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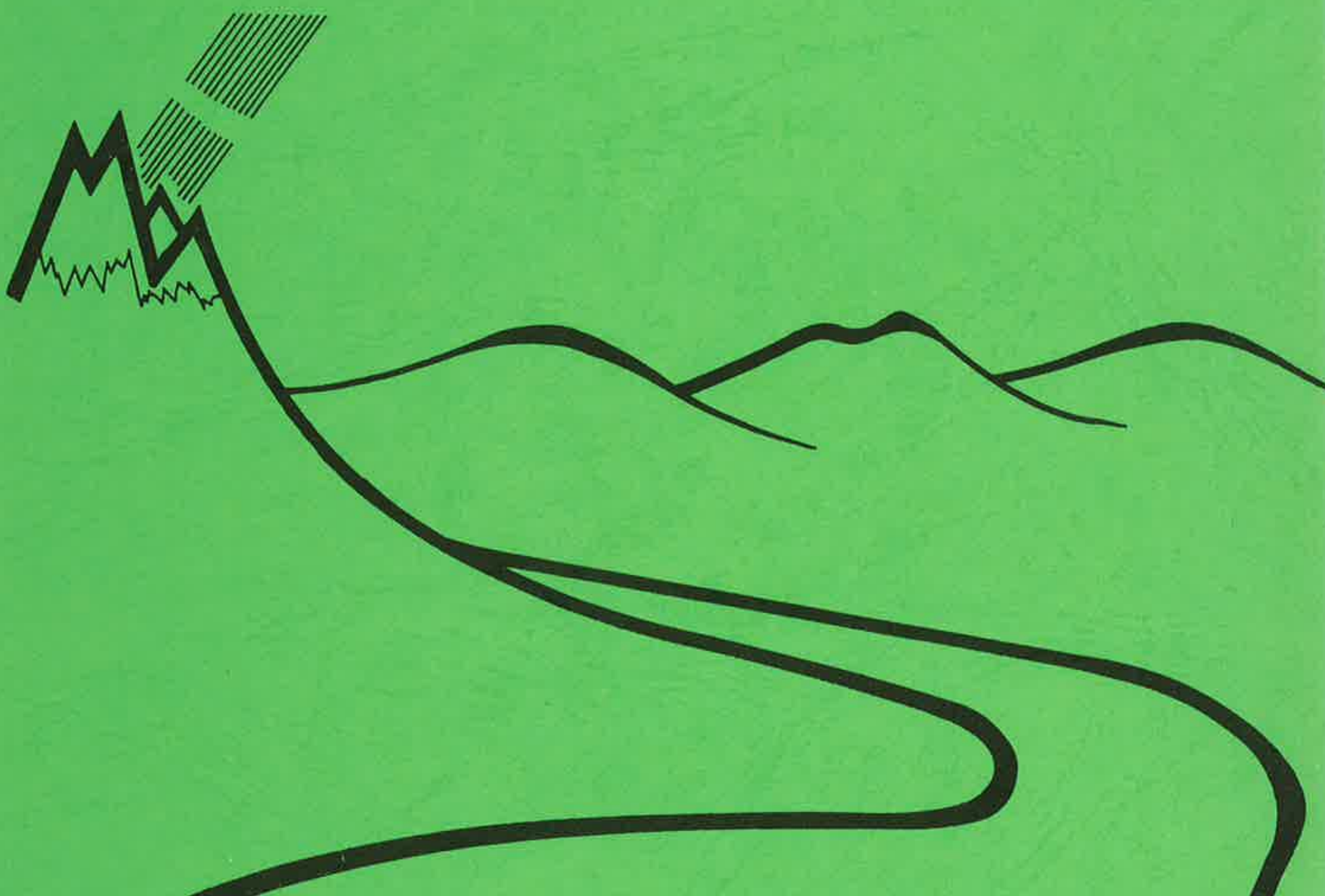
M. E. CLOSE AND R. F. McCALLION



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Publication No. 16 of the Hydrology Centre, Christchurch, 1988, ISSN 0112-1197

Two groundwater quality surveys carried out in proposed power development areas in the Clutha Valley, Central Otago, are described. The likely effects of hydroelectric and related irrigation developments on the groundwater quality are assessed.

National Library of New Zealand
Cataloguing-in-Publication data

CLOSE, M. E. (Murray Edwin), 1958-
Groundwater quality and the likely effects of proposed hydroelectric development, Clutha Valley, Otago / M.E. Close and R.F. McCallion. - Christchurch, N.Z. : Published for the National Water and Soil Conservation Authority by the Hydrology Centre, Ministry of Works and Development,c1988. - 1 v. -(Publication ... of the Hydrology Centre Christchurch, 0112-1197 ; no. 16)
"March 1988."
553.790993183
1. Water, Underground--New Zealand--Clutha River Valley--Quality. 2. Hydroelectric power plants--Environmental aspects--New Zealand--Clutha River Valley. I. McCallion, R. F. (Rosemary Fiona), 1957- . II. Hydrology Centre (Christchurch, N.Z.). III. National Water and Soil Conservation Authority (N.Z.). IV. Title. V. Series: Publication of the Hydrology Centre Christchurch ; no. 16.

Published for the National Water and Soil Conservation Authority by the Hydrology Centre, Ministry of Works and Development, P.O. Box 1479, Christchurch

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ABSTRACT

Two groundwater quality surveys were carried out in proposed power development areas in the Clutha Valley, Central Otago. Samples from a total of 35 sites were analysed for 15-16 chemical determinands.

The total ionic content of the groundwater in both the Upper and Lower Clutha Valleys increased towards the central portion of the Clutha Valley. Levels of nitrogen and phosphorus were generally low throughout the valley and did not change along the climatic gradient. Temporal trends in nitrogen and phosphorus concentrations were generally not marked. There were slight increases ($p < 0.1$) in groundwater nitrate concentrations between irrigated and non-irrigated areas in the Upper Clutha Valley. Nitrogen, phosphorus and salt levels did not exceed World Health Organisation recommended health limits for drinking waters at any of the sites.

An assessment of the likely effects of hydroelectric and related irrigation development on the groundwater quality was made. The major effect in the Upper Clutha Valley would be the expanded irrigation schemes which would probably cause groundwater nitrate concentrations to increase slightly. In the Lower Clutha Valley the major effect of impoundments will be raised groundwater levels which may flood some septic tank systems.

INTRODUCTION

Many surface water resources in New Zealand are being progressively committed to uses such as power generation and irrigation. The use of these waters often directly affects the local groundwater resources. For example, changes in groundwater quality following the implementation of major irrigation schemes have been noted in mid-Canterbury (Quin and Burden, 1979) and in the Waiau Plains (Close, 1987).

Planned hydroelectric development in the Upper Clutha Valley consists of a high dam at Clyde (under construction), a dam at Luggate and possibly a dam at Queensberry (Figure 1). In conjunction with this, an expanded irrigation scheme is proposed which will incorporate existing Government schemes and private irrigation into a total area of 8000 ha. The current area under government irrigation is 3600 ha with 1350 ha irrigated privately (Royds, Sutherland McLeay, Ltd, 1982).

Hydroelectric development is also under investigation in the Lower Clutha Valley, with two or three 'run of the river' type impoundments proposed between Roxburgh and Tuapeka Mouth (Figure 2). The proposals are likely to affect a significant proportion of the groundwater resource because, with the exception of the Ettrick area, this occurs in close proximity to the river because of the surrounding hills.

The options for hydroelectric development in the Lower Clutha Valley are:

(a) A dam at Tuapeka Mouth banking up to Beaumont; a dam at Beaumont banking up to Dumbarton Rock; a dam at Dumbarton Rock banking up to Roxburgh.

(b) A dam at Tuapeka Mouth banking up to Dumbarton Rock; a dam at Dumbarton Rock banking up to Roxburgh.

(c) A dam at Birch Island banking up to Dumbarton Rock; a dam at Dumbarton Rock banking up to Roxburgh.

(d) A dam at Tuapeka Mouth banking up to Birch Island; a dam a Birch Island banking up to Beaumont; a dam at Beaumont banking up to Dumbarton Rock; a dam at Dumbarton Rock banking up to Roxburgh.

This report describes the results of groundwater quality surveys of the Upper and Lower Clutha Valleys. The surveys were undertaken to provide baseline chemical quality data for the area and to assess the effects of hydroelectric/irrigation development on the groundwater quality.

DESCRIPTION OF STUDY AREA

(a) Upper Clutha Valley

The study area extends from Lake Hawea to Cromwell (Figure 1) and consists of the Hawea Flat and the Clutha River Valley. The valley is lined by mountains composed mainly of mica-schist. The valley floor is partially filled with Tertiary deposts overlain by weathered greywacke and recent gravels. Glacial moraines are present in some areas of the valley (Rickard and Cossens, 1968).

Duncan (1965) noted that there is considerable local climatic variation within the valley, with a marked north to south decrease in rainfall. There are three major climatic zones (Figure 1), each of which is marked by a change in soil type:

(1) Humid/sub-humid : 890-660 mm rainfall per annum; dry hygrous yellow-brown and sub-hygrous yellow-grey earths.

(2) Sub-humid : 660-480 mm rainfall per annum; dry sub-hygrous yellow-grey earths.

(3) Semi-arid : < 480 mm rainfall per annum; brown-grey earths below which $CaCO_3$ accumulation is common. High concentrations of soluble salts in these soils sometimes result in saline patches forming on the surface (Leamy and Saunders, 1967; Rickard and Cossens, 1968).

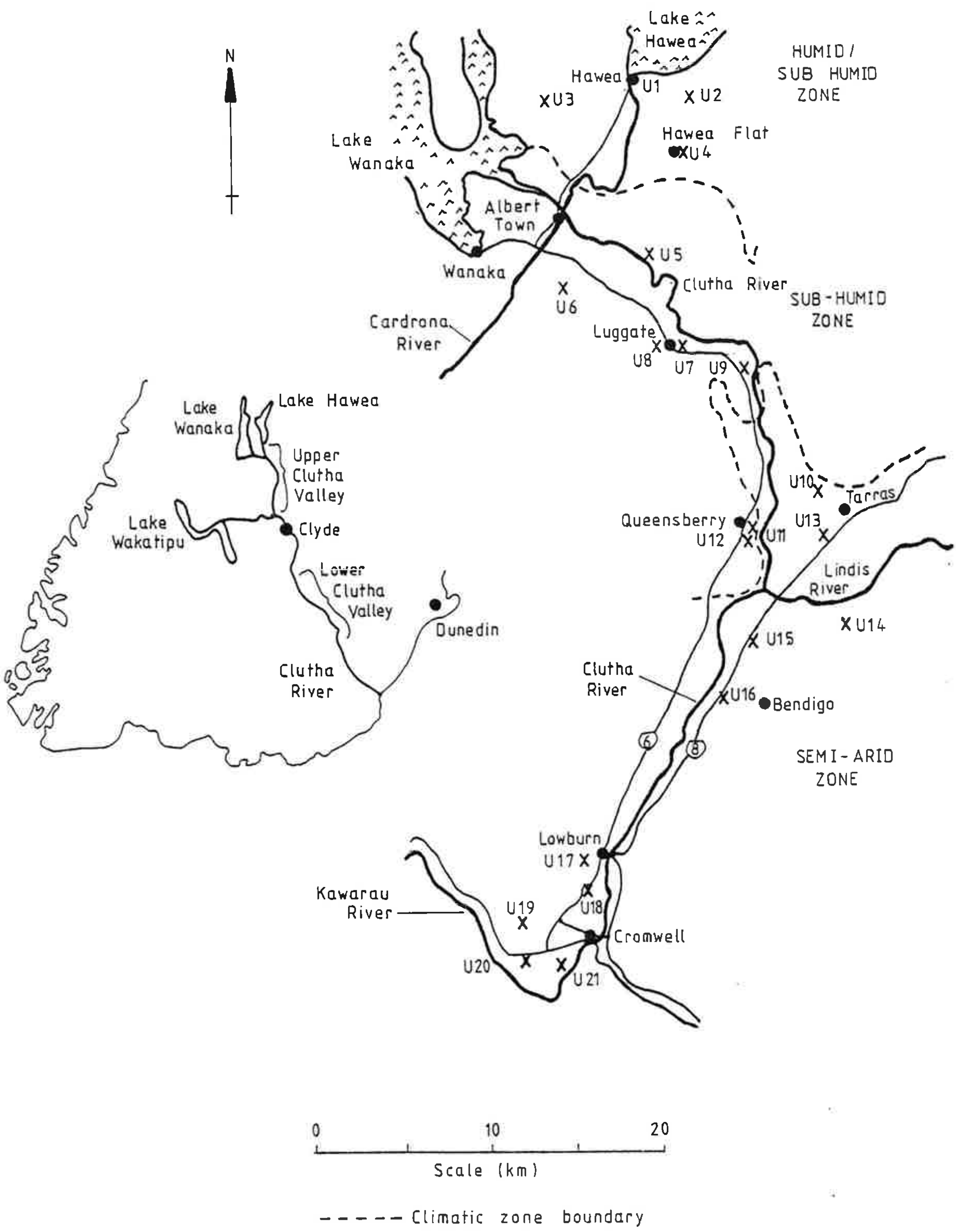

Figure 1 : Climatic zones (after Leamy and Saunders, 1967) and sample collection sites (x) in the Upper Clutha Valley.

The dominant land use in the valley is sheep farming, with some cropping around Tarras and orcharding around Lowburn. Perennial ryegrass/white clover or lucerne pastures are usually sown on irrigated land, providing autumn and winter feed for stock which graze the ranges until the end of summer. If fat lambs are produced, the valley floor is also grazed throughout the summer. Sulphur fortified super-phosphate is applied to pastures throughout the valley. Nitrogenous fertiliser is used for cropping and lime is added for lucerne establishment (S. Hughes, MAF, Alexandra, pers. comm.). Border-strip irrigation is the most commonly used method of water application, especially on the Government schemes.

There is very little information available on the groundwater resources of the Upper Clutha Valley. Details of groundwater flow direction and velocity are unknown, although Lake Hawea is believed to be the major recharge source, especially for the Hawea Flat. In this area, static well water levels fluctuate in response to lake level (unpublished data, NZED, Roxburgh). This observation is supported by the presence of springs along the base of the Hawea terraces.

In the remainder of the valley, the direction of groundwater movement is assumed to be from the hills towards the Clutha River. Springs are found near Luggate, Tarras, Queensberry and along the Kawarau River. Data on the chemical quality of groundwater resources in the valley were almost non-existent. A sample from a well in the Cromwell Flat indicated low levels of nitrate-N, nitrite-N and ammonia-N (unpublished data, Department of Health, Dunedin). Cossens (Ministry of Agriculture and Fisheries, Invermay, pers. comm.) analysed water from several wells in the area for conductivity, calcium, magnesium, sodium, potassium and chloride. Conductivity ranged from 7 to 40 mS m^{-1}, depending on location within the valley. Low to medium concentrations of the ions were measured with calcium ranging between 2 and 15 g m^{-3}, magnesium between 0.2 and 5 g m^{-3}, sodium between 1 and 29 g m^{-3}, potassium between 0.4 and 3 g m^{-3} and chloride between 3.5 and 7 g m^{-3}.

(b) Lower Clutha Valley

The Lower Clutha Valley study area (Figure 2) extends approximately 55 km from Roxburgh down to Tuapeka Mouth. The Clutha River flows swiftly in an entrenched channel between a series of flat topped ranges throughout this stretch. The valley narrows near Roxburgh and above Beaumont to form small gorges, but between these sections, river flats up to several kilometres in width occupy the valley floor.

The climate is in the transition zone between the near continental climate of Central Otago and the temperate climate of South Otago. Precipitation decreases steadily northwards, with Beaumont (969 mm) receiving nearly double the rainfall received by Roxburgh (546 mm). The amount of sunshine increases steadily northwards.

The soils in the Lower Clutha study area are mapped as Recent Clutha and Gladbrook soil sets on floodplains and fans alongside the river, with some yellow grey earth Straun soil set on higher terraces around Etrrick and Teviot (NZ Soil Bureau, 1968). The basement rock is greywacke and semi schist, with the semi schist occurring more towards the Roxburgh end of the valley. The terraces consist of alluvial gravels. Land use in the area is mainly sheep grazing, with some cropping and cattle grazing.

Groundwater in the Lower Clutha system occurs in discrete pockets where the valley opens out to form river terraces. These areas are around Beaumont, Island Block, Millers Flat, Ettrick, Teviot and Roxburgh (Figure 2). Little was known about the groundwater levels in the area and even less information was available on groundwater quality. Five bores were sampled in 1974 in the Ettrick area and were analysed for soluble salts (Cossens, MAF, Invermay, pers. comm.). Domestic water supplies in the Lower Clutha Valley are obtained from a number of sources including rivers, creeks, rainwater, groundwater and springs.

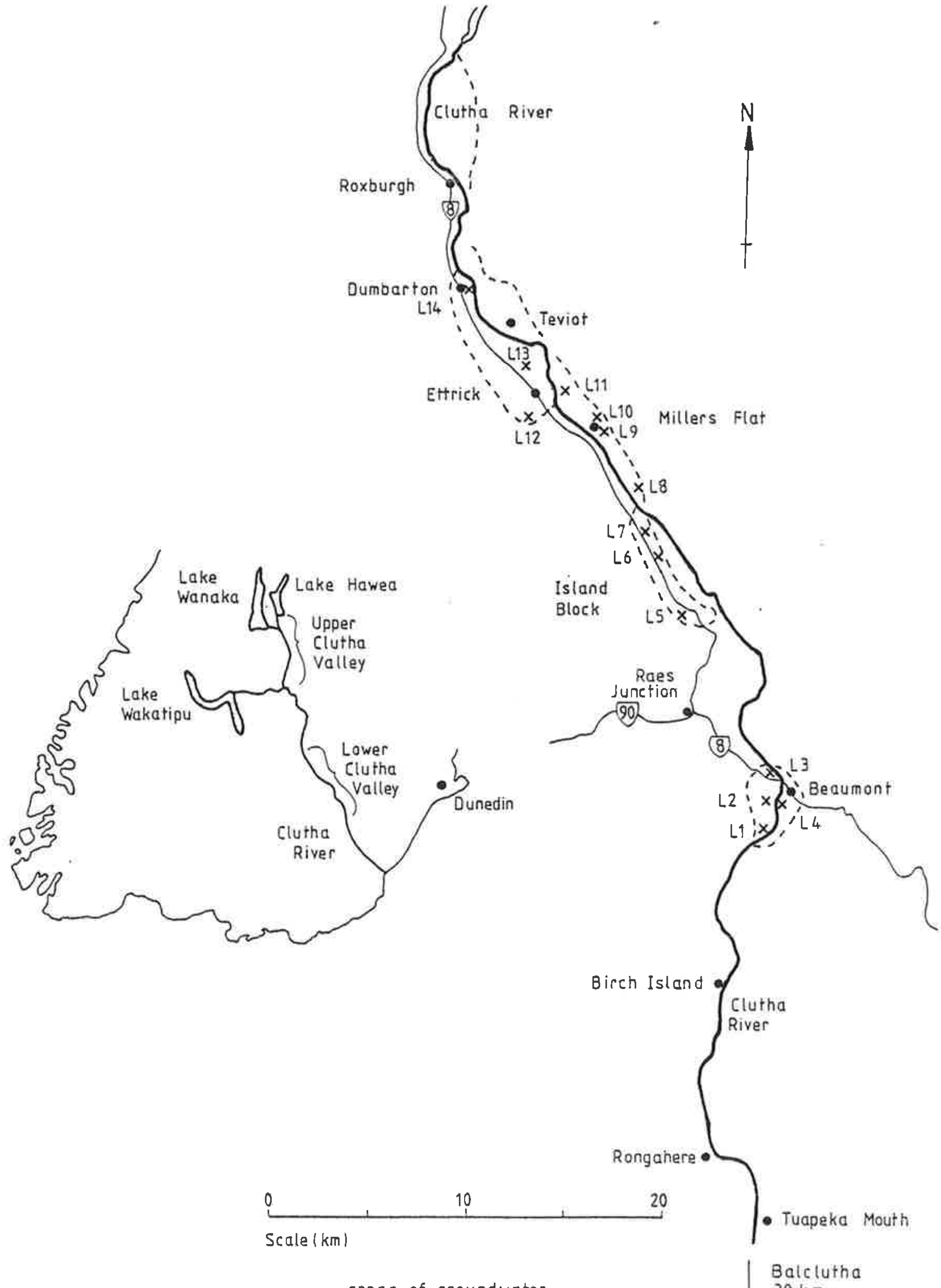

Figure 2 : Location of the Lower Clutha study area and sample collection sites (x).

METHODS

Sampling

Twenty one sites in the Upper Clutha study area (each site number is prefixed with a "U") were sampled every three weeks during the period June 1980 to June 1981 to give a maximum of 20 samples per site. The sites were Lake Hawea, three springs and 17 pumped bores (Figure 1). Fourteen sites in the Lower Clutha study area (each site number is prefixed with an "L") were selected and sampled on a monthly basis from November 1982 to November 1983. Sampling was concentrated around Beaumont, Island Block and Millers Flat because these areas appeared the most likely to be affected by hydroelectric development. The Lower Clutha study area and location of the wells are shown in Figure 2. Water levels were recorded for the Lower Clutha sites. Descriptions of the well sites are given in Appendices 1 and 2 for the Upper and Lower Clutha Valley study areas, respectively.

A selection of wells in Millers Flat was sampled on one occasion and analysed for total and faecal coliform bacteria. Millers Flat was selected because the area had the highest concentration of septic tanks and therefore, the greatest likelihood of bacterial contamination.

A continuous water level recorder was installed on a bore in Millers Flat (near L10) and a Foxboro recorder was installed on the Clutha River (500 m from the bore) from April to November 1983 to assess what effect changes in river levels were having on groundwater levels.

Sampling methods varied with the type of well. The pumped wells were run until a constant water temperature was reached and then the samples were taken. Non-pumped wells were sampled using either a vacuum apparatus or a bailer, depending on the depth to the water table at the site. Samples were collected in acid washed plastic bottles and transported to the Christchurch laboratory. Analyses started within 48 hours of collection.

Analyses

The water samples were analysed for bicarbonate (HCO_3), nitrate (NO_3-N), ammonium (NH_4-N), dissolved reactive phosphorus (DRP), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), sulphate (SO_4), and silica (SiO_2) according to the methods set out in Table 1. Total dissolved phosphorus (TDP) was determined for the Upper Clutha samples only. Bicarbonate was estimated either by titration (Table 1) or by ionic balance calculation. Conductivity (at 25°C) and pH were measured using Radiometer meters. If a sample contained concentrations lower than the detection limit, the value was taken as the detection limit and the mean was tabulated as less than the calculated mean value. An additional sampling round in July 1985 was undertaken to provide information on iron (Fe) and manganese (Mn) concentrations.

Water balances for drainage in the Upper Clutha study area were calculated by the NZ Meteorological Service.

Table 1 : Methods used in chemical analyses

Determinand	Method	Reference
NO_3	Automated hydrazine reduction followed by colorimetric determination	Kamphake *et al.*, 1967
NH_4	Automated indophenol blue method	APHA, 1980
DRP	Automated molybdate method with ascorbic acid reduction	APHA, 1980
TDP	Acid persulphate digestion followed by determination as DRP	Lennox, 1979
HCO_3	Acid titration to pH 4.8	APHA, 1980
Cl	Automated ferricyanide method	APHA, 1980
SO_4	Automated methyl thymol blue method	APHA, 1980
SiO_2	Automated molybdate method with ascorbic acid reduction	USGS, 1979
Na, K, Ca, Mg	Atomic absorption	APHA, 1980
Fe	1,10 Phenanthroline method	APHA, 1980
Mn	Persulphate method	APHA, 1980

RESULTS AND DISCUSSION

(a) Upper Clutha Valley

The data from the 12 month sampling programme, summarised in Table 2, indicate that the groundwaters in the Upper Clutha Valley are generally of high quality for domestic purposes. Levels of determinands did not exceed recommended health limits (WHO, 1971) for drinking waters in any of the samples.

The anion composition of the groundwater expressed in meq l^{-1} was dominated by bicarbonate (85%) with sulphate, nitrate and chloride being 6.5%, 4.5% and 3.5%, respectively. The cations were dominated by calcium, which averaged 60.5%. Sodium and magnesium had levels of 17% and 20%, respectively, while potassium, at 2%, was only a minor component of the groundwater. The composition of groundwater was fairly constant throughout the valley, with the main anomaly being in site U3 (Figure 1) which had lower calcium and higher sodium levels.

Table 2 : Summary of groundwater quality for each site in the Upper Clutha study area; mean concentrations with standard deviations in brackets.

Site Number	Distance down valley (km)	Conductivity ($mS\ m^{-1}$)	pH	HCO_3 ($g\ m^{-3}$)	NO_3-N ($g\ m^{-3}$)	Cl ($g\ m^{-3}$)	SO_4 ($g\ m^{-3}$)	SiO_2* ($g\ m^{-3}$)
U1	0	5.0 (0.1)	7.6 (0.1)	29.9 (3.6)	0.01 (0.02)	0.6 (0.2)	3.3 (1.1)	3.2 (0.6)
U2	1.4	8.8 (0.3)	7.8 (0.2)	51.4 (2.9)	0.08 (0.02)	0.5 (0.1)	3.5 (1.2)	8.7 (0.9)
U3	2.5	11.0 (1.1)	6.7 (0.1)	50.6 (7.2)	2.78 (0.52)	2.6 (0.4)	2.0 (1.0)	12.6 (1.5)
U4	5.9	19.5 (1.3)	7.3 (0.1)	116.3 (3.3)	1.09 (0.12)	1.3 (0.2)	8.1 (1.4)	11.4 (1.3)
U5	10.1	18.2 (1.4)	8.0 (0.1)	106.4 (23.4)	0.76 (0.07)	1.0 (0.2)	4.8 (1.3)	9.9 (1.1)
U6	12.1	28.1 (3.3)	7.9 (0.1)	155.7 (20.9)	2.40 (0.35)	1.5 (0.3)	14.4 (5.2)	10.6 (2.7)
U7	15.3	4.4 (0.5)	6.3 (0.1)	21.4 (2.3)	0.57 (0.38)	0.6 (0.2)	1.6 (0.7)	8.2 (1.1)
U8	15.3	4.6 (0.6)	6.4 (0.2)	24.8 (2.9)	0.28 (0.17)	0.7 (0.3)	1.5 (1.1)	9.5 (1.1)
U9	16.9	15.6 (1.9)	7.0 (0.2)	92.7 (8.7)	0.62 (0.54)	2.5 (0.3)	2.7 (2.1)	15.3 (1.8)
U10	23.8	27.7 (3.0)	7.5 (0.1)	151.4 (18.4)	5.39 (1.49)	3.7 (0.8)	6.3 (2.2)	17.4 (2.4)
U11	25.6	7.2 (1.2)	6.7 (0.1)	37.4 (6.1)	1.00 (0.20)	1.2 (0.3)	<2.1 (1.4)	17.3 (1.8)
U12	25.6	5.2 (0.5)	6.8 (0.2)	29.2 (2.0)	0.24 (0.09)	0.9 (0.2)	2.1 (1.1)	15.2 (1.1)
U13	26.2	20.1 (1.4)	7.3 (0.2)	120.8 (3.6)	1.40 (0.08)	1.9 (0.2)	4.4 (1.2)	15.3 (1.9)
U14	30.7	23.7 (4.4)	7.5 (0.2)	144.8 (26.0)	1.30 (0.42)	2.4 (0.5)	7.0 (2.6)	11.5 (1.8)
U15	31.8	16.5 (1.1)	7.3 (0.2)	96.3 (5.3)	0.67 (0.06)	2.1 (0.4)	6.3 (1.9)	9.6 (1.3)
U16	35.4	15.8 (5.2)	7.4 (0.3)	91.9 (31.4)	0.48 (0.23)	3.7 (2.5)	3.7 (1.6)	11.1 (1.4)
U17	44.5	24.5 (1.6)	7.6 (0.2)	155.7 (6.8)	0.44 (0.09)	3.1 (0.3)	5.0 (1.9)	10.8 (1.4)
U18	46.5	37.4 (6.2)	7.7 (0.1)	221.8 (33.6)	2.65 (0.65)	6.4 (1.4)	8.7 (3.4)	12.9 (2.7)
U19	49.5	56.8 (6.7)	7.5 (0.3)	314.6 (23.5)	2.85 (0.38)	11.7 (2.6)	58.3 (22.2)	11.7 (1.3)
U20	50.5	33.1 (3.7)	7.7 (0.2)	222.3 (16.3)	0.55 (0.10)	1.5 (0.2)	7.2 (1.7)	9.3 (1.0)
U21	50.6	25.7 (2.3)	7.6 (0.1)	154.0 (7.4)	0.91 (0.35)	6.4 (0.7)	7.2 (1.9)	11.0 (1.8)

Table 2 (Contd)

Site Number	Na ($g\ m^{-3}$)	K ($g\ m^{-3}$)	Ca ($g\ m^{-3}$)	Mg ($g\ m^{-3}$)	Fe* ($g\ m^{-3}$)	Mn* ($g\ m^{-3}$)	NH_4-N ($mg\ m^{-3}$)	DRP ($mg\ m^{-3}$)	TDP ($mg\ m^{-3}$)
U1	1.4 (0.2)	0.6 (0.1)	7.5 (0.4)	0.7 (0.1)	0.2	<0.05	<11 (8)	<1 (1)	10 (7)
U2	1.9 (0.3)	0.5 (0.1)	13.6 (0.7)	1.8 (0.1)	0.1	<0.05	<4 (3)	<2 (1)	13 (12)
U3	12.0 (2.1)	0.9 (0.1)	9.1 (0.5)	2.0 (0.1)	<0.05	<0.05	17 (14)	<3 (3)	24 (17)
U4	6.1 (0.7)	1.2 (0.1)	24.2 (1.5)	7.7 (0.4)	0.7	<0.05	<9 (7)	<3 (3)	18 (13)
U5	4.9 (0.2)	1.0 (0.1)	29.8 (2.9)	3.3 (0.2)	0.4	<0.05	<6 (4)	9 (3)	21 (12)
U6	6.8 (0.9)	1.3 (0.4)	44.3 (6.5)	6.9 (1.1)	0.1	<0.05	<20 (49)	<13 (36)	16 (10)
U7	2.2 (0.5)	0.9 (0.1)	4.6 (0.6)	0.9 (0.1)	0.5	<0.05	<4 (2)	<2 (2)	16 (14)
U8	2.2 (0.3)	0.9 (0.1)	5.3 (0.7)	1.0 (0.2)	0.6	<0.05	<4 (4)	9 (4)	25 (12)
U9	8.6 (2.1)	0.9 (0.2)	19.8 (1.7)	3.9 (0.5)	0.4	<0.05	<4 (2)	58 (17)	70 (16)
U10	8.2 (0.6)	1.2 (0.2)	47.5 (6.8)	4.8 (0.9)	0.2	<0.05	<10 (14)	<2 (2)	31 (21)
U11	4.2 (0.6)	1.3 (0.2)	7.1 (1.2)	2.4 (0.4)	<0.05	<0.05	<3 (2)	9 (4)	22 (12)
U12	3.3 (0.3)	0.7 (0.1)	5.1 (0.6)	1.5 (0.2)	0.2	<0.05	<4 (3)	11 (4)	23 (13)
U13	8.0 (0.3)	0.8 (0.1)	27.9 (2.3)	5.5 (0.2)	0.2	<0.05	<4 (3)	4 (3)	19 (15)
U14	12.0 (2.0)	1.1 (0.1)	28.3 (5.7)	9.3 (1.9)	0.7	<0.05	<6 (6)	<3 (5)	16 (16)
U15	6.8 (0.3)	0.9 (0.1)	19.8 (1.7)	6.4 (1.3)	0.4	<0.05	<4 (3)	<2 (3)	17 (15)
U16	8.6 (3.6)	1.1 (0.1)	18.5 (6.8)	5.0 (1.4)	0.7	0.24	<4 (4)	10 (7)	23 (16)
U17	12.5 (1.1)	1.3 (0.4)	37.5 (5.1)	4.6 (0.2)	1.0	<0.05	<7 (10)	<2 (2)	10 (7)
U18	13.1 (2.4)	2.6 (0.4)	55.7 (10.5)	11.5 (2.1)	<0.05	<0.05	<5 (3)	6 (4)	14 (9)
U19	20.2 (4.7)	1.8 (0.3)	81.7 (11.7)	25.4 (3.0)	0.6	<0.05	<5 (5)	<2 (2)	<8 (7)
U20	3.8 (0.6)	1.2 (0.3)	60.7 (9.8)	10.6 (1.4)	0.1	<0.05	<6 (4)	<2 (1)	<6 (5)
U21	11.0 (0.6)	1.3 (0.3)	36.5 (5.6)	6.3 (0.5)	<0.05	0.08	<5 (5)	<2 (1)	<21 (22)

Note: Distance down valley is the distance from the latitude of Lake Hawea to the latitude of the sampling site.

* Only analysed for July 1985 sampling occasion.

< indicates that sites had some samples below the detection limit of the method.

Spatial trends in groundwater quality

(i) Main valley

Significant increases down the valley were demonstrated for conductivity, chloride, bicarbonate, sulphate, sodium, potassium, calcium and magnesium, while TDP showed a significant decrease (Table 3). The increases reflect the changes in soil type summarised by Rickard and Cossens (1968), which, in turn, reflect the climatic change down the valley.

Salts accumulate in the soils of the semi-arid zone because of low precipitation and high evaporation. Therefore, drainage in the southern (down river) part of the valley contains higher salt concentrations than that from the northern (humid and sub-humid) soils. The decrease in TDP concentration down the valley is probably controlled by phosphate mineral equilibria. In natural waters the stable solid phase controlling phosphate concentrations is likely to be hydroxyapatite (Stumm and Morgan, 1970). Calculations using SOLMNEQ (Kharaka and Barnes, 1973) indicate that the phosphate concentrations are being controlled by this equilibria near Cromwell, where calcium concentrations are high, which results in the observed lower phosphate concentrations. Further up the valley, where calcium concentrations are lower, the waters are sometimes unsaturated with respect to hydroxyapatite, and phosphate concentrations can be higher.

Iron and manganese concentrations were low throughout the area with the exception of site U16. The elevated manganese concentration indicates the presence of deoxygenated water in this area. Concentrations of ammonia were variable at most sites and many samples had concentrations below the detection limit of the method.

No significant trends in other determinands were recorded. Accumulation of nitrate similar to that recorded in parts of

Canterbury (Quin and Burden, 1979) would not be expected to occur to the same extent in the Upper Clutha Valley, because the local groundwater system is not as extensive or continuous. The distance of groundwater movement from the base of the hills to the river channel, except in the Hawea Flat and Tarras areas, is less than 3 km. The groundwater quality at a number of sites was probably related to relatively localised pedological and hydrological conditions. For example, the relatively high levels of all determinands at site U6 could be attributable to the different soil type (Wanaka yellow grey earth) in this area and the possibility that groundwater may be from the Cardrona River catchment. The low levels of all determinands found at sites U7 and U8 are probably a result of groundwater recharge from the nearby Luggate Stream.

Table 3 : Correlation coefficients between chemical determinands and distance down the valley from Lake Hawea and Roxburgh for the Upper and Lower Clutha Valleys respectively.

Determinand	Upper Clutha Valley (n=21)	Lower Clutha Valley (n=14)
pH	0.218	- 0.750 **
conductivity	0.662 **	- 0.573 *
HCO_3	0.702 **	- 0.737 **
NO_3-N	[a] 0.356	0.117
Cl	[a] 0.715 **	- 0.408
SO_4	[a] 0.478 *	0.283
SiO_2	[a] 0.304	0.233
Na	0.568 **	- 0.629 *
K	[a] 0.660 **	0.209
Ca	0.650 **	- 0.543 *
Mg	[a] 0.664 **	- 0.561 *
NH_4	- 0.401	0.367
DRP	- 0.140	0.150
TDP	[a] - 0.506 *	-
Fe	0.111	- 0.297

* - $p < 0.05$

** - $p < 0.01$

[a] - log transformation applied to data

(ii) Hawea Flat

Groundwater is assumed to flow from Lake Hawea to the Clutha River under the Hawea Flat and Lake Hawea (shown by site U1), and sites U2 and U4 were assumed to be in a continuous groundwater flow line in the same aquifer system. Generally, the levels of determinands increased with distance from Lake Hawea: most changes were significant ($p < 0.01$, Mann-Whitney U test). These changes in groundwater quality could be attributed to the more intensive agricultural land use between Lake Hawea and site U4. The area under irrigation on the Hawea Flat is small (2670 ha), when compared with Canterbury schemes, and therefore the large increases in nitrate-N following irrigation development and the accumulation of nutrients with increasing distance of groundwater movement, noted by Quin and Burden (1979), would not be expected to occur.

Temporal variation in groundwater quality

Temporal variations in groundwater quality occurred at most sites, although the magnitude and timing of these variations differed between sites and for different determinands. Nitrate-N levels were generally low throughout the valley and exhibited only slight temporal fluctuations (Figure 3). Generally, levels increased following periods of peak drainage. This was especially noticeable at site U10 where the levels increased from 3.9 to 7.0 g m^{-3} in one month (Figure 3). In some instances, however, the levels dropped during the peak drainage period. This was probably due to the effects of dilution in those areas where drainage contained lower concentrations of dissolved ions than the underlying groundwater. At some sites, ammonium levels also increased at times of increased drainage but levels were still low throughout the valley.

Effect of present irrigation schemes on groundwater quality

Because a significant portion of the irrigated land is used to provide winter feed, the effect of irrigation is not limited to the period of

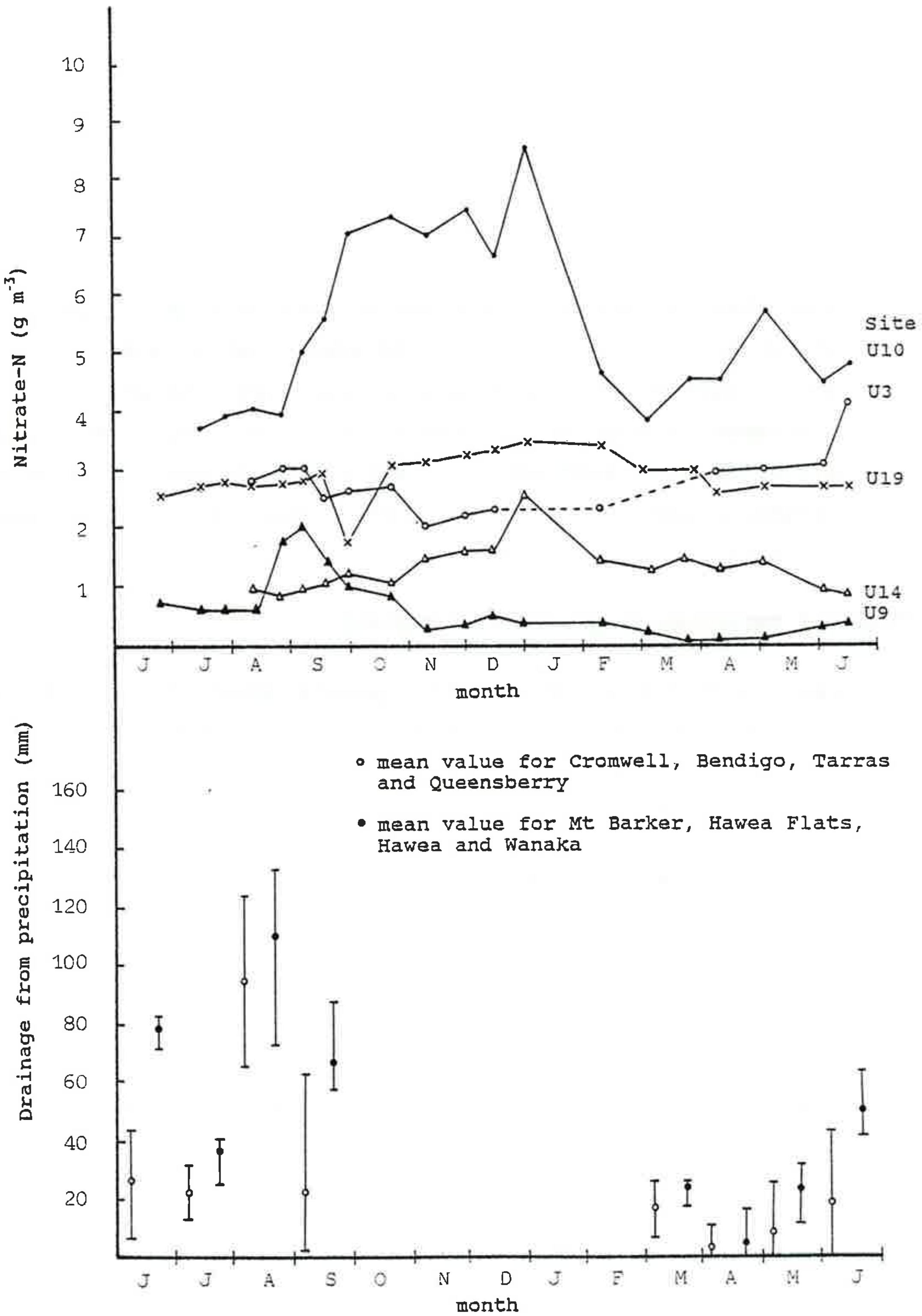

Figure 3 : Nitrate-N concentrations for selected Upper Clutha Valley sites and natural drainage for the period June 1980 to June 1981.

the irrigation season only, but is spread throughout the year. The sites were separated into those affected by irrigation and those that were not, and were tested for significant differences using the Mann-Whitney U test. This test was used because not all parameters were normally distributed.

The results indicated that the irrigated sites had significantly higher levels of nitrate and magnesium at $p < 0.1$. The mean nitrate concentrations were 0.9 and 1.7 g m^{-3} for the non-irrigated and the irrigated sites, respectively, but the variability of the nitrate concentrations precluded a higher significance level.

Many other factors are also thought to affect groundwater quality in the Upper Clutha Valley. These include recharge from the river, velocity and direction of groundwater movement, proximity to the hills, and timing and areal extent of fertiliser application.

(b) Lower Clutha Valley

Groundwater levels

(i) Monthly sampling programme

Generally, water level fluctuations were less than 1.4 m, except for site L8 in Millers Flat which was affected by pumping for irrigation and site L3 which had a perched water table. The average range in levels for all the sites was 0.92 m, with the minimum range being 0.24 (site L13) and the maximum range being 2.0 m (site L3). The above average rainfall over the study period (detailed later in the text) makes it difficult to determine whether these water levels were "normal".

Groundwater levels were higher than adjacent river levels, indicating flow towards the river. The distance of each well from the river was regressed against the difference between the mean well water level and the adjacent river level. The regression line was forced through the origin, because the river and groundwater systems were believed to be connected. The slope of this line gives an indication of the hydraulic gradient that can be expected in the area. Sites L3 and L14, which were believed to have perched water tables, were deleted from the regression analysis. The regression equation was:
"water level diff. (m)" = 3.5 x "dist. from river (km)" (n=18 r=0.91). It should be noted that most of these data were from sites less than 1.5 km from the river and extrapolation beyond this point could be misleading. Because site L6, which is the site furthest from the river and is confined, had a large influence on the regression analysis, it was omitted to see if this made a significant difference. The slope of the regression line changed to 4.6 and the correlation coefficient became 0.81. Thus an estimate of the hydraulic gradient away from the river would be 3-5 m km^{-1}.

(ii) Hydraulic relationships between groundwater and river levels

The hydraulic relationships between groundwater and river levels have been investigated by P.J.T. Smith (MWD, Dunedin, pers. comm.). The data from the continuous water level recorders at Millers Flat are plotted at the same datum of mean sea level Dunedin (Figure 4). The river level record has had the daily fluctuations (from Roxburgh Power House discharges) smoothed by using a four hourly moving mean. P.J.T. Smith (MWD, Dunedin, pers. comm.) suggested that river levels in the Clutha River at Millers Flat influenced local groundwater levels in an apparent response lagged by 8 to 18 days. The response depended on the rate of rise and the average increase in river levels: greater and faster rises of the river resulted in shorter response times in the groundwater.

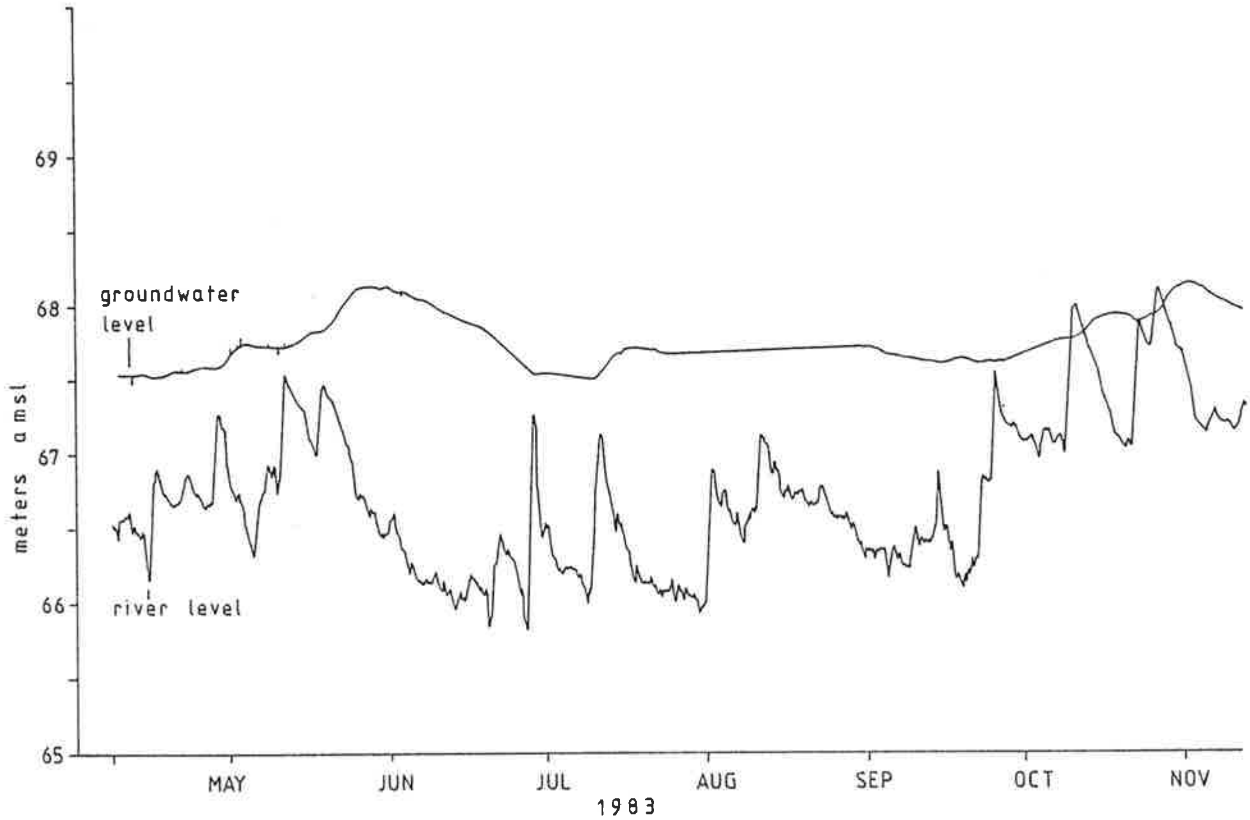

Figure 4 : Relationship between groundwater level at Millers Flat and Clutha River level (data from P.J.T. Smith, MWD, Dunedin, pers. comm.).

P.J.T. Smith suggested that the magnitude of groundwater level response at approximately 500 m from the river was around 30% of the corresponding rise in river level. However, these results should be treated with caution because the record did not contain extreme events and care should be taken with extrapolation of the effect of impoundments on groundwater levels.

Groundwater quality

The results of the water quality analyses are summarised in Table 4. The cation composition of the groundwater, calculated in meq l^{-1}, was fairly constant. The average composition was 42%, 33%, 22% and 3% for calcium, sodium, magnesium and potassium, respectively. The anion composition was much more variable and possibly reflects the greater sensitivity of anions to local land use. The overall average composition was 56%, 23%, 14% and 7.5% for bicarbonate, chloride, sulphate and nitrate, respectively. The proportion of bicarbonate increased from Beaumont to Roxburgh, while the proportion of sulphate and nitrate decreased and the chloride proportion remained constant. Chloride concentrations in the Lower Clutha Valley were consistently higher than in the Upper Clutha Valley. This would be a result of increased transport of chloride in the rainwater, which results from closer proximity to the sea.

Spatial variations of groundwater quality

The overall ionic content of the groundwater, as indicated by the conductivity values, decreased with increasing distance down valley from Roxburgh (Figure 5). This is a reflection of the climatic trend noted earlier; the Roxburgh end of the valley, with its higher evapotranspiration and lower rainfall, produces a smaller amount of more concentrated drainage resulting in higher groundwater concentrations. The hardness values, with the exception of sites L7 and L12 which were thought to be affected by nearby creeks, also followed this trend. The groundwater around Beaumont was mainly soft; it was soft to moderately soft in Island Block and moderately soft to hard around Millers Flat, Ettrick and Dumbarton Rock.

The nitrate values do not show any correlation with distance down river from Roxburgh, unlike the above determinands, and are probably most influenced by the local land use. At site L6 in Island Block, where the groundwater is confined, the nitrate-N value was very low (0.18 g m^{-3}). Elsewhere, the mean concentrations ranged from 0.3 to 5.5 g m^{-3}. These levels are below the WHO recommended level for nitrate-N in drinking water of 10 g m^{-3} (WHO, 1971).

During the whole sampling period, the only samples which exceeded 10 g m^{-3} were two initial samples from site L3. The water table at this site was very shallow (0.2-2.2 m below ground level) and nitrogenous fertiliser had been applied to the surrounding orchard in October/November which would result in these high concentrations. Subsequent samples from this site were around 2-3 g m^{-3}. Correlation coefficients of groundwater level with nitrate concentration for the individual sites ranged from -0.66 to 0.73 and no particular inference can be drawn from the data. Similar patterns were found for the other chemical species and indicate that groundwater levels were not the controlling or dominant factor for groundwater chemical concentrations.

The iron and manganese data showed considerable variation throughout the valley, with high levels in both occurring in the Millers Flat and Dumbarton areas. These indicate that groundwater in these areas was deoxygenated and probably confined. Elsewhere levels of iron and manganese were fairly low.

Table 4 : Summary of groundwater quality for each site in the Lower Clutha study area; mean concentrations with standard deviations in brackets.

Site Number	Distance from Roxburgh (km)	Conductivity ($mS\ m^{-1}$)	pH*	HCO_3 ($g\ m^{-3}$)	NO_3-N ($g\ m^{-3}$)	Cl ($g\ m^{-3}$)	SO_4 ($g\ m^{-3}$)	SiO_2* ($g\ m^{-3}$)
L1	36.3	15.0 (1.4)	6.2	34.2 (9.6)	0.8 (0.6)	11.0 (2.3)	21.5 (3.5)	7.4
L2	35.3	15.6 (1.1)		31.9 (7.4)	3.6 (1.0)	12.8 (1.5)	13.9 (1.5)	
L3	35.0	24.2 (8.6)		42.0 (18.1)	3.0 (4.5)	11.1 (6.0)	28.9 (15.3)	
L4	34.8	19.2 (1.8)	6.1	48.0 (9.9)	5.0 (1.8)	15.9 (1.3)	11.0 (3.3)	9.5
L5	25.3	19.3 (1.4)	6.4	71.1 (11.4)	1.8 (0.5)	15.2 (1.9)	8.2 (1.4)	9.7
L6	21.3	28.2 (3.1)	6.9	94.1 (16.3)	<0.2# (0.2)	21.5 (1.6)	23.0 (6.0)	9.5
L7	19.8	11.9 (1.7)	6.7	49.2 (10.6)	0.4 (0.4)	10.7 (2.4)	3.3 (1.1)	8.2
L8	16.5	25.7 (5.4)	6.6	76.9 (15.0)	2.1 (1.4)	28.0 (7.6)	11.0 (4.4)	7.5
L9	14.5	36.0 (3.9)	7.0	115.7 (25.6)	3.3 (1.7)	31.8 (4.9)	15.3 (3.3)	4.8
L10	14.3	40.7 (2.7)	6.8	136.4 (24.7)	4.6 (0.9)	31.3 (4.8)	16.4 (1.9)	8.0
L11	12.5	32.2 (2.7)	6.5	109.3 (17.1)	2.8 (0.6)	23.3 (3.1)	19.2 (4.5)	6.6
L12	12.4	11.3 (0.9)	6.6	40.2 (10.5)	0.6 (0.4)	12.4 (2.0)	4.7 (1.2)	5.2
L13	10.3	42.6 (5.9)	7.4	191.3 (46.3)	5.1 (0.7)	7.2 (2.3)	16.7 (3.1)	8.0
L14	5.4	33.0 (4.6)	6.9	132.1 (21.2)	<0.6# (0.6)	20.6 (5.4)	13.6 (4.8)	10.1

Table 4 (Contd)

Site Number	Na ($g\ m^{-3}$)	K ($g\ m^{-3}$)	Ca ($g\ m^{-3}$)	Mg ($g\ m^{-3}$)	Fe* ($g\ m^{-3}$)	Mn* ($g\ m^{-3}$)	NH_4-N ($mg\ m^{-3}$)	DRP ($mg\ m^{-3}$)
L1	11.2 (0.9)	2.2 (0.5)	10.0 (1.9)	3.9 (0.5)	1.0	<0.05	51 (62)	4 (3)
L2	11.6 (0.8)	2.8 (0.3)	10.5 (1.2)	3.8 (0.5)			15 (11)	6 (5)
L3	8.3 (3.7)	6.3 (4.6)	19.1 (7.9)	3.8 (2.1)			271 (214)	12 (26)
L4	16.1 (1.4)	1.6 (0.2)	12.0 (1.5)	5.2 (0.9)	0.5	<0.05	18 (11)	31 (10)
L5	15.7 (1.3)	1.8 (0.6)	14.1 (1.1)	5.3 (0.9)	0.4	<0.05	50 (72)	5 (5)
L6	22.5 (3.8)	3.6 (0.4)	20.1 (3.6)	7.1 (1.8)	0.5	<0.05	32 (27)	14 (21)
L7	10.3 (1.1)	1.9 (0.7)	8.7 (1.9)	3.5 (0.5)	3.8	0.21	33 (28)	15 (17)
L8	21.2 (4.6)	2.8 (0.6)	16.5 (3.2)	7.2 (1.7)	16.3	0.18	27 (31)	29 (16)
L9	23.0 (2.1)	3.2 (0.5)	33.8 (8.3)	7.6 (1.4)	31.5	0.82	50 (76)	2 (2)
L10	25.0 (2.1)	3.4 (0.3)	36.6 (7.1)	9.7 (1.1)	3.4	<0.05	12 (10)	14 (7)
L11	23.3 (2.4)	3.7 (0.9)	24.9 (3.4)	8.5 (1.3)	0.8	<0.05	30 (19)	6 (4)
L12	10.9 (1.0)	1.3 (0.2)	7.4 (0.8)	3.2 (0.5)	0.2	<0.05	19 (20)	17 (7)
L13	15.3 (2.5)	2.4 (0.4)	58.5 (14.2)	5.6 (1.5)	2.6	<0.05	33 (28)	5 (4)
L14	26.5 (5.3)	2.0 (0.4)	26.2 (5.2)	7.4 (1.6)	9.0	0.16	42 (47)	5 (7)

Note: * only analysed for July 1985 sampling occasion

sites L6 and L14 had 4 and 3 samples respectively with concentration analysed as less than 0.01 $g\ m^{-3}$ which is the specified detection limit of the method

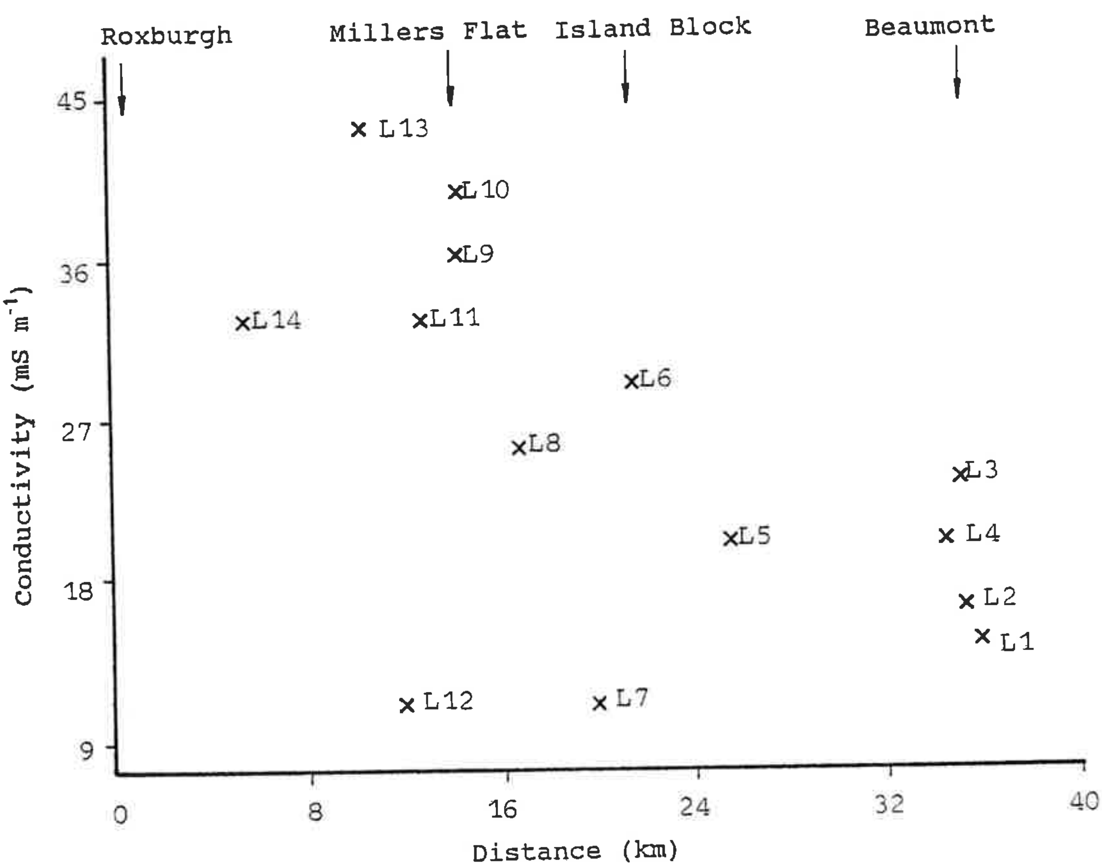

Figure 5 : Groundwater conductivity versus distance from Roxburgh Township

Dissolved reactive phosphorus levels were generally low and ranged from 2 to 31.5 mg m^{-3} with an overall mean of 12 mg m^{-3}. These levels are similar to levels found in the Upper Clutha Valley study area. Ammonium levels were extremely variable and site means ranged from 12 to 271 mg m^{-3}, with an overall mean of 50 mg m^{-3}. The high value of 271 mg m^{-3} at L3 was associated with the shallow water table and fertiliser application discussed above.

The microbiological analyses indicated no faecal or total coliform bacteria in any of the samples, suggesting that the groundwaters were free of any widespread contamination from sewage or animal wastes.

Temporal variation in groundwater quality

The values from all of the sites were averaged for each month and plots of nitrate. Conductivity and groundwater levels versus time are shown in Figure 6. The study period was atypically wet. Three rainfall stations within the study area (Roxburgh, Raes Junction and Beaumont) have sufficient length of record to justify comparisons with the study period. During the study period these stations received 163%, 165% and 150%, respectively, of mean annual rainfall. The main inputs of rainfall came in October and December 1982, and March, May and September 1983, with each of these months receiving more than double their normal rainfall. The groundwater level variation correlates well with these inputs. However, the conductivity and nitrate graphs do not show the same behaviour, with only the peak for these in may coinciding with the rainfall inputs and groundwater levels. These higher than average rainfall inputs may have disturbed any seasonal trends that would normally be present. The means and standard deviations from Table 4 indicate that while there was some temporal variation, the sites were generally well characterised by their means.

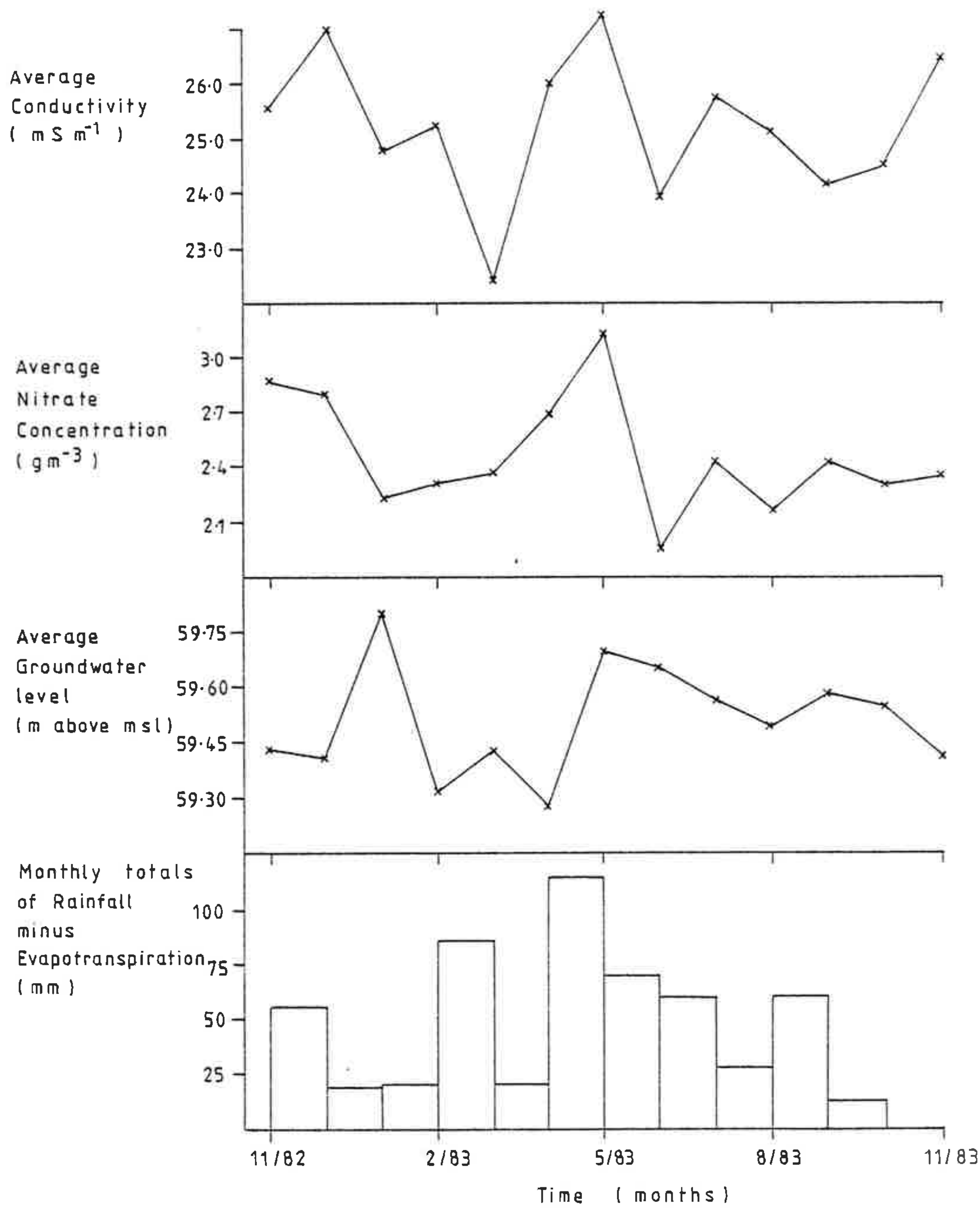

Figure 6 : Groundwater levels, conductivity, nitrate concentrations (average of Lower Clutha sites) and effective rainfall (average of 3 Lower Clutha rainfall stations) versus time from November 1982 to November 1983.

LIKELY EFFECTS OF POWER DEVELOPMENT ON GROUNDWATER QUALITY

(a) Upper Clutha Valley

The major effect of hydroelectric development on groundwater quality in the Upper Clutha Valley will be related to the degree to which there is accompanying increased irrigation. This may result in increased amounts of nutrients being leached into the groundwater system and from there, discharging into the newly formed impoundments.

Little detailed information is available on the interactions of land use practices, drainage and nitrate leaching losses in the area. Therefore, nitrate leaching loss data from Canterbury (Quin, 1977) were used in the calculations to predict future trends in nitrate levels in the Clutha groundwater system. Details of the calculations are available from the authors on request. A leaching loss for nitrate-N of 22.5 kg N ha^{-1} yr^{-1} was used for all non-irrigated land, 70 kg N ha^{-1} yr^{-1} for all existing irrigated land and 100 kg N ha^{-1} yr^{-1} for all predictive calculations, based on Quin (1977). Drainage due to irrigation was assumed to be 500 mm.

The calculations indicated that present nitrate-N levels of between 0.2 and 2.7 g m^{-3} could rise following irrigation to between 0.6 and 4.4 g m^{-3}. Site U10, which currently has a higher nitrate-N level (5.4 g m^{-3}) than other Upper Clutha sites, could increase to 8.0 g m^{-3}.

Phosphorus concentrations in the groundwater are not likely to increase because of increased irrigation. This is because the increased amount of phosphorus associated with increased stock faecal material would be adsorbed in the soil layer and would not leach through to the groundwater.

Some of the soils near Cromwell contain accumulations of soluble salts. A desk assessment, based on existing data, was carried out to determine the effect of irrigation of these soils on the quality of the Clutha River. It was considered that, under the progressive implementation of the irrigation schemes, leaching of the salts to the groundwater and into the river system would increase but not sufficiently to be a problem. However, if large quantities of water were applied to the area over a short period of time (e.g., 1 month), rapid leaching of salt could occur. With appropriate management, this problem is unlikely to arise.

(b) Lower Clutha Valley

Raised groundwater levels

Present long term groundwater levels are controlled by the Clutha River, and after construction of the dams, will be controlled by water levels in the impoundments.

The regression equation presented in a previous section indicates the present hydraulic gradient. There is no evidence to suggest that permeabilities would be significantly different in the newly affected areas and hydraulic gradients of around 3-5 m km^{-1} could be expected. The hydraulic relationship between the river and the groundwater system indicates that medium term operating ranges of 1 m could result in groundwater fluctuations of around 0.3 m, 500 m from the impoundments.

The raised groundwater levels may have a number of effects, including flooding of septic tank systems, "wet feet" for trees in orchards and pugging of fields. If groundwater rises into the soil layer, there may be a transient rise in groundwater nutrient concentrations due to a dissolution of soil nutrients. In this report only the effects of the proposed impoundments on groundwater levels and the implications for groundwater quality are considered. The physical effects of the raised groundwater levels will be dealt with in a separate report by Dunedin District Office of Ministry of Works and Development. Thus, the following comments deal primarily with the possible flooding of septic tank systems and the consequent effect on groundwater quality.

Effects of raised groundwater levels on groundwater quality

Except for Roxburgh Township, which has a sewage treatment plant, most households in the Lower Clutha Valley are served by septic tanks. If groundwater levels rise sufficiently, flooding of septic tank effluent disposal structures may occur with resulting unhygienic conditions and deterioration in groundwater quality. The likely impact of the four hydroelectric development options, described in the introduction, on septic tank flooding was considered. Because all the options would result in the same impoundment water levels above Beaumont, the impact assessment was done on a regional basis. An estimate of the number of households that may be affected was made based on maximum water levels for the proposed impoundments. One septic tank per household was assumed and the number of houses potentially affected was assessed from a 1 : 5000 map which had 5 m ground level contours. Houses were distinguished from other buildings using aerial photographs. Two levels of impact were considered: (a) total flooding, which would result in no further use of that septic tank, and (b) affected operation, defined as groundwater levels within 2 m of the ground level, which could result in unhygienic conditions and deterioration of groundwater quality. The 2 m distance would apply to shallow soakage structures, but if deeper boulder pits are used, a greater number of septic tanks could be affected.

Near the Rongahere area, options A and B would flood 3 septic tanks with the use of an additional tank affected by option B. Option C would not affect any septic tanks in this area and option D would affect two septic tanks. In the Beaumont area, 1 tank would be flooded and approximately 4 affected under options A and D. Under options B and C, essentially all the tanks would be flooded in this area and another 2 septic tanks of the remaining houses could be affected. In Island Block all septic tanks would be flooded or affected in all schemes and approximately 8 septic tanks could be affected in the Millers Flat area. Once more definite levels for the impoundments are known, more precise estimates of the number of tanks affected can be made, particularly in the Millers Flat and Beaumont areas.

These estimates indicate that there could be continuing problems under options A and D in the Beaumont area, and with all options in the Millers Flat area. The severity of the problems depends to a large extent on the type of drainage or soakage structure used for the septic tank. Boulder pits are frequently 5 m deep while soakage trenches are only 1 m deep. Thus rising groundwater levels are more likely to affect the boulder pit structures.

Two types of problem could occur. If the groundwater level rises into the soakage structure, the "biological mat" associated with the structure would probably break down, allowing the effluent to discharge directly into the groundwater. If the groundwater remains below the soakage structure, then the residence time of effluent in the unsaturated zone below the soakage structure will be reduced, although the biological layer should remain intact. Because septic tank effluent will affect the top of the groundwater system, the depth at which surrounding wells are screened will be a factor in the resulting quality of drinking water. Deeper wells are generally associated with better water quality. No bacterial contamination was detected when the drinking water wells were sampled, but it would be advisable to monitor for bacterial contamination as the impoundments fill.

Increased irrigation

There is a small amount of private irrigation at present, with some additional water use by orchardists for frost fighting. Raised groundwater levels may reduce pumping costs and make irrigation more economic. There are possibilities for using the water from the proposed dam at Dumbarton Rock to provide irrigation for the Teviot and Ettrick Flats. Irrigation would result in increased leaching of soil nutrients, particularly nitrate. This may result in increased nitrate concentrations in the groundwater in this area.

SUMMARY AND CONCLUSIONS

The groundwaters in both the Upper and Lower Clutha Valleys were generally of a high quality for drinking purposes with mean nitrate-N levels ranging from < 0.2 to 5.3 g m^{-3}. There was no evidence of bacterial contamination in the wells tested in the Lower Clutha Valley. Nitrate concentrations were generally low as were ammonium and phosphorus concentrations. The groundwater system in the valley is not continuous and there is no noticeable accumulation of nutrients and salts with increasing distance from the source of recharge. A major influence on total ion content is the climatic trend, from humid near Hawea to semi-arid near Cromwell in the Upper Clutha Valley, and from humid near Beaumont to sub-humid near Roxburgh in the Lower Clutha Valley. Another influence is the control due to mineral equilibria. This is seen in the calcium and TDP concentrations in the Upper Clutha Valley. There was some temporal variation of groundwater quality which was largely correlated with rainfall inputs, but long term seasonal variations could not be determined.

In the Upper Clutha study area, increased irrigation accompanying power development may increase nitrate concentrations in the underlying groundwater, but they are unlikely to rise above WHO recommended limits for drinking water, because the short distances of groundwater travel would preclude significant nitrate accumulation. Irrigation may cause a temporary increase in salt concentration in the groundwater near Cromwell but this is not likely to be a problem under careful management, which would consist of avoiding the application of large volumes of water over a short time period.

In the Lower Clutha study area the major effect on groundwater would be the increase in groundwater levels in the vicinity of the impoundments. These levels may fluctuate in response to operating conditions. Raised levels may cause some problems such as flooding of septic tanks and water logging of ground surfaces. The flooding of septic tanks or their soakage areas could cause some deterioration of groundwater quality in more densely populated areas, such as Millers Flat, but this may only be transient. Longer term problems would be related to a higher water table decreasing the effective effluent treatment time and distance. A transient increase in mineralisation of groundwater may result from soil leaching and interception of percolating drainage by rising groundwater levels during impoundment filling.

A survey to identify those wells and septic systems likely to be affected by impoundments will be necessary once a development scheme is chosen and monitoring of drinking water bores for coliform bacteria should be carried out during impoundment filling.

ACKNOWLEDGEMENTS

The authors wish to thank Mr G Stewart, Cromwell Project Office, for collecting the samples and supplying background information for the Upper Clutha study area, and the staff of Dunedin District Office for sample collection and information for the Lower Clutha study area. Thanks are also due to the householders of the Upper and Lower Clutha Valleys for their co-operation in the sampling programme, Mr L W Sinton for advice on the study, Mr P H Woods and Mr G J Tod for the laboratory analyses, and Dr B F Quinn, MAF, Hamilton, and Dr C D Stevenson, DSIR, Wellington, for valuable comments on the presentation of this material.

FURTHER INFORMATION

Further information concerning this area and the likely impacts of hydroelectric power developments can be found in the following internal reports of the Hydrology Centre, Christchurch:

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McCallion, R.F. 1982 : The likely effects of the proposed irrigation scheme in the Upper Clutha Valley - a second assessment. Hydrology Centre Internal Report WS 557. Unpublished.

Smith P.J.T. 1984 : Relationships between groundwater and river levels : Millers Flat region. Hydrology Centre Internal Report WS 902. 7p. Unpublished.

(Copies of these reports may be obtained by writing to: Technical Information Officer, Hydrology Centre, P O Box 22037, Christchurch.)

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APPENDIX 1 : DESCRIPTION OF UPPER CLUTHA WELL SITES

Site Number	Total Well Depth (m)	Depth of Sampling (m)	Pump	Irrigation
U1		Sample from Lake		
U2	27	NA	Yes	No
U3	NA	NA	Yes	No
U4	NA	NA	Yes	Yes
U5		Sample from Spring		Yes
U6	69	68	Yes	No
U7	14	13	Yes	No
U8	15	10	Yes	No
U9	NA	5	Yes	No
U10	37	NA	Yes	Yes
U11		Sample from Spring		Yes
U12	NA	NA	Yes	Yes
U13	35	20-35	Yes	Yes
U14	NA	NA	Yes	Yes
U15	32	25	Yes	No
U16	NA	NA	Yes	No
U17	50	NA	Yes	No
U18	27	18	Yes	Yes
U19	NA	NA	Yes	Yes
U20	NA	NA	Yes	Yes
U21		Sample from Spring		No

Note: NA = Data not available

APPENDIX 2 : DESCRIPTION OF LOWER CLUTHA WELL SITES

Site Number	Diameter of Well (m)	Total Well Depth (m)	Mean Depth To Groundwater (m)	Pump
L1	1.000	5.0	1.9	Yes
L2	0.050	5.7	4.6	Yes
L3	0.100	2.5	1.1	No
L4	1.200	7.3	6.2	Yes
L5	0.100	4.5	1.4	Yes
L6	0.100	13.1	-0.4	No
L7	0.100	15.0	1.1	No
L8	0.075	6.0	4.3	No
L9	0.500	10.2	7.0	Yes
L10	0.100	9.8	8.5	Yes
L11	0.075	9.8	9.0	Yes
L12	Sample from Spring : Water Level from Open Well			
L13	0.100	19.0	9.7	No
L14	0.100	NA	3.9	No

Note: NA = Data not available

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