Central Southland Plains Groundwater Study;

Results from Field Surveys & Assessment.

Southland Regional Council
August, 1998

Private Bag, Invercargill, NZ.

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Executive Summary.

The Central Southland Plains, lying between the Aparima and Oreti Rivers and south of the Tauringatura Hills, is underlain by a relatively thin veneer of alluvium. The alluvium hosts a variety of gravelly unconfined aquifers. Beneath the alluvium confined and semi-confined aquifers of low to moderate yield are found, hosted in lignite measures and limestone.

On the whole, the alluvial aquifers are recharged by precipitation excess, mostly during the period May to October each year. Estimates of annual mean groundwater recharge rates varying between 200 and 440 millimetres are made using baseflow analysis and chloride concentration ratios. Infiltration of excess precipitation takes with it, dissolved contaminants such as nitrate nitrogen into the underlying aquifers and ultimately surface water, into which the shallow groundwater discharges.

Apart from the area of Oreti Plains district between the Hundred Line and Ryan Road, the nitrate nitrogen status of the Central Southland Plains groundwater was found to be impacted, but not significantly elevated. Evaluation of chloride in rainwater and groundwater in the Central Southland Plains, from near the coastline to the Tauringatura foothills reveals a significant trend of declining concentration. This is suggestive of common recharge processes and of groundwater recharge making up about 40% of precipitation.

1. Introduction.

The Central Southland Plains, for the purposes of defining this study's extent, are bounded by the Oreti River to the east, and the Aparima River to the west. South Hillend marks the northern extent of the study area, which extends southwards to the sea. This groundwater study intends to provide an outline of the present state of the area's groundwater resource, particularly its water quality.

In response to a well water quality complaint received in early 1996 from an Oreti Plains' resident, a group of water wells having elevated nitrate nitrogen concentration (>11.3 $gNO_3\text{-}N/m^3$) were found. A follow-up soil and groundwater study (Rekker and Greenwood, 1996[1]) found distinct zones of elevated groundwater nitrate-N in the underlying alluvial, unconfined aquifer. The probable cause of these zones' elevated nitrate-N concentration lying significantly above the regional drinking water average was considered to be the unique macro-pore drainage of the local clay soil and intensive pastoral agriculture practised in the Oreti Plains. One of the recommendations of the 1996 study was for broader focused water quality surveys to be undertaken of Southland's unconfined aquifers under agricultural land, particularly for nitrate-N. In implementation of this recommendation, a region-wide survey of such a nature is underway this 1997 – 1998 local body financial year to establish benchmarks of the general state of the resource. The primary objective of this study of the Central Southland Plains is to assess the present water quality and vulnerability of the study area.

Southland Region has scant knowledge of its' groundwater resource. This fact is noted in the proposed regional policy statement by Southland Regional Council. A scoping study with the objective of identifying the existing information and future information needs relating to the region's groundwater resource (Rekker, 1994[2]), detailed the extensively used unconfined aquifer system and lightly used confined aquifer resource, usually found within the sedimentary basins intervening basement blocks. The confined aquifers within Tertiary lignite measures predominates in Eastern Southland and have been characterised in several reports (Applied Geology *et al.*, 1986[3]; Isaac & Lindqvist, 1990[4]; and Rekker, 1996[5]). Anecdotal information supplied by local drilling contractors have alluded to a confined or semi-confined limestone aquifer which is used for domestic and agricultural water needs in the lower Aparima catchment area (Maurice Pascoe, McNeill Drilling Co. Ltd, *pers. comm.*, September 1994). A similar sandy limestone aquifer is referred to in an unpublished report to the NZ Forest Service by the Geological Survey (Woods, 1950[6]) and a Tertiary limestone formation is mapped in this general area (Woods, 1966[7]). A secondary study objective is to examine the nature and role of this confined aquifer groundwater resource.

1.1 Method.

The Central Southland Plains Groundwater Study has entailed gathering what little literature information on the area from existing publications, making field visits and spatial analysis of the derived information.

1.1.1 Literature.

The Central Southland Plains has scant available information on geology or groundwater conditions that could be used to support this study. The lignite resource investigations of the 1970's and 1980's did not include the plains west of the Oreti River. Mineral drilling has tended to be restricted to a handful of wildcat petroleum exploration drill holes of the 1960's (Browning, 1965[8]; and Browning, 1966[9]). Some formalised groundwater investigation was done in the Thornbury area by New Zealand Forest Products Ltd in 1976 and is recorded in correspondence with the Dunedin office of NZ Geological Survey whom assisted with geological interpretation (Ian Turnbull, *written communication*, April 1996; IGNS Techfile E46/410). Only indicative groundwater information is provided on the 10 separate drill holes logged in the area.

The Tertiary sediments of the area have been studied by geologists without any direct attention as to groundwater resources contained within them. The geological knowledge is found in the geological sheet map (Wood, 1966) and a summary of stratigraphy (Turnbull *et al.*, 1989[10]).

Some records of Middlemiss Drilling Company of Invercargill were preserved in 1976 by a Mr B Dreaver of Southland Catchment Board. Approximately 35 partial bore logs were identified for Central Southland Plains from 1962 to 1976 in this manner. Information on 38 water bores drilled by McNeill Drilling Company Ltd in the area was obtained for the period 1990 to 1994.

A Southland Regional Council commissioned groundwater quality investigation (Rekker and Greenwood, 1996) considered the potential causes of the occurrence of elevated groundwater nitrate concentration in parts of the Oreti Plains district. This study involved extensive groundwater sampling, water table surveying and soil property evaluation.

1.1.2 Field Visits.

Field visits began in January 1998. Twenty-nine separate water bores and wells were visited in the course of three days of field visits. Samples of groundwater were taken in each instance and subsequently analysed for a full range of dissolved constituents and parameters. Where possible, details of the depth, water level and construction of the water bore or well were obtained. All too often, these details could be obtained only partially, or not at all due to lack of access to the wellhead.

1.1.3 Water Analysis.

Samples taken during field visits were taken in separate bottles for dispatch to the Southland Regional Council and ChemSearch Laboratories. The SRC laboratory undertook all nutrient and iron analysis, while a full cation / anion analysis was undertaken by the ChemSearch laboratory attached to Otago University.

Details of analysis are given in the table below.

Analyte / Parameter	**Laboratory**	**Method**	**Resolution/ Detection Limit**
pH	Field measurement	Field meter	± 0.1 pH unit
Electrical conductivity	Field measurement	Field meter	± 5 μS/cm
Nitrate nitrogen	SRC Laboratory	ALPHA 4500-NO3	± 0.2 $gNO_3\text{-}N/m^3$
Ammoniacal –N	SRC Laboratory	ALPHA 4500-NH3	± 0.01 $gNH_3\text{-}N/m^3$
Dissolved Reactive Phosphorous (DRP)	SRC Laboratory	ALPHA 4500-P	± .005 $gDRP/m^3$
Calcium (Ca^+)	ChemSearch	ALPHA 3111B	> 1.0 g/m^3
Magnesium (Mg^+)	ChemSearch	ALPHA 3111B	> 0.4 g/m^3
Sodium (Na^+)	ChemSearch	ALPHA 3111B	> 0.5 g/m^3
Potassium (K^+)	ChemSearch	ALPHA 3111B	> 0.5 g/m^3
Alkalinity (HCO_3^-)	ChemSearch	ALPHA 2320 B	> 1.0 g/m^3
Chloride (Cl^-)	ChemSearch	ALPHA 4500-Cl	> 0.6 g/m^3
Sulphate (SO_4^-)	ChemSearch	USEPA 375.4	> 0.2 g/m^3
Total Iron	SRC Laboratory	HACH Kit	> 0.1 g/m^3

All cation / anion balance results fell within an acceptable 12% error, excepting one sample taken from a bore with suspected localised contamination.

1.1.4 Data Analysis.

Standardised analysis of study data modelled on the approach taken with the Oreti Plains study (Rekker and Greenwood, 1996) will be employed in this study. Hydro-chemistry is used to differentiate various chemical provinces and also to provide information on recharge process by mass balance of atmospheric loading. Correlation of hydrogeological conditions and hydro-chemistry is attempted.

Mapping of pastoral land use is also attempted using existing information on its distribution. Interactions between surface water and groundwater are considered.

2. Physical Setting of the Central Southland Plains.

Topographically, the Central Southland Plains, set between the north-south flowing Aparima and Oreti Rivers, have their northern bound against the foot-hills of the Tauringatura Hills. The Plains' elevation profile grades approximately southeast towards the sea. The bed gradient of the Aparima River is steeper, and the bed elevation higher than the Oreti River for the same latitude. This results in an oblique slope in the surface of the Plains to the southeast. In the mid-south of the Plains, two areas of raised terraces are found in the Wrights Bush and Isla Bank districts. These terrace blocks are divided by the Waimatuku catchment which drains the central part of the Plains directly out to the sea.

2.1 Geology.

The pre-Tertiary basement of the Plains area is composed of the full range of basement lithologies present in the Aparima – Oreti catchment. The northeast of the Plains is underlain by the southern limb of the Southland Syncline composed of Triassic – Jurassic indurated (hardened) marine sediments dominated by sandstone and siltstone. The southwest of the Plains is underlain by Paleozoic volcanic and intrusive rocks. The pre-Tertiary basement geology is largely unimportant to this study since they are overlain by hundreds of metres of Tertiary marine and terrestrial sediments throughout the study area.

2.1.1 Tertiary Sediments.

The Tertiary sediments underlie the full extent of the Central Southland Plains. A deep drill hole on the banks of the Oreti River near Winton found a thickness of 1,034 metres of Tertiary sediment overlying the Permian – Jurassic basement (Browning, 1966). Based on gravity anomalies, it is believed that at least this thickness of sediments underlie the rest of the Plains.

The sediments are comprised of two main groups:

1. Marine shelf deposits composed of sandy limestone, glauconitic sandstone and mudstone. These deposits have stratigraphic correlation with the Forest Hill Formation of mid-Miocene age.
2. Terrestrial riverine deposits composed of quartz sands, clays and lignite seams. These late Miocene deposits may be younger than the marine deposits and overlie them.

The Plains' Tertiary deposits are mildly warped by a synclinal fold, which results in the Forest Hill limestones being found outcropping in the western <u>and</u> eastern margins of the Plains. The lignite measures tend to be found beneath the alluvium in the central and southeastern parts of the basin.

2.1.2 Quaternary Deposits.

These deposits have not been explicitly described except for the sub-division provided by the southern region District Geologist (Wood, 1996) in the geological map sheet. The early Quaternary gravels are mapped on degree of weathering and topography. These are the "Wn-c…very weathered rusty-brown, slightly warped and faulted gravels" of Wood (1966). In turn, younger generations of gravel deposits and terraces are divided in "h1" and "h2", corresponding to the penultimate and last glacial outwash periods, respectively. Apart from the observation of the early Quaternary gravel deposits, further division of the Quaternary gravels is less clear-cut than for the Mataura Valley where distinct flights of terraces can be profiled down the valley.

Wood (1966) maps the Quaternary terraces at broad scale. The Oreti Plains – South Hillend – Centre Bush triangle is mapped as "h1". Two separate blocks of "Wn-c" early Quaternary gravel deposits as two separate blocks are mapped in the Ringway Ridges, Isla Bank and Flints Bush districts, and in the Otahuti, Spar Bush and Waianawa districts. The shallow valley drained by the Middle Creek, Ayr Creek and Waimatuku Stream, lying between these blocks is mapped as "h1". All remaining Plain surface is mapped as "h2", or the 18-metre height marine terrace defined as "h60" (average 60 feet above sea level) towards the coast.

Generalisations that may be made drawn concerning the overall composition of the Quaternary gravel deposits are as follows:

- Grain-size is generally lower than for the Mataura Valley,
- In even the younger gravel deposits, the gravels are 'dirtier' than for their age-equivalent in the Mataura Valley, resulting in the gravels being "silt-bound" or "clay-bound",
- There are fewer quartz gravel and sand grains in the gravels, which contrasts with the quartz dominated Mataura catchment.

The "h2" deposits give the appearance that the Aparima River has flowed across the Central Southland Plains into the present Oreti River. Terrace Creek provides a perfectly graded path for the Aparima River to join the Oreti above Northope. McIntosh *et al.* (1990[11]) give evidence that the Oreti River headwaters were captured by the Mataura River forming the combined "Lumsden River" and flowed to the sea through Toetoe Bay. A similar shifting of river outlets may have occurred in the case of the Aparima and Oreti Rivers.

Information from water well drilling indicates that the Quaternary alluvium is comparatively thin. Depths up to 24 metres below ground are recorded in drill holes presumed to be penetrating the Quaternary gravel deposits. In fact, the Quaternary gravel deposits make up a simple thin veneer over the Tertiary sediments without any indications as to the presence of deepened alluvial basins. This has important implications for the pattern of groundwater occurrence and availability outlined further below.

2.2 Soil Classes and Properties.

The nomenclature of the New Zealand Soil Map series, which is carried over into the New Zealand Land Resource Inventory is used in this study. The principal soil classes of the Central Southland Plains are listed as follows:

Yellow-brown Earths Intergrade.

- Drummond (80)
- Glenelg (80a)

Yellow-grey to Yellow-brown Earths Intergrade.

- Pukemutu (25c)
- Aparima (26)

Lowland Yellow-brown Earths.

- Waikiwi (33)
- Mokotua (43d)

Gley Soils.

- Dacre (89f)

Organic Soils.

- Otanomomo (87)
- Invercargill (86c)

Recent Soils.

- Mataura / Tuatapere (98f / 98g)
- Makarewa (90f)

The soils approximately follow the patterns of surface geological deposits.

1. The “Wn-c” early Quaternary terrace correlate with the Aparima and Waikiwi soil classes,
2. The yellow-brown earths intergrades of Drummond and Glenelg correlate with the extent of the “h2” terrace,
3. The “h1” terrace in the Oreti Plains – South Hillend – Centre Bush triangle correlates closely with the extent of the Pukemutu soil class.
4. Recent soils correlate with modern flood-plain alluvial deposits.

In very general terms, the younger the deposit, the thinner the covering soil. This is the case for the highly variable Recent soil classes, which have formed on old river flat surfaces. The Recent soil class tends to be thin and stony, and well drained. The

Pukemutu class soil has been noted as ‘clay’ soil with an inherent clay loam and blocky structure. This structural pattern and the tendency for macro-pore formation during the drying cycle is implicated in enhanced bypass infiltration of soil drainage (Rekker and Greenwood, 1996). The correspondence between soil class distribution and landform are illustrated in the figure overleaf.

2.3 Surface Water Hydrology.

The study area margins are defined by the Aparima and Oreti Rivers.

2.3.1 Aparima River Hydrology.

Hydrological statistics on the Aparima River at Thornbury recorder have been provided by Southland Regional Council’s hydrology section. The period 1986 to 1998 is covered.

	Discharge (m^3/s)
Mean Discharge	26.14
Median Discharge	16.09
Highest Flood Recorded (1986 – 1998)	935.5
Low Flow with 10 year Return Period (7d)	2.63
Low Flow with 25 year Return Period (7d)	2.05

Few significant streams or creeks enter the Aparima River from the Central Southland Plains.

2.3.2 Oreti River Hydrology.

The hydrological statistics for the Oreti River at Riverton Highway Bridge are given in the table below (Riddell, 1990[12]).

	Discharge (m^3/s)
Mean Discharge	45.6
Median Discharge	31.2
Flood with 10 year Return Period	1,562
Flood with 100 year Return Period	2,514
Low Flow with 10 year Return Period (7d)	3.60
Low Flow with 100 year Return Period (7d)	1.90

Figure 1 Distribution of soil classes on the Central Southland Plains

The Oreti River can be divided into the headwaters north of the crossing of the Southland Syncline, and the tributaries and mainstem south of the structural gap. The majority of the catchment's streamflow accrues upstream of Lumsden where the Oreti River crosses the structural high joining Tauringatura Hills and the Hokonui Hills. The lesser tributaries of the Makarewa and Waihopai Rivers join the mainstem in its tidal reaches. From the Central Southland Plains, Bog Burn, Terrace Creek and Waianawa Stream join the Oreti River.

2.3.3 Waimatuku Stream Hydrology.

The Waimatuku Stream drains a low gradient area of farmland without hill country headwaters. The catchment occupies about half of the Central Southland Plains area. Little is known concerning the hydrological statistics due to the absence of hydrological recording. However, a tributary of Waimatuku Stream, Middle Creek has been subject to continuous recording for the period 1970 to 1976 by the Water & Soil Directorate of the Ministry of Works & Development. The hydrology has been examined in the course of the Oreti Plains groundwater study (Rekker and Greenwood, 1996) to evaluate the transportability of the information to the rest of the Central Plains.

The table below summarises the streamflow – baseflow analysis for the 7 years examined.

	Mean Annual Flow and Equivalent Depth Values			
Middle Creek @ Otahuti	**Streamflow**	**Baseflow**	**Total flow**	**Surface Runoff**
Year	(litres/second)	(mm/yr)	(mm/yr)	(mm/yr)
1970	244	178	281	103
1971	253	178	292	113
1972	524	343	603	260
1973	120	89	138	49
1974	138	118	159	41
1975	279	233	334	101
1976	286	202	329	127
Mean	**263**	192	305	113

One of the difficulties acknowledged in assessing the transportability of this information is the uncertainty of catchment boundaries in such a low gradient setting and the high potential for groundwater by-pass of the recorder site (David Murray, *pers. comm.*, April 1997).

2.3.4 Precipitation & Evapotranspiration.

Climate statistics are taken from the Winton climate station. Mean precipitation and evaporation data for the period of 1967 to 1984 (NZ Meteorological Service, 1986[13]) are tabled below:

Month	**Mean Precipitation (mm)**	**Mean Evapotranspiration (mm)**	**Surplus (+) / Deficit (-)**
January	104	120	-16
February	57	93	-36
March	83	70	+13
April	81	40	+41
May	99	22	+77
June	65	12	+53
July	60	15	+45
August	59	30	+29
September	77	52	+52
October	73	84	-11
November	56	106	-50
December	86	120	-34
Yearly Mean	900	764	

This water balance uses an inferred available soil - water capacity of 160 millimetres. The resulting annual pattern of mean precipitation shows that rainfall is reasonably evenly spread throughout the year. Evapotranspiration, on the other hand, varies considerably through the year as the pattern of monthly water deficit and surplus shows. This pattern suggests that most runoff and groundwater replenishment occurs in the water surplus months of May to September.

This pattern of precipitation surplus is reflected in the pattern of streamflow in creeks and streams draining the Central Southland Plains, as is demonstrated in the figure below.

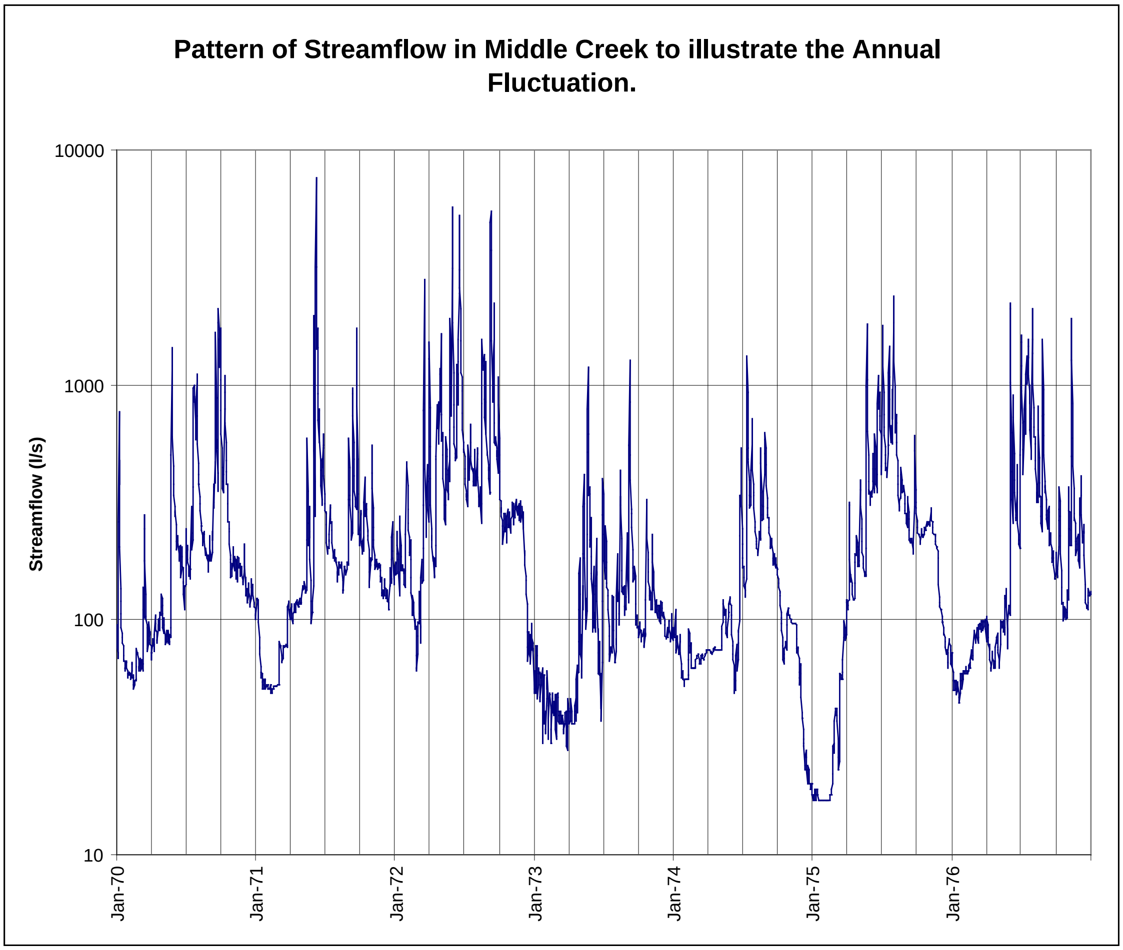

Figure 2 Annual pattern streamflow in Middle Creek, Central Southland Plains.

Precipitation is in surplus for the period May to November and this is the period of higher than average streamflow and the majority of groundwater recharge.

2.3.5 Baseflow and Interflow.

The Central Southland Plains have a unique setting with respect to surface and ground water hydrology. The Plains are of very low gradient, which has required extensive land drainage to allow grazing land use since the 1870's. Land drainage involves the excavation of creeks and ditches to improve drainage efficiency. To drain soil effectively, farm ditch digging and tile drain laying are required to convey water to the surface water network. This fundamentally alters the hydrology of the Plains. In place of the peat bog hydrological characteristics it replaces, the artificial drainage network intercepts a large part of the excess precipitation and diverts it rapidly into the surface water network.

With the exception of Bogburn, which has headwaters in the Tauringatura foothills, all streams and creeks on the Central Southland Plains rise in the low relief area of the Plains. This results in the streams and creeks lacking hill country headwaters, as is more often the case with Southland catchments. This results in the streams, almost entirely, draining moderate to high intensity agricultural land with little dilution of water quality from low intensity headwaters. The streams and creeks are more likely to be affected by interaction with underlying groundwater of unconfined aquifers throughout their entire course. This setting makes it more probable that infiltration and seepage of water takes place between the unconfined aquifer and the creek as a function of stream gradient, bed conductance and water table fluctuation through the seasonal cycle. The degree of communication between surface and groundwater that this setting implies makes the distinction between groundwater and baseflow in creeks less significant.

2.4 Hydrogeology.

This section on Hydrogeology integrates much of the preceding information on geology and recharge into more of a focus on groundwater processes. In general terms, very little is known specifically concerning the hydrogeology of the Central Southland Plains. A water table survey and pumping test were conducted as part of the Oreti Plains groundwater study in 1996.

2.4.1 Water Table.

A survey of 28 bores / wells in the Oreti Plains district measuring the depth to water table conducted in April 1996 found the mean depth to be 3.0 metres below ground level. In low-lying areas, the water table could rise as high as 1.1 metres below ground level. The survey included correction of water table depth to elevation using GPS surveying. The resulting contoured water table map is shown below.

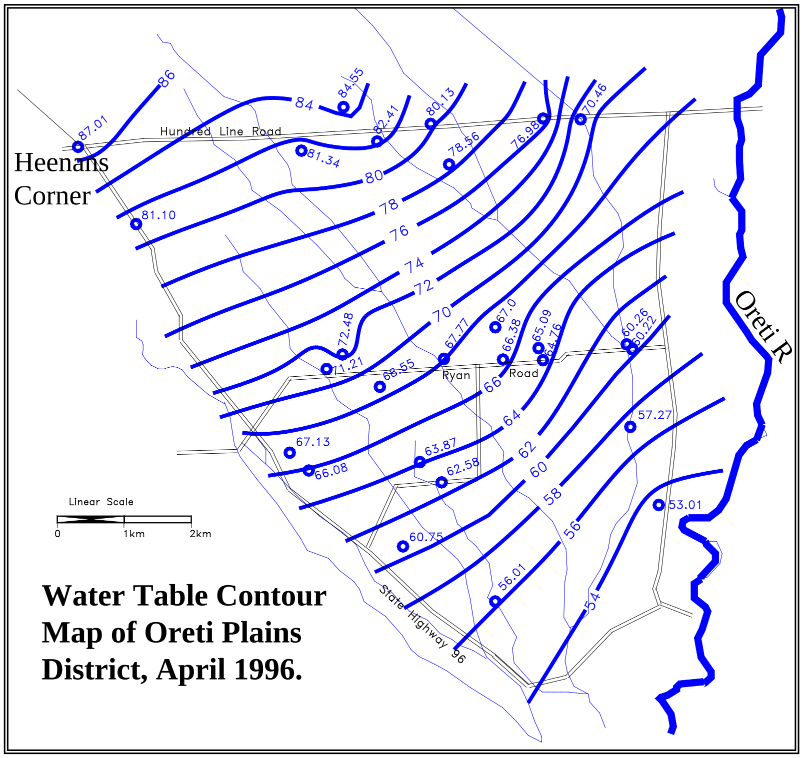

Figure 3 Map of water table contours drawn from measurements of depth to water table in bores and wells tapping the unconfined aquifer beneath Oreti Plains.

Little information of as high quality has been obtained in the current survey. Less wellhead access was available for measurement of water table depth, nor was any surveying of bore collar elevations undertaken. A few of the drilling records contain depth to water level. The mean depth to water table in 29 drilling records distributed over the full extent of the Plains is 3.1 metres below ground, with a standard deviation of 1.6 metres. This indicates that the water table follows the land surface, and that groundwater flow is likely to be sub-parallel to surface water drainage. This fits with the pattern of baseflow observed in sections above.

2.4.2 Aquifer Properties (Unconfined Alluvium).

The aquifer properties of the Central Southland Plains unconfined aquifers have not been tested to any great extent. Even lithology is not well known, there being no good quality recording of drilling information. Analysis of step drawdown tests undertaken in November 1964 and February 1965 in the Waianawa district derives an estimated transmissivity of only 4.5 and 4 m^2/d, respectively. The general pattern, which is discernible, is of low permeability (2 – 10 m/d) and thin saturated thicknesses (5 metres to, at most, 20 metres). A pumping test was undertaken on Ryan Road, Oreti Plains (Rekker, 1996). This test derived a transmissivity of 170 m^2/d for the silty gravel deposits found there. This is a moderate to low transmissivity for Quaternary alluvium.

Such low permeabilities in gravel alluvium are possibly explained by the general drilling observation that the gravel contains a significant concentration of fine sediment in the silt and clay range. Fine material has the effect of clogging the interstitial pore space and significantly inhibiting permeability to groundwater. Storage properties have not been determined in any known test. A value of about 0.10 is assumed, based mainly on lithology.

2.4.3 Aquifer Properties (Confined Tertiary Sediments).

Some hydrogeological testing of the inter-seam clastic horizons (sandstone) within the lignite measures at Waituna (Applied Geology *et al*., 1986[14]) and Morton Mains (Rekker, 1996). The permeability in both pumping tests lay in the range given below:

Waituna Pumping Test (Applied Geology *et al*., 1986)	**Middle Lignite Measure Aquifer**	**Lower Lignite Measure Aquifer**
Horizontal Permeability (K_H, in m/d)	4.3	1.7
Vertical Permeability (K_V, in m/d)	0.008	0.007
Transmissivity (m^2/d)	80	100
Storage Coefficient (S, dimensionless)	0.001	0.001
Characteristic Length (Leakance, in m)	680	965
Vertical Flow Resistance of lignite seams (d)	6,000	9,300
Depth to Top of Aquifer (m BGL)	57	85
Morton Mains Pumping Test (Rekker, 1996)	**Lower Lignite Measures**	
Horizontal Permeability (m/d)	1.4	
Transmissivity (m^2/d)	21.5	

Dairy farm units sometimes resort to the more expensive option of drilling between 60 – 90 into the lignite measures to obtain higher yields of groundwater than are available in the unconfined alluvium. A similar situation was found in the upper Waihopai catchment (Rekker, 1996).

In the south-west of the Central Southland Plains, namely in the districts of Thornbury, Isla Bank and Ringway Ridge, the Tertiary sediments beneath low yielding gravel deposits are sandy limestone of the Forest Hill Formation. From 1990 – 1994, six bores of 4-inch diameter were drilled into sandy limestone within this general area by McNeill Drilling Company Ltd (Maurice Pascoe, *pers. comm.*, September 1994). The drillers perceived the limestone to have a higher yield than the overlying silty gravel. The highest yield delivered from a 4 inch bore tapping the sandy limestone (without a screen) was 1.8 litres per second. This is equivalent to the yield provided by a moderate permeability material. The higher yield may in fact be due to the greater depth allowed for pump installation and allowance for drawdown, rather than a significantly higher permeability. There is no source of information on the mode of groundwater occurrence within the sandy limestone. Frequently, flow of groundwater within limestone is dominated by water movement along joints and dissolution voids.

2.4.4 Hydro-chemistry.

By way of background on the quality of the unconfined aquifers, information derived in the Oreti Plains groundwater study is repeated here.

The ionic hydro-chemistry is summarised in the Schoeller plot below.

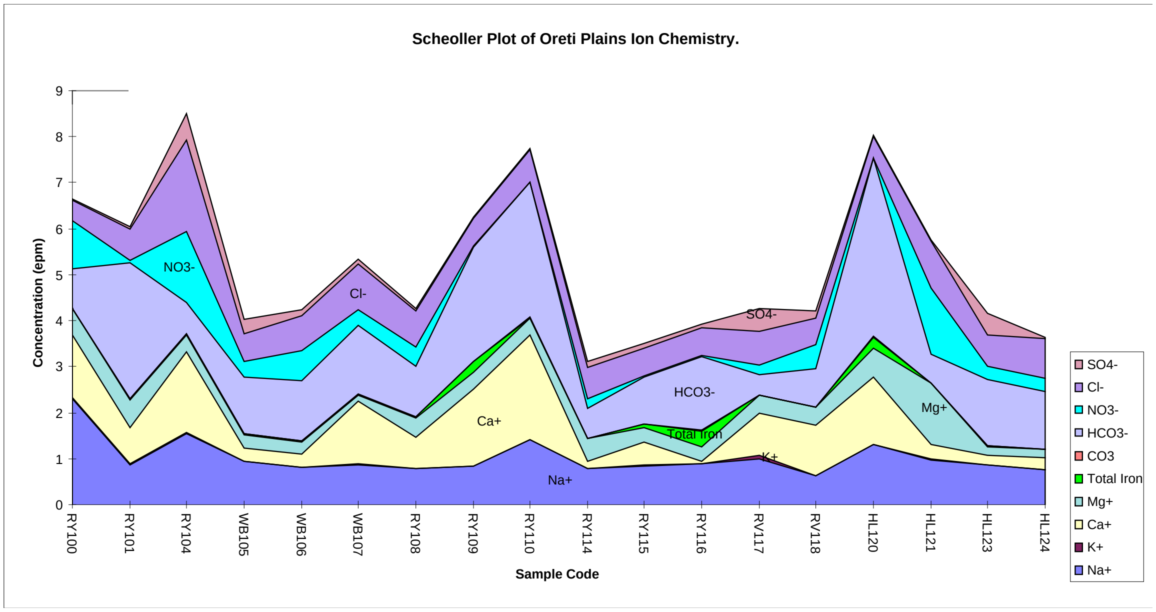

Figure 4 Schoeller Plot of major ion chemistry in shallow to medium depth (<15 metres BGL) groundwater. Seventeen groundwater samples and one creek water sample are displayed to provide representative chemical profiles. The plot is grouped with anions (SO_4^- to HCO_3^-) overlying cations (Total iron to Na^+).

In general, the water type is sodium chloride type and is reasonably dilute for groundwater. Some samples are elevated with respect to nitrate or alkalinity, which balanced by the paired ions. The elevation of some groundwater ionic concentrations is reflected in electrical conductivity values as the bar graph below shows.

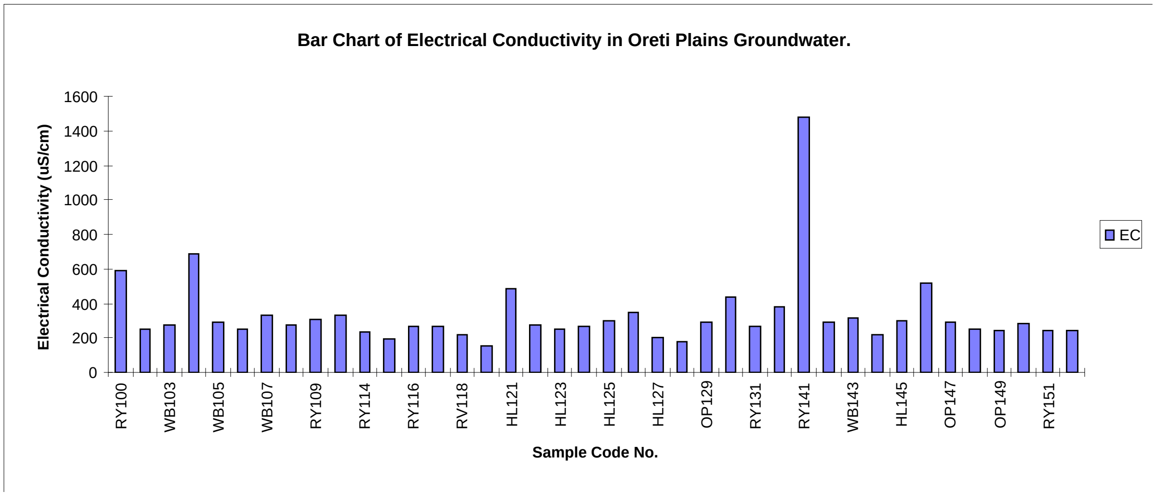

Figure 5 Distribution of Electrical Conductivity in Oreti Plains groundwater. The mean electrical conductivity measurement is 330 μS/cm.

Overall, hydro-chemistry in the Oreti Plains district was characterised by two divergences from the general pattern.

- Significant agricultural influences, due probable to bypass infiltration of high strength soil leachate. This results in elevated nitrate, ammonia and ions characteristic of dung and urine breakdown products,
- Elevated bicarbonate concentrations compensating for calcium and sodium cation abundance, especially in deeper bores. This is inferred to be due to significant water – rock chemical interaction leading to dissolution of minerals, or the influence of heavier than ambient application of soil treatment such as lime and gypsum.

The primary contaminant initiating the groundwater study was nitrate. The areal distribution of elevated nitrate in unconfined groundwater at Oreti Plains proved to be very ‘patchy’ with isolated hot spots of concentrations above the drinking water standard. The bar graph below shows the results for nitrate nitrogen determined in 1996.

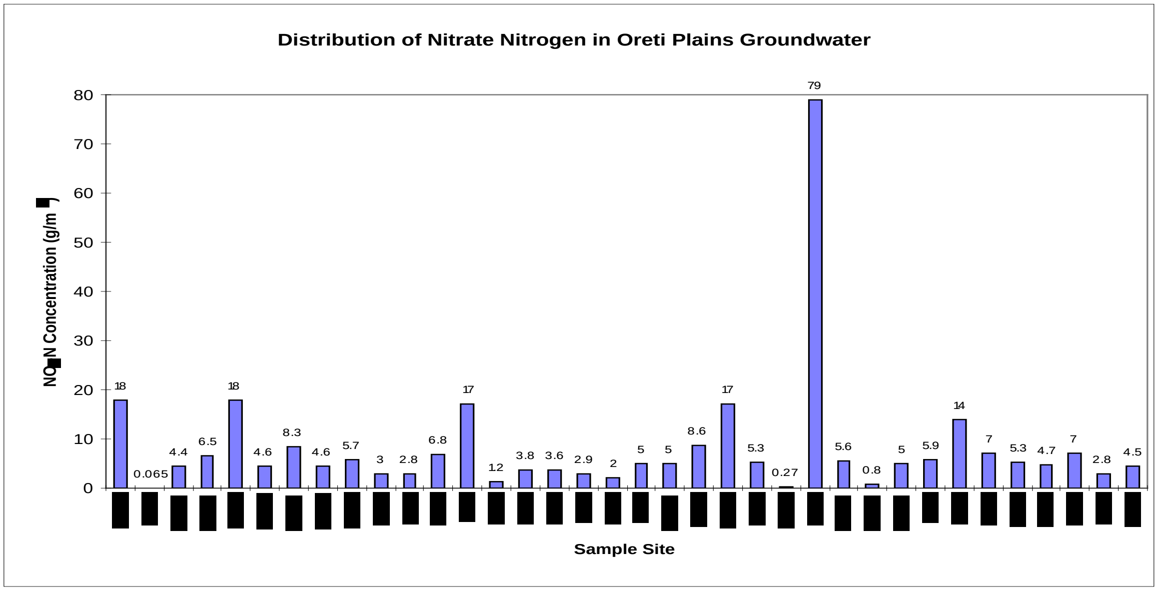

Figure 6 *Bar plot of nitrate nitrogen concentration in shallow Oreti Plains groundwater. The mean is 8.2 g/m^3. The extreme value of 79 g/m^3 was due to direct contamination of a well with effluent.*

In some cases, the concentration of nitrate nitrogen was suppressed by the presence of reduced geochemical conditions indicated by elevated total iron concentration.

3. Results of 1998 Field Survey.

Field survey of Central Southland Plains' water bores and wells was undertaken in February and March 1998. A total of 28 groundwater samples and one rainwater sample were taken in the course of field visits.

3.1 Groundwater Quality.

The range of constituents and parameters is specified in Methodology. The results are reported as individual constituents or combined constituent as best befits the interpretation as to their significance.

3.1.1 Nitrate Nitrogen.

As the primary contaminant in unconfined groundwater, nitrate-N is the chief constituent of interest in this study.

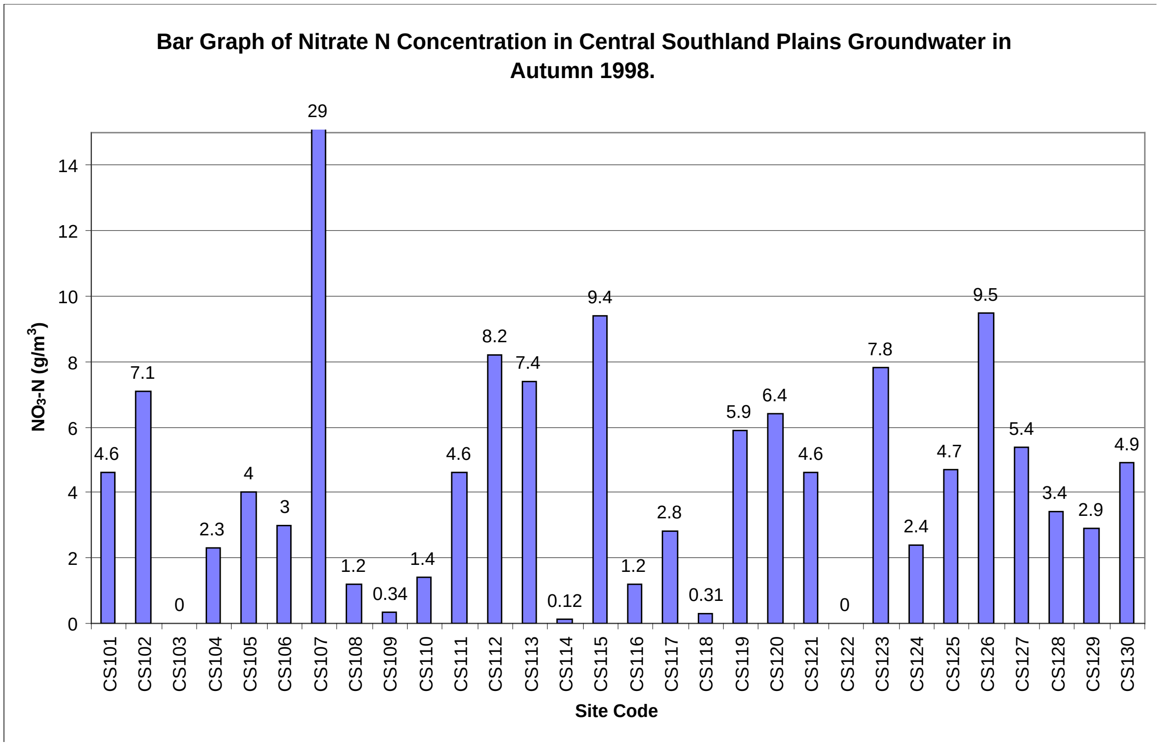

Figure 7 Groundwater nitrate nitrogen measured in the Central Southland Plains field survey.

There is some degree of mutual exclusion between elevated nitrate concentration and elevated iron concentration. This effect is due to the consumption of nitrate in a reducing environment. Elevated total iron concentration in groundwater is only a hallmark of reduced geochemical conditions. The figure below shows the degree to which this effect is observed in Central Southland Plains groundwater.

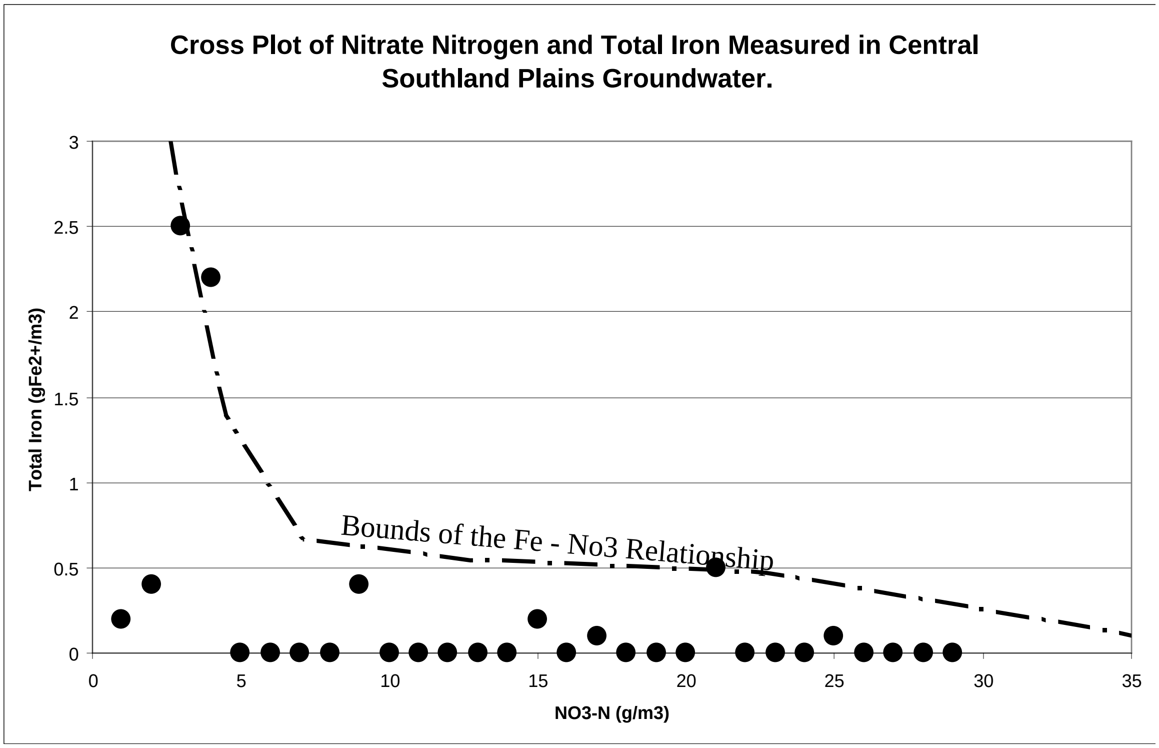

Figure 8 Cross plot illustrating relationship between nitrate and total iron concentration in Central Southland Plains groundwater.

Similar relationships have been observed elsewhere in Southland (Rekker, 1994) and New Zealand (Selvarajah, 1993[15]; Bekesi, 1995[16]; and McTavish, 1997[17]). In two instances, the relationship was further examined by measurement of *in situ* redox. Bekesi (1995) found that limitation on nitrate abundance developed at a measured redox potential (as Eh) below +200 mV in Horowhenua groundwater. McTavish (1997) found the limitation occurred at measured redox potentials below 100 mV, and that dissolved iron increased significantly in concentration at measured redox potentials less than +100 mV in Mosgiel groundwater. Eighty-three percent of Central Southland Plains groundwater samples showed no significant suppression of nitrate by elevated iron concentration.

The survey of nitrate nitrogen of all Central Southland Plains' area *excluding* the Oreti Plains district found only one instance of concentration over the drinking water standard of 11.3 gNO_3-N/m^3. This concentration may be as a result of localised contamination of the immediate wellhead area.

3.1.2 Cations & Anions.

A full range of significant ions was analysed for in Central Southland Plains groundwater. In most cases, an acceptable ion balance was achieved which provided confidence that that the ion results were volumetrically correct. It was apparent that several samples displayed significant enrichment with respect to calcium and bicarbonate concentration. The figure below shows the balance of cations (+) and anions (-).

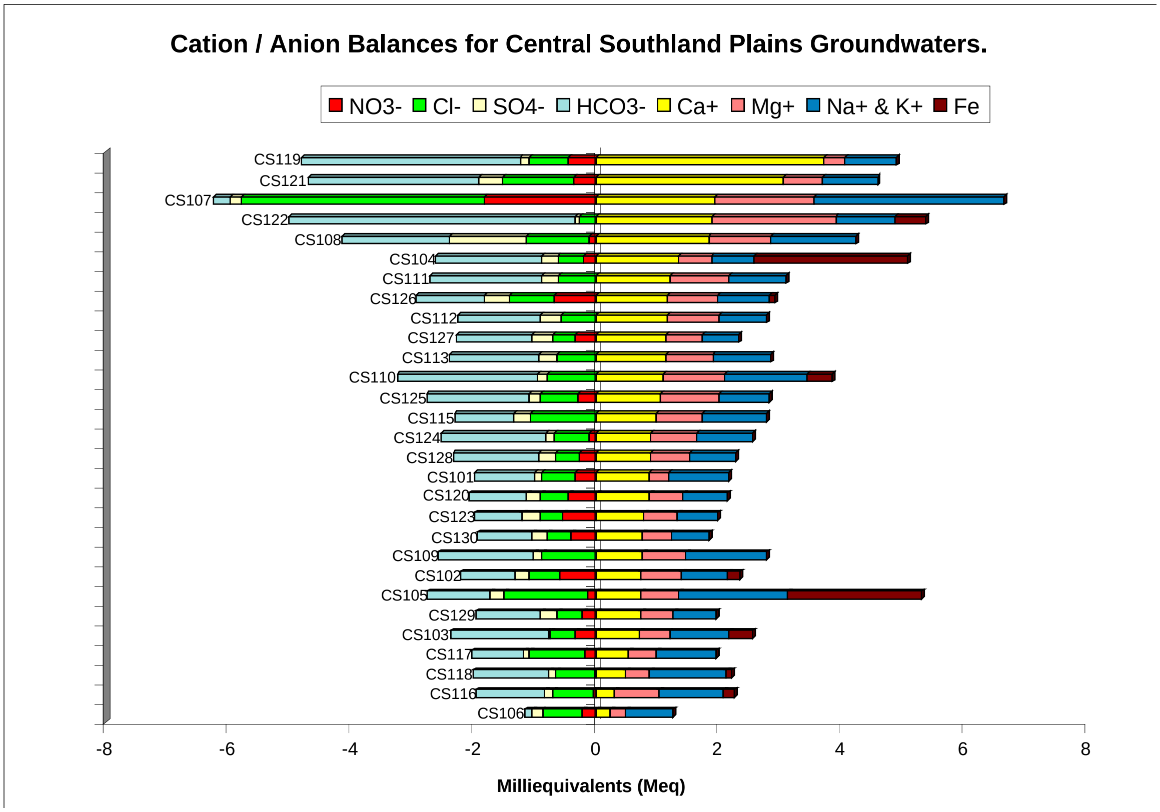

Figure 9 *Ion balance for Central Southland Plains groundwater sorted according to calcium concentration. The bars are arranged as positive magnitude for cations and negative magnitude for anions. In most cases, a balance in the cation and anion mass is evident in even length of the bars.*

The significance of the highest calcium – bicarbonate ion balances is that the water sample is taken from the sandy limestone aquifer in the southwest of the Plains. A map of the Central Southland Plains and the magnitude of calcium concentration are shown overleaf.

Elevation of calcium concentration in groundwater indicates:

- The presence of abundant soluble calcium in the form of calcium carbonate that is dissolved by acid groundwater percolation,
- Calcium derived from weathering of soils, perhaps promoted by the maintenance of a soil calcium pool through the use of soil acidity correction applications (lime).

One result for calcium (CS119) exhibits clear elevation at a concentration of 74.4 gCa/m^3. The geological map indicates that this bore is upon an early Quaternary gravel terrace underlain by sandy limestone. While it was not possible to measure a depth of the bore, the elevated calcium concentration is certainly indicative of the bore tapping the sandy limestone.

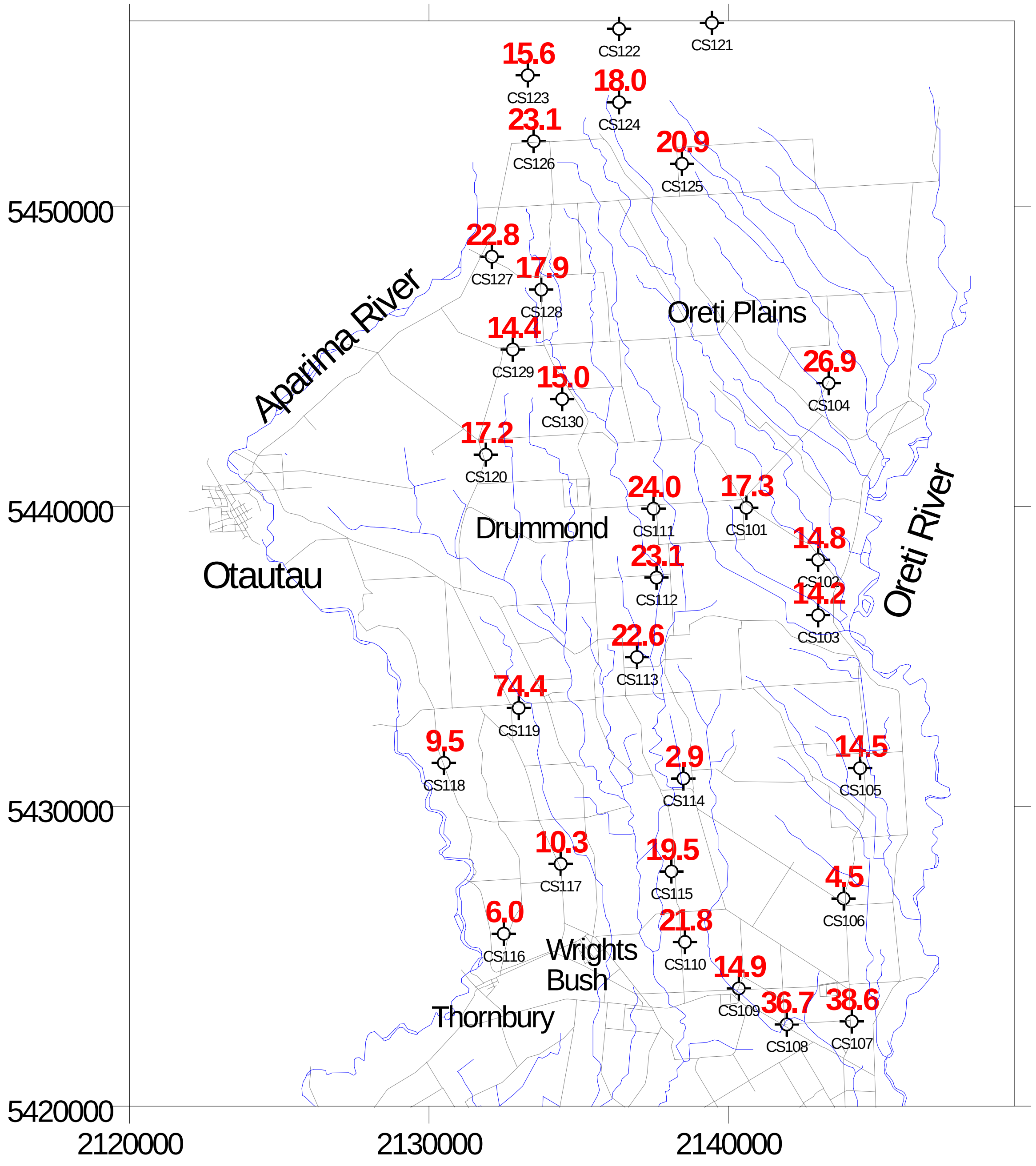

Figure 10 Posted map of Calcium concentrations determined in analysis of bore water samples in the 1998 field survey.

3.1.3 Atmospheric Chloride Influences.

Precipitation in any coastal area contains a loading of a number of seawater constituents. This is derived from sea-spray aerosols, generated by wave action on the shore, which are carried inland by on-shore winds. As precipitation condenses and falls, it includes some of the seawater droplets. The South Coast of the Plains receives a majority of southerly and southwesterly airflows generating sea-spray at the coastline. The concentration of seawater in precipitation generally follows a downward trend with distance inland from the coastline. Orogenic (hill/mountain) or other topographic effects may also influence the airflows, but in the case of the Central Southland Plains these are believed to be slight (Boswell *et al.*, 1992[18]).

Precipitation falling on the Plains takes various pathways in the hydrological cycle. Some of the precipitation, particularly during high soil moisture or storm periods, will tend to runoff directly by overland flow to surface water, and will be subject to little evaporation. The other portion of precipitation will be accepted by the soil is available for evapotranspiration or drainage. During the process of infiltration and retention as soil-water, until the excess precipitation drains from the soil by artificial or natural soil drainage, the water will be subject to evaporation. Evaporation has the effect of concentrating the solute load within the soil-water, so the concentration of seawater derived solutes increases.

The most conservative (non-reactive, nor subject to retardation) solute with the seawater derived solute load in precipitation is chloride. Chloride concentration in rainwater monitored along transects progressing inland from the coast to the interior along the Aparima and Oreti Valleys graphs as a sharp decline for the first five kilometres followed by a steadily declining gradient inland. Mass loads of chloride at 30 kilometres from the coastline along the Aparima and Oreti Valleys are 54 and 42 kgCl/ha/yr (Boswell *et al.*, 1992). This equates to a rainwater chloride concentration of between 5 and 7 gCl/m^3.

However, groundwater chloride concentrations at 30 kilometres from the coast lie at about 14 – 15 gCl/m^3, a factor of 2 to 3 higher than the rainwater chloride concentration. A similar ratio of increase is observed elsewhere along transects. This level of concentration may be due to two principal processes:

1. Concentration of solute strength by evaporation,

2. Addition of chloride in fertilisers.

Chloride is added to the soil as fertiliser in the forms of ‘potassic superphosphate’ or ‘muriate of potash’ (KCl). Potassium based fertilisers are mostly prescribed for dairy farms and hay paddocks (Warwick Catto, *pers. comm.*, June 1997). Approximations of the application rates for dairy farms lie between 50 and 100 kgCl/ha/yr (Warwick Catto and Ross Monaghan, *pers. comm.s*, June 1997)

The posted map below shows the distribution of chloride in unconfined groundwater found in sampling.

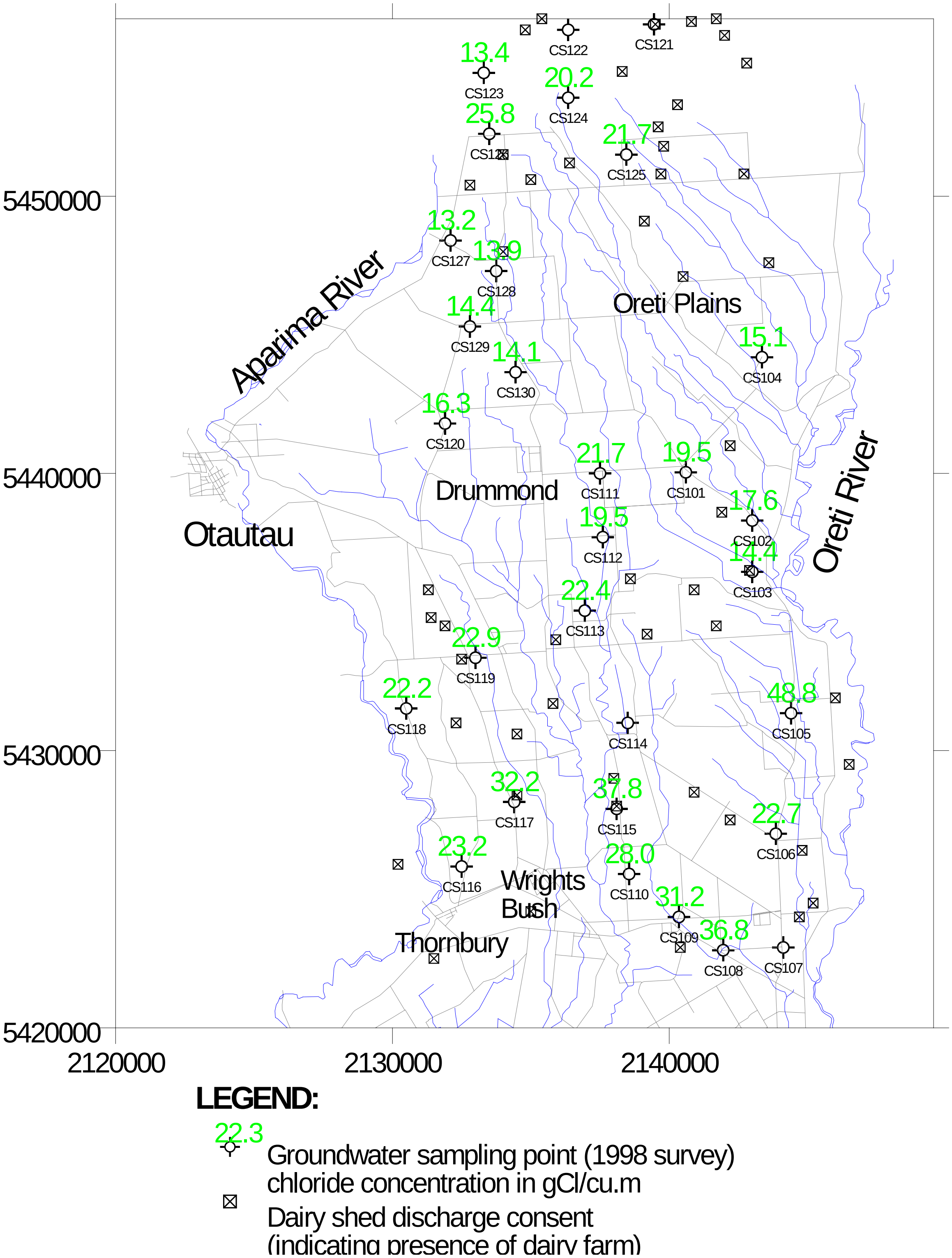

Figure 11 *Distribution of groundwater chloride in Central Southland Plains. The distribution and density of dairy farms is also symbolised to provide indication as to the areas potentially contributing artificial chloride sources.*

The distribution of chloride follows a reducing trend with distance inland. Perturbations to this general pattern may be explained by one of the following:

1. The sampling point is close proximity to the Aparima or Oreti River, therefore on recent soils with higher recharge rates,
2. The sampling point is in close proximity to, or in an area of high density of dairy farms. Potassium chloride fertilisers potentially interfere with the ‘natural’ choride signature.

The general dual trend of rainwater and groundwater chloride concentration declining with distance inland suggests that recharge processes are mostly uniform across the Plains. The best estimate as to the ratio between rainwater chloride concentration and groundwater chloride concentration is approximately 2.5. The long-term mean precipitation over the Central Southland Plains is 900 to 1,100 millimetres per year (Riddell, 1990). The annual precipitation divided by the chloride concentration ratio derives a groundwater recharge rate in the range of 360 to 440 millimetres per year. This range for groundwater recharge is higher than those of the mean baseflow estimate of 192 millimetres from 1970 to 1976 (see section 2.3.3). However, the Waimatuku Creek former recorder site has suspected inaccuracy by way of groundwater bypass, which if the suspicion were correct would lead to the baseflow to be under estimated.

4. Conclusions.

The Central Southland Plains is directed towards answering some outstanding questions arising from previous studies of the region's groundwater resource and agricultural non-point source water quality effects. The outcomes of this study are grouped according to questions raised.

What is the State of Groundwater Quality in Central Southland Plains?

The Oreti Plains stands out as an area in which patches of anomalous elevated nitrate nitrogen in groundwater are found. Elsewhere in the Central Southland Plains, only one other bore was encountered with elevated nitrate nitrogen concentration. The mean nitrate nitrogen of borewater sampled in January to May 1998 lay at 5.0 gNO_3-N/m^3. While this, perhaps, little cause for complacency. This broader assessment points to the uniqueness of the Oreti Plains nitrate-N hot spots, and perhaps confirms the inference of a particular susceptibility of the Pukemutu soil overlying Oreti Plains groundwater.

Nevertheless, this study confirms strong interaction between groundwater and the surface. The shallow groundwater is often used for human consumption and pervasively used for stockwater. The vulnerability to nitrate accumulation, agricultural chemical residues and faecal coliform contamination of the groundwater resource remains.

What of the Deeper Groundwater?

Groundwater from the Tertiary lignite measures and sandy limestones is exploited in small quantities by rural landowners. Only second-hand information could be obtained on these aquifers since the study did not coincide with water well drilling into these layers. However, there are some indications that the sandy limestone communicates freely across the Quaternary – Tertiary contact and has at least moderate yield. The lignite measures are better understood from investigations in Eastern Southland. The lignite measures would also appear to have lower yield with marked isolation from the Quaternary alluvium groundwater.

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