

The importance of long-term, seasonal monitoring of groundwater wells in the New Zealand National Groundwater Monitoring Programme (NGMP)

Michael R. Rosen

Wairakei Research Centre

Institute of Geological & Nuclear Sciences Limited

Private Bag 2000, Taupo, New Zealand

Abstract

The New Zealand National Groundwater Monitoring Programme (NGMP) aims to assess the long-term trends in the water quality of New Zealand's significant aquifers. Although the current programme includes close to 100 groundwater wells from 14 regions across New Zealand, long-term (greater than four years) data exist for only 17 wells in the Tasman, Waikato, Manawatu-Wanganui and Bay of Plenty regions. Trends in groundwater quality of these wells over five years are varied. The variations in chemistry show the seasonal effects of fertiliser application and some detrimental effects of landuse on water-quality. Most sites show little change in water quality with time and in some cases water quality has improved over time. The systematic collection of long-term groundwater quality information in New Zealand has only just begun, so national assessments of groundwater quality cannot be made at this time. However, the variability over time in observed trends indicates that the collection of this type of information is critical for determining strategies for long-term protection of groundwater quality.

Introduction

Long-term groundwater monitoring and assessment programmes with a national focus over time are not common in the world because concern about groundwater pollution is relatively recent and monitoring groundwater on a large scale can be costly and resource-intensive. The United States of America has had a national water quality assessment programme (NAWQA) for over 10 years (Ackerman, 1987). The programme includes both surface and groundwater analysis, and is probably the largest water monitoring pro-

gramme of its kind in the world. The NAWQA programme analyses samples from 60 of the nation's most important river basins and aquifers, although only 20 areas are studied at one time. For example, Mueller *et al.* (1995) examined nutrient data from over 12,000 groundwater wells and 22,000 surface water samples from 20 study areas as part of the network. European national groundwater monitoring programmes are extensive, particularly in the smaller countries that are heavily industrialised; the Dutch groundwater monitoring programme is a good example. Their network covers 38,000 km² and consists of 380 shallow wells installed specifically for the programme (Duijvenbooden, 1993). Two groundwater monitoring programmes have recently been developed in South Korea (Kim *et al.*, 1995) and South Africa (Parsons and Tredoux, 1995), although the Korean programme will not be fully implemented until 2001. The Korean groundwater monitoring programme was put into place because of the severe stress that over-pumping was putting on the groundwater resources during rapid industrialisation in the 1980's. Over-pumping resulted in the deterioration of groundwater quality through seawater intrusion in coastal areas (Kim *et al.*, 1995). In New Zealand, a pilot national groundwater monitoring programme was put in place in 1990 and recently has been considerably expanded (Rosen, 1997).

The New Zealand National Groundwater Monitoring Programme (NGMP) is a "Nationally Significant Database" (designated as such by the New Zealand Foundation for Science and Technology in 1996) that seeks to identify trends in groundwater quality with time. Although limited regional studies of groundwater quality through time have been conducted in New Zealand (Burden, 1982; Close *et al.*, 1995), no national comparisons have been made.

The NGMP also provides data for research on interactions between water and rock by comparing the chemistry of the aquifer water with the lithology of the aquifer material through which it passes. The NGMP is a relatively recent database, but its significance is increasing as more regional data are collected and more groundwater wells are included in the sampling programme. The NGMP is a cooperative project between the Institute of Geological & Nuclear Sciences and local government organisations that are responsible for environmental monitoring (i.e. regional councils and unitary authorities). The NGMP fills a national and regional role within the framework of the Resource Management Act (RMA, 1991) by providing information on the state of the environment (in this case groundwater quality) that enables local authorities to effectively carry out their functions under the Act (section 35 (2a) of the RMA). The RMA is the legislation that covers all environmental issues in New Zealand. The NGMP augments regional groundwater monitoring programmes carried out by indi-

vidual regional councils, and provides a national perspective on groundwater quality monitoring in New Zealand.

This paper presents long-term (greater than four year) trends in water quality from groundwater wells sampled for the NGMP. In this way, the importance of collecting this type of information can be demonstrated and the information can be used to help make management decisions to protect groundwater quality in areas where it is under threat.

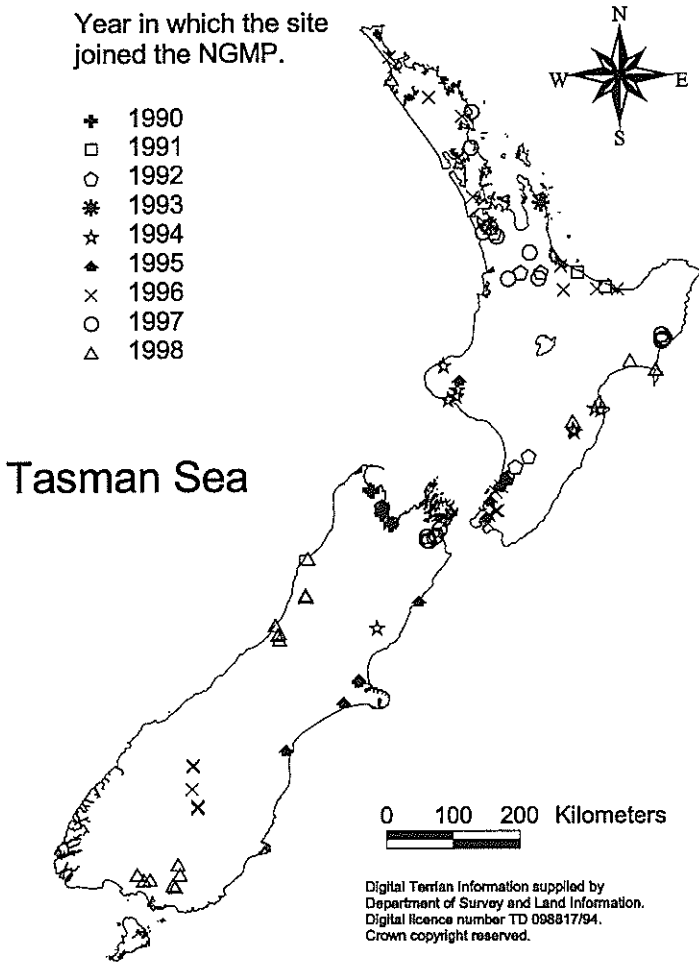


Figure 1. – Map of New Zealand showing the locations of the groundwater wells in the NGMP, including the year that sampling started.

Selection of monitoring sites

The general location of current groundwater wells (105 wells) included in the NGMP, and the date analyses began, are shown in Figure 1. The 17 monitoring sites included in this paper (Fig. 2) have the earliest sampling dates. Detailed regional maps showing well locations can be found in Rosen (1997). Monitoring sites have been selected in consultation

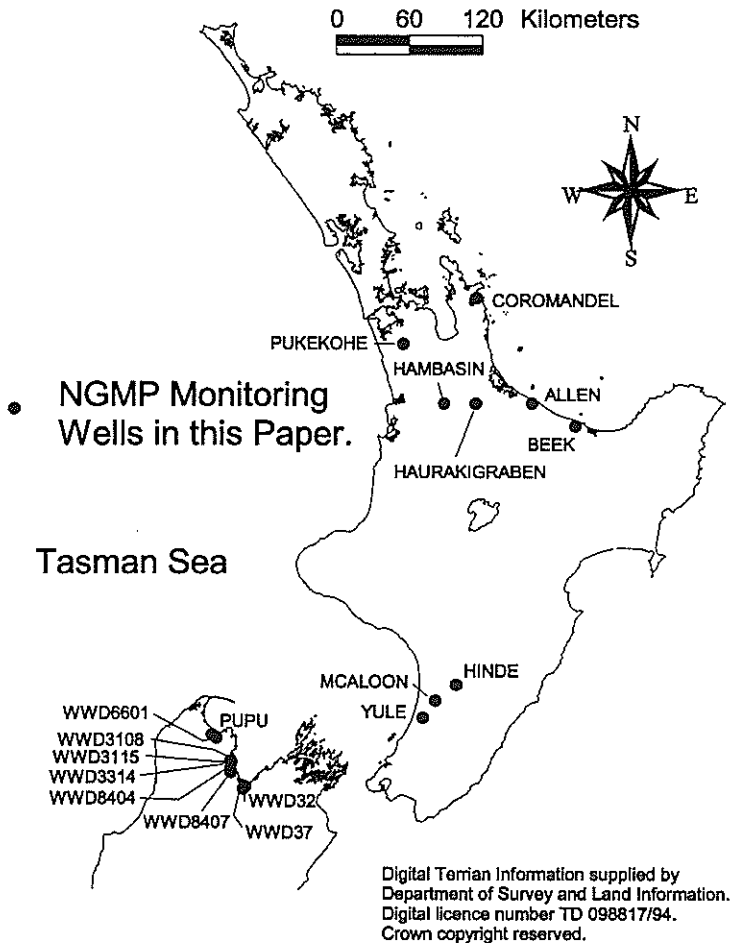


Figure 2. – Map showing the 17 wells from 4 regions in the Tasman, Waikato, Manawatu-Wanganui and Bay of Plenty with long-term water quality data that are included in this paper.

with regional council and unitary authority technical staff using a number of selection criteria. Monitoring sites were selected that give early warning of trends but are not in the immediate recharge area. Shallow, usually unconfined, groundwater systems were targeted originally, as these would be more likely to show trends in quality before deeper systems. However, as concern about pollution to deeper aquifers has strengthened, many deeper, confined systems have since been added to the network. Potential land-use changes or intensification of a particular land use were also considered in well selection. The range of aquifer lithologies in a region was considered, and a drillers' log for the wells had to be available. The wells had to be appropriately designed and constructed, so that the water level was measurable and the wells could be sampled using standard methods.

Sampling methodology

Groundwater samples are collected for the NGMP at 3-monthly intervals in March, June, September and December. Sample bottles are sent to the staff of the collaborating regional councils who collect the samples and send them to the Analytical Facility at the Wairakei Research Centre, Institute of Geological & Nuclear Sciences within 2-3 weeks.

Sampling protocols (Rosen, 1997) have been distributed to each regional council. Some have sampling teams that are ISO9002 registered, and so have additional training in sample collection techniques.

Until January 1997, the samples were collected in 500 mL acid-washed polyethylene bottles. The samples were filtered, then analysed for pH, sulfate, chloride, nitrate, sodium, potassium, calcium, magnesium, iron, manganese and silica. Alkalinity (to pH 4.5) and conductivity (mS/cm at 25°C) were measured on unfiltered aliquots of the sample. Ammonium has always been analysed for samples from the Manawatu-Wanganui region, as it is present in these samples in significant amounts. However, ammonium is now routinely measured for all samples collected. Ionic balances are carried out following analysis as a data quality control procedure.

Filtering up to 2-3 days after sample collection was not yielding accurate results, particularly for elements such as iron and manganese. Samples that were high in reduced iron and manganese oxidised during transport to the lab and precipitated out of solution as oxyhydroxides, which were filtered out of the sample. This resulted in lower than expected concentrations of these elements. Three smaller bottles (two 250 mL bottles and one 100 mL bottle) have been used since March 1997 for each sample. Each sample is field-filtered using a 0.45 mm disposable filter and syringe. The 100 mL bottle contains a few drops of concen-

trated nitric acid. Field-filtered water is collected in this bottle for cation and metal analyses. One of the 250 mL bottles is filled with unfiltered water and is used for alkalinity determinations, and the other 250 mL bottle is field-filtered and kept cold ($<4^{\circ}\text{C}$), and is used for nutrient and anion determinations. This new sampling method should result in more accurate analyses of the groundwater samples.

Analytical techniques

A number of analytical techniques have been used to analyse the water samples collected for the NGMP and 'best practice' principles are still evolving in the project. New analytical equipment has become available over time and new procedures for sample preparation have been adopted. However, whenever a procedural or analytical change has been made, analyses have been carried out to ensure that any changes found in the water chemistry were due to changes in the groundwater and were not due to changes in sampling techniques, laboratory techniques or laboratory practice.

The majority of samples have been analysed on two pieces of equipment. All cations (Na, Mg, Ca, K, Fe, Mn) were analysed using a Perkin-Elmer 1100 atomic absorption spectrophotometer up until June 1996. Cations are now analysed on a Thermo Jarrell Ash - Iris - Inductively Coupled Plasma Optical Emission Spectrometer. However, K and Na have been checked against the atomic absorption spectrophotometer because of instabilities in the methodology. Anions (Cl , SO_4 , $\text{NO}_3\text{-N}$), ammonium ($\text{NH}_4\text{-N}$) and silica (SiO_2) have been measured on a Technicon Auto Analyzer II. Chloride and SO_4 have been routinely measured on a Dionex Ion Chromatograph since September 1996. All anions and $\text{NH}_4\text{-N}$ (except HCO_3 as alkalinity) are now measured on the ion chromatograph using a low-detection-limit ion exchange column. Silica is measured on the optical emission spectrometer as total silica. Alkalinity measurements have been done by manual titration to pH 4.5. Since March 1996, samples have been analysed using an automated method, on an Auto Titrator that uses the same titration technique as the manual method. The conductivity of each sample is measured upon receipt of the sample in the laboratory. Measurements are made in a constant temperature bath kept at 25°C , using a Hach conductivity meter with automatic temperature compensation.

Table 1a,b shows the means, standard deviations, maxima, and minima of chemical concentrations in water from the 17 wells included in the study. Individual data are plotted on the graphs. Table 2 shows pertinent information about each well, including uses of the land surrounding the wells.

Table 1a. Mean, standard deviation, maximum and minimum concentrations of groundwater collected from wells.

		Conductivity	Na	K	Ca	Mg	SiO ₂	Alkalinity	Cl	SO ₄	NO ₃ -N	NH ₄ -N
		(mS/cm)	g/m ³	g/m ³	g/m ³	g/m ³	g/m ³	g/m ³	g/m ³	g/m ³	g/m ³	g/m ³
Units:												
Tasman												
WWD32												
N=29*												
	Mean	0.35	9.8	0.7	18.9	25.6	28	101	16.0	21.0	12.48	
	Std. Dev.	0.01	0.2	0.1	0.8	1.8	2.1	5	0.9	2.7	1.071	
	Max.	0.38	10.1	1.0	20.8	28.9	31	110	18.0	25.1	14.38	
	Min.	0.33	9.2	0.6	17.2	22.0	22	93	14.6	15.5	10.90	
WWD3115												
N=23												
	Mean	0.21	5.7	1.1	13.9	12.2	24	82	7.5	26.7	0.125	
	Std. Dev.	0.01	0.2	0.1	0.7	1.0	1.3	4	0.9	3.2	0.174	
	Max.	0.22	6.2	1.3	15.2	14.2	27	88	9.0	31.8	0.550	
	Min.	0.19	5.4	0.9	12.6	10.9	21	73	5.4	20.6	<0.001	
WWD37												
N=29												
	Mean	0.54	11.0	0.9	11.3	55.6	36	171	18.8	33.9	21.15	
	Std. Dev.	0.04	0.5	0.1	0.6	3.3	2.0	9	2.5	2.2	2.017	
	Max.	0.60	13.2	1.2	13.0	64.4	40	190	29.5	37.4	26.46	
	Min.	0.39	10.3	0.4	10.0	46.1	30	139	16.4	27.8	18.10	
WWD6601												
N=29												
	Mean	0.25	4.8	0.8	43.0	2.8	10	132	6.4	3.8	2.171	
	Std. Dev.	0.02	0.2	0.2	3.7	0.2	1.1	12	1.7	0.8	0.454	
	Max.	0.28	5.2	1.7	50.0	3.3	14	154	13.5	6.0	4.040	
	Min.	0.22	4.3	0.5	37.0	2.4	8	110	4.0	2.2	1.200	

Table 1a. Continued.

	Conductivity (mS/cm)	Na g/m ³	K g/m ³	Ca g/m ³	Mg g/m ³	SiO ₂ g/m ³	Alkalinity g/m ³	Cl g/m ³	SO ₄ g/m ³	NO ₃ -N g/m ³	NH ₄ -N g/m ³
WWD8407 N=29	Mean	24.9	0.6	29.9	6.6	22	178	5.7	2.0	0.010	
	Std. Dev.	0.01	0.1	1.2	0.4	2.3	5	0.5	0.6	0.013	
	Max.	0.30	28.6	33.6	7.6	25	187	7.0	3.0	0.050	
	Min.	0.27	21.0	27.6	5.7	13	168	5.0	<0.5	<0.001	
WWD8404 N=29	Mean	20.0	1.2	16.3	6.2	63	128	5.1	3.5	0.012	
	Std. Dev.	0.005	0.6	0.5	0.3	4.3	3	0.5	2.0	0.017	
	Max.	0.22	21.0	17.4	7.0	69	134	5.9	11.0	0.080	
	Min.	0.21	17.9	15.2	5.8	46	122	4.0	<0.5	<0.001	
WWD3314 N=29	Mean	7.2	4.2	21.6	11.9	16	47	10.4	62.9	1.670	
	Std. Dev.	0.05	0.7	5.3	3.6	0.9	3	1.4	22.6	1.318	
	Max.	0.37	8.6	34.0	20.0	18	55	12.8	123.8	4.780	
	Min.	0.18	6.2	14.7	7.7	13	42	7.3	31.0	0.190	
'Pupu Springs N=29	Mean	57.9	4.6	62.8	7.9	6	203	93.5	16.3	0.320	
	Std. Dev.	0.07	8.5	4.0	1.4	0.6	11	16.6	2.2	0.147	
	Max.	0.77	75.7	73.4	9.6	8	229	121.0	20.2	0.902	
	Min.	0.36	32.2	51.4	3.0	4	183	45.0	10.4	0.120	

Table 1b. Mean, standard deviation, maximum and minimum concentrations of groundwater collected from wells.

	Conductivity (mS/cm)	Na g/m ³	K g/m ³	Ca g/m ³	Mg g/m ³	SiO ₂ g/m ³	Alkalinity g/m ³	Cl g/m ³	SO ₄ g/m ³	NO ₃ -N g/m ³	NH ₄ -N g/m ³
Waikato											
Pukekohe											
N=22											
Mean	0.24	16.3	4.3	14.2	10.5	51	88	20.9	6.0	3.235	
Std. Dev.	0.05	2.0	4.9	5.1	1.2	4.6	5	2.4	6.2	4.417	
Max.	0.43	25.0	22.0	36.2	12.5	56	93	24.2	23.0	22.47	
Min.	0.22	15.1	1.9	11.5	6.5	32	67	14.3	1.6	0.790	
Coromandel											
N=17											
Mean	0.23	8.5	1.9	34.9	2.3	13	118	9.9	3.8	0.552	
Std. Dev.	0.05	3.8	0.9	5.9	0.7	2.0	21	2.8	2.4	0.713	
Max.	0.33	22.0	4.1	44.0	4.2	19	160	16.4	9.0	2.900	
Min.	0.15	5.3	0.8	24.1	1.3	9	81	4.9	1.6	0.080	
Hamilton Basin											
N=22											
Mean	0.22	20.6	4.0	11.9	5.9	35	59	9.6	22.8	5.499	
Std. Dev.	0.02	2.7	0.8	1.3	0.9	10	7	2.9	5.6	0.992	
Max.	0.24	27.6	6.7	14.6	7.3	79	70	16.7	34.0	8.000	
Min.	0.17	14.6	2.8	8.3	3.9	28	41	6.1	10.0	4.440	
Hauraki Graben											
N=22											
Mean	0.18	13.9	6.2	9.4	4.5	71	39	10.2	9.8	6.599	
Std. Dev.	0.04	2.8	1.8	2.4	1.8	19	14	2.8	3.2	2.657	
Max.	0.24	17.1	8.4	13.8	10.4	84	90	21.0	14.0	10.60	
Min.	0.05	5.3	1.2	2.6	0.6	15	11	7.5	1.9	0.340	

Table 1b. Continued

	Conductivity (mS/cm)	Na g/m ³	K g/m ³	Ca g/m ³	Mg g/m ³	SiO ₂ g/m ³	Alkalinity g/m ³	Cl g/m ³	SO ₄ g/m ³	NO ₃ -N g/m ³	NH ₄ ⁺ -N g/m ³
Manawatu-Wanganui											
Yule											
N=21	0.10	11.4	1.1	4.5	3.1	29	41	10.3	3.1	0.324	0.017
	0.01	0.4	0.7	0.4	0.3	2	2	0.3	0.7	0.137	0.009
	0.12	11.9	3.6	5.3	3.6	33	45	11.0	5.0	0.860	0.030
	0.10	10.4	0.7	3.7	2.6	25	38	9.7	1.9	0.170	<0.001
Hinde											
N=21	0.31	14.1	3.0	38.6	7.2	44	147	20.7	11.5	0.011	0.332
	0.01	0.6	0.5	2.5	0.4	1.3	3	1.7	0.8	0.012	0.050
	0.33	15.5	4.7	42.5	7.8	46	153	22.8	13.0	0.050	0.390
	0.30	12.8	2.5	31.0	6.5	41	141	16.0	9.5	<0.001	<0.001
McAloon											
N=21	0.32	23.9	8.3	24.3	8.5	51	174	16.4	3.0	0.017	2.917
	0.01	0.9	0.7	1.6	1.1	1	5	0.9	0.3	0.031	0.302
	0.33	26.1	9.3	27.5	9.6	55	180	17.5	3.0	0.120	3.560
	0.30	21.7	6.2	20.0	4.3	49	164	14.0	<0.5	<0.001	2.200

Table 1b. Continued

	Conductivity (mS/cm)	Na g/m ³	K g/m ³	Ca g/m ³	Mg g/m ³	SiO ₂ g/m ³	Alkalinity g/m ³	Cl g/m ³	SO ₄ g/m ³	NO ₃ -N g/m ³	NH ₄ -N g/m ³
Bay of Plenty											
Allen N=26	Mean	22.2	9.2	13.1	5.6	80	70	33.4	5.3	1.473	
	Std. Dev.	0.01	0.4	1.2	0.4	2.8	5	4.9	1.1	1.134	
	Max.	0.27	24.0	15.3	6.5	84	81	42.0	8.2	4.100	
	Min.	0.23	21.0	11.1	5.1	73	58	26.3	3.3	0.210	
van Beek N=25	Mean	0.42	51.0	4.9	29.6	68	242	22.3	16.3	0.110	
	Std. Dev.	0.14	51.5	3.5	6.1	5.7	122	4.7	5.6	0.208	
	Max.	0.97	223.0	16.8	38.3	85	630	36.8	26.0	0.830	
	Min.	0.10	29.0	2.0	12.3	62	164	19.0	1.4	<0.001	

*N = maximum number of analyses per sample. Less than concentrations were not used in the mean and standard deviation calculations

Table 2. – Lithological characteristics, landuse, and depths of aquifers.

Well Name	Aquifer Name	Aquifer Lithology	Aquifer Type
Waikato			
Coromandel	Holocene Beach Barrier Dune	Sand	Unconfined
Hamilton Basin	Shallow Hinuera Formation	Sandy Gravel	Unconfined
Hauraki Graben	Tauranga Group (Waillon Sub-Group)	Pumice Gravel	Confined
Pukekohe	South Auckland Volcanics	Fractured Basalt	Semi - Confined
Bay of Plenty			
Allen	Maketu Pumice Aquifer	Pumice	Unconfined
van Beek	Rangitaiki Plains Sand	Grey Sands and Pumice Sands	Unconfined
Manawatu-Wanganui			
Hinde	No Name	Gravel	Confined
McAloon	No Name	Gravel	Confined
Yule	No Name	Gravel	Semi - Confined
Tasman			
Pupu Springs	Takaka Marble Aquifer	Marble	Confined
WWD3115	Motuoka Gravel Aquifer	Gravels derived from granite, granodiorite, sand, siltstone	Unconfined
WWD32	Lower Confined Aquifer	Well sorted sandy gravel: sands & siltstones, greywacke	Confined
WWD3314	Motuoka Gravel Aquifer	Gravels derived from granite, granodiorite, sands, siltstone	Unconfined
WWD37	Upper Confined Aquifer	Well sorted sandy gravel: sands & siltstones & greywacke	Confined
WWD6601	Takaka Limestone Aquifer	Limestone	Confined
WWD8404	Shallow (S) & Middle (M) Moutere Aquifer	Greywacke gravels in a clayey silt matrix	Confined
WWD8407	Shallow (S), Middle (M) & Lower (L) Moutere Aquifer	Greywacke gravels in a clayey silt matrix	Confined

Table 2. - Continued

Well Name	Aquifer Thickness (m)	Depth to Top of Aquifer (m)	landuse within 10 m	landuse within 200 m	landuse in recharge area (Confined aquifers only)
Waikato					
Coromandel	4.5	1.6	Lawn	Fire Station	
Hamilton Basin	3.0+	3.0	Residential	Residential, Dairy	
Hauraki Graben	7.4	14.6	Grass Reserve	Reserve, Residential	
Pukekohe	11.2+	23.8	Market Garden	Market Garden	
Bay of Plenty					
Allen	7.0	3.0	Kiwifruit	Kiwifruit	
van Beek	7.0	2.0	Cow shed, Tanker track	Pasture	
Manawatu-Wanganui					
Hinde	2.0	32.0	Garden	Garden, Cattle, Sheep	Forest, Cattle, Sheep
McAloon	3.0	33.5	Shed	Dairy	Forest, Cattle, Sheep
Yule	2.0	27.0	Garden	Horse Paddock	
Tasman					
Pupu Springs	>300	30.0	Native bush, Dairy	Native bush, Dairy, Fish farm	Native bush, Dairy, Forest
WWD3115	6-15	5.0	Orchard, Residential	Orchard, Residential	
WWD32	10-12	28.0	Orchard	Orchard, Factory	Market garden, Orchard
WWD3314	6-15	3.0	until 1993 Kiwifruit orchard	Paddock, Domestic, Orchard	
			until 1995 Fallow	until 1995 Fallow	
			until 1997 Market garden	until 1997 Market garden	
			present landuse: Fallow	present landuse: Fallow	
WWD37	4-6	18.0	House, Paddock	Orchard, Residential	Market garden, Orchard
WWD6601	100.0	30.0	Dairy	Dairy, School, Orchard	Market garden, Orchard
WWD8404	60 (S) 100 (M)	50.0	Orchard	Orchard, Paddock	Sheep, Dairy
WWD8407	60 (S) 100 (M) 200 (L)	70.0	Clear	Orchard, Paddock	Sheep, Forestry

Water quality trends in the Tasman District

The Tasman District has the longest record in the NGMP, with 10 sites currently being analysed. The first samples were collected in September 1990, and samples have been collected at 3 month intervals since that time. Eight wells were originally sampled in the Tasman District; 2 from the Waimea catchment, 2 from the Moutere aquifers, 2 from the Motueka area and 2 from the Takaka valley (Rosen, 1997). In March 1992 one site in the Motueka Plains was changed to another well nearby in a similar groundwater zone because of difficulties in access to the original well. Two additional samples from unconfined aquifers, one from the Motueka Gravel up-gradient of Motueka township, and the other from the Appleby Gravel, were added in 1996.

Significant variations in dissolved chemical concentrations with time have been observed in several wells in the Tasman District. Most notable has been the increase in sulfate (SO_4), potassium (K), and nitrate-nitrogen ($\text{NO}_3\text{-N}$) in well WWD3314 (Fig. 3). The well is located near the sea amongst market gardens. The well takes water from the Motueka gravel aquifer at a depth of >3 m, and is down-gradient of market gardens that have been in place since 1994. Prior to 1994 the area was planted in kiwifruit. An area of bare, or fallow, land has been located immediately up-gradient of the well since 1990. For the 1997 season the area was not planted and remained fallow (Table 2).

Increasing concentrations of SO_4 , K, and $\text{NO}_3\text{-N}$, with a delay of a few months, coincide with the change of land use from kiwifruit orchard to

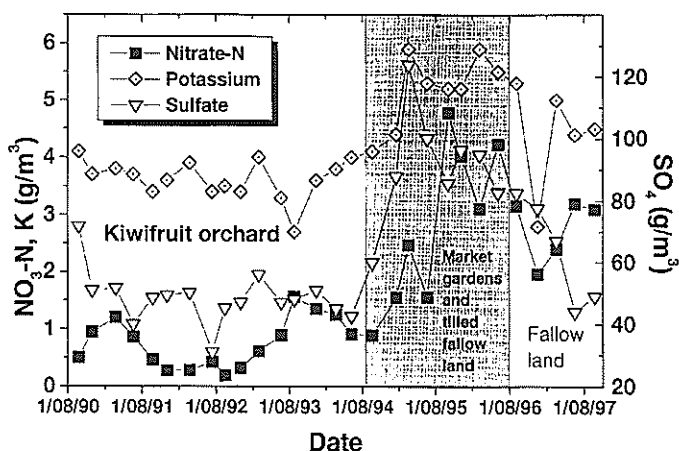


Figure 3. – Plot of K, $\text{NO}_3\text{-N}$ and SO_4 concentrations versus time for well WWD3314. Concentrations increased after 1993 when the kiwifruit orchard was replaced by market gardens and leveled off and decreased after the market gardens stopped planting and fertilising in 1996.

market gardens in the area around the well (Fig. 3). In addition, increases in calcium (Ca), magnesium (Mg), and sodium (Na) have also been observed. Alkalinity (HCO_3^-) and other ions such as chloride (Cl) and silica (SiO_2) have remained relatively constant. The large increases in SO_4 , K, and $\text{NO}_3\text{-N}$ relative to other ions in solution suggests that the source of these ions is not from the natural soil and rock in the area, but from the application of fertilisers to the soil. Excess nutrients and other cations that are not used by the plants are washed down into the groundwater and selectively increase the concentration of those ions in the groundwater.

Because of complaints from local residents about the spraying of crops in the area, the market gardens were not planted for 1997. Figure 3 shows that the increases in $\text{NO}_3\text{-N}$, SO_4 , and K stopped about the time that planting (and fertilising) ceased. Although $\text{NO}_3\text{-N}$ concentrations for well WWD3314 are currently below the New Zealand maximum acceptable value for drinking-water of 11.3 g/m^3 (Drinking-Water Standards for New Zealand, 1995), the 4-fold increase in $\text{NO}_3\text{-N}$ concentrations in less than 3 years during market garden operations indicates that the situation should be monitored carefully.

The conductivity and Mg concentration of well WWD37, located near Nelson (Fig. 2), shows a decrease with time over the monitoring period (Fig. 4). The Mg concentrations in this well and in nearby well WWD32

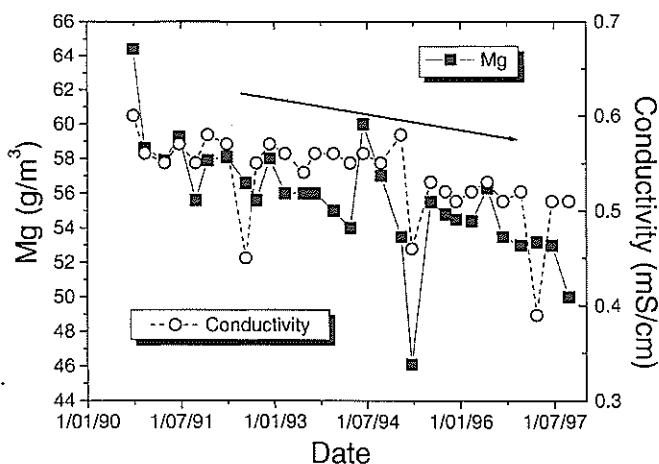


Figure 4. – Trends in Mg concentrations and conductivity with time in the upper confined aquifer (well WWD37) in the Waimea Plains. The general decrease in both Mg and conductivity, and high concentrations of $\text{NO}_3\text{-N}$ (Table 1a), point to past land uses having had an impact on groundwater quality in the area. The water quality is now improving, although $\text{NO}_3\text{-N}$ concentrations have not yet showed a systematic decrease with time.

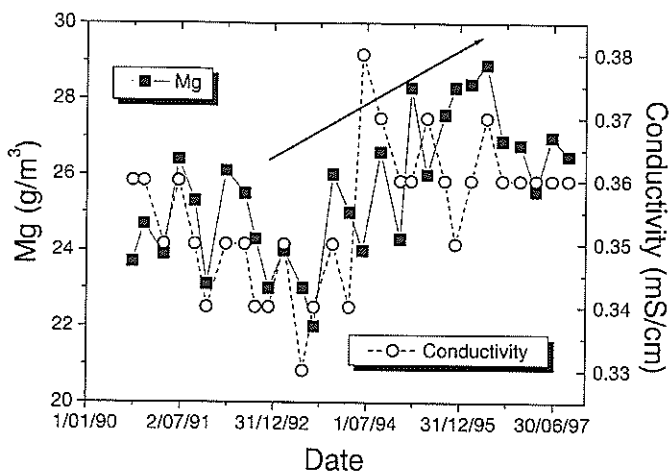


Figure 5. – Trend in Mg and conductivity with time in well WWD32 from the lower confined aquifer in the Waimea Plains. This well is located down gradient of Well WWD37. The general increase in both Mg and conductivity and relatively high concentrations of $\text{NO}_3\text{-N}$ (Table 1a), point to leakage of water from the upper to the lower confined aquifer.

(Fig. 5) are high relative to Mg concentrations in most other wells in the Tasman District, and to New Zealand groundwaters in general. This is probably because the recharge area for the aquifer contains the mineral serpentine, which contains a large amount of leachable Mg. However, if these elevated Mg concentrations were due solely to natural inputs of Mg to the system, it is unlikely that they would decrease with time. No other wells in the area show decreases in conductivity or Mg, indicating that the decreasing conductivity in well WWD37 is due to local conditions. Indeed, well WWD32, which is down-gradient from WWD37, shows increasing Mg concentrations with time, particularly after January 1994 (Fig. 5), suggesting that water with higher Mg concentrations may be migrating down-gradient as a pulse. In addition, the Mg concentration of well WWD37 is more than twice the concentration of WWD32. Well WWD37 is taking water from the upper confined aquifer in the Waimea Plains aquifer system and WWD32 is taking water from the lower confined aquifer. This suggests that there is some downward leakage from the upper to the lower confined aquifer.

High concentrations of $\text{NO}_3\text{-N}$ in both wells (average $\text{NO}_3\text{-N}$ for WWD37 = 21.1 g/m^3 and average for WWD32 = 12.4 g/m^3) indicates that land uses have affected the water quality in these wells, and leakage from the upper to the lower confined aquifer may be the reason for observed increases in concentrations in well WWD32. The decrease in conductivity is caused mostly

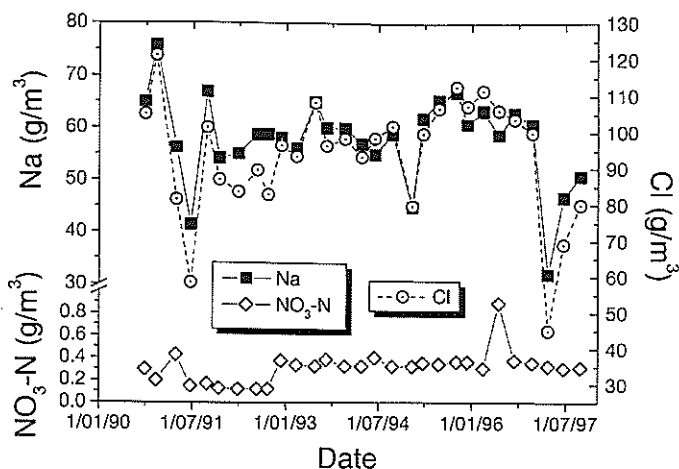


Figure 6. – Plot of changes in the chemical composition of Pupu Springs. Significant variations in Na and Cl suggest that large recharge events could be responsible for the observed changes. Although NO₃-N concentrations are relatively low in Pupu Springs, a sharp increase in NO₃-N concentrations late 1992 is apparent, but the reason for this change is not known.

by the decrease in Mg concentrations, although the low conductivity value in 1992 was due to a low SO₄ concentration for that sampling period.

A natural cause for the observed trends in Mg concentrations is unlikely, as few if any land uses require the application of large amounts of Mg. Fertilisers do contain Mg, but because other ions such as SO₄, K and NO₃-N do not vary in the same way as the Mg concentrations, it is unlikely that fertiliser application alone can account for the observed trends.

The other groundwater wells monitored in the Tasman area (WWD8407, WWD3115, WWD8404, WWD6601) do not show significant variations in their chemical compositions over the seven years of record. Monitoring at Pupu Springs however does show large changes in chemical composition that are probably related to large recharge events (Fig. 6).

Water quality trends in the Bay of Plenty

Two wells were sampled in the Bay of Plenty region from April 1991 to 1994 (Fig. 2), one in the Rangitaiki Plains near Whakatane (van Beek well) and one in the Te Puke/Maketu area (Allen well). No samples were collected in June 1992. Four additional sites were added to the NGMP in 1996 (Rosen, 1997) but data from these wells are not included in this paper.

The Allen well is located in an area of kiwifruit orchards, although approximately 10% of the area around the well is used for market gardens.

The well shows a typical seasonal pattern of increased $\text{NO}_3\text{-N}$ concentrations over the summer period, when fertiliser applications to either the kiwifruit or market gardens are likely, and decreased $\text{NO}_3\text{-N}$ concentrations in winter when more abundant winter rain flushes through the groundwater system (Fig. 7). However, there is an overall trend to lower concentrations of $\text{NO}_3\text{-N}$ at this site. This suggests that the nitrogen input (presumably from fertiliser application) is reducing each year. The lower values of the summer $\text{NO}_3\text{-N}$ peaks also suggests that the $\text{NO}_3\text{-N}$ inputs are declining. The rapid response of this well to $\text{NO}_3\text{-N}$ inputs suggests that if nitrogen inputs were to increase again, there would be a build up of $\text{NO}_3\text{-N}$ in the groundwater. A rapid response to fertiliser inputs is likely because the well is shallow (three metres deep) and unconfined (Table 2).

The concentration of most ions in groundwater samples taken from the van Beek well, located near Whakatane, do not vary significantly over the sampling period (1991-1997), although Cl , SO_4 , and SiO_2 have been increasing, and Na and alkalinity have been decreasing over the sampling period. In addition, there is a nine month period in 1994 - 1995 and a three month period in the summer of 1996 that shows major changes in the chemistry of the groundwater (Fig. 8). During this period, Na concentrations increased to as much as 7 times their pre-1995 concentration, alkalinity levels tripled, Cl concentrations nearly doubled, and there were large increases in K , and SiO_2 as well. At the same time however, SO_4 , Ca , Mg , and total Fe concentrations decreased dramatically.

The changes suggested that a solution composed of Cl , Na , K with high alkalinity was the contaminant. The pre-1995 concentration of these ions can be subtracted from the January 1995 concentration of these ions. If the solution was composed mainly of these ions, then the mass of the remaining amounts of these four ions should balance (because SiO_2 does not have a charge, it is not included in the mass balance). The mass balance of the remaining alkalinity, Cl , Na , and K in solution is within 5% of unity, indicating that the contaminant solution could have been highly alkaline and composed of mostly Cl , Na , and K .

It is unlikely that any natural solution could cause this. It is more likely that a large amount of some contaminant was spilled in the area (or directly down the well) near the end of 1994 and 1995. The contaminant was an oxidising solution because total Fe concentrations, which were generally $> 3 \text{ g/m}^3$ before 1995, decreased to 0.2 g/m^3 during the nine month period at the end of 1994. Similarly, $\text{NO}_3\text{-N}$ concentrations, which are normally close to, or below, the detection limit for the method, increased slightly over this time period. Evidence that the groundwater in the area is normally reducing can also be seen in the few ammonium concentrations recorded for the well, which are $> 1 \text{ g/m}^3 \text{ NH}_4\text{-N}$.

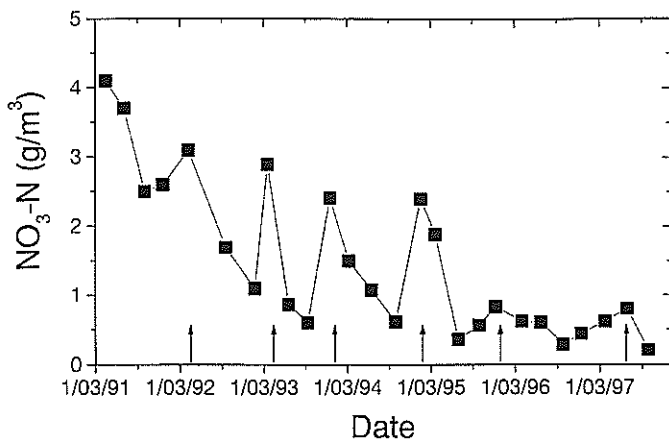


Figure 7. – Nitrate-nitrogen concentrations versus time for Allen well in the Bay of Plenty. Arrows indicate peak nitrogen concentrations in summer/autumn.

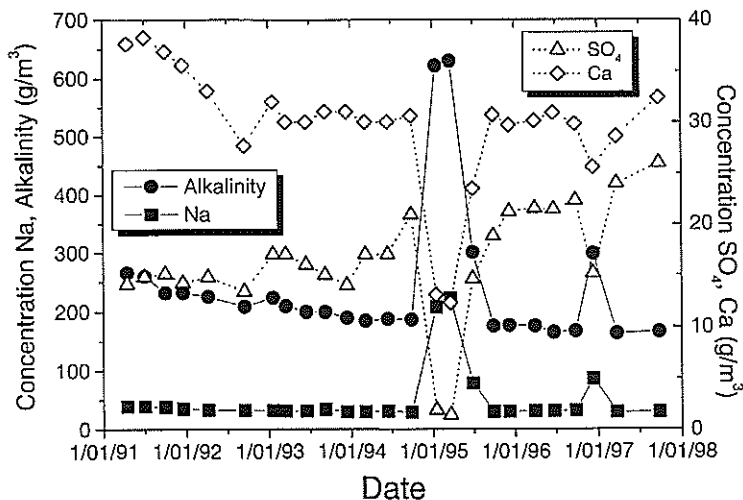


Figure 8. – Concentrations of Na, alkalinity, Ca and SO₄ versus time for van Beek well, Bay of Plenty. Notice the sharp increase in Na and alkalinity and decline in SO₄ and Ca during 1995 and late in 1996. K, SiO₂ and NO₃-N also increased and Mg and total Fe decreased during these periods.

Based on the observed changes in the groundwater chemistry, the contaminant must have been low in SO_4 , Ca, and Mg, been highly alkaline, and consisted almost entirely of Cl, Na, K, and SiO_2 . The concentrations of SO_4 , Ca, Mg would have then been lowered by dilution rather than precipitation. The increase in SiO_2 and K (not shown) may have been caused by leaching of these ions from the volcanic soils in the area rather than being directly added by the contaminant. Although the land surrounding the well is predominantly pasture, there is a cow shed and tanker track within 10 metres of the well. It is possible that biocides and/or caustic soda used for cleaning the cow shed could have seeped into the groundwater. Biocides would be strongly oxidising, contain large amounts of chlorine (which would be converted to chloride in the groundwater), and caustic soda will greatly increase alkalinity and Na concentrations.

Water quality trends in Manawatu-Wanganui

Three wells were originally sampled in this region: a well near Aokautere, Palmerston North (Hinde), a well near Shannon (McAloon), approximately 30 km south west of Palmerston North, and a well in the Ohau-Levin area (Yule), approximately 60 km southwest of Palmerston North. The first samples were taken in June 1992. All three wells are in shallow confined aquifers in discharge areas, although the Yule bore may tap the bottom of the confined aquifer (Bekesi, pers. comm. 1998). At the time, no wells from unconfined aquifers were suitable for inclusion in the monitoring programme, as the water quality is poor and the aquifers are not used. A fourth well (Reesby well) from a shallow unconfined aquifer near the Ohau-Levin area was found to be suitable and was added to the NGMP in 1995. Data from Reesby well are not included in this paper.

Chemical concentrations in the three wells sampled in the Manawatu-Wanganui region generally do not show large variations or directional trends. One exception is increases in $\text{NO}_3\text{-N}$ and K concentrations in the Yule well, located near the southern border of the region (Fig. 9). The trend is significant (i.e. the change is greater than the analytical error for each result), but does not represent a large change in concentration of either ion. For example, the maximum $\text{NO}_3\text{-N}$ concentration of 0.86 g/m^3 is well below the New Zealand maximum acceptable value of $11.3 \text{ g/m}^3 \text{ NO}_3\text{-N}$, and so does not represent any large deterioration in water quality in the groundwater, although it represents a two-fold increase in $\text{NO}_3\text{-N}$ concentration in the well. Bekesi (1998) identified a similar trend for the same well. However, the increase of $\text{NO}_3\text{-N}$, coupled with increases in K and Cl, suggests that the increase is due to fertiliser application or increases in animal waste in the area. Long-term monitoring of the site will help provide early detection of any changes that may be of concern.

Water quality trends in the Waikato

Three wells were originally sampled in this region starting in June 1992; one in Pukekohe, one in the Hamilton basin, and one in the Hauraki Graben. A fourth well was added from the Coromandel in 1993.

Variations in chemical concentrations occur seasonally in some Waikato wells (Fig. 10, 11A and B). In the case from Pukekohe illustrated in Figure

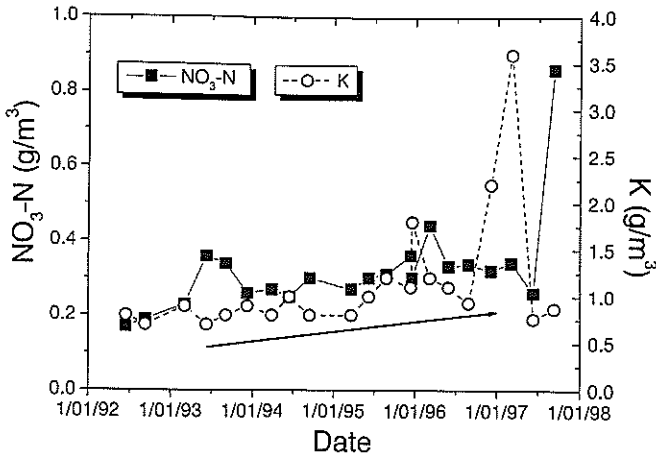


Figure 9. – NO₃-N and K concentrations versus time for Yule well. Although concentrations are relatively low, the trend to increasing concentrations must be monitored to prevent any significant deterioration in groundwater quality.

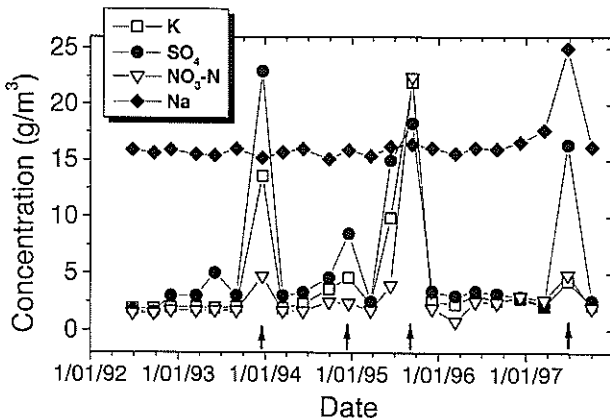


Figure 10. – Time-related changes in NO₃-N, SO₄, Na and K concentrations in the Pukekohe groundwater well. High concentrations of K, SO₄ and NO₃-N occur each year in summer (arrows), but Na concentrations are relatively constant over this time span.

10, the changes are most likely due to anthropogenic chemical inputs because, while K, $\text{NO}_3\text{-N}$, and SO_4 increase markedly in spring and summer, Na does not change over the same time period. In addition, the rapid rise and fall of the ions that do increase suggest a concentrated input at a specific time of year. Both of these patterns are unlikely to be due to natural variability. The increase in nitrogen, sulfate and potassium suggests the addition of fertilisers on a seasonal basis, near the beginning of summer. Market gardening is the main land use in Pukekohe, and detecting the effects of individual fertiliser application in groundwater samples is relatively likely.

The importance of seasonal sampling is also demonstrated by the Pukekohe data. If samples had been taken annually in winter, the large increases in $\text{NO}_3\text{-N}$ concentrations would have gone unnoticed. Conversely, if samples were only taken in summer, the groundwater $\text{NO}_3\text{-N}$ concentration would appear higher. In addition, the peak $\text{NO}_3\text{-N}$ concentrations appear at slightly different times in the summer, presumably due to the timing of fertiliser application and/or irrigation and rainfall. This influence would be difficult to interpret using only annual data.

The relatively large increase in $\text{NO}_3\text{-N}$ during some summers, which may be greater than 10 times the winter concentrations, suggests that large amounts of fertiliser may be applied within a relatively short period. Relatively large groundwater throughflow in this aquifer is probable, as the $\text{NO}_3\text{-N}$ groundwater concentrations always return to a concentration of around $2 \text{ g/m}^3 \text{ NO}_3\text{-N}$ within 3 months of the high $\text{NO}_3\text{-N}$ concentrations.

Peak concentrations in some ions such as K, $\text{NO}_3\text{-N}$ and HCO_3 occur in the Hamilton Basin well in the September samples of most years (Fig. 11A and B). These peaks are relatively minor but consistent, and suggest that winter recharge may wash additional ions from the soil into the groundwater at this location.

Groundwater quality in the Coromandel well site appears to have improved since sampling began in 1993. Conductivity and almost all ions in solution have decreased in concentration over the years to almost half the values of the initial samples (Fig. 12). The well at this site is in the lawn of the fire station. Overflow of rainwater from a buried rainwater tank infiltrates to the groundwater near the well. The improvement in water quality may be due to the addition of this relatively pure water to the groundwater at this site (J. Hadfield, pers. comm., 1998), and may not reflect improved conditions in the aquifer as a whole.

Conclusions

Trends in water quality at different sites in the Tasman, Bay of Plenty, Manawatu-Wanganui, and Waikato regions that have been monitored for over 5 years show patterns of chemical variations that have differed from

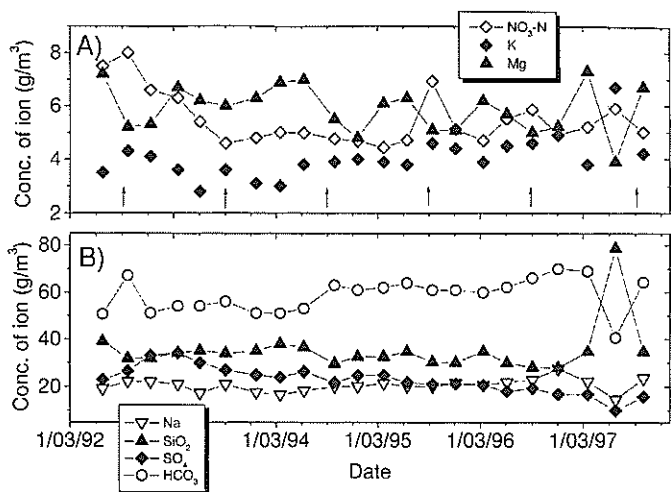


Figure 11. – Plots of A) NO₃-N and K and B) Na, SO₄, SiO₂, and alkalinity versus time for a well in the Hamilton Basin. Small peaks in concentrations of K, NO₃-N and alkalinity in September (arrows) suggest that winter rains leach these ions into the groundwater.

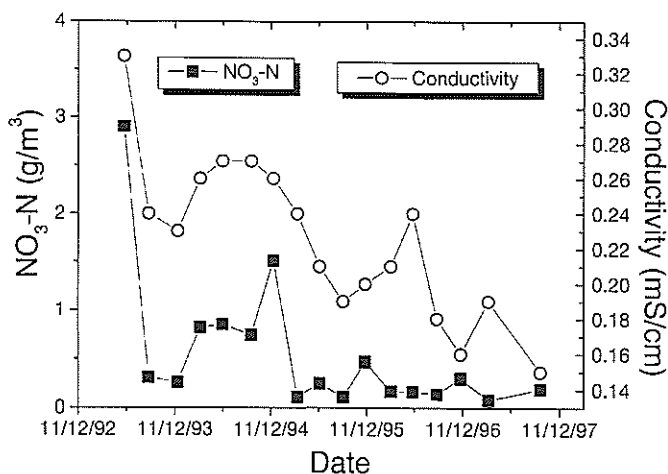


Figure 12. – Plot of conductivity and NO₃-N concentrations with time in a Coromandel well. Most ions have decreased in concentration over the sampling period, possibly related to input of rainwater from a buried rainwater tank located near the well.

area to area and well to well. Some wells have shown seasonal detrimental effects on water quality related to land use. Others have shown little change in water quality with time, or improved water quality over time.

Monitoring of groundwater quality on a quarterly basis for the NGMP appears to be the most suitable frequency for long-term monitoring, because it allows seasonal influences to be discriminated from long-term changes to water quality.

Long-term and seasonal changes in groundwater quality can be related to uses of the land that surrounds wells tapping unconfined aquifers. Changes in water quality in semi-confined and confined aquifers may be more complex, but relatively rapid responses to recharge events can be seen in semi-confined aquifers in the Manawatu-Wanganui region.

The importance of long-term monitoring of groundwater in New Zealand is demonstrated by the wide variety of trends observed from only 17 wells with long-term records. Now that the NGMP includes over 100 wells from all major groundwater use areas in New Zealand, long-term surveys of groundwater quality can achieve a national scope by providing better geographic coverage of New Zealand's aquifer systems, and providing representation of all aquifer types.

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References

- Ackerman, W.C. 1987: Objectives of national water quality monitoring and assessment. *National Water Quality and Assessment*; National Academy Press, Washington, D.C.
- Bekesi, G. 1998: Nitrate-nitrogen in Horowhenua groundwater - Monitoring results. Manawatu-Wanganui Regional Council Report No. 98/INT/129, 9 p.
- Burden, R.J. 1982: Hydrochemical variations in a water-table aquifer beneath grazed pastureland. *Journal of Hydrology (NZ)* 21 (1): 61-75.
- Close, M.E.; Tod, J.L.; Tod, G.J. 1995: Effect of recharge variations on regional groundwater quality in mid-Canterbury, New Zealand. *Journal of Hydrology (NZ)* 33 (1): 1-16.
- Drinking-Water Standards for New Zealand 1995: Compiled by the National Drinking-Water Standards Review Expert Working Group, Ministry of Health. 87p.
- Duijvenbooden, W. van 1993: Ground-water-quality monitoring in the Netherlands. in W.M. Alley (ed.) *Regional Ground-Water Quality*, Van Nostrand Reinhold, New York, 515-535.
- Kim, N.J.; Cho, M.J.; Woo, N.C. 1995: Developing a national groundwater-monitoring network in Korea. *Hydrogeology Journal* 3: 89-94.
- Mueller, D.K.; Hamilton, P.A.; Helsel, D.R.; Hitt, K.J.; Ruddy, B.C. 1995: Nutrients in ground water and surface water of the United States—An analysis of data through 1992. *United State Geological Survey Water-Resources Investigations Report* 95-4031. 74 p.
- Parsons, R.; Tredoux, G. 1995: Development strategy to monitor groundwater quality on a national scale in South Africa. *Hydrogeology Journal* 3: 50-56.
- Resource Management Act 1991: Published under the authority of the New Zealand Government, Wellington, 382 p.
- Rosen, M.R. 1997: *The national groundwater monitoring network (NGMP): Structure, implementation and preliminary results*. Institute of Geological & Nuclear Sciences, science report 97/26, 47 p.
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