the ground surface.

3.2.2 Potential Contaminants.

Contaminants can be grouped into following classes based on their common attributes.

Biological.

These contaminants are viruses, bacteria and parasites which have the potential to cause serious health effects. The detection of bacteria as indicated by coliform and faecal coliform analyses in a water sample indicate that disease causing organisms may be present. The term 'total coliforms' is used to encompass non-specific bacteriological organisms and includes faecal coliforms (Ministry of Health, 1995). Another method of detecting microbiological organisms is by measuring the Dissolved Oxygen (BOD_5) (CRC, 1996 a).

Organic Compounds.

Forms of anthropogenic organic compounds that can contaminate groundwater are chlorinated and aromatic hydrocarbons and some pesticides (Smith, 1993 a). Usually these are quite toxic, hard to eliminate from groundwater and can be very mobile. However, their detection is very unlikely in Canterbury groundwater and they have therefore been omitted from the sampling programme.

Inorganic Constituents.

Presence of inorganic constituents in groundwater can indicate a saline water solution. A mixture of compounds and elements are found in this group and can pose a danger to

health if found in sufficient quantities in groundwater (Domenico and Schwartz, 1990). Examples of these are contained in Table 3.2. These are normally found in groundwater, having derived from natural sources, such as CO₂ from plant respiration.

Trace Metals.

Many metals can be found in groundwater, both from natural and human induced sources. They too pose a threat to human health if found in large enough quantities. Most trace metals are found in small quantities in groundwater.

Nutrients.

The commonly identified nutrients are organic compounds and inorganic constituents containing nitrogen or phosphorus. Nitrate (NO₃) and ammonia (NH₃) are the most common forms of nitrogen found in groundwater. Nitrogen compounds measured in this study are represented by their normal notation, but are calculated by detecting the nitrogen content of each compound. For example the nitrate compound, NO₃ really equates to NO₃N, the N being the nitrogen detected. Many reactions can occur in which the form of the nitrogen compound is changed, but can still remain as a source of contamination. Phosphorus is less soluble than nitrogen compounds and tends to sorb on solids (Domenico and Schwartz, 1990).

3.2.3 Sources of Contamination.

Surface contamination can be from point and/or non-point sources. Point source contamination occurs when one site-specific identifiable source contributes to contamination, for example a septic tank discharge (Domenico & Schwartz, 1990). Non-point source contamination refers to relatively diffuse contamination generally over a large geographic area, perhaps with many smaller sources of poor locational definition (Domenico & Schwartz, 1990). An example of the latter is a field in which stock graze. Several hundred contamination points (urine patches) are present, but they cannot be individually linked to the contamination of groundwater. Alternatively, fertiliser top dressing is diffuse over an area and can be a source of non-point source contamination. Both types of contamination can occur together, which can make the interpolation of groundwater quality analyses difficult.

A review of general literature (Bekesi, 1995; Domenico and Schwartz, 1990; Keeney, 1989; Burden, 1984; Ball, *et al.*, 1979; Grinstead and Wilson, 1978; Edwards, 1972;

Harrold, 1971) identifies specific groundwater contamination sources:

- 1). Animal wastes:
 - areas of high animal concentration, e.g., holding areas and transport lanes.
 - faeces deposited in grazed paddocks,
 - effluent disposal from animal holding areas,
 - dead carcasses.

- 2). Human wastes:
 - septic tanks that dispose directly into soil/strata,
 - dumping refuse on land or in pits.

- 3). Chemical wastes:
 - excess fertiliser application (surplus),
 - herbicide/pesticide/insecticide residue,
 - spillage of chemicals at point sources,
 - industrial discharges,
 - leaking pipelines.

Much of this waste can be directly attributed to specific landuses. This is "...because landuse often determines the types and amounts of chemicals introduced at the land surface." (Eckhardt and Stackelberg, 1995). Factors controlling contaminant loadings to groundwater include "...the type, strength and number of contaminant sources at the land surface." (Eckhardt and Stackelberg, 1995). A review of the literature suggest that particular landuses characteristically discharge most contaminants onto and/or into the land. Table 3.1 gives a general indication of the contributions of various areal scale landuses to contaminants.

Landuse	Contaminant Group	Biological	Organic Compound	Inorganic Constituent	Trace Metal	Nutrient
Agriculture		H	L	H	L	H
Urban (unsewered)		H	L	M	M	L
Urban (sewered)		M	L	L	H	L
Industrial		L	L	H	H	L
Key: L = Low M = Medium H = High						

Table 3.1: Contribution of landuse to contaminant loading of groundwater. Source: Eckhardt and Stackelberg, 1995; Ferrier, *et al.*, 1995; Hamilton and Helsel, 1995; Cooper, *et al.*, 1992; Domenico and Schwartz, 1990; Keeney, 1989; Sinton, 1982; Sinton, 1979; Freeze and Cherry, 1979.

Each landuse could also be broken down into subclasses, such as farm types for

agriculture. It is to be expected that variation will occur in contributions to contaminant groups as the level of classification of landuse decreases (i.e., tends towards the micro scale).

3.3 Groundwater quality investigations in the study area.

3.3.1 Introduction.

Reasoning is given by MAF (1993) as to why groundwater sampling may take place:

It would seem reasonable that monitoring should be carried out where landuse practices suggest that there is a potential for impacts to occur (i.e. where stock rates are high) and where groundwater quality is sensitive to pollution (taking into account soil permeability, depth to groundwater and uses of the groundwater - especially for domestic supply).

The CRC decided that the groundwater of the Morven, Glenavy and Ikawai area should be sampled because it was seen to be at risk from the aforementioned factors. The groundwater quality in the area was also of concern local residents and the district council who perceived increasing landuse changes could affect its quality. Given that Section 30 (Appendix Two) of the RMA (1991) specifies that regional councils are required to monitor and enhance groundwater quality and the lack of historical groundwater quality data, a sampling program to determine ambient groundwater quality in the study area was initiated.

Initial fieldwork carried out by CRC staff involved locating all the wells in the area between the Waihao and Waitaki Rivers. As a result well attributes, e.g., depth, grid reference, etc., were collected and a well location map compiled. Following this information gathering phase, was an analysis phase in which a sample group from the possible 150 - 160 wells was selected. This selection process was influenced by a variety of factors, including suitability of wells for water sample collection, relative well location and spatial coverage. Ninety of the original wells were chosen for sampling on two occasions: February and May 1996. The February sampling round took place on weekdays between 8th-27th February; the May sampling round spanned over the period from the 4th-24th of May. The timing of the sampling programme was to coincide with the highest water table levels expected in the area from work undertaken on the southern side of the Waitaki River by the Otago Regional Council. It was originally anticipated that only half of the wells were to be sampled again in May 1996, but in the event, groundwater from all but five were resampled. The ongoing

sampling programme, to establish temporal changes in groundwater quality consists of quarterly sampling at approximately 20 wells, four of which will be sampled monthly.

3.3.2 Groundwater sampling locations and variables.

The sampling of groundwater was carried out at the 90 wells shown in Figure 3.1. As can be seen from a comparison of Figure 3.1 and Figure 1.2, an extensive spatial coverage of wells or sampling locations was used. Points around the fringe were chosen to examine the influence of the surrounding topography and geology. Within the towns of Morven and Glenavy a cluster of wells were chosen to investigate the possible effects of sewage discharges from unsewered urban areas on groundwater quality.

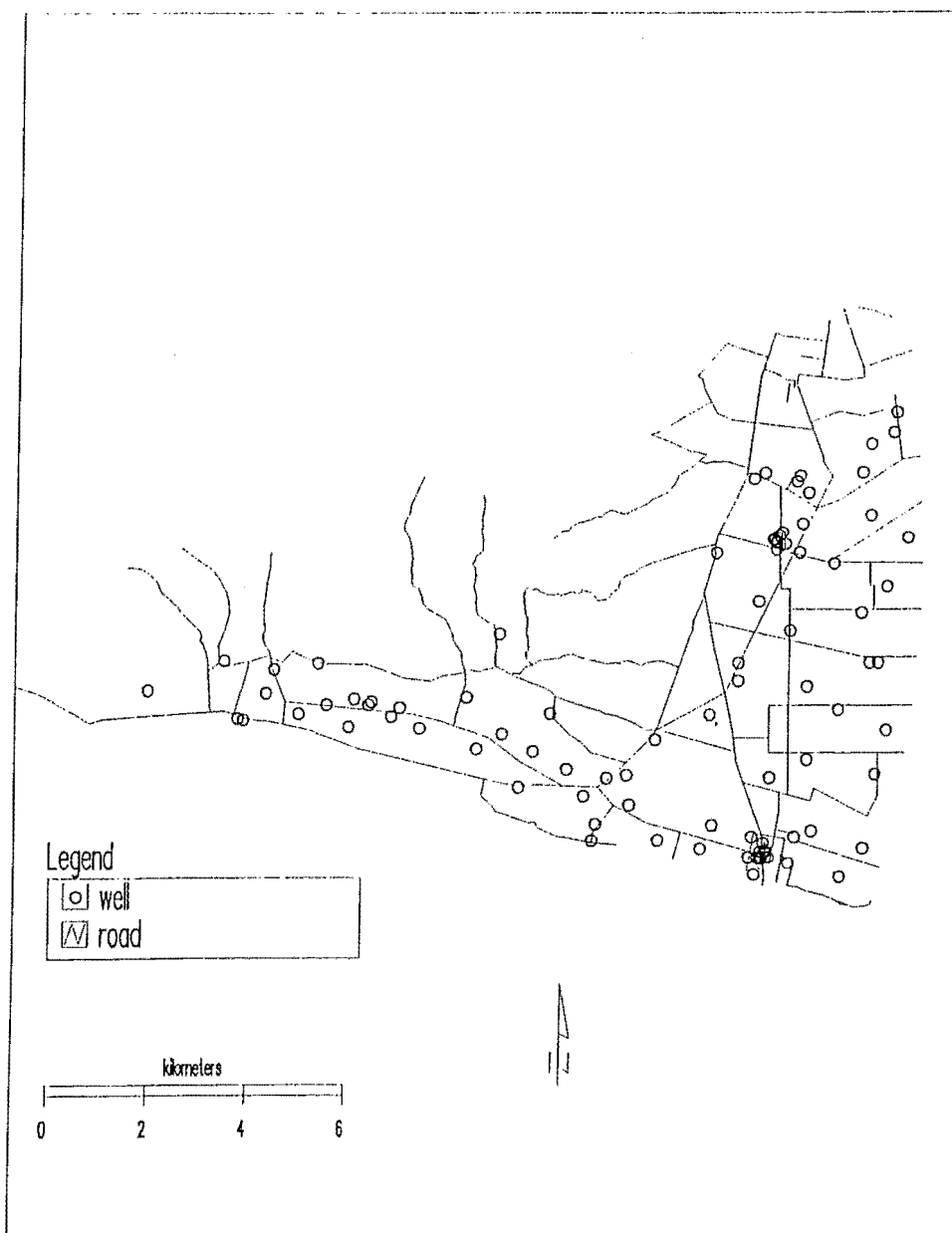


Figure 3.1: Location of wells from which groundwater was sampled.
Source: CRC, 1996 (a).

Indicators of groundwater quality used for this study are listed in Table 3.2. Elevated concentrations of some of these determinants affect human and animal health, while others affect the aesthetic properties of the water. Acceptable concentrations in drinking water for New Zealand, are shown in the table for comparative purposes.

Indicator (symbol)	Acceptable level	Category
Concentration of hydrogen ions in water (pH)	6.5-8.5 (7-8 pref.)	General indicator
Conductivity (COND)	NA	General indicator
Nitrate Nitrogen (NO ₃)	11.3 mg/L *	Inorganic Constituent/Nutrient
Nitrite Nitrogen (NO ₂)	3 mg/L α	Nutrient
Ammonia (NH ₃)	1.3 mg/L	Nutrient
Nitrate-Nitrite-Nitrogen (NNN)	11.3 mg/L #	Inorganic Constituent
Total Phosphorus (TP)	NA	Nutrient
Total Alkalinity (ALKT)	NA	Inorganic Constituent
Carbon Dioxide (CO ₂)	NA	Inorganic Constituent
Sulphate (SO ₄)	250 g/m ³	Inorganic Constituent
Chloride (Cl)	250 mg/L	Inorganic Constituent
Calcium (Ca)	NA	Inorganic Constituent
Magnesium (Mg)	NA	Inorganic Constituent (trace metal also)
Sodium (Na)	100 g/m ³	Inorganic Constituent
Potassium (K)	NA	Inorganic Constituent
Total Hardness (HDT)	200 g/m ³	Inorganic Constituent
Dissolved Oxygen (BOD ₅)	NA	Inorganic Constituent
Total Dissolved Solids (TS)	500 g/m ³	General indicator
Faecal Coliforms (FC)	0/100ml	Biological
Total Coliforms (COL)	0/100ml	Biological
* calculated from nitrate expressed as NO ₃ in the Drinking Water Standards of 50mg/L		# used as a surrogate guideline
α calculated as nitrite expressed as NO ₂ in the Drinking Water Standards of 3mg/L		

Table 3.2: Indicators of groundwater quality used for this study (NA is Not Applicable i.e., no standard has been set for drinking water).

Source: CRC, 1996 (a); Eckhardt and Stackelberg, 1995; Hamilton and Helsel, 1995; Ministry of Health, 1995; Domenico and Schwartz, 1990; Department of Health, 1989.

This list reflects the desire to collect an optimum range of measurements which reflect both the general composition of groundwater (major cations and anions) along with

indicators of contamination from the specific landuses and activities found in the study area. Landuse is predominantly rural with two small settlements providing some urban influence. Some of the measurements made, such as pH and inorganic constituents, are standard to many water quality investigations, while others, such as NO₃ and faecal coliforms, are directed at the contaminant groups which score highly in Table 3.1.

3.3.3 Groundwater sampling methods.

Groundwater samples were collected using standard methods as outlined in the CRC (1996 b) document "Surface Water and Groundwater Quality Field and Office Procedures Manual." This includes quality assurance procedures as the data rigidity and consequent interpolation depends on an appropriate sampling methodology. Of relevance to the thesis is the groundwater section (5.2.2) of this document which discusses the selection of sampling points, spring sampling, sampling unpumped wells and purging wells. These are now discussed in more detail.

(i) Selection of the Sampling Point. Care is needed so as "...to ensure that the sample collected will be representative of the water in the well." (CRC, 1996 b) To achieve this, a common sense approach is needed, whereby the sample is taken from "...the closest clean sampling point to the well head." (CRC, 1996 b) If a sample has to be taken from tanks or pipelines, then the water should be purged (see section (iv) following).

(ii) Spring Sampling. Not applicable here as no springs were encountered in the study area.

(iii) Sampling Unpumped Wells. Care needed when pumping wells, but emphasis is on the specialised devices available for sampling less accessible well water. The next section covers this aspect.

(iv) Purging Wells. "To obtain a representative sample of groundwater from an unused well it is necessary to pump the well until two to three times the volume of water standing in the well has been discharged." (CRC, 1996 b) The amount of water in the well can be calculated based on the well dimensions. This can then be used in combination with the pump capacity to calculate the length of time required to purge the well. When running the pumped water, the effects on the surrounding environment should be minimised to avoid localised flooding and to prevent water re-entering the well or down the outside of the well casing.

Other sections of the manual discuss sampling handling considerations. Of particular relevance is the filling of sample bottles, which requires care to avoid outside contamination from external sources, e.g., where possible collection points are flame sterilised so that the microbiological indicators reflect the water quality, not bacteria on the sampling point. Air of course will generally become part of the sample but the air space in the bottle is minimised to prevent equilibrium changes from the water into the air. Careful handling is needed, especially bottle tops and caps and any fittings used in which the water flows through. Water samples are stored at 4° C to minimise chemical changes before reaching the laboratory, and chilly bins were used to do this. All laboratory analyses were performed at CRC laboratories following standard procedures as required under the Telarc accreditation.

Measurements taken in February included the extra variables Total Solids (TS) and Biological Oxygen Demand over a 5 day period (BOD₅). The May sampling round dropped these two. Nitrate-Nitrite-Nitrogen (NNN) was measured where NO₃ could not be measured because of a sample being too dirty. Sampling in May did not include five of the wells sampled in February, reducing the number of wells common to both periods to 85. Only these 85 are discussed in following sections.

3.4 Groundwater quality results.

The full set of results (a 90 [wells] by 20 [measurements] data matrix) for both February and May, is provided in Appendix One. Where the data are reported in the format '<xxx>' these were transformed for statistical purposes by dividing the threshold value by two, e.g. <0.004 equates to 0.002. Frequency distributions of measurements at each of the two sampling times are given in Tables 3.2 and 3.3. Calcium and Mg have been excluded from these results because they have an excellent correlation with HDT, with an R-square of 0.99 for linear multiple correlation. Individually their linear correlation with HDT are 0.911 and 0.983 for Mg and Ca respectively. The units for values shown along the x axis of the following graphs are given for each variable in Table 3.2.

3.4.1 February results.

Of all the results shown in Figure 3.2, only pH and CO₂ display relatively normal distributions, with the remainder being positively skewed to some extent. Because of the high frequency of lower values, the groundwater quality can be considered to be of a good standard. Table 3.2 provides a summary of this and some other elementary

statistics associated with each variable. Hardness, COND, ALKT, SO₄, TS and Na tend to have few samples at zero, with a more staggered start to their distributions. Given that these are normally found in groundwater, having been induced by natural factors, it is to be expected that the distributions begin at a point away from zero. 68% of FC and 80% of COL samples exceed the acceptable level of zero counts per 100m and only one NO₃ sample exceeds the acceptable level of 11.3 g/m³. The remainder all fall within their acceptable levels.

DATE	Variable	No. Obs	Mean	Std Dev	Minimum	Maximum	Skewness
FEB96	PH	85	6.621	0.283	6.2	7.5	1.115
FEB96	HDT	85	67.059	46.461	30	310	3.229
FEB96	COND	85	21.388	12.865	8.6	80.9	2.405
FEB96	CO2	85	22.235	9.9	2	57	0.994
FEB96	ALKT	85	58.671	46.991	27	337	4.216
FEB96	BOD5	85	1.125	0.563	1	5	5.158
FEB96	CL	85	15.071	16.89	2	96	2.746
FEB96	SO4	85	16.781	9.567	2.2	68	2.655
FEB96	NA	85	15.328	11.331	3.6	62	1.998
FEB96	TS	85	132.765	77.588	55	470	2.118
FEB96	FC	85	26.024	71.555	0	400	4.174
FEB96	COL	85	118.035	319.145	0	2000	5.051
FEB96	NO3	85	3.027	2.77	0.1	20	3.195
FEB96	NO2	85	0.004	0.003	0.003	0.028	5.563
FEB96	NH3	85	0.011	0.028	0.003	0.175	4.509
FEB96	TP	85	0.031	0.036	0.004	0.23	2.792
FEB96	K	85	1.913	1.907	0.9	18	7.398

Table 3.3: Summary of February results.

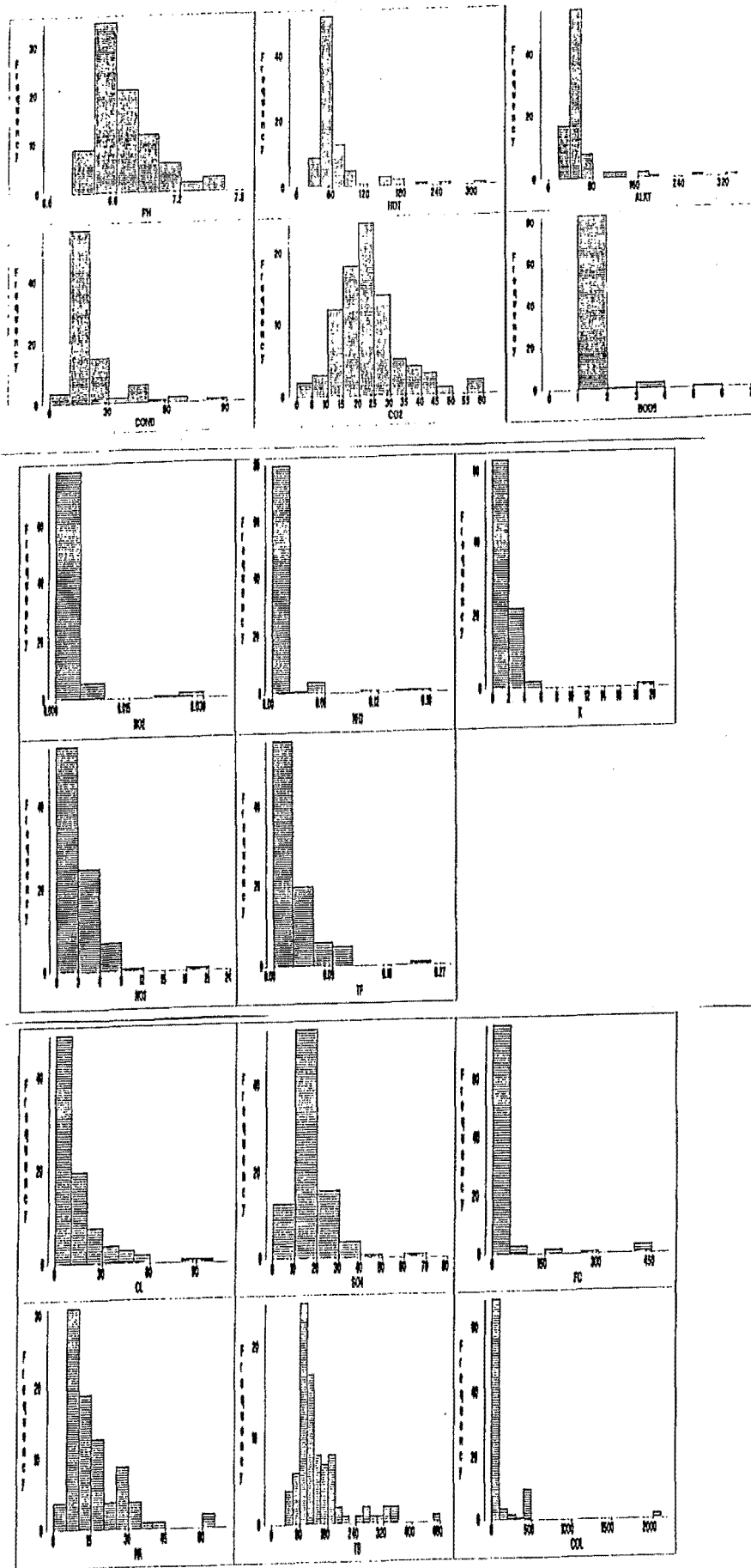


Figure 3.2: February results of indicators of groundwater quality and contaminants.

3.4.2 May results.

All results shown in Figure 3.3 are distributed in a skewed manner with only pH, CO₂ and NNN giving a relatively normal distribution. This can be attributed to the same reasons outlined for February. Table 3.4 summarises these results, giving key statistics for each. All variables except HDT, pH, FC, COL and NO₃ fall within the acceptable levels. Twenty seven pH values fall below 6.4, 47% of the FC samples and 59% of the COL samples recorded counts exceeding the acceptable level of less than 1 FC count/100ml of sample and two NO₃ samples exceed the acceptable level of 11.3 g/m³. It is important to note that one COL sample for May of 10,000 has been omitted from Figure 3.3 as it created difficulties when trying to plot the x axis on a linear scale.

DATE	Variable	No. Obs	Mean	Std Dev	Minimum	Maximum	Skewness
MAY96	PH	85	6.478	0.231	6	7.5	1.233
MAY96	HDT	85	70.906	58.125	25	370	3.196
MAY96	COND	85	23.107	19.245	8.8	144.5	3.934
MAY96	CO2	85	32.953	14.415	10	101	1.524
MAY96	ALKT	85	63.059	47.256	27	351	3.843
MAY96	CL	85	13.753	29.991	2	250	6.442
MAY96	SO4	85	17.066	14.335	6.5	120	4.939
MAY96	NA	85	17.232	19.703	4.2	160	5.101
MAY96	FC	85	7.894	24.122	0	180	5.212
MAY96	COL	85	161.929	1084.478	0	10000	9.101
MAY96	NO3	57	4.056	4.297	0.6	32	5.229
MAY96	NO2	85	0.004	0.008	0.002	0.05	4.186
MAY96	NH3	85	0.017	0.055	0.003	0.48	7.568
MAY96	NNN	28	1.626	0.865	0.07	3.7	-0.021
MAY96	TP	85	0.025	0.024	0.004	0.105	1.292
MAY96	K	85	1.859	1.743	0.9	16	6.906

Table 3.4: Summary of May results.

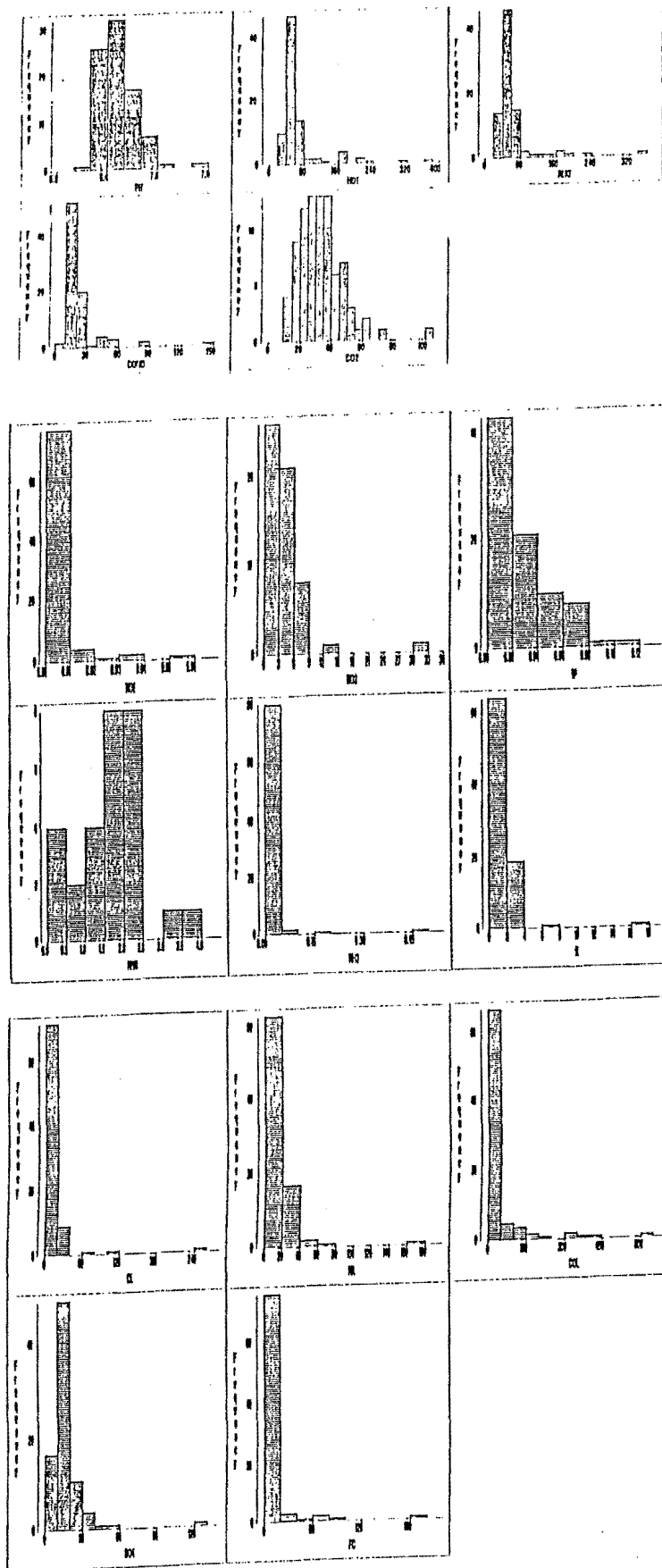


Figure 3.3: May results of indicators of groundwater quality and contaminants.

3.4.3 February and May results.

Mean values for the two sampling periods are shown in Table 3.5. In general the May results tend to be slightly higher than the February results. A simple paired t-test was carried out on each variable to see if the differences of means were significant. Normality of skewed distributions was improved using a logarithmic transformation before conducting the test. The significance for both logarithmic and non-logarithmic comparisons are calculated based on a two tailed t-test. Differences that are significant at the 1% level are shown in Table 3.5; Y indicates there is a significant difference.

Variable	Feb mean	May mean	Diff. of means (may-feb)	Sigt
PH	6.621	6.478	-0.143	*
HDT	67.059	70.906	3.847	Y
COND	21.388	23.107	1.719	Y
CO2	22.235	32.953	10.718	Y*
ALKT	58.671	63.059	4.388	Y
CL	15.071	13.753	-1.318	Y
SO4	16.781	17.066	0.285	
NA	15.328	17.232	1.904	Y
FC	26.024	7.894	-18.130	Y#
COL	118.035	161.929	43.894	#
NO3	3.027	4.056	1.029	Y
NO2	0.004	0.004	0.000	Y
NH3	0.011	0.017	0.006	Y
TP	0.031	0.025	-0.006	
K	1.913	1.859	-0.054	
# denotes chi square test				
* denotes non log				

Table 3.5: Comparison of February and May results.

Faecal and total coliforms, although showing positively skewed distributions, are not transformed using the logarithmic function. This is because the computation ignores <1 values and hence gives a false representation of the sample. It was decided to calculate

the level of significant difference between February and May by using the number of wells with coliform counts equalling and exceeding zero, the acceptable level of contamination. This was carried out by using the Chi-square calculation which is a simple test between a set of observed frequencies and the corresponding expected frequencies (Shaw and Wheeler, 1994; McGrew and Monroe, 1993; Ebdon, 1977). The outcomes of this test were Chi-square values of 7.806 for FC and 2.522 for COL, both with one degree of freedom, results that would be expected by chance with probabilities of 0.005 for FC and 0.112 for COL. The inference can be made that the FC contamination changed significantly from February to May but that COL contamination did not. Chapter 5 will provide a description of the results in respect to the environmental characteristics at, or near, the wells.

3.5 Summary.

Groundwater quality can be highly variable and is dependent upon the influences inflicted on it by natural and human factors. Natural influences produce an initial groundwater quality signature which can be described using various measures, such as pH and conductivity. Human elements can alter natural groundwater quality, perhaps by inducing higher levels of substances into the groundwater environment. If acceptable levels are exceeded, then these substances are said to contaminate groundwater. The types of landuses and activities carried out at or near the ground surface can be linked to potential contaminants. Groundwater sample collection and analyses undertaken by the author and CRC staff in February and May 1996 sought to identify the groundwater quality of the study area. Results indicate virtually nil groundwater contamination by chemical contaminants, except isolated cases of NO_3 , but high levels of contamination by faecal and total coliforms. May results tended to be slightly higher than February although the FC contaminant seems to be less widespread in May. There is a significant statistical difference between February and May for several variables.

Chapter 4.

Characteristics of the study area.

4.1 Introduction.

The study area of Morven, Glenavy and Ikawai lies at the south east of the Waimate District in Canterbury, New Zealand. It has been described as "...predominantly droughty coastal plains..." (Griffiths, 1971), extending from the Waitaki River in the south to the Waihao River in the north and from the Pacific Ocean in the east, to the Waikakahi Downs in the northwest. The downs are dominantly Tertiary sandstone, siltstone, mudstone and greywacke piedmont gravels with some underlying areas of Quaternary gravels. The Tertiary sequence includes Calcareous sediments (Mutch, 1963). Topographically, the plains are part of the Waihao and Waitaki River outwash fans. The Waitaki fan, which also occurs to the south of the Waitaki River in North Otago, runs through what is now known as the Ikawai and Glenavy areas. The Waihao fan merges with the Waitaki fan near Morven.

In general terms the climate of the study area is temperate and relatively dry. Frosts in winter are common and snow can sometimes fall to sea level. The summer season can experience drought conditions, although irrigation tends to alleviate this problem. Rainfall for the area averages 642mm annually. The mean temperature is 11.1 degrees Celsius (C) with a January mean daily maximum of 21.2 degrees C and a July mean daily minimum of 0.7 degrees C. Mean monthly rainfall and temperature trends are shown in Table 4.1.

February and April rainfall values for 1996 were noticeably higher than average, while January, March and May were lower. May in particular recorded almost half of the average rainfall. Monthly mean temperatures generally indicate a slightly cooler period, with December 1995 being the only warmer month. Local climatic conditions can be influenced by surrounding topography. Much of the study area experiences morning sea breezes, which extend up the Waitaki Valley. Breezes also come down the Waitaki Valley at night and early morning.

Month	Mean monthly rainfall 1898-1980	Total monthly rainfall Oct 1995-May 1996	Mean monthly temperature 1914-1980	Mean monthly temperature Oct 1995-May 1996
October	53	50	11.3	11.2
November	58	44	12.9	12.1
December	70	66	14.6	15.7
January	63	51	15.7	15.7
February	55	76	15.6	15.0
March	59	46	14.1	12.4
April	52	113	11.8	11.6
May	47	27	8.8	8.7

Table 4.1: Monthly rainfall and temperature trends: long term average and 1995/96 actual.

Source: NIWA, 1996; New Zealand Meteorological Service (NZMS), 1983.

The study area can also be described in human terms. Although being distant from much of the early colonisation in Canterbury and Otago, settlers, once in the area, found the land to be useful for agriculture because of its flatness. It could also be easily accessed once road and rail were completed and production from the land could be transported to markets. During the earlier part of this century the area developed with small towns and settlements forming to meet local needs, Morven and Glenavy being the main two. However the later half of the century proved to be a testing time for agriculture and this affected local services with some shops and schools closing down.

The study area is well served by transport and is less than one hours drive from the Port of Timaru and three hours drive from Christchurch International Airport. The road network over the study area is extensive and links closely with State Highway One (SH 1) and State Highway 82 (SH 82), which run through parts of the study area. Although the railway runs through the study area, it no longer gives easy access to its services. The nearest train stops are at Timaru and Oamaru which are 30-50 kilometers travel by road. A small aerodrome is located just off SH 1 to the north of the Waihao River and is used by fertiliser application (top dressing) and private planes.

Previous chapters have drawn attention to a range of factors which are liable to influence groundwater quality. Many of these are related to the general characteristics reported above. For instance topography is related to depth to water table, direction of

water flow and distribution of soil types. Climatic characteristics are assumed to be constant throughout the study area as a lack of micro-scale data prevents any detailed analysis of this parameter. The remainder of this chapter identifies and describes the environmental variables which will be used in the spatial analysis in the study area; firstly the physical characteristics of soil permeability and the piezometric surface; and secondly the relevant human characteristics, looking at farm type, irrigation, resource consent to discharge waste and settlement patterns. Finally the chapter revisits the wells, explaining why they are used to investigate problems this thesis is addressing and links these to characteristics of the study area.

4.2 Physical Characteristics.

4.2.1 Soil Permeability.

The soils and underlying parent material of the study area derive from two main sources, the Waitaki and Waihao Rivers. Soils are characteristically yellow grey earths. The soils of the Waitaki fan overlie "...greywacke detritus in which gravels and stones predominate." (Griffiths, 1971). Mixed with alluvium and colluvium is loess, which forms a surface layer in many places or fills voids between stones. Gravels are characteristically rounded and of varying sizes. Streams from the Waikakahi Downs contribute to the building of the terrace at its upper (western) end. The Waihao fan has spread alluvium and reworked loess over its extent. Loess has also been deposited on much of the Waihao fan and has contributed to the fertility of the Morven area.

Because of the mainly fluvial source of the soils, a coarse texture of gravel, sand and silt can be found in most places. Soils tend to be more fertile and less stony in the Morven area than those found in Ikawai and Glenavy. Because the sources and size of the two rivers are very different, the resulting sediments are also quite different and tend to reflect the nature of the source river. Thus a high proportion of soils are highly permeable, allowing for free draining unless a hard pan of cemented gravels lies beneath the surface. Infiltration rates were measured by Pieters (1996) in June and July 1996 at four sites between Morven and Glenavy. and were found to range from 25.5 mm/hour to 150.3 mm/hour. Griffiths (1971) found that most of the soils of the area were suitable for irrigation. Figure 4.1 shows shows the three classes of permeability of soils of the study area.

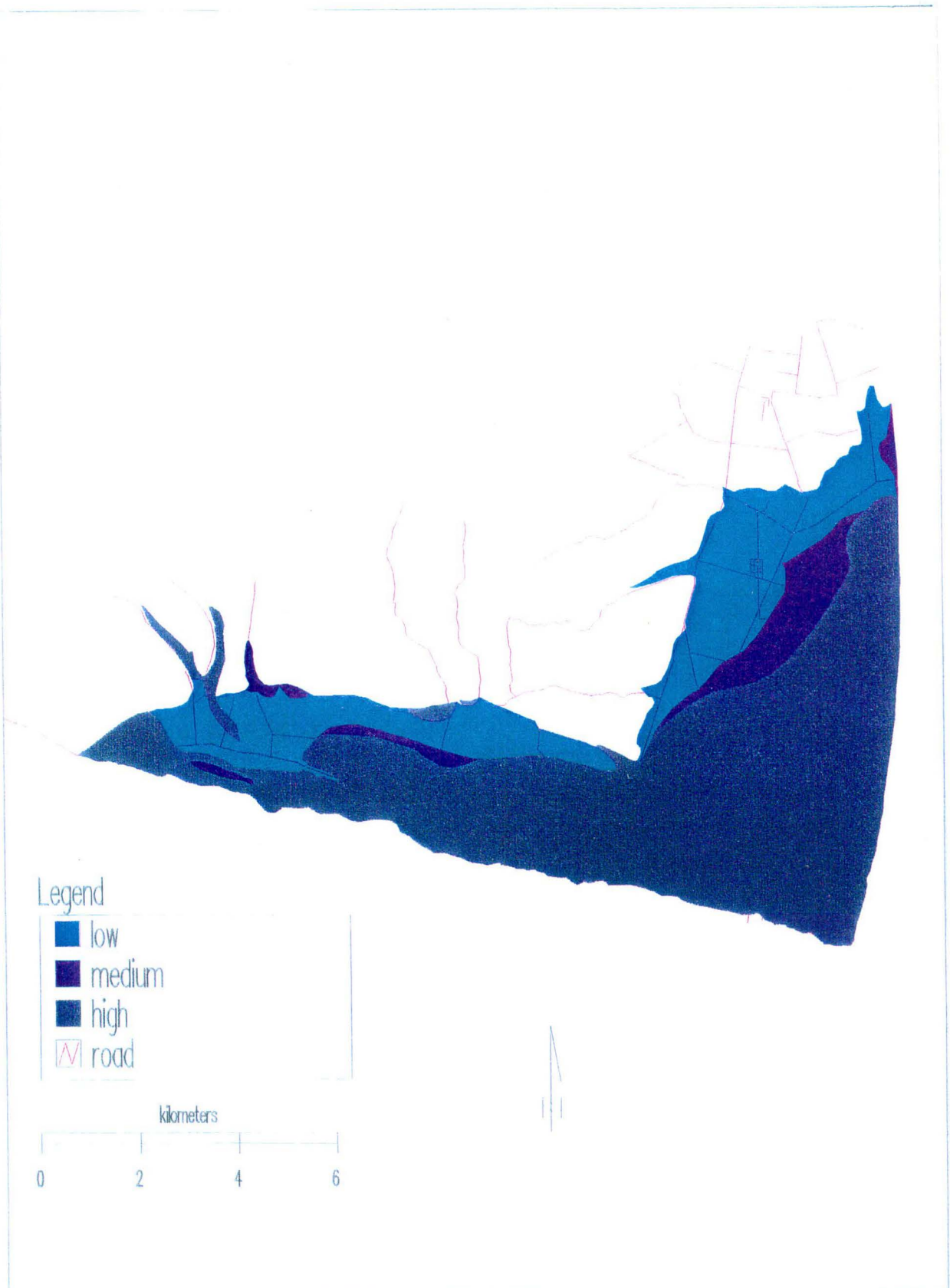


Figure 4.1: Soil permeability classification of the study area.

Source: Author, 1996 and Department of Scientific and Industrial Research (DSIR), 1954.

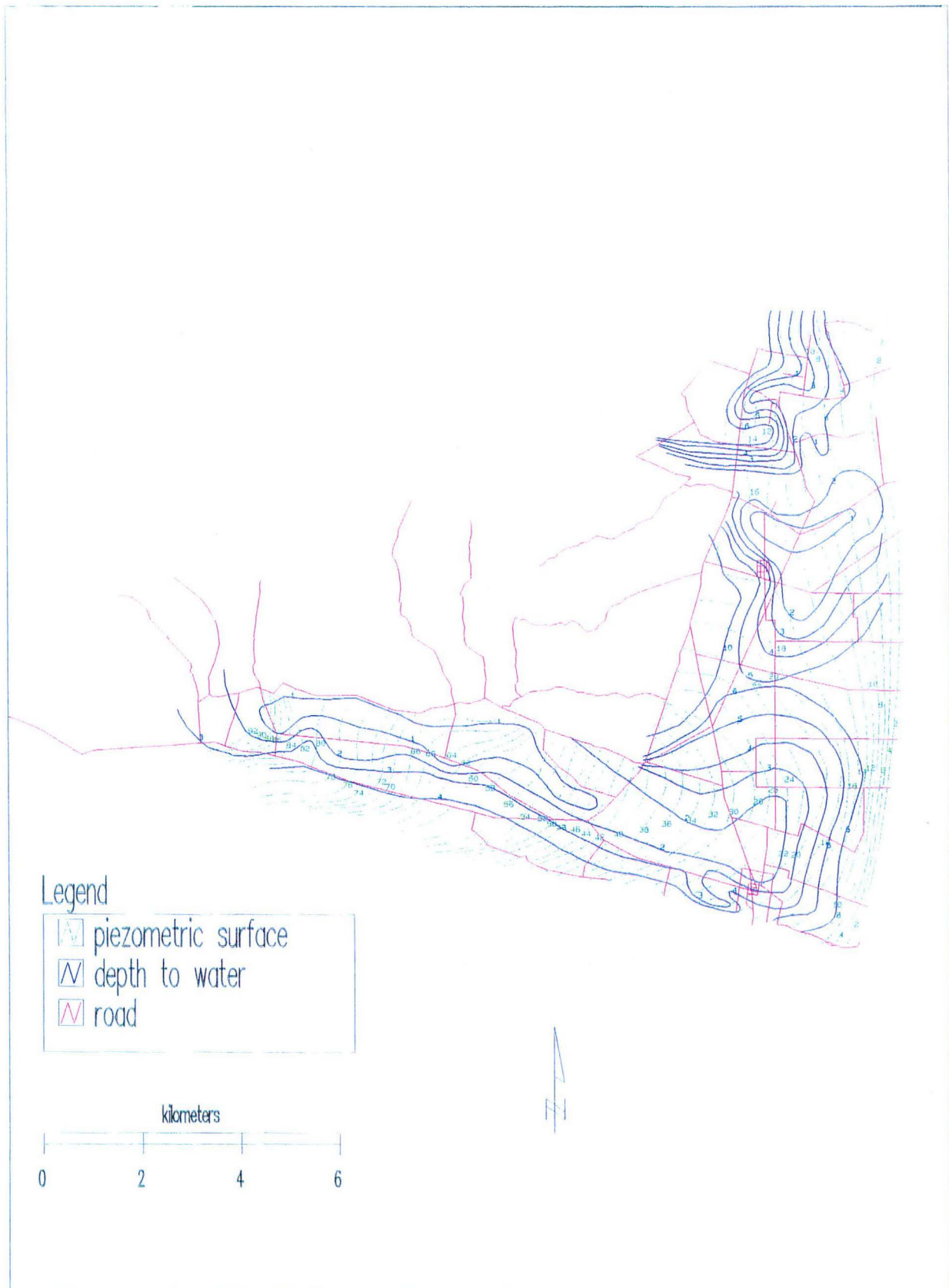
Three classes were distinguished by the relative stoniness of each soil type as described by the DSIR (1954). Soils described as loams with no stoniness were classified as having low permeability. Those with stoniness as part of their description were classified as having high permeability. Soils falling between these two classes, those that were sandy, were assigned a medium permeability. Few soil areas (less than 10%) filled this category.

4.2.2 Piezometric surface.

Measurements of depth to water can be made from wells using a tape measure fitted with a water sensor at the end. The sensor indicates when the end of the tape makes contact with water and you can then proceed to read the tape measurement at the surface. Measurements such as these can be utilised to interpolate a depth to water surface as represented by contour lines. A piezometric surface can then be derived from both depth to water measurements and ground surface elevations. The depth to water measurement is subtracted from the surface elevation and the result is the height above sea level of groundwater. This can also be represented as a surface by contour lines.

A relatively high water table exists over much of the study area, with the Ikawai and Morven areas having higher water tables than Glenavy, although this pattern varies depending on the elevation above sea level. Morven is nearer to sea level than Glenavy, hence is closer to the water table. Figure 4.2 shows the piezometric surface as taken from a map produced by the South Canterbury Catchment and Regional Water Board (1978), titled "Waimate County Groundwater Survey."

Depths recorded in 1996 were of comparable levels to those represented in Figure 4.2 but the 1978 map is presented here because the 1996 data provided insufficient sampling points for such detailed contouring. The depth to water surface shows the vertical distance to groundwater from a point on the topographic surface. The groundwater is very shallow, ranging from less than one metre to ten metres below the surface. The piezometric surface ranges from zero metres at sea level to 92 metres at the western end of the study area.



1978.

Source: Canterbury Regional Council, 1996 (a) and South Canterbury Catchment and Regional Water Board, 1978.

4.3 Human Characteristics.

Recent landuse activities have tended towards dairy farming. This has been made possible to a significant extent by the availability of irrigation through two extensive irrigation schemes. Over the last decade the proportion of the study area used for dairy farming has risen dramatically to almost 40%. Changes are still occurring with 12 dairy farm conversions in the last 12 months (CRC, 1996 a).

4.3.1 Farm type.

Until recent times most of the study area was dry and of low productivity. The Morven area was an exception and parts of it were often used for arable purposes. Early efforts to increase productivity of the land were made, with the Redcliff Irrigation Scheme (RIS) in the 1930's and the Morven Glenavy Irrigation Scheme (MGIS) in the 1970's providing a valuable water resource to a typically dry area. Sheep farming practices dominated the farming activities with changes being made to accommodate local farming conditions. In the 1980's, rather than rely on government support, farms had to become profitable businesses. The nationwide trend was towards changing livestock to dairying, with a 6% increase in the number of dairy farms between 1983 and 1993 (Statistics New Zealand (SNZ), 1995). In the South Island of New Zealand a 33% increase in the number of dairy farms between the same periods was recorded (SNZ, 1995). Total dairy cattle numbers for the Waimate district were 15000 as at 30 June 1993, with total sheep numbers at 1.16 million (SNZ, 1995). Total dairy cattle numbers as at 30 June 1983 were 2000 and total sheep 1.51 million (Department of Statistics, 1984). These results indicate a change in stock numbers between the two dates of 650% for dairy cattle and -30% for sheep, much of which occurred in the study area. As with the increase in dairy farms, the increase in dairy cattle numbers is a lot higher than the New Zealand and South Island rates. Farm conversions are still occurring at a rapid rate, with overseas, North Island and corporate interests making up many of the current land owners. Approximately 8000 hectares, (36% of the study area) are utilised for dairy farming, with a further 14000 hectares (64%) being used for other farming practices. Figure 4.3 shows the two main farm-types as classified in the field this year.

The selection of two classes for farm type was made in the field in June 1996. To simplify classification, only two classes were assigned, dairy or non-dairy. The non-dairy farm type generally relates to sheep farming, but also includes some other landuses and farm types which are quite small scale. Sheep farming dominates the non-dairy class, with no other farm types being significantly large enough to warrant their

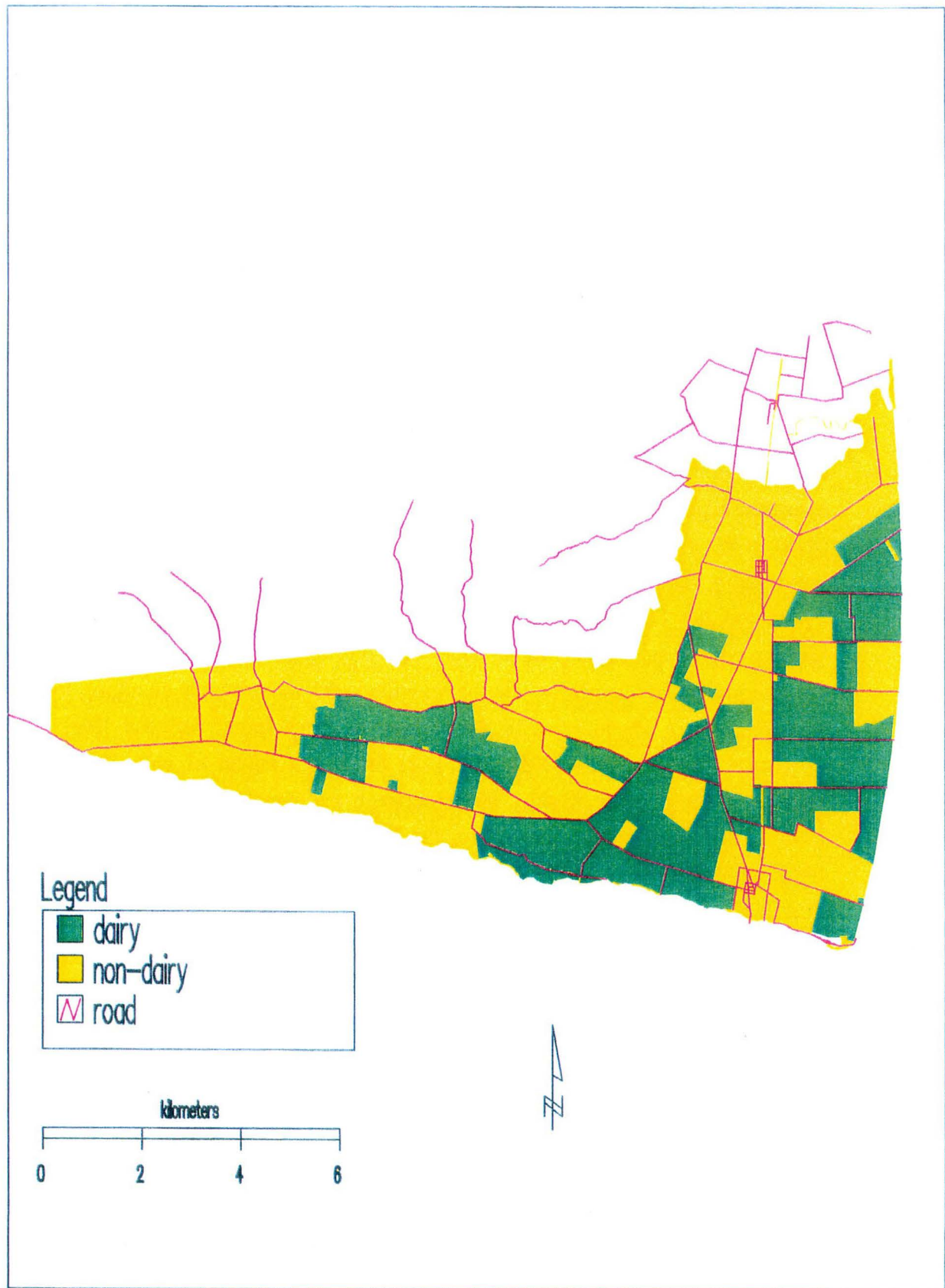


Figure 4.3: Two main farm types of the study area.
Source: Author, 1996; WDC, 1996 (a).

own class. Identifying dairy farms is important because they seem to contribute to groundwater contamination in other parts of New Zealand.

4.3.2 Irrigated Land.

Two irrigation schemes provide water to over half of the study area as shown in Figure 4.4. The first and smallest of the two, the RIS, developed in the 1930's using contour ditches to deliver water to farms. In 1946/47 border dike techniques were introduced and constructed in the area up until the 1970's.. The scheme has its intake at the top end of Ikawai. The bottom end of the scheme extends just below the top end of the MGIS. Delivering 3.6 cumecs to around 4000 hectares, the RIS is well utilised and is used by almost all of the farms in the commanded area. The MGIS was constructed in the 1970's and serves the Morven and Glenavy areas. This scheme supplies just under 10000 hectares with 11.3 cumecs and is widely utilised as landuse requirements demand the full quota of water available.

The irrigation season operates from 15 August to 15 May each year, with high demand over spring and summer (MGIS, 1996). With each scheme, water is typically available on a roster system every 17.5 days. The amount given to a farm depends on the irrigable farm area. Water can be delivered at a rate which covers 1.8 hectares per hour. If a farm was 180 hectares in size, then 100 hours of irrigating would be required to irrigate it all. Typically 75-100 mm (millimetres) of water is applied each time and around 610 mm is applied per season on a farm. Water is purchased from the MGIS Company at the rostered time, and enough water is purchased to cover up to one third to one half of the property. Full property irrigation may be achieved after two to four successive irrigations at the application rate stated earlier. Individual property irrigation techniques will vary, and will have subsequent affects on soil moisture levels at both spatial and temporal scales. The effects on soil moisture and groundwater recharge will be similar to those discussed in Chapter Two. A more detailed description of the pattern of soil moisture and groundwater recharge resulting from irrigation techniques would lend itself to a micro-scale approach which is beyond the scope of this thesis.

For the purposes of this study it is assumed that each property is either entirely irrigated or not irrigated at all. Classifying irrigated and non-irrigated properties was carried out using the irrigation network coverages to identify properties to which water was delivered. This was checked by using other databases (Patterson, 1983; Patterson, 1982) to verify the properties served by both schemes.

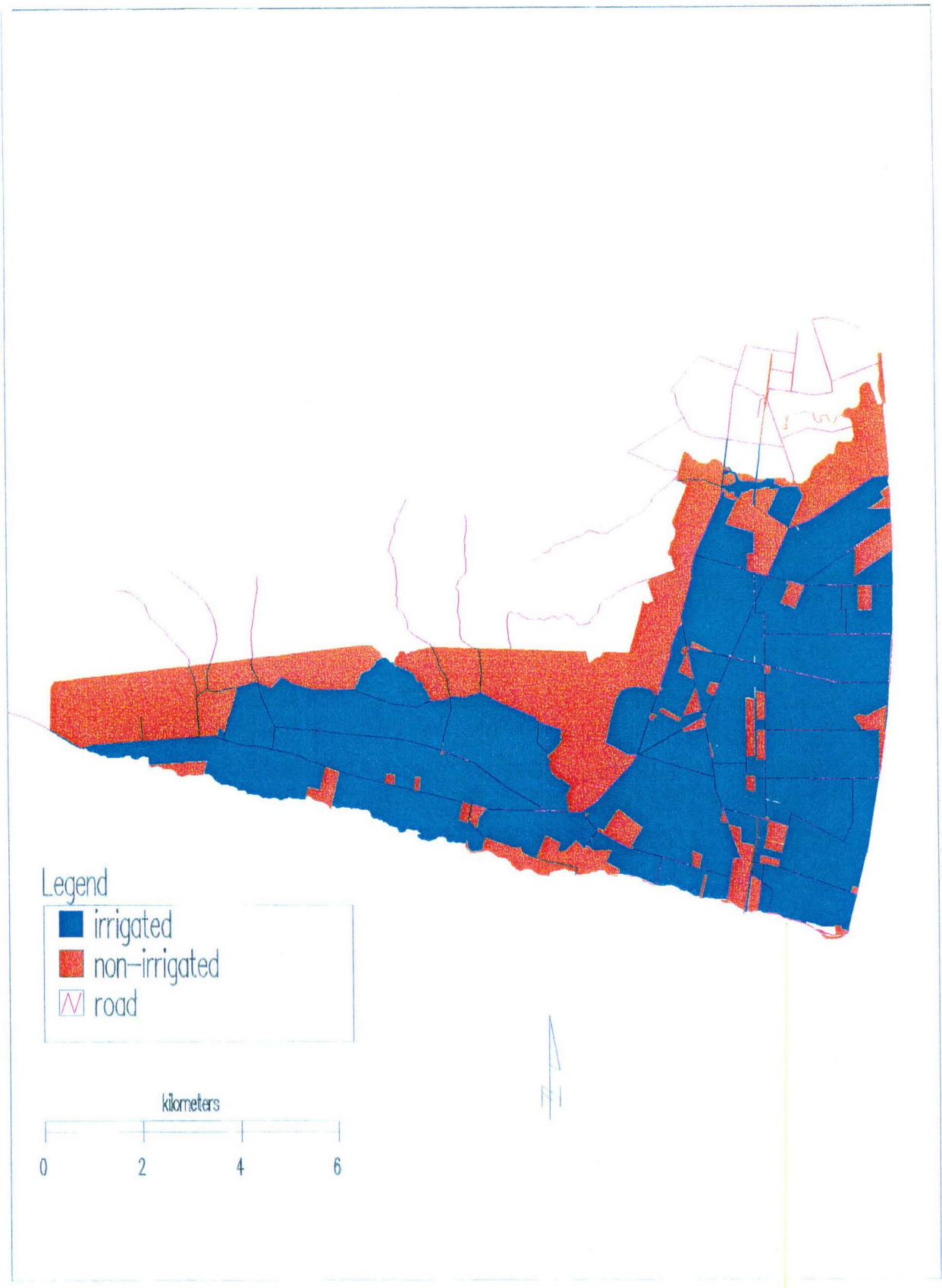


Figure 4.4: Irrigated area covered by the two schemes over the study area.
Source: Author, 1996; Canterbury and Aorangi United Councils, 1989; DOSLI, 1984; Patterson, 1983; Patterson, 1982.

4.3.3 Resource Consents to Discharge Wastes.

This information is obtained through querying a CRC resource consent database. Of the approximately 200 resource consents issued by the CRC in the area, most consist of issues relating to water use (permits to take water) and waste management (permits to discharge wastes). Waste discharge consents given in the study area are linked to farming activities involving the disposal of animal effluent. "The most common examples include effluent washed from dairy sheds and collected from factory farms." (CRC, 1994). Generally with effluent disposal by irrigation "...any adverse effects are localised to within a few hundred metres of the irrigation sites." (MAF, 1993). The type of waste disposal techniques used and the subsequent distribution of wastes on farms is variable in the study area. Resource consents to discharge wastes are represented spatially as points in the CRC database. Each property in which such a point lay was classified as a property in which the discharge of waste occurs. These areas represent potential contributing areas to groundwater contamination. They are mapped in Figure 4.5.

4.3.4 Settlement Patterns.

The study area is sparsely populated with approximately 1000 people living there. Three settlements exist, all with small populations of no more than 200. Ikawai is located in the western portion of the study area and has a school and a hall. It does not have much in the way of settlement around these facilities, but is easily accessed being located alongside SH 82. The settlements of Morven and Glenavy contain private dwellings and are both unsewered. The density of buildings in these two settlements could lead to a potential groundwater contamination problem from septic tanks. Glenavy, being located on SH 1, has some services which could increase the chances of groundwater contamination, such as a motor garage, motor camp and a public bar. Seasonal fluxes of visitors to Glenavy occur when the fishing seasons are open. A small fishing camp is located to the east of Glenavy at the far south eastern corner of the study area, but has virtually no effect on groundwater quality because of its close proximity to the sea. The landuse of the study area tends to determine the density of population, with most farming practices not requiring much labour. Figure 4.6 shows a representation of all buildings contained in the study area, obtained from DOSLI map databases.

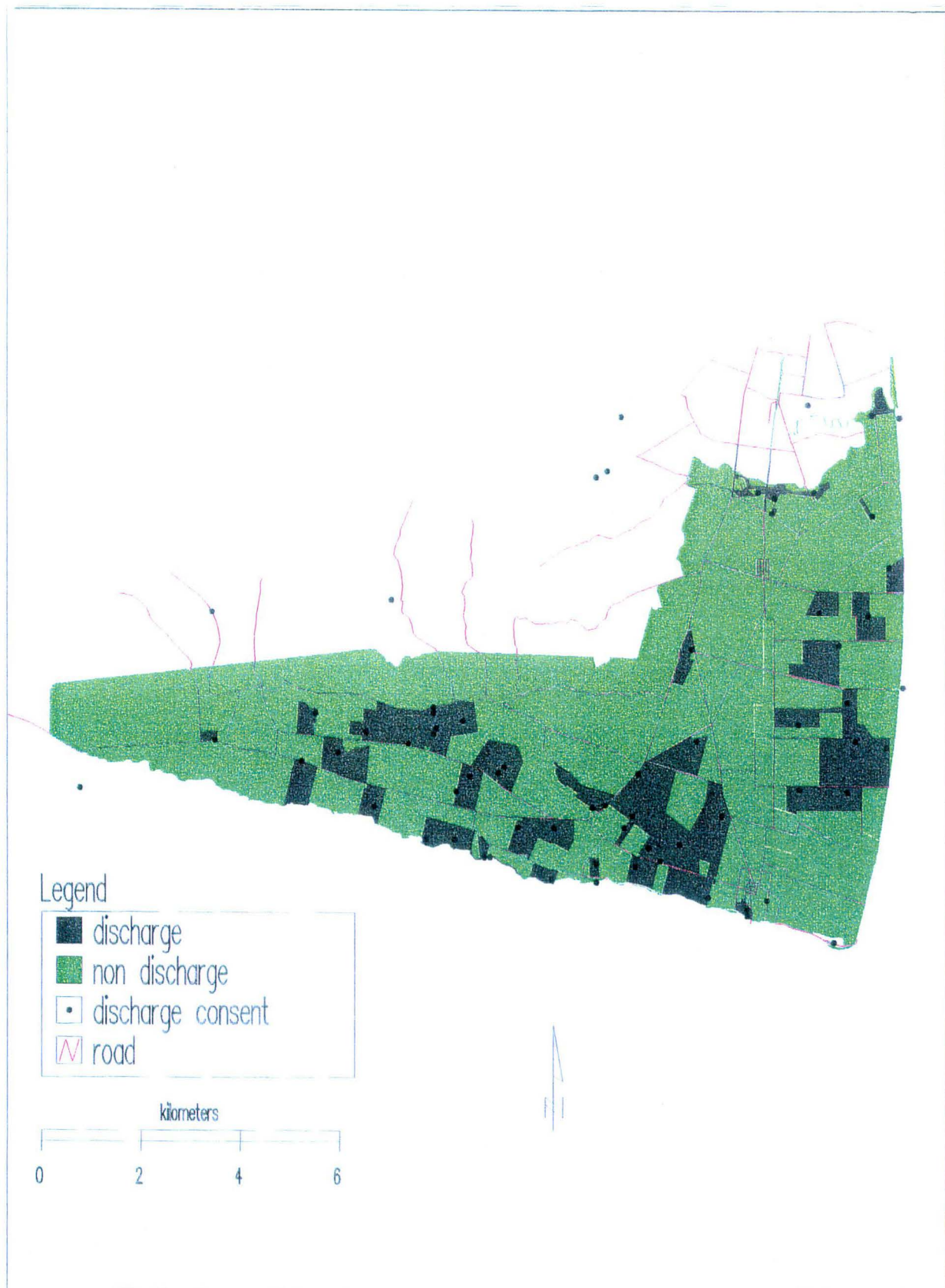


Figure 4.5: Properties given resource consent to discharge waste.
Source: Canterbury Regional Council, 1996 (a).

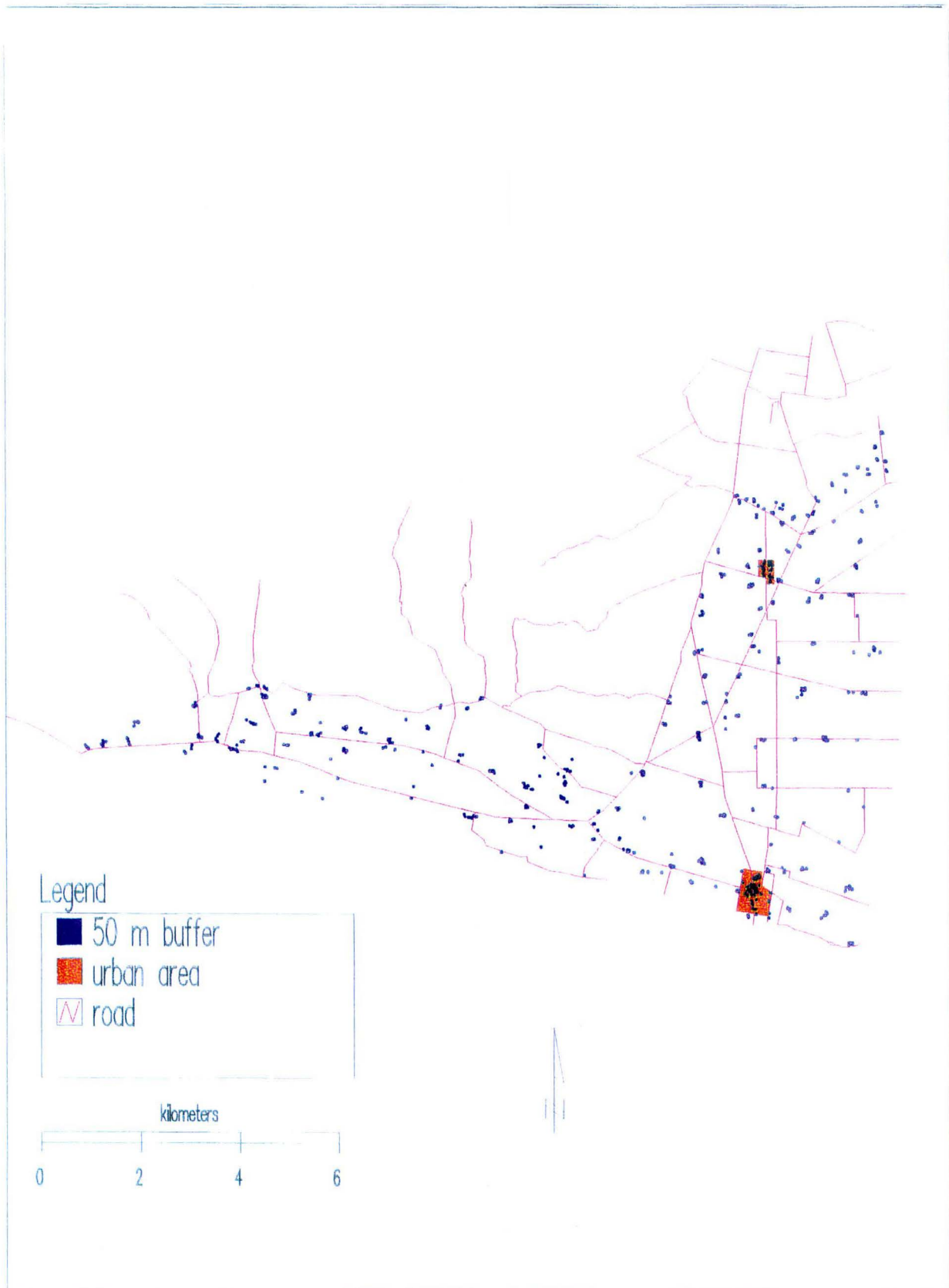


Figure 4.6: The 50 metre building buffer and urban areas.
Source: Author, 1996; DOSLI, 1984 (b and c).

The urban class was defined by placing a polygon around each of the urban areas of Morven and Glenavy. Wells falling within either of these two settlements (polygons) were classified as urban. This class ignores the buffer zone which takes account of buildings, or the lack of buildings, outside the two urban areas. An arbitrary 50 metre radius or buffer was placed around buildings. This enabled buildings to be represented as polygon features so as to be able to spatially relate them to wells, i.e. wells falling within the buffer were close to buildings, whereas those outside it were not. Wells outside the buffer tend to be distanced from any form of settlement.

4.4 Wells.

The extensive network of sampled wells throughout the study area is shown in Figure 3.1. These wells were used to collect the groundwater samples discussed previously. Half of the wells did not have a sufficient opening to allow water level to be measured. The depths to water levels, measured in February and May are shown in Figure 4.7 and are seen to be fairly normally distributed.

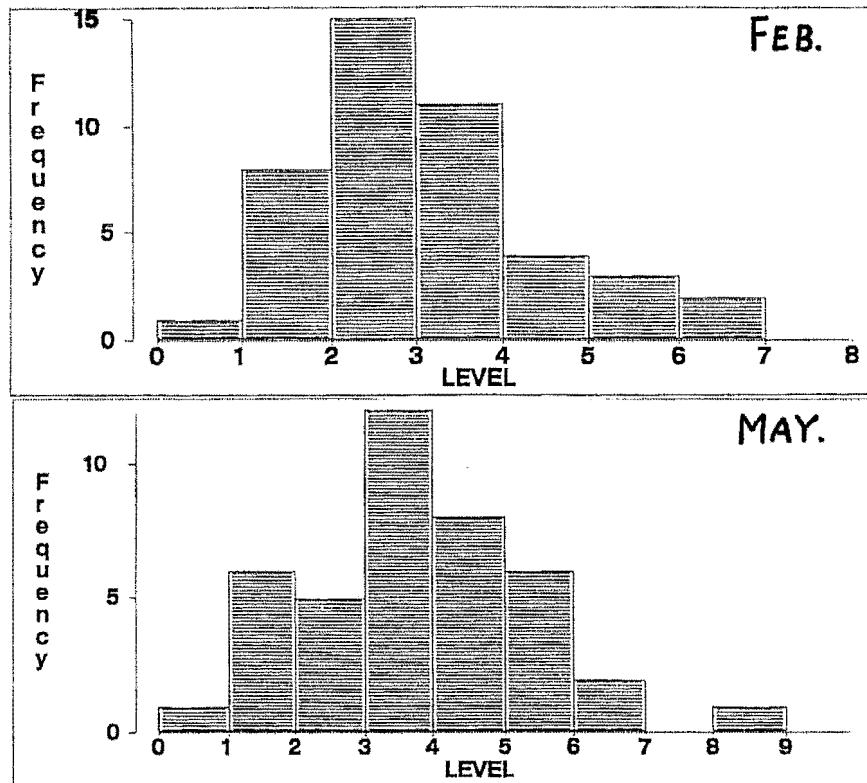


Figure 4.7: Depth to water distributions for February and May 1996 (units in metres).

Source: Author, 1996.

The February mean is 3.174 metres, while the May mean is 3.711 metres, a positive increase of 0.54 metres. A paired t-test based on the sample of just over 40 wells, indicates that the difference of means is significant at the 1% level. The difference represents an average drop in actual groundwater levels of half a metre, which may seem a little unusual for a late autumn month. However, it does correspond to the end of the irrigation season, which means water inputs from this source are almost negligible. Rainfall data, given earlier in Table 4.1, shows that May received 27 millimetres (mm), well under half of the rainfall of February (76mm). Rainfalls for the previous months show a different pattern with January recording 51.4mm and April 112.9mm. Potential water inputs to groundwater are highly variable around the two sampling periods. Evaporative losses from soil in May would be expected to be less than in February, given that the average temperature for May is 8.7 degrees C and for February 15 degrees C, allowing more soil moisture to recharge groundwater if it was available.

In the early part of this century farmers used the relatively accessible groundwater resource because of the often droughty climate and lack of water schemes. It was accessible because of its closeness to the ground surface. Local water supply schemes now partially serve the area, with many wells becoming redundant as a result. Some wells have also fallen into disrepair, meaning that they are unsuitable for drawing and sampling from.

Most of the wells sampled were classified as unprotected, meaning that they were not adequately covered and were exposed to potential outside influences. Wells varied significantly in age and type, but most sampled from were still in use. The types of wells can also influence groundwater quality. Hamilton and Helsel (1995) point out that the casing material, frequency of pumping (associated with well type, e.g. stock, domestic, or public supply), and the circulation of water through holding tanks can all affect samples taken. Sampling procedures can generally overcome some of these problems, but small differences in groundwater quality may still occur. The numbers of wells in each of the land classes is shown in Table 4.2.

Factor	Class	Number of wells in each class	Percentage of well in each class
Farm-type	dairy	34	40
	non-dairy	51	60
Zone	urban	16	19
	inside buffer	39	46
	outside buffer	30	35
Discharge	discharged	26	31
	did not discharge	59	69
Irrigation	irrigated	53	62
	did not irrigate	32	38
Permeability	high	52	61
	medium	5	6
	low	28	33

Table 4.2: Number of wells in each land class.

Source: Author, 1996.

4.5 Summary.

Although the study area was once regarded as flat and of relatively low productivity, it has been transformed by the actions of those using it now and in the past. The greatest assets are its proximity to a major river and the gentle slope of the land which has aided in the development of irrigation. Physical attributes of the study area allow for relatively easy contamination of groundwater. Outcomes of human activities on or near the land can produce contaminants which will reach groundwater. These can be traced by measuring the quality of groundwater from wells, and linking the measurements to factors discussed in this chapter - specifically the five variables noted in Table 4.2.

Chapter 5

Influences of groundwater quality

5.1 Introduction.

Two sets of measurements (February and May) have been presented and possible causative factors have been identified and mapped. The next step is to link the two groups of data for analysis and subsequent display. Figure 5.1 shows a schematic representation of this.

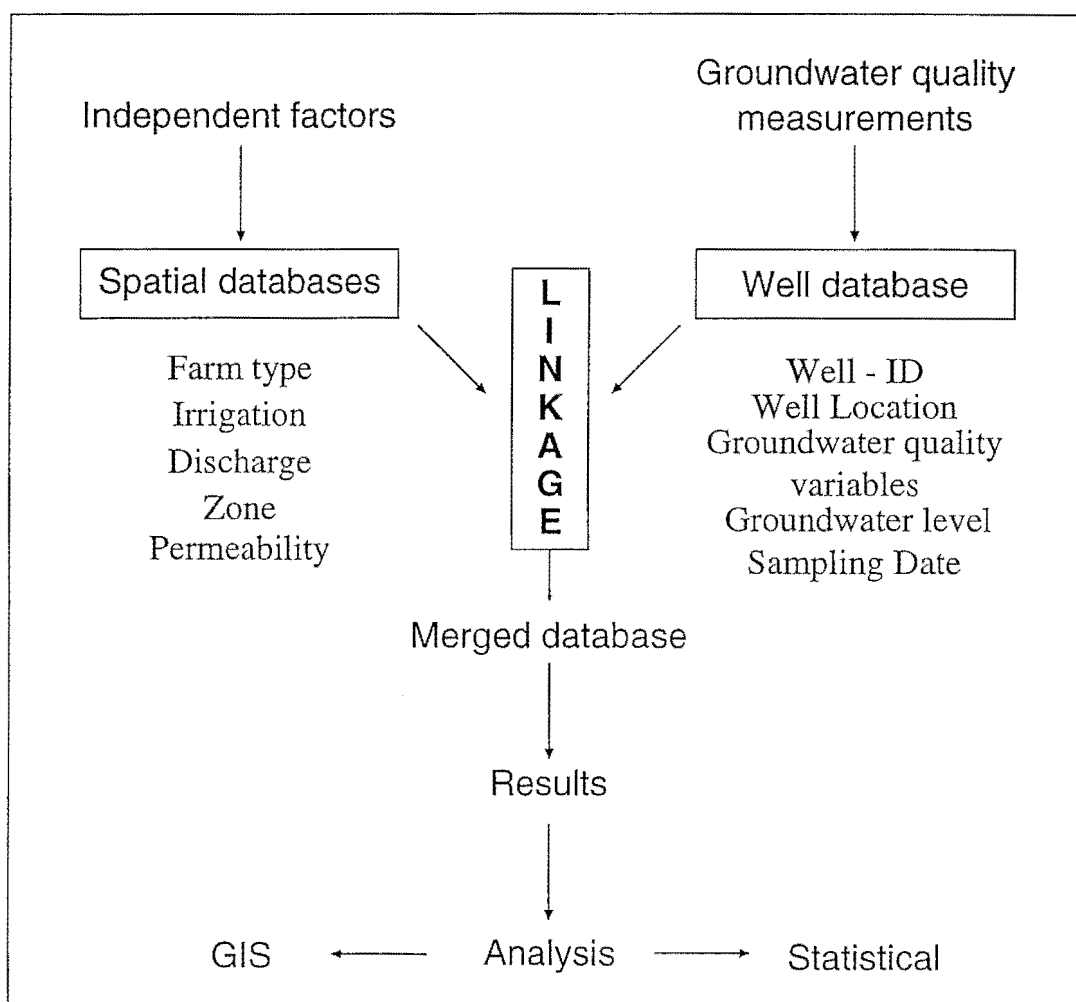


Figure 5.1: Linking the environment to groundwater quality measurements.

Linking the well database with the spatial database creates a merged database containing fields (items) pertaining to the independent factors at or near each well and

to the well water. Site specific factors, such as well head protection are not analysed because of data inadequacies. This establishes a database which links groundwater quality measurements to the independent factors. This chapter will now go on to discuss the processes involved in achieving this objective and will answer the final objective: 'to determine if the independent factors influence the spatial pattern of groundwater quality'.

5.2 Linking Groundwater Quality Measurements to Independent Factors.

Attaching groundwater quality measurements to a spatial database enables spatial analysis to be carried out. Bailey (1994) describes spatial analysis as being "A general ability to manipulate spatial data into different forms and extract additional meaning as a result." Because wells are located in space, the groundwater quality measurements taken from them also represent the spatial pattern of groundwater quality. This can be represented as either a general pattern for a group of groundwater quality indicators, or as a separate pattern for each indicator. The latter representation is preferred as each indicator can show different patterns resulting from different processes. An approach such as this follows one method of representing vulnerability maps described by Barrocu and Biallo (1993):

- (ii) an atlas of maps on the same scale, representing different databases and partial and collateral elaborations aimed at presenting all analytical information and leaving the synthesis to the user.

Maps shown in Chapter Four are a series of databases represented in space. These show patterns of physical and human phenomena which are to be linked to groundwater quality so that for a given groundwater quality indicator, it will be possible to describe the level of influence each factor may have on it.

Linking the spatial and well databases was achieved by using location as the common denominator to relate items between the groundwater quality measurements (as a point coverage in ArcInfo) and the independent factors of farm type, irrigation, zone, permeability and discharge (as polygon coverages in ArcInfo). Because each coverage is stored as a spatial database in ArcInfo it is possible to overlay each factor with the wells. Once this was done, the independent factor type (e.g., dairy and non-dairy for farm type) could be attached to the merged coverage as a field or database item. The merged database contains fields with classes as shown in Table 4.7. For each well a class for each factor is given, being either a 1, 2 or 3 depending on the factor involved.

It is then possible to analyse the groundwater quality measurements against the spatial classes.

5.3 The Influence of Independent Factors on Groundwater Quality.

Statistical analysis was carried out using SAS for groundwater quality indicators that exceeded the acceptable levels for drinking water (pH, HDT, FC, COL and NO₃). Initially the analysis of variance in SAS's General Linear Model (GLM) procedure was used to identify which factors seemed to be explaining the variability in each of these indicators. A model statement representing

$$\langle \text{INDICATOR} \rangle = f(\text{DATE}, \text{WELL}, \text{LU}, \text{DISCH}, \text{PERM}, \text{ZONE}) \quad (5.1)$$

was used for each indicator. The analysis seeks to link widespread factors, such as those discussed in Chapter Four, to groundwater quality measurements. The F statistics calculated in this analysis are related to the probability of each effect being explained by chance. Only DATE and WELL gave F values that indicate significant sources of variation as shown on Table 5.1. Probability values for the WELL factor were below the 5% (0.05) significance level for all analyses, the highest being 0.0039. Results for DATE were more variable with values ranging from 0.2160 to 0.0001 and only two indicators, pH and FC, giving a significant result. This form of analysis suggests that none of the other factors influence the indicators. This observation could be affected by the location or suitability of wells, which may not necessarily reflect the activities carried out at or near the ground surface.

Variable	Date	Well
pH	0.0001	0.0001
HDT	0.0128	0.0001
Log-FC	0.0031	0.0002
Log-COL	0.0659	0.0039
Log-NO3	0.2160	0.0001

Table 5.1: Probability values for Date and Well against groundwater quality variables.

The means for each variable in each factor class are summarised in Table 5.2. As can be seen, means are quite variable between factor classes. Statistical analysis techniques are used to assess differences between factor classes and will now be discussed.

Variable	Factor	Irrig		Lu		Disch		Perm			Zone		
	Class	1	2	1	2	1	2	1	2	3	1	2	3
		Yes	No	Dairy	Non-dairy	Yes	No	Low	Med.	High	Rural	Bldg	Urb
pH		6.53	6.57	6.51	6.57	6.51	6.57	6.59	6.58	6.52	6.54	6.56	6.55
HDT		65.5	74.6	59.9	74.9	65.5	74.6	86.1	86.0	57.3	73.4	71.9	52.2
log-NO ₃		0.74	1.16	0.80	0.97	0.80	0.94	1.05	0.83	0.81	0.95	0.66	1.26
FC		16.5	17.7	13.9	18.9	28.0	12.2	14.3	4.8	19.8	18.6	10.8	24.8
COL		148	127	182	113	110	153	104	76	168	50	221	212

Table 5.2: Means and their significance for pH, HDT, log-NO₃, FC and COL.

The difference of means for pH, HDT and log-NO₃ are compared for all the factor classes. The analysis technique used for IRRIG, LU and DISCH is the paired t-test and for PERM and ZONE the piece-wise comparison, with the results of this shown in Table 5.3. Only one of the means for factors are significantly different for pH, however most are significant for HDT and log-NO₃.

Factor	Difference of means		
	pH	HDT	log-NO ₃
Irrig 1-2	-0.04	-9.1*	-0.42*
Lu 1-2	-0.06	-15*	-0.17*
Disch 1-2	-0.06	-9.1*	-0.14*
Perm 1-2	0.006	0.14	0.221*
Perm 1-3	0.064*	28.86#	0.244#
Perm 2-3	0.058	28.72#	0.022
Zone 1-2	-0.074	1.5	0.288#
Zone 1-3	-0.08	21.14#	-0.309#
Zone 2-3	0.008	19.64#	-0.597#
* denotes significant at 5% level			
# denotes significant at 1% level			

Table 5.3: Difference of means for pH, HDT and log-NO₃.

The Chi-square test was carried out for FC and COL variables because of the reason outlined in Chapter Three, i.e., the logarithmic transformation ignores zero values, hence data is lost for t-test comparisons on log-FC and log-COL. Table 5.4 illustrates

the result of this analysis. Only three factors show a significant difference between the number in each 'clean' (zero counts), and 'dirty' (counts above zero) class for FC and COL. The Zone factor displays a marked difference for both FC and COL, while Perm classes are only significantly different for FC. Given that these two factors have three classes, the degrees of freedom (DF) are two instead of one. This has the effect of increasing the critical value at the 5% significance level from 3.84 (1 DF) to 5.99 (2 DF). The critical value of 3.84 (1 DF) for the 5% significance level or even 2.71 (1 DF) for the 10% significance level is not reached by the other three factors.

Factor	FC		COL	
	Chi-square	prob	Chi-square	prob
Irrig	0.221	0.639	0.026	0.873
Lu	0.014	0.905	0.494	0.482
Disch	0.294	0.588	0.179	0.672
Perm	6.047	0.049*	3.578	0.167
Zone	6.205	0.045*	7.718	0.021*

* denotes significant at 5% level

Table 5.4: Chi-square test for FC and COL.

5.3.1 Cross Tabulation of Landuse Activities with HDT and log-NO₃

Variables HDT and log-NO₃ are chosen for further analysis. Results from Table 5.2 indicate that these two variables are being influenced by the three factors, Irrig, Lu and Disch which are outcomes of farming activities. Table 5.5 shows the outcome of a cross tabulation of these two water quality indicators with the farming activity factors. Note that the class Dairy, no Discharge and no Irrigation does not exist.

Factor	Lu	Disch	Irrig	HDT		log-NO ₃	
				No.	Mean	No.	Mean
Class	Dairy	Yes	Yes	40	67.6	34	0.79
			Yes	21	49.0	19	0.69
			No	6	46.2	6	1.24
	Non-dairy	Yes	Yes	6	52.7	5	1.06
			No	5	54.2	4	0.54
			No	38	74.5	31	0.67
		No	54	79.6	43	1.21	

Table 5.5: Cross tabulation of Lu, Disch and Irrig with HDT and log-NO₃.

Amongst non-dairy farms the mean for HDT is higher for those which do not discharge wastes and declines as discharge and irrigation are used. The opposite occurs for dairy farms, with those irrigating and discharging having the highest mean which declines as discharge and irrigation are not used. Note that the proportion of wells in each class differs markedly and may have some influence on the means. Trends for log-NO₃ differ in that wells in which dairy farming, discharge and irrigation occur have a low mean. When irrigation is not used on dairy farms the log-NO₃ means increase. Wells in which non-dairy farming, no discharge and no irrigation occur record the highest mean. However, when irrigation is used, holding the other two factors the same, the mean decreases about one half (55%), a result similar to that on Dairy farms. When discharge on non-dairy farms is involved the opposite trend is associated with irrigation, with an increase for the log-NO₃ mean by almost 200%, which can be interpreted as a 50% decrease if irrigation is not used.

The number of wells in each cross tabulated class is representative of the activities associated with the two landuses. Dairy farms tend to irrigate (over 90%), with 60% discharging and 31% not discharging. Non-dairy farms tend not to discharge (89%) but 58% do irrigate, with the remaining 42% likely to be farms outside the areas able to be irrigated and smaller urban properties. Figures 4.3 and 4.4 show this to be the case. An important consideration with the above analysis is that the non-dairy class contains all other landuses, so will represent some of the effects of these on groundwater quality results. It may also help explain some of the differences between dairy and non-dairy, which upon reflection of what has been found in the past, seems to be contradictory.

5.3.2 Influence of Permeability and Zone.

Permeability (PERM) and proximity of wells to buildings (ZONE) are factors which are not changed by farming activity. The statistical tests reported in Table 5.3 provided an indication that some of the water quality indicators differed significantly between classes of these factors.

For Perm there are only strong differences between means of classes 1 and 3, which represent the two extremities of permeability, hence a difference is most likely between this pair. HDT also differs very significantly between Permeability classes 2 and 3. Zone class comparisons yield a different pattern, with no significant difference of means for pH. Difference of means for log-NO₃ occur in all classes and occur in all but the 1 and 2 comparison for HDT. Differences between the extreme Zone classes (1 being rural and 3 being urban) are the opposite for HDT and log-NO₃. The difference

between rural and urban wells (1-3) for HDT is positive, indicating higher HDT levels in wells away from urban areas. Whereas a negative difference occurs for log-NO₃, with higher levels for wells located in urban areas. HDT values are clearly separated into two groups, with values averaging 52g/m³ for the urban wells and some 20g/m³ for the non-urban wells. The log-NO₃ pattern is not so straightforward with significant differences between all classes but with the rural class having levels intermediate between the other two classes.

The significance of Perm and Zone for FC and COL, discussed earlier, can be further explored. Table 5.6 shows the frequencies of wells in the clean and dirty FC and COL classes against the Perm and Zone effects found to be significant in Table 5.4. Higher permeabilities appear to be associated with FC contamination. The high proportion of dirty FC counts in the high permeability class may suggest that more permeable soils promote the movement of FC to groundwater.

	Factor	Zone			Permeability			
Indicator	class	rural	bldg	urban	low	medium	high	total
FC	clean	38	27	7	31	6	35	72
	dirty	41	33	24	27	5	66	98
COL	clean	27	13	3				43
	dirty	52	47	28				127
	total	79	60	31	58	11	101	170

Table 5.6: Frequencies of FC and COL clean and dirty wells for significant Perm and Zone effects (Includes all February and May measurements).

5.4 Groundwater Contamination Across the Study Area.

Measurements of pH, HDT, FC, COL and NO₃ were mapped spatially as another way of describing the results. The classes shown are described in Table 5.7 below.

Indicator	Class		
	low	medium	high
HDT	0-40	40-99	100+
pH	6-6.4	6.5-6.8	6.9+
FC	0	1-99	100+
COL	0-1	2-299	300+
NO ₃	0-4	5-9	10+

Table 5.7: Class descriptions for Figure 5.2.

It was decided for mapping purposes to combine the February and May results. The following maps provide an illustration of the spatial trends of the means of each five variables. The distribution of COL values shows a vague separation of high, medium and low classes. High classes tend to favour isolated areas around the study area. Low values group loosely to the north of Ikawai and a corridor around Morven. The spatial pattern of FC is similar to that shown by COL. Low FC results generally occur around the fringes of the study area to the north of Ikawai, Morven and to the northeast of Glenavy. An irregular pattern of pH is shown, with some acidic (low) results towards Ikawai, but no other distinct patterns emerge. HDT results provide a distinct decrease as sample points move away from the Waikakahi Downs in the north to west. Noticeably low levels are found near the Waitaki River. This pattern indicates dilution of HDT as groundwater flows out of the hills to the north of Ikawai and Glenavy. However this pattern is not replicated to the same extent in the Morven area, with only two samples recording high HDT near the hills and no clear trend of low values towards the sea or Waihao River. A rather noticeable pattern of NO₃ results, with a cluster at Morven, but very few medium to high values elsewhere.

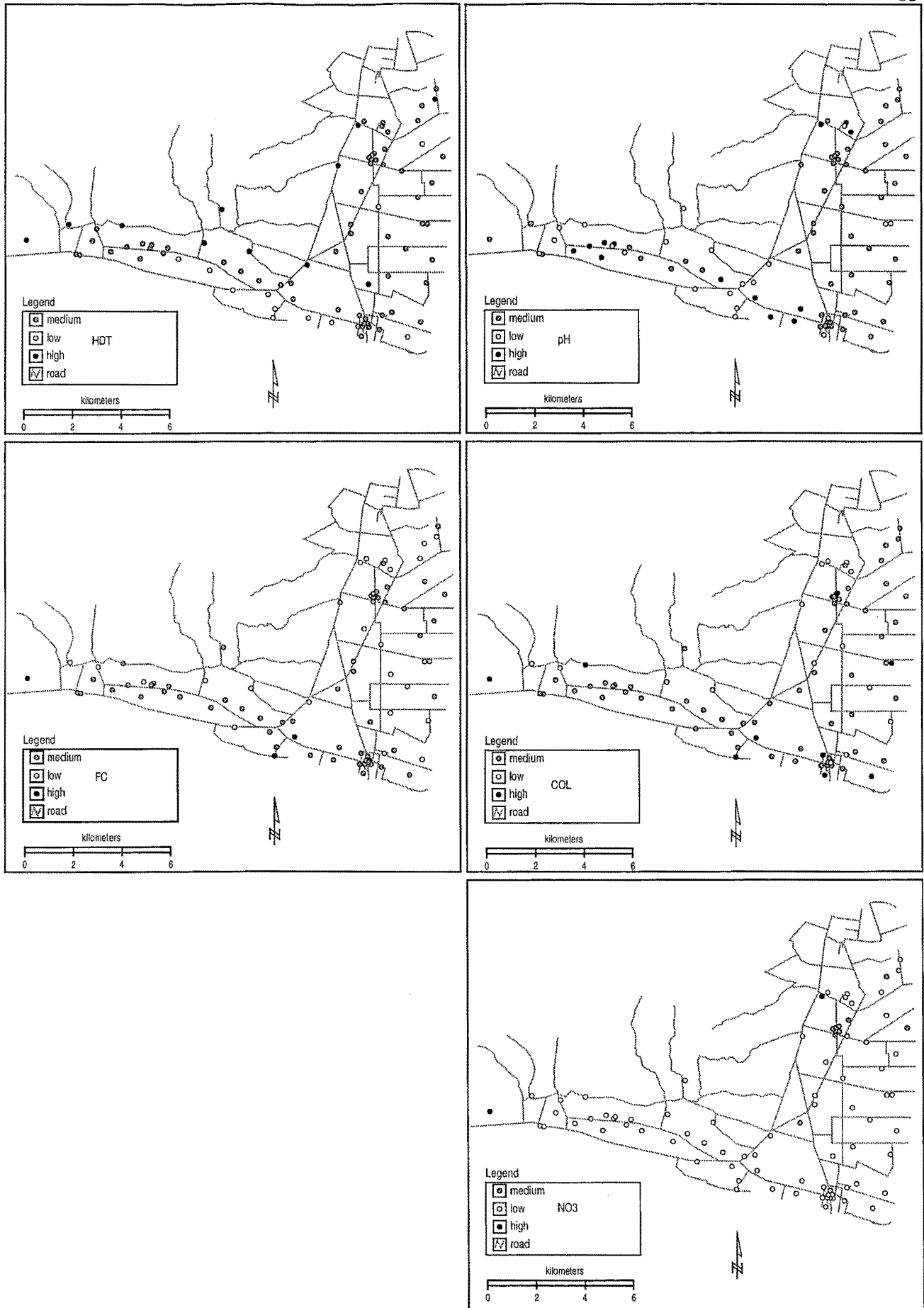


Figure 5.2: Spatial trends of pH, HDT, FC, COL and NO₃.

5.5 Discussion

It is quite evident that Date and Well have a strong influence on the measurements of groundwater quality. Further analysis of the five factors, Irrigation, Landuse, Discharge, Permeability and Zone reveal some interesting and unexpected patterns in relation to each groundwater quality variable.

pH.

Only Permeability had any influence on pH, with the difference between means for high and low permeability being significant. Given that the most permeable class has lower pHs than the least permeable class, a process could be occurring which would explain this. The plant reaction (Equation 3.2) produces CO₂ which becomes available to mix with water. If the CO₂ reaches groundwater faster, such as through rapid transportation assisted by highly permeable soil, then it may be converted to Carbonic Acid, lowering the pH. Rainwater, which can be acidic (CRC, 1995 c), may also reach groundwater faster if soils are highly permeable. If irrigation is involved the process of water transportation may speed up. pH values for Irrigation are slightly lower than those for Non-irrigation, which may also suggest that irrigation is contributing to lower pH values, especially where soils are highly permeable. However an increased rate of water movement to groundwater may actually provide less time for water to entrain chemicals from the surrounding soil.

HDT.

Higher means for HDT favour Non-dairy farms which do not Irrigate or Discharge. For Dairy farms the opposite occurs, with higher means where Irrigation and Discharge occurs. Despite this result giving a good statistical relationship, HDT is not heavily influenced by landuse activities. A more meaningful trend emerges when comparing means for Permeability classes. A decrease in means occurs as Permeability becomes higher which can be expected given that highly permeable areas are located away from the hills to the north and west of the study area. Low permeability classes, shown in Figure 4. 1, tend to be located nearer the hills, hence would be related to higher HDT values. The relationship between Permeability and HDT may be coincidental and changes in HDT may be affected to a greater extent by the proximity to surrounding calcareous sediments, such as those found in the Waikakahi Downs. Figure 5.2 shows a pattern of HDT decline moving from north to south across the Ikawali area.

NO₃.

Patterns of NO₃ are rather mixed, but with higher values being in the Morven area, particularly in the urban area. High NO₃ values for urban areas are evident from Table 5.2, with Figure 5.2 showing the cluster of medium NO₃ values in the Morven urban area but not in Glenavy. Higher NO₃ levels the Morven area, but not Glenavy or Ikawai suggest that different activities may be affecting this result. Landuses around Morven, tending to favour non-dairy, maybe using fertilisers, especially arable (cropping) activities. A most likely cause of higher NO₃ in Morven is the discharge of sewage from septic tanks, which can introduce nitrates to groundwater. Previous research, e.g. Burden, 1982 and 1979; Tillman, 1995 and Ball *et al*, 1979, suggest that dairy farming in particular can introduce nitrates to groundwater. Moreover, research also links irrigation and discharge of waste to nitrate contamination of groundwater. The data presented here seem to contradict this relationship. When irrigation is used on Dairy farms (both discharging and not discharging) and on Non-dairy farms not discharging the NO₃ means actually decrease. The only increase in NO₃ means associated with irrigation occurs on Non-dairy farms that do discharge. A quick t-test carried out for NO₃ means with the two Irrigation classes for both Dairy and Non-dairy indicate a significant difference at the 1% level. The NO₃ means were higher for both Non-irrigation classes by 40-50%. It should be noted that the two extreme values of NO₃ shown in Figure 5.2 are located on properties not irrigated (see Figure 4.4) and may distort the statistical relationships given.

FC.

The Chi-square test carried out shows the difference of FC means for both Permeability and Zone are significant. Looking at Permeability, it seems that the spatial trend of FC, shown in Figure 5.2, is similar to that of Permeability (Figure 4.1). The statistical result between FC and Permeability may be more coincidental although it seems that the highly permeable class does promote FC contamination recording almost twice as many dirty than clean results. Differences of means for Zone are more representative of contamination resulting from settlement patterns. The urban class mean is the highest, followed by the rural class. If this is linked to the pattern shown in Figure 5.2, it seems that a grouping of medium FC results are found at both Morven and Glenavy, with a rather mixed spatial distribution elsewhere. Analysis of frequencies in each class showed that considerably more dirty than clean FC counts were found in the urban class. Isolated windows of low FC results occur in areas around the study area fringes, which suggests that the landuse activities around the fringe, being Non-dairy, Non-

irrigating and Non-discharging are not introducing FC contamination to groundwater.

COL.

Wells located in rural areas near buildings and in urban areas give higher COL results, than those in rural environments. The urban trend is similar to that of FC as previously discussed, but the spatial pattern is not so similar. Dirty COL counts are also influenced by the proximity to buildings. Although the difference of means for Landuse and Irrigation are not significant, they do point towards dairying and irrigation increasing the mean for COL. However, some high COL results are found around the fringes where these activities are not so common.

Influences on groundwater contamination.

From this analysis three main influences on groundwater contamination can be identified. Firstly the surrounding topography, particularly the geology and soils affect hardness concentrations. The Waikakahi Downs contain calcareous sediments which contribute enhanced calcium and magnesium loads to groundwater, increasing its hardness. It so happens that the pattern of hardness also corresponds to that of permeability. Statistical tests showed that rural landuses have minimal effect on groundwater quality, with generally low or nil contamination associated with dairying, irrigation and discharge of wastes. Finally the effect of septic tank discharge in urban areas is significant in that wells located in both Morven and Glenavy contribute to higher levels of NO_3 , FC and COL contamination. The effect of proximity to buildings and hence septic tanks, is also significant for COL contamination.

5.7 Summary

Establishing a link between groundwater quality measurements and independent factors is an important step for allowing further data analysis. Because groundwater sampling points (wells) and independent factors are located throughout the study area they can be related by an overlay process. Analyses carried out found some interesting patterns, which are not always to be expected. Factors in space do not seem to have any affect on pH, with a rather random spread of pH values. Hardness, however, tends to be influenced by many factors, although closer examination of the spatial patterns of Hardness and Permeability show the relationship to be associated with the proximity to the Waikakahi Downs and the associated limestone and other calcareous lithologies in the catchment. Hardness values are highest near the Downs while Permeability values

are lowest there, thus the two relate quite well statistically. The NO_3 is generally higher near urban areas, in particular Morven. Rural effects are a little obscure, with NO_3 values increasing when the Non-irrigation class is considered. An exception to this occurs for Non-dairy farms which also Discharge, with NO_3 increasing when the Irrigation class is considered. The FC results are difficult to explain, although the relationship with Permeability is statistically significant. This may be coincidental and may also reflect the analysis technique employed. The urban Zone class has a quite a significant effect on FC. The COL results are only significant for the Zone factor and are highest near buildings and in urban areas. In general urban areas seem to have quite an effect on groundwater quality, tending to contaminate it to some degree. Rural activities contribute moderately to some groundwater contamination, but there is no clear trend pointing towards a specific landuse activity. Physical factors influence groundwater quality to some extent, for example, the proximity to calcareous lithologies affects hardness levels. Relationships established in this chapter show that some groundwater contamination is occurring, with linkages being made to widespread landuse activities and physical factors..

Chapter Six

Conclusion

6.1 Addressing the Problem

A question has arisen recently in the Morven, Glenavy and Ikawai area concerning the quality of groundwater. This problem has only come under pressure in the last few years because of a dramatic change in landuse activities. Dairy farming has become an increasingly popular farming practice, now occupying close to 40% of the study area. The physical resources of the study area are very suitable for dairy farming, with flat land close to sea level, free draining soil and a favourable climate. Coupling this with two well established irrigation schemes, the Lower Waihao water scheme and/or groundwater near the surface, gives an attractive option for dairy farming. Corporate investors and both overseas and North Island farmers realised this and purchased land in the area from existing sheep farmers. Dairy farm conversions from sheep farms by existing land owners have also taken place as they too see the economic advantages of this farming practice.

Such changes have meant that under the RMA (1991), regional and local authorities have had to keep a close watch on landuse activities to prevent any adverse effects on the environment. They must also keep a close watch on environmental resources, such as groundwater, especially where it is used for human consumption. There are essentially two tasks:

- 1). to monitor and safeguard environmental resources, being groundwater in this case;
- 2). to monitor the effects of landuse activities in order to minimise their effects on the environment.

The CRC have begun to monitor the groundwater quality in the study area, with chemical and microbiological analyses for February and May 1996 being presented in this thesis, along with an attempt to relate them to factors which can influence groundwater quality. Chapter Two outlined the hydrological influences relevant to groundwater quality. Key factors identified in this chapter were soil permeability, the piezometric surface or depth to groundwater and irrigation, factors which might affect the movement of contaminants to groundwater. Chapter Three discussed the human influences on groundwater quality, looking specifically at contaminants introduced by

landuse activities associated with a rural environment and unsewered urban settlements.

The use of GIS in this thesis was important as a precursor to and tool for integrated factor analysis. Firstly it was used to map the patterns of independent factors over the study area. These were obtained from hard copy maps, existing GIS coverages (from CRC) and from fieldwork undertaken by CRC staff and the author. The GIS could also be used to map and store information relating to each well. Because both wells and independent factors were spatially related, an overlaying process was used to link the two different data sets. Another important function of GIS was to create the building buffer and the urban polygons to use in the overlay process. Chapter Four provides details of the coverages and summarises the spatial classes assigned to each well. A visual representation of key groundwater contaminants was also obtained from the well coverage and GIS allowed this to be presented spatially.

6.2 Patterns of Groundwater Quality

Before groundwater quality sampling took place in February 1996 the feeling among locals, CRC staff and the author was that results would indicate high levels of contamination in parts of the study area. To an extent this initial concept has proven to be correct. Faecal and Total coliform results in both February and May indicate high levels of contamination from bacteriological organisms in over half of the wells. The variables pH, HDT and NO_3 exceeded acceptable drinking water criteria, but at fewer wells. Other indicators of groundwater quality fall within acceptable levels of the Drinking Water Standards for New Zealand (1995). In total over 60% of water sampled from wells had unsatisfactory quality for potable use on at least one occasion during the study period.

Differences of determinand means between the February and May sampling periods indicate a slight increase in acidity and NO_3 and a decrease in FC. Faecal and Total coliform results exceeding the acceptable level decrease from February to May. This could be linked to changes in stocking levels on farms which generally decline prior to winter months, coinciding with the end of the irrigation season. The pH values are lower in May, indicating a more acidic pattern of groundwater, possibly as a result of high rainfall for the previous month (April). The two sets of results show generally good groundwater quality, but biological organisms are frequently recorded in wells, almost two thirds, high enough to warrant further investigation.

6.3 Independent Factors Influencing Groundwater Quality.

A review of overseas and New Zealand literature suggests that several physical and human factors can influence groundwater quality, possibly contaminating it. Activities carried out at or near the land surface can easily contaminate a shallow unconfined aquifer. Physical factors tend not to contribute to the contamination of groundwater, whereas human factors generally introduce contaminants as an outcome of landuse activities. These factors were identified and described in the study area.

Physical Factors.

The topographic and climatic nature of the study area is relatively uniform, allowing the detection of other influences to be fairly straight forward. The permeability of soil is quite high which allows free movement of water and contaminants to groundwater. Areas of low permeability were classified, but these are relative to the study area and do not indicate an impermeable soil. Coupled with a shallow unconfined aquifer with a water table less than 10 metres below the surface (frequently closer), the potential for contaminants to reach groundwater is quite high.

Human Factors.

Within the study area, activities carried out at the land surface by people tend to be rural in nature, with some urban influence. Rural activities include sheep farming, with dairy farming becoming increasingly more common, presently occupying close to 40 % of the study area. The two farm types are seen to contribute to groundwater contamination through their land management techniques, with dairy farming being a more intensive farming activity. Both utilise irrigation to increase pasture production which can act to increase flows of water and contaminants to groundwater. Dairy farming in particular often needs to discharge concentrations of animal wastes. Discharge of wastes increases the contaminant input to the surface and/or water. Urban effects on groundwater quality are felt where households, in particular those in small unsewered settlements, discharge waste through septic tanks untreated into underlying groundwater. Contamination in extreme cases can render the groundwater unsuitable as an untreated drinking water supply. Wells too can allow contaminants to directly enter groundwater if they are not adequately protected from the surrounding surface environment.

6.4 Linking Groundwater Quality Measurements to Independent Factors.

To link the two sets of data required a simple process of overlaying the well points with the factor polygons. Points falling in certain polygons were assigned the polygon value relating to the land feature class. The resulting well database could then be exported out of ArcInfo to SAS, a statistical package, for further analysis. Alternatively the results of groundwater quality indicators can be linked to other spatial phenomena by mapping their trends across the study area.

6.5 Do Independent Factors Influence the Spatial Pattern of Groundwater Quality?

Findings from Chapter Five indicate that certain factors do influence spatial patterns of groundwater quality. Firstly the physical environment affects patterns of hardness, with areas of high HDT being nearer the Waikakahi Downs, and low HDT near the Waitaki River. This pattern also happens to coincide with that of Permeability which is highest near the Downs and lowest near the Waitaki River. Two aspects of the human environment affect groundwater quality. Settlement patterns, in particular urban areas, contribute to higher NO₃, FC and COL levels. Rural activities on the other hand exhibit little or no effect on groundwater quality when dairy farming, irrigation or discharging are considered. Higher levels of contaminants found in the rural area tend to be associated with farms around the fringes, which tend to be non-dairy, do not irrigate, nor do they discharge waste. This generalised pattern is dependent on results from existing wells which may not necessarily be best placed to reflect the full impact of the activities. Likewise no attempt has been made to separate site specific effects, such as inadequate well head protection from wider landuse impacts. Other nonparametric statistical techniques would allow further exploration of data relationships. Likewise, a different spatial representation of groundwater sampling points may provide better linkages to the factors influencing groundwater quality.

6.6 Implications for Future Researchers and the Study Area: A Summary.

It has been observed that groundwater quality of the Morven, Glenavy and Ikawai is at risk from certain factors. However it appears from this research that dairying at the present time is not shown by the analysis to have a significant effect on groundwater

quality. It is not surprising that urban influences are felt on groundwater quality, but even these are quite specific, for example, Morven and Glenavy have quite different patterns for nitrate levels, and serve as an example of a situation one would expect. Fluctuations in groundwater levels and the quality of it are to be expected over the period of a few months, especially when the aquifer is shallow and unconfined. Given that the aquifer is relatively unprotected and is overlaid with permeable soils it would be expected that any form of activity producing contaminants would pollute the groundwater. This would seem to be exacerbated by the use of irrigation which acts as a transporting agent for contaminants. However, it may also act to dilute water and may even flush the groundwater body of contaminants. This may be happening in the study area, especially when wells not located on irrigated land show high contamination levels.

More detailed investigation of these seemingly opposing impacts on groundwater quality is required at the micro or farm scale. Detailed on-farm studies would act to verify or confute these observations. Ongoing monthly monitoring of a restricted number of wells in the study area, which the CRC began in July 1996 is a useful tool in assessing changes over both short and long term periods. This monitoring program would also be useful in conjunction with detailed on farm studies by providing regular groundwater quality results. This data would lead to an enhanced understanding of the impacts of landuse activities on groundwater quality. Via land planning and resource consent mechanisms used by local and regional authorities this would assist to minimise the environmental impact of landuse activities, especially dairy farming, in an area where the health and livelihood of a community are, or may be affected.

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Appendix 1: Section 5 RMA, 'Sustainable Management':

- (a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonable foreseeable needs of future generations; and
- (b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
- (c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Appendix 2: Relevant parts of Section 30, 'Functions of regional councils under this Act' to groundwater quality.

- "(a) The establishment, implementation and review of objectives, policies and methods to achieve integrated management of the natural and physical resources of the region;
- (b) The preparation of objectives and policies in relation to any actual or potential effects of the use, development, or protection of land which are of regional significance;
- (c) The control of the use of land for the purpose of:
- (ii) The maintenance and enhancement of the quality of water in water bodies and coastal water;
 - (iii) The maintenance of the quantity of water in water bodies and coastal water;
 - (iv) The avoidance or mitigation of natural hazards;
- (e) The control of the taking, use, damming and the diversion of water and the control of the quantity, level and flow of water in any water body, including:
- (i) The setting of any maximum or minimum levels or flows of water;
 - (ii) The control of the range, or the rate of change of levels or flows of water;
- (f) The control of discharges of contaminants into or onto land, air or water and discharges of water into water."

Appendix 3: February and May results.
February Results.

Well no.	LEVEL	PH	COND	TS	HOD5	NO2	NO3	NH3	TP	ALKT	CL	CO2	SO4	CA	MG	NA	HDT	K	FC	COL
J400018		6.5	25.7	160	1	0.003	5.9	0.0025	0.114	50	21	26	21	16	4.9	27	60	2.5	29	70
J400044	1.6	6.6	14.3	120	1	0.003	0.9	0.0025	0.029	51	6	21	16	11	2.6	12	38	2.1	3	5
J400046		6.7	18	110	1	0.003	3.5	0.007	0.012	44	9	14	20	11	4	15	44	3.2	6	55
J400051	2.50	6.2	28.8	180	1	0.003	4.8	0.0025	0.028	53	36	55	26	19	5.6	27	71	3.3	0	4
J400053		7.1	18.2	110	1	0.003	4.5	0.006	0.004	46	8	6	12	12	3.6	18	45	1.7	0	4
J400074		6.7	16	85	1	0.003	2	0.0025	0.004	53	5	17	11	12	3.6	15	45	1.2	1	100
J400076	2.65	7.1	43.1	240	1	0.003	0.1	0.009	0.004	164	15	21	20	53	9.4	24	170	2.1	0	0
J400077	5.58	6.7	23.2	160	1	0.003	5.9	0.005	0.004	45	20	15	17	23	5.4	12	80	1.4	22	36
J400079		6.7	24.4	150	1	0.003	6.4	0.0025	0.035	54	19	18	21	15	4.6	24	56	1.9	1	2
J400086	1.6	6.6	14.5	85	1	0.003	3.5	0.0025	0.004	44	6	18	15	12	3.6	10	45	1.1	0	8
J400089	2.6	6.2	18.5	130	1	0.007	4.9	0.0025	0.027	41	11	42	17	19	4.7	9.6	67	2	34	41
J400097	3.83	6.5	19.1	130	1	0.003	6	0.0025	0.004	37	11	19	17	13	4.2	17	30	1.3	5	0
J400101	5.8	7	49.1	340	5	0.003	11	0.146	0.116	124	31	20	18	56	7.1	19	170	18	400	400
J400104		7.2	42.9	300	3	0.003	1.1	0.0025	0.004	64	96	7	20	45	8.6	18	150	1.9	0	0
J400105		6.4	13.9	90	1	0.003	3.7	0.006	0.004	37	7	24	17	12	3	9.6	42	1	1	3
J400106		6.8	15.5	90	1	0.003	2.4	0.0025	0.004	53	5	14	9.6	12	3.4	13	44	1	0	0
J400108		6.8	17.9	170	1	0.003	2.8	0.0025	0.004	74	34	19	26	26	6.7	21	93	1.7	0	25
J400109	6.65	6.2	61.2	330	1	0.009	20	0.007	0.008	55	85	57	39	17	14	62	100	1.2	0	0
J400110	4.9	6.6	13.6	80	1	0.003	0.1	0.0025	0.019	42	4	17	16	13	2.9	8.2	44	0.9	0	0
J400112	3.95	7	17.2	100	1	0.003	0.3	0.059	0.23	48	9	8	17	18	3.1	11	58	1.4	3	23
J400113		6.5	28.7	170	1	0.003	3.5	0.0025	0.012	64	34	33	24	18	5.4	29	67	2.2	0	9
J400114	3.7	6.4	42.1	280	1	0.003	7.3	0.0025	0.018	58	47	38	68	24	8.6	44	95	2	0	140
J400115		6.4	22.2	140	1	0.003	3.1	0.0025	0.016	45	21	29	23	16	4.4	20	56	1	0	0
J400116		6.5	19.1	110	1	0.003	2.9	0.0025	0.023	50	9	26	15	12	3.6	17	45	1.5	1	7
J400117		6.7	24.1	150	1	0.003	5.2	0.0025	0.045	53	18	17	20	13	3.9	26	49	2.1	34	400
J400118		6.5	17.2	110	1	0.003	3.2	0.0025	0.004	49	8	25	13	14	3.8	13	51	1.2	11	45
J400119		6.9	16.8	110	1	0.003	3.1	0.0025	0.01	53	7	11	14	16	3.9	13	56	1.5	3	5
J400120		6.6	15.6	110	1	0.028	0.9	0.053	0.012	56	5	23	9.8	9	3.2	17	36	1.3	0	1
J400121	2	6.5	16.5	100	1	0.003	3.5	0.0025	0.004	50	7	26	17	13	4.1	13	49	1.2	0	0

Well no.	LEVEL	PH	COND	TS	HOD5	NO2	NO3	NH3	TP	ALKT	CL	CO2	SO4	CA	MG	NA	HDT	K	FC	COL
J400122		7.4	17.5	140	1	0.009	3	0.119	0.011	62	6	4	13	14	4.4	13	55	1.3	0	310
J400123		6.9	26.1	160	1	0.003	7.1	0.0025	0.075	69	22	14	23	18	4.7	28	64	2.3	180	270
J400124	2.8	6.6	24.6	170	1	0.003	6.6	0.028	0.084	52	19	21	22	14	4.8	25	55	2.3	270	400
J400125	2	6.5	30.2	200	1	0.003	7.9	0.01	0.067	53	28	27	29	17	5.5	31	65	1.8	4	400
J400126		6.5	15.7	90	1	0.003	2.6	0.0025	0.011	44	8	23	11	16	3.8	8.6	56	1.5	0	86
J400127	2.4	7.1	80.9	470	2	0.003	0.1	0.008	0.045	337	56	44	37	94	19	61	310	1.8	1	2
J400129		6.8	27.9	170	1	0.007	4.2	0.175	0.118	59	24	24	18	16	5.3	30	62	2.4	96	2000
J400130	3.9	6.6	24.7	160	1	0.003	6.1	0.0025	0.046	44	10	18	18	15	4.7	25	57	2.4	0	0
J400131		6.5	21.8	130	3	0.008	1.1	0.0025	0.031	68	7	35	16	24	5.1	12	81	1.5	35	58
J400132		6.5	10.4	60	1	0.003	1.7	0.0025	0.011	30	4	16	8.3	10	2.4	5.3	35	1.2	84	110
J400133		6.4	17.7	100	1	0.003	3	0.012	0.024	42	11	27	15	17	3.8	9.2	58	2.7	3	10
J400134		6.4	18.1	100	1	0.003	4.4	0.0025	0.024	40	11	26	15	17	3.9	9.3	59	2.6	3	60
J400135	1.5	6.4	14.3	90	1	0.003	2.3	0.0025	0.004	35	8	23	13	15	2.7	8.1	49	1.5	4	15
J400136		6.4	18.8	110	1	0.003	1.8	0.0025	0.025	51	10	33	16	18	4.2	12	62	1.5	34	76
J400137		6.4	17.3	110	1	0.003	2.8	0.0025	0.022	44	11	29	15	16	5.2	9.8	61	1.8	0	20
J400138	3.35	6.9	19.3	110	1	0.003	0.4	0.085	0.031	62	9	13	15	19	3.9	12	64	1	0	0
J400139		6.5	15.9	85	1	0.003	0.6	0.0025	0.045	45	10	23	13	14	3.8	11	51	1	1	24
J400140		6.8	18.2	110	1	0.003	2	0.041	0.047	45	19	12	12	15	4.1	13	54	1.5	20	21
J400141	6.14	6.5	16	75	1	0.003	1.4	0.006	0.033	39	17	20	9.5	13	3.5	12	47	1.2	3	4
J400142	3.7	7.4	60.5	350	1	0.003	1.2	0.042	0.054	275	44	18	28	77	13	33	250	1.9	36	400
J400143		6.4	19.4	110	1	0.003	2.5	0.005	0.041	47	13	31	17	17	4.9	13	63	1.3	6	6
J400145		6.7	14	80	1	0.003	1.7	0.009	0.004	47	4	15	9	13	2.7	11	44	1.1	1	0
J400146	4.3	7.3	53.3	330	1	0.003	3.4	0.0025	0.051	196	48	16	38	64	12	35	230	1.9	0	10
J400147	2.15	6.6	24.3	150	1	0.003	4.9	0.0025	0.091	53	18	22	18	16	4.5	25	58	2	3	10
J400148	3.55	6.6	45.5	270	1	0.02	5.4	0.0025	0.004	79	55	33	48	36	12	34	140	2.1	0	400
J400149	1.6	6.9	43.2	260	1	0.003	0.7	0.0025	0.004	136	23	28	34	48	8.4	28	150	2.1	0	0
J410001		7.5	9.7	55	1	0.003	1.2	0.005	0.004	34	2	2	2.2	8.8	1.9	5.8	30	0.9	0	2
J410002		6.5	15.1	95	1	0.003	2.1	0.0025	0.017	48	8	25	10	16	3.6	7.7	55	1.4	1	21
J410003	1.35	6.4	8.7	55	1	0.003	0.7	0.005	0.011	32	2	21	5.6	9.9	1.8	4.6	32	1.1	400	400
J410004		7	23.8	140	1	0.003	0.8	0.007	0.004	101	11	17	16	24	6.7	15	88	1.7	4	150

Well no.	LEVEL	PH	COND	TS	BOES	NO2	NO3	NH3	TP	ALKT	CL	CO2	SO4	CA	MG	NA	HDT	K	FC	COL
1410006		6.6	19	120	1	0.003	7.6	0.0025	0.004	53	9	22	17	16	4.3	16	58	1.4	0	0
1410007	3.05	6.7	10.8	55	1	0.003	2.2	0.0025	0.004	31	3	10	7.3	9.9	2.5	5.1	35	1.1	3	7
1410008		6.5	11.1	70	1	0.003	2.2	0.0025	0.004	33	2	17	7	11	2.1	4.9	36	0.9	9	26
1410011		6.2	12	80	1	0.003	1	0.009	0.009	35	4	37	11	13	2.5	5	43	1.6	170	400
1410012	2.2	6.6	12.9	80	1	0.003	3.1	0.015	0.006	28	4	12	13	12	2.6	5	41	3.1	27	55
1410013	2.7	6.3	15.3	95	1	0.003	2.4	0.0025	0.001	38	8	31	12	16	3.4	6.3	54	1.5	4	2
1410014	2.9	6.3	16.8	100	1	0.003	2.6	0.0025	0.004	44	11	36	14	14	3.8	12	51	1.2	3	3
1410015		6.6	17.8	120	1	0.003	2.4	0.0025	0.007	57	5	23	20	17	3.7	8.9	58	5.1	17	66
1410016	1.3	6.4	13.8	90	1	0.003	2.3	0.0025	0.003	38	7	25	14	15	3	6.5	50	1.4	29	46
1410017		6.5	13.9	90	1	0.003	1.9	0.008	0.023	44	6	23	11	16	4.5	6.3	58	1.5	1	9
1410018	4.4	6.5	13.2	85	1	0.003	1.8	0.006	0.007	42	6	22	12	15	2.8	5.9	49	1.6	0	11
1410019	5.8	6.8	13.9	90	1	0.003	0.8	0.0025	0.043	43	5	11	11	15	2.9	5.9	49	1.8	15	30
1410020	3.5	6.5	14.1	90	1	0.003	2.2	0.0025	0.025	44	6	23	11	16	3	6.3	52	1.5	1	70
1410021		6.8	15.3	100	1	0.003	2.7	0.0025	0.025	44	7	11	12	16	3.4	7.1	54	1.5	1	0
1410022	3.7	6.6	15	95	1	0.003	2.7	0.0025	0.022	44	8	18	13	16	3.4	7.1	54	1.5	12	9
1410023		6.5	15	95	1	0.003	2.2	0.0025	0.004	40	8	21	13	13	3.8	10	48	1.3	0	0
1410024	3.6	6.4	18.8	130	1	0.003	3.6	0.007	0.009	45	15	29	16	15	4.5	16	56	1.4	0	0
1410025	2.4	6.2	8.6	55	1	0.003	0.6	0.0025	0.023	27	2	14	8	9.2	1.7	3.6	30	1.4	7	11
1410026	2.77	6.3	9.1	60	1	0.003	1.1	0.0025	0.016	27	2	12	8.5	9.5	2	3.9	32	1.3	52	60
1410027	2.5	6.3	17.2	120	1	0.007	1.6	0.042	0.074	49	6	40	13	18	3.8	7.8	61	4.7	42	49
1410028	2.7	6.5	14.3	85	1	0.003	0.1	0.01	0.003	46	7	24	13	15	3.1	7.6	50	1.8	40	400
1410029	1.6	6.5	13.7	80	1	0.003	2.8	0.0025	0.021	36	6	19	10	13	3.4	7.9	46	1.3	25	76
1410030	1.2	6.4	12.9	85	1	0.003	2.3	0.005	0.004	36	5	24	9.5	13	2.7	6	44	1.3	5	9
1410031		6.6	13.6	70	1	0.003	0.8	0.0025	0.008	43	5	18	11	14	2.9	5.9	47	2	4	13
1410032	4	6.5	13.5	75	1	0.003	1.3	0.008	0.001	41	5	21	14	14	2.9	5.5	47	1.5	1	37
1410033		6.9	16.1	95	1	0.003	0.8	0.01	0.009	53	7	11	8.1	16	3.4	8.6	54	2.4	1	2000
1410034		6.5	13.7	80	1	0.003	1.3	0.0025	0.017	43	5	22	11	16	2.9	5.6	52	1.5	0	210
1410035		6.8	20.8	140	1	0.003	3.1	0.0025	0.004	179	10	47	15	19	4.4	17	66	1.4	0	20
1410036	0.96	6.8	30.1	180	3	0.028	1	0.042	0.075	106	11	28	20	8	5.7	18	43	2.3	400	400
1400128		7.1	138.8	1000	2	0.003	0.3	0.019	0.005	178	240	23	190	90	36	140	370	2.4	0	510

May Results.

Well no.	LEVEL	PH	COND	NO2	NNN	NO3	NH3	TP	ALKT	CL	CO2	SO4	CA	MG	NA	HDT	K	FC	COL
J400044	1.5	6.4	18.1	<0.004	1.9	*	0.007	0.073	53	9	35	18	12	3.8	16	46	2.9	8	10
J400051	3.1	6.2	26.2	0.005	*	3.4	0.005	0.02	60	27	62	25	15	5.4	27	60	3.2	<1	1
J400053	4.4	6.4	18.6	<0.004	*	5	0.007	0.015	47	7	31	12	13	3.9	17	49	1.8	<1	<1
J400074	*	6.6	16.2	<0.004	*	2.4	0.006	<0.008	53	3	22	12	13	3.6	14	67	1.1	2	4
J400076	2.6	6.6	43	<0.004	0.25	*	0.01	0.009	169	18	70	21	52	9.5	25	170	2.2	<1	<1
J400077	*	6.5	20.2	<0.004	*	4.9	0.006	<0.008	54	4	28	11	20	4.4	12	68	1.4	74	150
J400079	*	6.5	22.8	<0.004	*	6.1	0.008	0.052	57	15	30	17	14	4.2	24	52	1.9	<1	5
J400086	3	6.4	14.1	<0.004	*	2.6	0.007	<0.008	39	3	25	11	12	3.2	10	43	1.1	<1	<1
J400089	4	6.2	19.3	0.007	*	4.8	0.005	0.021	46	11	48	19	18	4.6	10	64	1.9	2	23
J400097	*	6.5	17.7	<0.004	*	4.3	0.009	0.074	45	5	23	18	12	4.1	15	47	1.2	<1	20
J400101	6.7	6.7	45.1	<0.004	*	32	0.026	0.073	124	26	41	20	52	6.4	18	160	1.6	180	320
J400104	*	6.5	35.5	0.004	*	0.8	0.006	<0.008	74	33	38	17	26	7.3	16	120	1.8	<1	<1
J400105	5.3	6.6	14.9	<0.004	*	3.6	<0.005	<0.008	41	2	17	28	13	3.2	11	46	1.2	<1	<1
J400106	*	6.4	15	<0.004	*	0.6	0.006	0.009	50	3	33	7.4	12	3.3	13	44	1.1	<1	<1
J400108	*	6.9	29.2	<0.004	*	2.6	0.006	<0.008	71	30	15	25	23	7.2	21	87	1.7	<2	<2
J400109	3.7	6.3	83.5	0.05	*	13	0.48	<0.008	74	110	61	17	43	23	77	200	1.4	<1	<1
J400110	8.2	6.5	13.1	<0.004	0.23	*	0.006	0.017	44	4	23	12	13	2.8	8.9	44	0.9	<1	<1
J400112	3.9	6.7	18	<0.004	0.55	*	<0.005	0.027	58	10	19	11	16	3	12	52	1.8	<1	100
J400113	*	6.6	28.2	0.013	*	3.1	<0.005	<0.008	69	29	28	24	16	5.3	30	62	2.3	<1	1
J400114	*	6.4	43.1	<0.004	*	6.5	<0.005	0.023	68	16	44	56	26	8.5	42	160	2	<1	35
J400115	*	6.3	20.7	<0.004	*	3.2	0.007	<0.008	52	18	43	15	13	4.2	20	50	1	<1	<1
J400116	*	6.5	16.6	<0.004	*	2.6	<0.005	0.018	47	7	24	9.4	11	3.4	14	41	1.5	<1	<1
J400117	*	6.8	23.6	<0.004	*	4.9	0.008	0.037	62	6	16	20	14	4.2	27	52	2	6	37
J400118	6.5	6.6	17.2	<0.004	*	2.9	0.006	<0.008	52	5	21	10	14	3.8	14	51	1.2	<1	<2
J400119	*	6.3	17.4	<0.004	*	3.3	0.007	0.008	49	2	40	13	15	4	13	54	1.3	<1	<1
J400120	5.2	6.5	15.7	0.03	*	1	0.082	<0.008	60	5	31	8.4	11	3.2	17	41	1.4	<1	<2
J400121	5.1	6.3	17	<0.004	*	3.3	0.006	<0.008	46	4	38	14	14	4.1	12	52	1.3	<1	11
J400123	3	6.5	25.2	<0.004	*	6.5	<0.005	0.06	59	16	31	20	14	4.5	27	53	2	10	300
J400124	2.7	6.5	24.9	<0.004	*	6.6	0.041	0.041	60	18	31	19	15	4.6	27	56	2.3	27	600

Well no	LEVEL	PH	COND	NO2	NNN	NO3	NH3	TP	ALKT	CL	CO2	SO4	CA	MG	NA	HPT	K	PC	COL
J400125	2.7	6.5	29.5	<0.004	*	7.1	0.006	0.064	57	23	30	25	16	5.3	31	62	1.7	1	350
J400126	*	6.5	15.8	<0.004	*	3.5	<0.005	<0.008	44	3	23	10	15	3.7	9.3	53	1.6	1	12
J400127	1.6	7.5	81.2	<0.004	0.07	*	<0.005	0.041	351	35	18	26	94	18	59	310	2	<1	<2
J400128	*	6.5	144.5	0.013	*	1.3	0.014	0.037	195	250	101	120	87	37	160	370	2.5	<2	<1
J400129	*	6.5	27	0.007	*	6.7	0.164	0.105	61	21	32	20	14	5	30	56	2.1	66	74
J400130	3.7	6.4	23.5	<0.004	*	7.2	0.007	0.058	52	10	34	18	14	4.3	24	53	2.4	<1	11
J400131	*	6.3	21	0.015	2.4	*	0.009	0.031	61	3	50	15	22	4.9	11	75	1.5	12	44
J400132	*	6.2	10	<0.004	1.9	*	0.007	<0.008	31	3	32	7.8	10	2.4	5.5	35	1.2	1	<2
J400133	1.5	6	19	<0.004	3.7	*	*	*	51	11	42	17	18	4.2	10	62	2.3	2	60
J400134	2.5	6.2	18	<0.004	*	3.4	<0.005	0.024	44	6	50	16	16	3.9	9.8	56	2.6	<1	<1
J400135	*	6.2	13.5	<0.004	3	*	0.006	<0.008	34	4	35	12	14	2.5	7.7	45	1.5	<1	1
J400136	3.6	6.3	20.6	<0.004	*	2.8	0.005	0.016	69	6	57	18	18	4.9	13	65	1.4	18	74
J400137	*	6.3	18.3	<0.004	*	2.7	0.005	0.024	55	11	45	17	17	4.2	11	60	1.9	<1	5
J400138	5	7	20.4	<0.004	1.2	*	0.005	0.027	73	8	38	16	20	4.3	13	68	1.2	<1	<1
J400139	*	6.4	17.5	<0.004	*	2.8	0.008	0.035	49	7	32	14	16	3.7	11	55	1	1	3
J400140	*	6.4	14.7	<0.004	*	1.6	0.011	0.009	44	8	29	8	12	3.3	11	44	1.7	3	100
J400141	*	6.3	16.6	<0.004	*	1.7	0.017	0.028	42	12	35	8.2	13	3.7	12	48	1.2	<1	8
J400142	4.1	6.9	58.8	<0.004	*	2.4	0.006	0.041	226	20	47	30	72	13	33	230	1.9	7	200
J400143	*	6.2	17.7	<0.004	*	2.5	0.005	0.041	51	4	53	15	14	3.8	12	51	1.4	<1	<1
J400145	*	6.4	16.1	<0.004	*	2	0.01	<0.008	53	2	35	9.1	16	3.1	9.9	53	1.2	<1	<1
J400146	3.6	6.8	54.5	<0.004	2.3	*	0.007	0.04	172	19	45	37	63	12	35	210	2	<1	3
J400147	1.5	6.3	24.2	<0.004	*	6.4	0.005	0.097	59	15	49	19	14	4.4	26	53	1.8	12	40
J400148	4.5	6.6	51.5	0.008	*	3.6	0.009	<0.008	88	72	36	49	40	14	35	160	2.2	<1	<1
J400149	*	6.9	43.9	<0.004	1.4	*	0.005	<0.008	141	15	29	38	49	8.8	30	160	2.2	<1	<1
J410001	*	6.3	10	<0.004	*	1.4	0.006	<0.008	36	2	30	6.8	10	2.1	6.7	34	0.9	<1	110
J410002	*	6.5	14.4	<0.004	*	2.1	0.008	0.02	45	5	23	9.2	16	3.1	7.9	25	1.4	1	10000
J410003	1.8	6.7	8.8	<0.004	1.2	*	0.007	<0.008	31	2	10	6.5	10	1.7	4.3	32	1	<1	<1
J410004	*	6.7	24.4	<0.004	0.65	*	0.009	<0.008	89	9	29	15	23	6.5	14	84	1.6	<1	<1
J410006	*	6.5	21.7	0.012	*	3.2	0.07	0.011	64	6	33	17	16	4.5	16	58	1.5	<1	<1
J410007	3.6	6.3	10.4	<0.004	*	2	0.008	<0.008	31	3	25	7	10	2.2	5.5	34	1.1	1	<1

Well no	LEVEL	PH	COND	NO2	NNN	NO3	NH3	TP	ALKT	CL	CO2	SO4	CA	MG	NA	HPT	K	PC	COL
J410008	5.8	6.3	10.7	<0.004	*	3	<0.005	<0.008	33	2	27	8.8	10	2.1	5.3	34	0.9	<1	6
J410011	*	6.2	12.5	<0.004	2	*	0.005	<0.008	36	2	37	10	13	2.7	5.8	44	1.5	<1	10
J410012	*	6.4	10.6	<0.004	*	2.6	0.009	0.013	28	2	18	9.2	11	2.2	5.1	37	1.4	3	28
J410013	4	6.2	13.8	<0.004	*	2.2	0.005	0.031	43	6	44	13	14	3	7.3	47	1.4	6	6
J410014	*	6.8	17.4	<0.004	*	3	0.007	<0.008	45	4	12	16	15	4	12	54	1.3	1	<1
J410015	*	6.3	13.3	<0.004	*	4.5	<0.005	0.036	48	10	39	35	21	4.8	10	72	7.5	33	56
J410016	2.9	6.4	14.8	<0.004	1.8	*	0.007	0.041	45	4	29	12	17	2.8	7	58	1.4	5	10
J410017	*	6.6	13.6	0.006	1.3	*	0.008	0.018	41	2	17	8.8	14	2.7	7.1	46	1.5	3	20
J410018	5.3	6.4	12.1	<0.004	1.5	*	0.01	0.022	43	3	28	9.2	13	2.6	6.3	43	1.5	3	40
J410019	*	6.6	12.7	<0.004	1.9	*	0.009	0.04	48	3	20	10	14	2.7	6.1	46	1.7	<1	7
J410020	*	6.5	14.3	<0.004	1.6	*	0.008	0.029	59	4	25	10	13	2.8	6.7	44	1.4	2	430
J410021	*	6.7	14.6	<0.004	2.1	*	0.007	0.017	45	2	15	11	16	3.1	7.7	53	1.5	<1	<1
J410022	4.6	6.5	13.9	<0.004	2	*	0.006	0.036	43	2	22	12	15	2.9	7.5	49	1.5	<1	<1
J410023	*	6.5	15.5	<0.004	2.4	*	0.013	<0.008	46	8	24	12	13	3.6	10	47	1.5	<1	<1
J410024	4.2	6.6	17.9	<0.004	*	3	<0.005	0.012	46	11	19	15	14	4	16	51	1.4	<1	24
J410025	3.35	6.4	10.6	<0.004	*	2.7	0.005	0.021	31	3	20	11	10	2.2	4.6	34	1.2	11	15
J410026	4.5	6.2	9.7	<0.004	*	2.2	<0.005	0.014	27	3	28	8.8	9.5	2	4.2	32	1.1	2	4
J410027	3.1	6.2	16.7	<0.004	*	3.2	0.015	0.052	47	9	49	13	16	3.6	7.2	55	2.4	2	30
J410028	3.8	6.3	14.4	<0.004	2.1	*	0.006	0.052	47	6	39	12	14	3.2	6.5	48	1.6	40	100
J410029	*	6.2	14.6	<0.004	2.4	*	0.009	0.017	37	9	38	10	15	3.1	7.9	50	1.3	31	2
J410030	1.3	6.2	12.2	<0.004	*	2.6	0.009	<0.008	36	5	37	8	13	2.6	6.5	43	1.2	3	9
J410031	*	6.9	16.1	<0.004	1.8	*	0.006	0.061	52	3	11	11	20	2.5	6.6	60	1.9	5	15
J410032	*	6.7	10.8	<0.004	0.27	*	0.01	0.032	34	2	11	7	12	2.2	5.8	39	1.4	<1	50
J410034	*	6.5	12.5	<0.004	1.6	*	0.007	0.017	42	4	22	10	14	2.5	6	45	1.5	4	20
J410035	*	6.6	21.5	<0.004	*	3.2	0.005	<0.008	69	3	28	15	20	4.4	17	68	1.5	<1	17
J410036	0.7	6.6	29.7	0.027	*	2.6	0.027	0.079	113	16	47	16	31	6.1	19	100	2.6	80	150