Oteramika Trial Catchment Groundwater Studies.

Studies into Non-point Source Groundwater Effects in Southland.

Southland Regional Council.
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Acknowledgements.

This study is merely a component part of a multi-disciplinary project by a variety of agencies. The sheer number individuals assisting in the project are too numerous to separately acknowledge, but thanks are given. AquaFirma Ltd has worked under commission to the Southland Regional Council since 1994 to provide hydrogeological investigative services. Key Council individuals with a role in the Oteramika Project (groundwater) were: Warren Tuckey, Director of Planning and Resource Management, Stefan Thomsen, Council Ecologist, Keith Hamill, Council Ecologist and Scott Crawford, Environmental Information Manager.

Many thanks to these people for their labour, guidance and constructive comments.

Executive Summary.

The Edendale Aquifer is an unconfined alluvial aquifer within Quaternary sandy gravel. The alluvium is capped by silty loess and silt loam soils. Overlying land uses include sheep and dairy grazing, cropping, horticulture, tree nursery, residential and industrial. All land uses affect the water quality of the underlying aquifer through leaching of dissolved contaminants. The aquifer has an extent of about 6,500 hectares.

The Edendale Aquifer is recharged by infiltration of precipitation surplus, typically in the period May to October. Irrigation of dairy factory and dairy shed wastewater is practised over scattered parts of the Edendale terrace, which leads to enhanced infiltration and leaching of contaminants. Surveys and monitoring of groundwater quality within the aquifer and issuing from the aquifer as springs indicate the groundwater to be impacted by non-point source contaminants. These contaminants, principally nitrate nitrogen and phosphorus have potential to threaten potability of the groundwater, or exacerbate dissolved plant nutrient loads in downstream aquatic environments. Nitrate nitrogen presently rests at concentrations ranging between 2 and 12 gNO_3-N/m^3, with a three-year mean of 6.1 gNO_3-N/m^3 throughout most of the aquifer's extent. Dissolved reactive phosphorus is found at concentrations between 0.017 and 0.026 g/m^3, which is elevated compared to the mean concentration of the Mataura River.

The measured groundwater discharge from the aquifer averages 820 litres per second, which is equivalent to an annual recharge rate of about 400 millimetres across the surface of the terrace surface. Long term sampling of bore and spring waters; in addition, measurement of water table elevation provides sufficient information from which to calculate estimates of the mass load for various constituents. Such loadings for principal contaminants are shown below:

	Flow Weighted Average of All Springs Water Conc. (g/m^3)	**Mass Load** (Calculated using recharge of 25.8Mm^3/yr) (kg/yr)	**Areal Loading** (Calculated using an area of 6,487 ha) (kg/ha/yr)
Nitrate-N	6.3	163,046	25.1
DIN	6.4	164,918	25.4
Total-P	0.073	1,879	0.29
DRP	0.048	1,244	0.19

Linkage between land use and leaching of contaminants has been modelled as part of the Oteramika Trial Catchment Project, and has derived a groundwater nitrogen loading of about 23.4 kg/ha/yr. Modelling in this study has allowed the simulation of changes in nitrate nitrogen concentration distribution resulting from hypothetical changes to land use across the land overlying the aquifer.

Modelled change of all grazing land to high intensity dairy farms results in transgression of the nitrate nitrogen drinking water limit across almost the entire Edendale Aquifer.

Modelled change of sheep and dairy farming to their highest intensity equivalent leads to a mean nitrate nitrogen increase of 3.2 $gNO_3\text{-}N/m^3$ to an average of 8.7 $gNO_3\text{-}N/m^3$, but without affecting any much greater areas with concentrations in excess the drinking water limit. Replacement of forage cropping areas with medium intensity sheep farming has a beneficial effect on groundwater quality by reducing the mean nitrate-N concentration by 0.8 $gNO_3\text{-}N/m^3$.

The Edendale Aquifer has similarities to many alluvial groundwater systems throughout Southland. Much of the knowledge gained in the course of this multi-disciplinary, investigative project has application beyond the boundaries of the Edendale Aquifer. Such an extension is the observation, should the intensity of agriculture presently practised on the Edendale Terrace extend to cover significant parts of downland Southland, that a significant increase in the areas of alluvial aquifers with elevated nitrate-N concentration above the drinking water standard would eventually manifest.

Questions and Answers on Salient Points.

The Introduction contains a list of questions salient to the current state of knowledge on non-point source contamination of groundwater in the Southland region. These questions, with answers drawing on the results of this study, are summarised below as a means of further expanding the executive summary and results of this investigation.

Question 1. A number of divergent nitrate leaching rate estimates have been advanced by different technical workers. Many rely on correlation with Waikato, Manawatu or Canterbury conditions of climate, soil processes and even farm practice. How transportable are these leaching rate estimates?

Answer *Southland probably has lower nitrogen leaching rates compared to Waikato, Hamilton Basin. This study has established the nitrogen areal mass loading for the Edendale terrace as 25.4 kgN/ha/yr, which is significantly lower than an estimate of 60 kgN/ha/yr under similar land uses in the Hamilton Basin, Waikato (Selvarajah et al, 1993). This study does not, nor does the soil-water nutrient modelling undertaken as part of this project, fully answer this question. Physically based measurement of nitrogen leaching rates are presently being undertaken with reporting scheduled in a year from now.*

Question 2. In view of the rapid changes of some elements of Southland's pastoral agriculture, the Council feels the need for reliable comparative information on rates of nutrient loss through leaching between different farm systems (e.g.; does dairy grazing lead to greater nitrate leaching than sheep grazing?).

Answer *This study indicates that high intensity dairy grazing is the most likely of all pastoral land uses to produce elevated nitrate nitrogen concentration in alluvial aquifers. The relative impact of each grazing intensity is derived in soil-water nutrient modelling associated with this project, but requires comparative verification (preferably physically based) before being available in deciding resource management planning.*

Question 3. What level of nutrient leaching can Southland’s aquifers sustain before groundwater use becomes limited by agriculturally induced water quality effects?

Answer *This study suggests should an aquifer become overlain by a preponderance of high intensity dairy farms, that the groundwater quality will ultimately rise over the drinking water standard.*

Question 4. Can Best Management Practices (BMP’s) be developed that meet the aim of making agriculture a more sustainable activity with respect to water quality protection?

Answer *This study, allied with the results of the associated soil-water nutrient model, indicates that avoidance of winter forage cropping has a beneficial effect on the nitrate nitrogen concentration of groundwater in an aquifer that might be stressed with respect to elevated nitrate levels.*

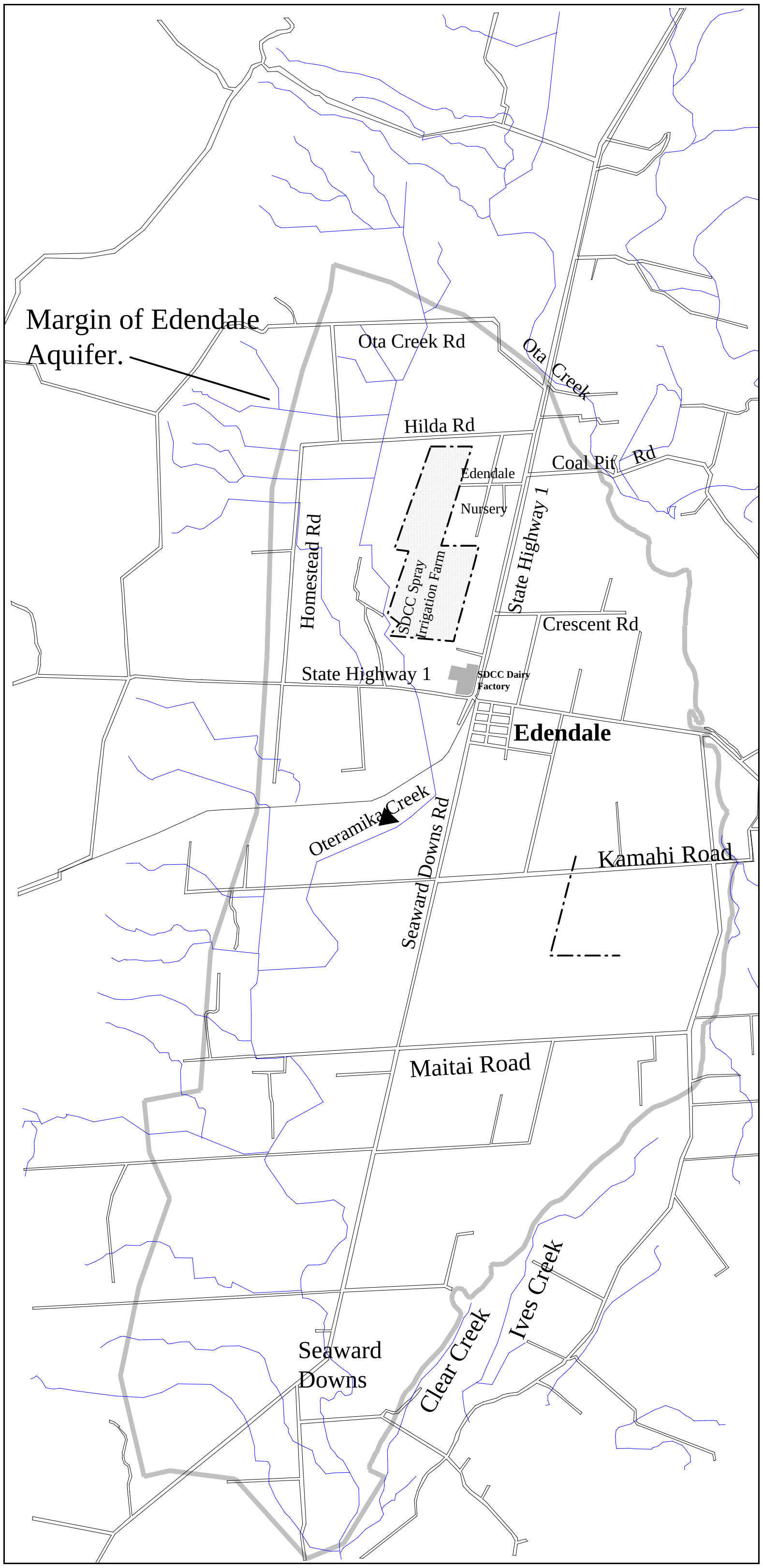

Figure 1 Orientation Map. The margins of the Edendale Aquifer are marked in grey.

1. Introduction.

This report on groundwater studies at Oteramika is the culmination of a wider multi-disciplinary trial catchment appraisal of non-point source impacts on surface and groundwater quality. The bulk of these studies have been co-ordinated by Southland Regional Council in accordance with its need for region-specific information on non-point source water quality effects.

1.1 Problem Definition.

The Southland Catchment Board (and subsequently, Southland Regional Council) have been responsible for managing water quality since 1967 with the passing of the Water and Soil Conservation (WSC) Act. The emphasis of water quality management under the WSC Act was to regulate point source discharges. Essentially, if a significant 'dirty' discharge went from a pipe to natural water, it required a water right. In this manner, industrial and municipal discharges of wastewater were increasingly regulated to control their effects on the aquatic environment. The Water and Soil Conservation Act 1967 was progressively expanded in scope under the guidance of the National Water & Soil Conservation Organisation (NWASCO). Jurisdiction over groundwater was added by amendment in 1981. During this period non-point contaminant sources were acknowledged in NWASCO technical publications, but considered part of the 'background' pollutant levels. Little control was exerted over non-point sources other than sediment load in hill country rivers, which fell under the heading of "soil conservation". There was a prevailing belief in the regional water quality management community that directing attention to the headwaters would solve the sediment transport and nutrient enrichment problems of the mid- and lower catchment.

The passing of the Resource Management Act 1991 had the effect of integrating consideration of air, land and water effects. The emphasis on discrete discharges was altered in the legislation, to an emphasis on monitoring and mitigating effects of all land and water use activities. This legislative shift has led to a gradual change in the perception of both regional council staff and the public concerning point source and non-point source effects on air, soil and water quality.

Conjunctive assessment of inland water quality effects in Southland (McKenzie and Rodmell, 1990[1]) and reviews of catchment water quality (Robertson 1992b[2]; and Robertson 1992b[3]) underlined the role played by largely agricultural diffuse pollution of surface water and signalled a shift in focus onto these impacts. In a region such as Southland, with the lowest population density in New Zealand and a preponderance of extensive and intensive pastoral agriculture, the effects of agricultural activities on water quality assume a larger proportion of net impacts on the aquatic environment.

A watershed in the consideration of the water quality status in Southland was reached in 1993 with the publication of an environmental impact assessment of the expansion of the region's dairy herd (Robertson Ryder & Associates, 1993[4]). This assessment considered nutrient, heavy metal, toxicant and microbiological effects on the region's water quality because of grazing agriculture. Comparison of sheep, deer, mixed cropping, town milk and seasonal dairy farming was made in terms of contaminant budgets. Nutrient balances concerning the loss of nitrogen from dairy-farming systems made a grim forecast for the future nitrate levels in the region's unconfined groundwater. The nutrient balance exercise suggested leaching rates under high intensity dairy grazing of up to 95 kgN/ha/yr. Concern was expressed as to the future nitrate status of Southland groundwaters. In the form of case studies, the assessment considered two sub-catchments, namely the Otautau Stream and Oteramika Creek. The Oteramika Creek catchment was identified as having the most intensive grazing agriculture, possibly of the whole region.

In 1994, the Southland Regional Council commissioned a scoping study of the regions groundwater resources (Rekker, 1994[5]). The scoping study concluded the following:

- There was a paucity of information on the region's groundwater occurrence, quantity or quality in comparison to almost all other regions in New Zealand,
- Water quality, both natural and induced, was the most profound actual and potential limitation on groundwater availability,
- Most accessible groundwater resources were found in the shallowest unconfined water bearing layer, which was directly recharged from the surface and tended to discharge most of its water back to the surface water network,
- Southland's groundwater resources were particularly vulnerable to non-point, agricultural impacts, particularly nitrate accumulation and pesticide toxicant contamination.

In addition, the scoping study nominated a critical catchment meriting further investigation. The Oteramika catchment was nominated on the following grounds:

1. High intensity of pastoral agriculture,
2. High dependence on the underlying unconfined aquifer for drinking water supply,
3. The presence of an export industry groundwater take and land discharge affecting groundwater quality (Southland Dairy Co-operative dairy factory).

The Southland Regional Council commissioned a characterisation study of the Edendale aquifer (Rekker, 1995). This was complete in April 1995 and reported on the general disposition of the Edendale Aquifer including geology, groundwater flow direction and rate, groundwater quality and the implications of those findings. Concurrently, the Southland Regional Council resolved to initiate a trial catchment assessment encompassing the Oteramika catchment and non-point source effects on surface and ground water quality. During the period of 1992 to present, the Southland Dairy Co-operative has undergone a period of sustained growth, which included expansion of their wastewater land treatment system near Edendale. Successive resource consent applications over this land irrigation farm heightened interest in the groundwater quality effects and the influence of surrounding land uses on nitrate concentration.

Out of these processes, a number of questions remained unanswered for the Southland Regional Council:

1. A number of divergent nitrate leaching rate estimates have been advanced by different technical workers. Many rely on correlation with Waikato, Manawatu or Canterbury conditions of climate, soil processes and even farm practice. The Council possessed no information on the transportability of these leaching rate estimates.
2. In view of the rapid changes of some elements of Southland's pastoral agriculture, the Council felt the need for reliable comparative information on rates of nutrient loss through leaching between different farm systems (e.g.; does dairy grazing lead to greater nitrate leaching than sheep grazing?).
3. What level of nutrient leaching can Southland's aquifers sustain before groundwater use becomes limited by agriculturally induced water quality effects?
4. What solutions by way of avoidance, mitigation or monitoring can be adopted to reduce the impact of non-point source pollution on groundwater quality? Can Best Management Practices (BMP's) be developed that meet the aim of making agriculture a more sustainable activity with respect to water quality protection?

1.2 Method.

The Oteramika Trial Catchment Study encompassed a number of different, allied investigations. These are described in the overview document covering the project. The groundwater aspects were largely self-contained and undertaken by AquaFirma Ltd and Southland Regional Council's field hydrology team. Some degree of project interaction was shared with all of the constituent groups and individuals in the Oteramika Trial Catchment Technical Working Group as the studies progressed. The principal area of cross-team interaction covering groundwater aspects was with the AgResearch – NIWA studies that used soil-water and nutrient field trials and modelling. Estimates of nutrient leaching were considered in the groundwater assessments.

1.2.1 Initial Characterisation.

The characterisation study of early 1995 (Rekker, 1995) provided the background for design of the longer term monitoring network. It also provided a preliminary definition of the issues and processes operative in the Edendale aquifer. The characterisation study employed the following investigative tools:

- A water table elevation survey that demonstrated the direction of groundwater flow and gradient
- Hydrogeological evaluation; composition and geometry of the aquifer
- Measurement of seepage-fed creeks to estimate groundwater discharge
- Sampling and analysis of a selected number of water bores
- Evaluation of other relevant reports and raw data

The characterisation study was used in disseminating information on the aquifer to the stakeholder groups and has become a reference document for other issues concerning the

Edendale Aquifer. Between 1995 and 1998 the groundwater programme comprised routine monitoring of aquifer flow and water quality and the development of a groundwater flow model for the area.

1.2.2 Monitoring / Long Term Data Collection.

1.2.2.1 Groundwater Quality.

A network of five water bores and six spring-fed creek stations were established for quarterly sampling of Edendale groundwater from September 1995 to June 1998. The groundwaters were analysed for a list of cations, anions and nutrients in each sample. Some use is made of groundwater quality results from other monitoring or investigative projects (e.g. Southland Dairy Co-operative consent monitoring, or District Council drinking water quality monitoring).

1.2.2.2 Groundwater Quantity and Elevation.

A network of ten farm bores was selected from which to take monthly measurements of the depth to the water table. This allowed compilation graphs illustrating water table fluctuation. The elevation of the water table is calculated using a benchmark elevation surveyed onto each survey bore during the 1995 characterisation study.

Six gauging stations were established on spring-fed creeks in the discharge zone of the Edendale aquifer. Waded streamflow gauging methods were used to determine the groundwater discharge received at the stations. Gauging and water sampling were undertaken simultaneously on a quarterly basis.

1.2.3 Analysis of Field Data.

The results of long term monitoring are integrated in the analyses of parameters through time (temporally) or to each other (spatially). For example, the rise and fall in ground water level might follow the same pattern through time as the rise and fall in nitrate nitrogen concentration. This sort of positive correlation may demonstrate aquifer recharge processes or the timing of higher nitrate influx.

A water balance can be developed from the aquifer discharge record, which, in turn may allow the estimation of loadings for nutrients and other constituents.

1.2.4 Modelling of Groundwater Flow and Composition.

The Edendale aquifer has been modelled using computer simulations of groundwater flow and solute transport models. The modelling is intended to extrapolate what is known concerning the Edendale aquifer and provide a numerical framework upon which to assess the impact of various nutrient loss rates on groundwater quality.

2. Edendale Aquifer Setting.

The Edendale groundwater system is a product of a variety of conditions:

- Geological formations
- Climate conditions
- Hydrological conditions
- Soil properties

The sub-sections that follow describe and quantify the groundwater system in its component parts.

2.1 Hydrogeology.

The Edendale aquifer is contained within a sheet of sandy cobble gravel lain down as a consequence of the outwash of glacial and peri-glacial materials from the upper Mataura and Oreti catchments (McIntosh *et al.*, 1990[6]). This sheet of gravel formerly filled the lower Mataura Valley from one side to the other. Subsequent to the Edendale terrace gravel deposit being lain down, the Mataura River has cut down through the terrace surface as a result of a change in sediment supply and/or change in the river gradient (by sea level or tectonic influences). The remnant Edendale terrace is thus stranded against the western side of the Mataura Valley with distinct bluffs or risers marking the erosional boundary between the Edendale and the lower elevation Wyndham terrace (White and Barrell, 1996[7]).

The Edendale terrace laps up to the flanks of the Edendale Hill that is composed of clayey siltstone, sandstone, lignite and occasional pebble conglomerates. The Lignite Measures making up Edendale Hill form the western, southern and basal boundaries of the Edendale terrace gravel sheet. The gravel sheet is between 5 and 20 metres in thickness and typically is saturated with groundwater through at least half of its thickness.

2.1.1 Aquifer Composition and Geometry.

The Edendale Aquifer is comprised of the aforementioned sandy, cobble gravel deposits. The principal composition of larger clasts can be characterised as follows. Grey, brown and green coloured clasts that are composed of lithified sandstone derived from the Muruhiku rocks of the Hokonui Hills and Catlins basement blocks. Grey and green rocks are derived from greywacke of the Caples and Torlesse Group lithologies found in the Eyre, Garvie and Umbrella Ranges. White, blue and green quartz are found extensively as medium size clasts derived from the higher metamorphic grade greywackes and schists of the higher elevation catchments. Accessory black, blue, green, brown and pale rocks are found in lesser abundance derived from exotic rock types; mainly volcanic, meta-volcanic, plutonic and ultra-mafic rocks of the Maitai Group of Permian basement blocks. The sand fraction is dominated by quartz, but also made up of lithic fragments from all of the lithologies mentioned above.

These gravel deposits have been overlain by aeolian (wind-lain) silt deposits known as loess. These deposits reach thickness of up to five metres and underlie the modern soil profile.

The geometry of the gravel sheet is not complex. Contouring of the elevation of the base of the gravel deposit suggests a paleo-channel incising the basement running north to south through the mid-line of the terrace. This is shown in the figure below.

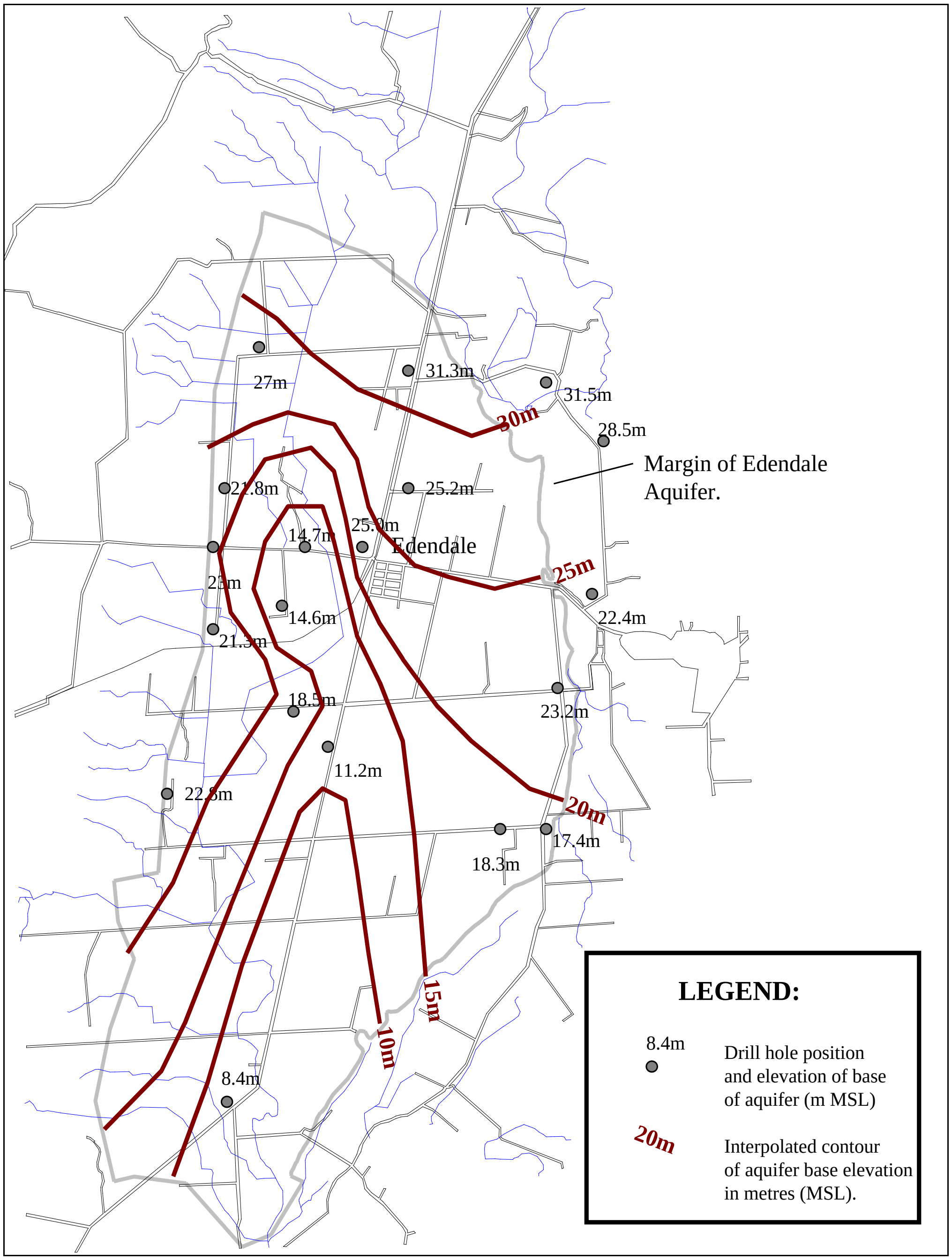

Figure 2 Elevation of the base of the gravel deposits illustrating the perceived paleo-channel underlying Edendale. Source data is taken from lignite investigation bore logs held by Southland Regional Council.

The gravel sheet is truncated by the emergence of the Lignite Measures on the western flank of Edendale Terrace and to the east by past lateral erosion. The margins of the aquifer thus delineated are shown in the figure above. The northern boundary of the aquifer is uncertain. However, a water table survey during 1995 found evidence for the presence of a groundwater flow divide separating the Edendale and Ota Creek systems lying between the Hilda and Ota Creek roads (Rekker, 1995).

2.1.2 Aquifer Properties.

The Edendale Aquifer, being composed of sandy cobble gravel is inferred to have a high hydraulic conductivity (permeability coefficient). Drilling investigations have found the aquifer to be unconfined by any overlying low permeability unit; hence, the water table is a free surface. The principal properties for which information from the Edendale Aquifer is available are as follows:

- Transmissivity, permeability coefficient or hydraulic conductivity,
- Storage coefficient (specific yield and storativity),
- Dispersion coefficients,
- Effective, or drainable, interconnected porosity

Only a few determinations or estimates have been made in the course of hydrogeological investigations of the aquifer.

1. A pumping test in the Southland Dairy Co-operative “E” well in July 1994 (Rosen *et al.*, 1994),
2. A pumping test in a farm bore on the Southland Dairy Co-operative factory farm from 23 March to 5 April 1995, including a step-drawdown test on 22 March (Rekker, 1995),
3. An estimate of through-flow used to infer bulk aquifer permeability (Rekker, 1995),
4. An estimate of groundwater transport parameters made in connection with groundwater modelling of the Southland Dairy Co-operative (White and Barrell, 1996)
5. A pumping test on March 10 1998 in a temporary well constructed for resource consent reporting on the Southland Dairy Co-operative’s Inglemere Farm property (Rekker, 1998).

The sedimentary environment of the braided river flood-plain believed to have formed the Edendale terrace is one where expected variability in the key grain size mediated factors such as sand and clay fraction will greatly affect the range of some aquifer properties. For instance, aquifer permeability coefficient may go through order of magnitude changes within 100 metres laterally or even within the vertical profile. Consequently, the results of aquifer testing will largely only be valid for the area sampled (i.e. the radius of influence of a pumping test).

Compounding the problem of variability is the difficulty of obtaining valid parameters form standard aquifers tests in high permeability, unconfined aquifers. The inaccessibility of the aquifer for testing increases the cost and difficulty of conducting tests.

The table below shows the range of aquifer properties previously used for the Edendale Aquifer.

Source of Parameter (including reference)	**Transmissivity (m^2/d)**	**Hydraulic Conductivity (m/d)**	**Specific Yield, or other Storage term (dimensionless)**	**Dispersion Coefficient [longitudinal / transverse] (m)**
1 Pumping Test (Rosen *et al.*, 1994)	10,650	1,065	1×10^{-5}	–
2 Pumping Test (Rekker, 1995)	1,016	170	–	–
3 Through-flow Estimate (Rekker, 1995)	–	635	–	–
4 Inferred (White and Barrell, 1996)	–	–	–	10 / 1.0
5 Pumping Test (Rekker, 1998)	3,226	~320	0.10	–

These values for parameters have a large range. This underlines the natural variability and difficulty of obtaining the parameters as outlined above. An estimate of bulk aquifer permeability range is developed through the calibration of a deterministic groundwater flow model for the Edendale Aquifer (see Groundwater Modelling).

2.1.3 Groundwater Recharge.

Being an unconfined aquifer, the Edendale Aquifer is open to recharge from above throughout its extent. Only the permeability of the overlying unsaturated soil and sub-soil impedes the entry of excess precipitation. Groundwater recharge estimates have been calculated for one of the slower draining soils on Edendale Terrace and validated against measured soil drainage at the AgResearch trial plot at Edendale (Ross Monaghan, *pers. comm.*, 25 May 1998.). The trial plot uses a 'V'-notch flow measurement weir and data logging to record the quantity of excess precipitation as a response to rainfall. This allows calculation of the quantity of percolate that would otherwise drain through the sub-soil to join groundwater.

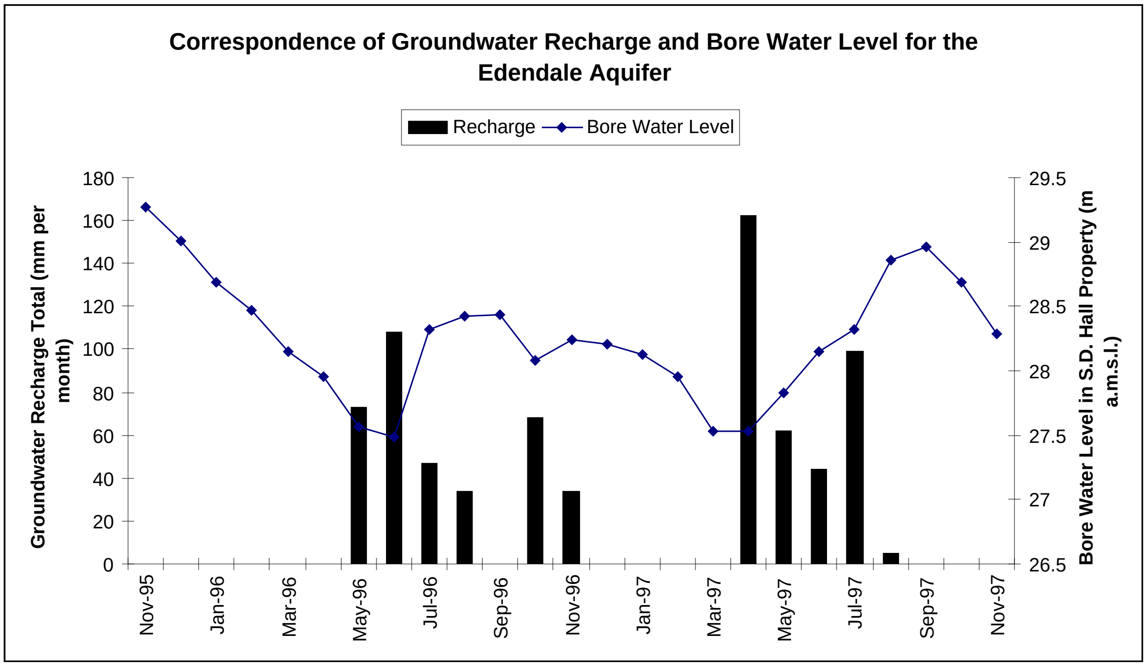

Figure 3 Plot of calculated groundwater recharge and bore water level. Groundwater recharge is calculated using a monthly water balance including precipitation, evaporation and soil-water retention capacity. This estimate has been validated against soil drainage yields from purpose made tile drainage outfalls (Ross Monaghan, AgResearch Ltd, pers. comm., 25 May 1998). Bore Water level data is taken from the S.D. Hall bore lying in the middle of the Edendale terrace. The annual mean recharge rate for 1996 and 1997 is 368 mm per year.

The timing of recharge is governed by the balance of precipitation, evapo-transpiration, soil moisture storage and the transit time across the unsaturated zone to the water table. Accordingly, periods of low evapo-transpiration correspond with higher groundwater recharge. The annual period from early June to late September appears to be the time of greatest groundwater recharge in any year. A seasonal rise of 1 – 2 metres is recorded in the Edendale Aquifer water table through this period, indicating the predominance of recharge during this period. A discernible lag between pulses of recharge and an upward change in bore water level in the order of 1 – 2 months is discernible in the figure above.

2.1.4 Groundwater Discharge.

Any groundwater system which is in balance will discharge a quantity of groundwater equivalent to its' recharge. Uniquely for a groundwater system, the Edendale Aquifer discharges most of its' groundwater back to the surface in a situation that allows the flow rate to be measured. A series of springs and seepage-fed creeks are found along the eastern margin of the aquifer. These have been regularly gauged quarterly over a three-year period. A summary of the mean spring discharge rates for the period September 1995 to March 1998 are given in the table below.

Springs Gauging Site	**Mean Spring flow (l/s)**
Halls Pit	39.4
Shield Road	37.2
Ives Creek # 1	199.5
Ives Creek # 2	283.6
Clear Creek # 2	331.9
Clear Creek # 3	359.1
Oteramika Creek seepage (measured on one occasion in February 1998)	100
Total Mean Aquifer Discharge from Springs	820
Total Discharge as an Areal Recharge Rate (area = 6,487 ha)	3,983 m^3/ha/yr 398 mm/yr

The rate of spring discharge does not vary significantly through the year. The variability in spring discharge is about 19% of annual mean flow, with a mean – median ratio of 1.02. Nonetheless, there is some degree of correlation between spring flow and corresponding water table elevation at an adjoining water bore as is shown in the figure below.

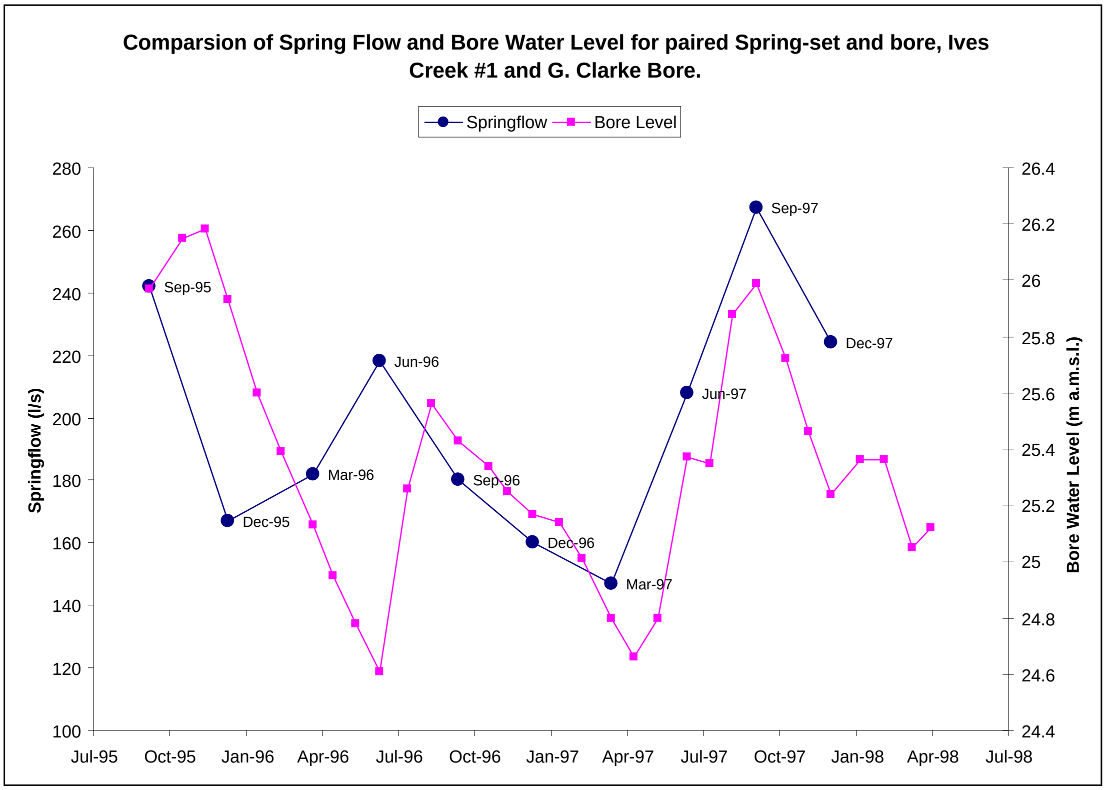

Figure 4 Comparison of spring flow and Bore water level fluctuation. Spring flow is measured at Ives Creek #1. Bore water level was measured in the nearby Clarke bore.

For the 1996 – 97 hydrological year, the relationship between spring flow and bore water level is strong. This suggests that spring flow fluctuation is driven by change in aquifer storage. The change in aquifer storage, and therefore groundwater discharge, is wholly expressed as fluctuation in the water table in response to recharge events.

2.1.5 Groundwater Level Fluctuation.

Ten monitoring bores have been measured for depth to water on a pattern of measurement every month since September 1995. The figure below illustrates the degree of fluctuation recorded in several water bores from 1995 to 1998.

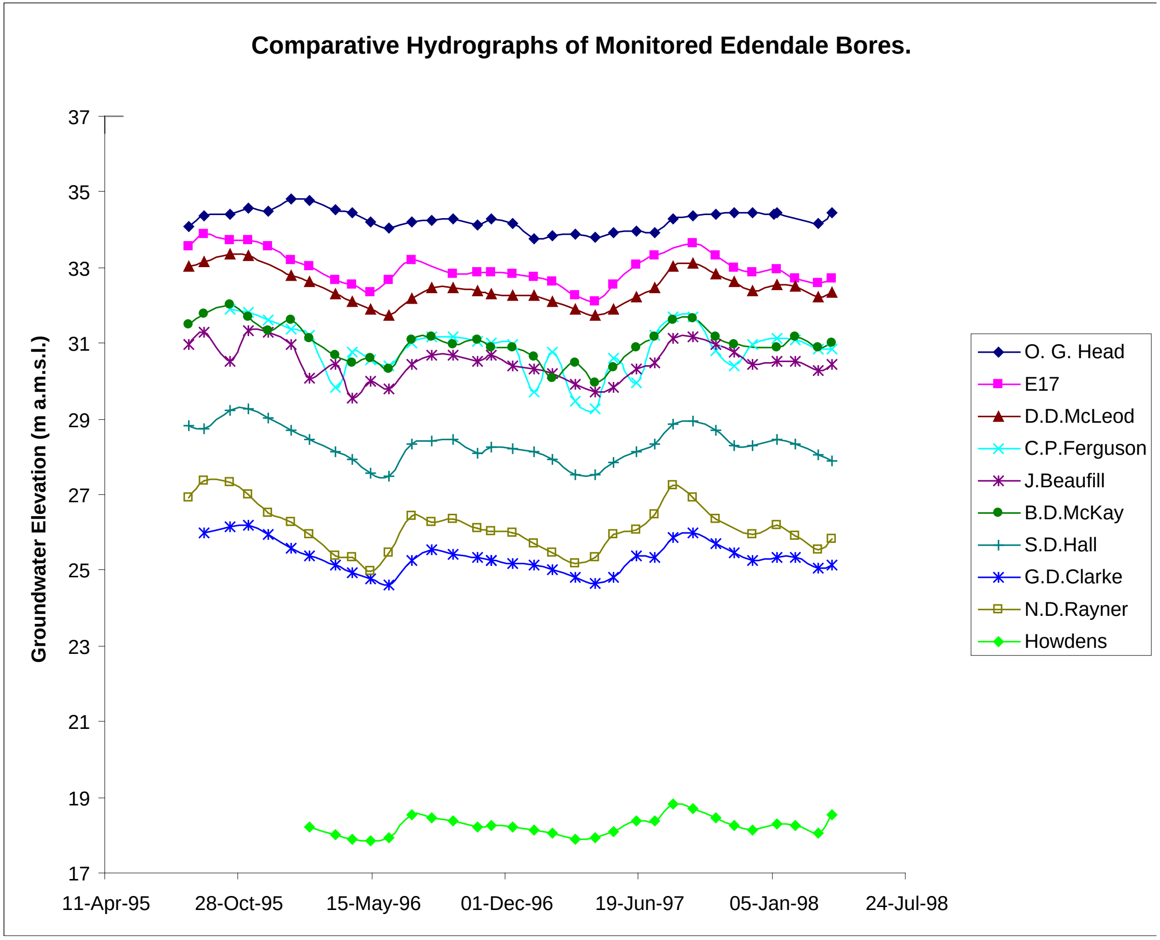

Figure 5 Water Table fluctuation as measured in several water bores in the Edendale Aquifer. A seasonal pattern of rise and fall in water level is evident in most hydrographs. The Ferguson and Beaufill records are believed to be affected by bore pumping interference.

A uniformity of fluctuation is evident in many of the hydrographs graphed above. A regression correlation analysis of two of the above water elevation records provides a regression correlation constant of 94%. Such a correlation is strongly indicative that the fluctuation of bore water elevation, from one site to another, are controlled by common processes. The most likely common processes are seasonal variation in recharge and groundwater discharge at aquifer margins. The high degree of correlation suggests that these processes are operative and reasonably uniform across the extent of the Edendale terrace. The figure below illustrates the correlation between two Edendale Aquifer monitoring bores.

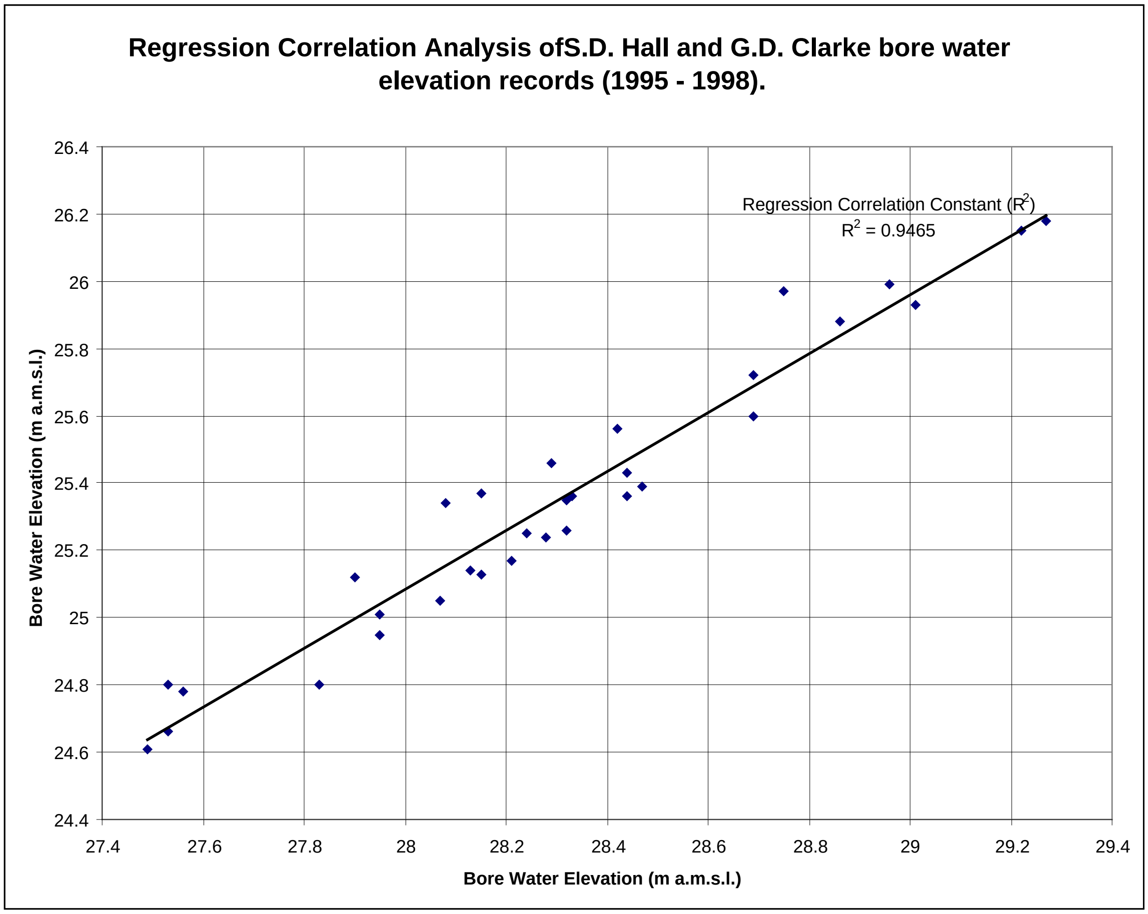

Figure 6   Regression correlation analysis of the commonality of bore water level fluctuation in two separate monitoring bores.

Furthermore, the validity of using manual monthly monitoring of groundwater level is assessed against automated measurements each quarter hour, as shown in the figure below. The close correlation is further illustrated in the linear regression correlation graph of the automated and manual measurements shown below.

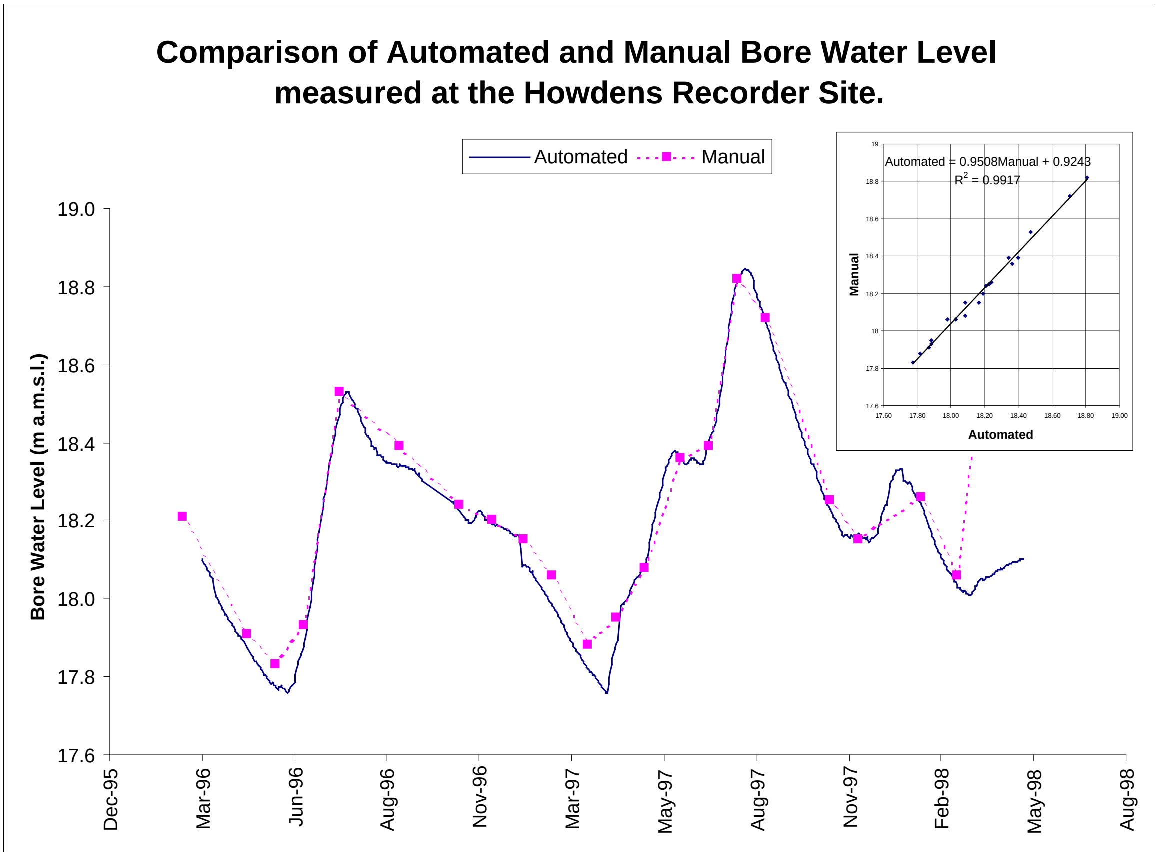

Figure 7 Graphs of Hydrological Station (Howdens) bore water level records measured by automated and monthly (manual) methods. The thumbnail plot to the left quantifies the linear correlation between automated and manual measurements.

The validity of monthly, manual water level measurements, and the demonstrable relationships between groundwater recharge timing, water table fluctuation and spring flow, provide solid information on which to build the conceptual model of groundwater flow in the Edendale Aquifer.

2.1.6 Aquifer Conceptual Model.

A conceptual model is a semi-quantitative representation of aquifer geometry, hydrologic properties, recharge and discharge. It summarises the present state of knowledge for the groundwater system. The essential elements of the model are as follows:

- The aquifer is a single gravel sheet, unconfined system,
- The system is recharged across the terrace surface by excess precipitation,
- Groundwater discharges at the terrace margins into springs and seepage fed creeks.

This concept of the aquifer in graphical format is shown in the figure below:

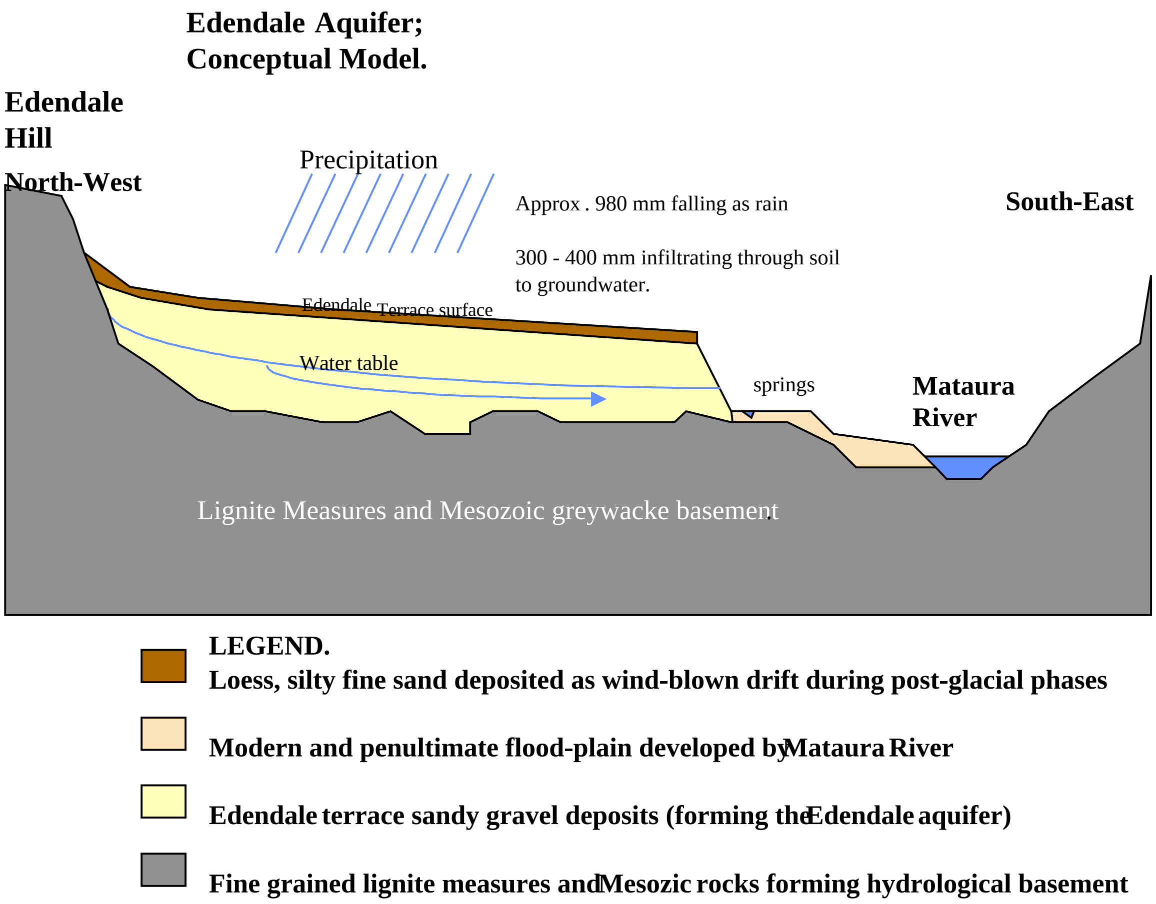

Figure 8 Schematic conceptual model of the Edendale Aquifer.

Long-term monitoring provides us with quantification of the rate of aquifer discharge and recharge. Independent soil and climate based estimates tend to confirm these estimates.

2.2 Soils.

Although not strictly part of the Edendale aquifer system, soils covering the Edendale terrace mediate the rate of recharge and leaching of nutrient dissolved in the recharge. Soils are also the vital element in the overlying agricultural systems.

Two principal soil classes are mapped on the Edendale terrace by McIntosh (1995). These are the *Edendale silt loam* and *Otikerama silt loam*. The Edendale silt loam is classed as a rapid draining soil, whereas the Otikerama silt loam is classed as being moderate to slow draining. An Ota silt loam (also known as Fleming) is found in the west of the aquifer and is lumped with the Otikerama silt loam in the map figure of soil distribution below.

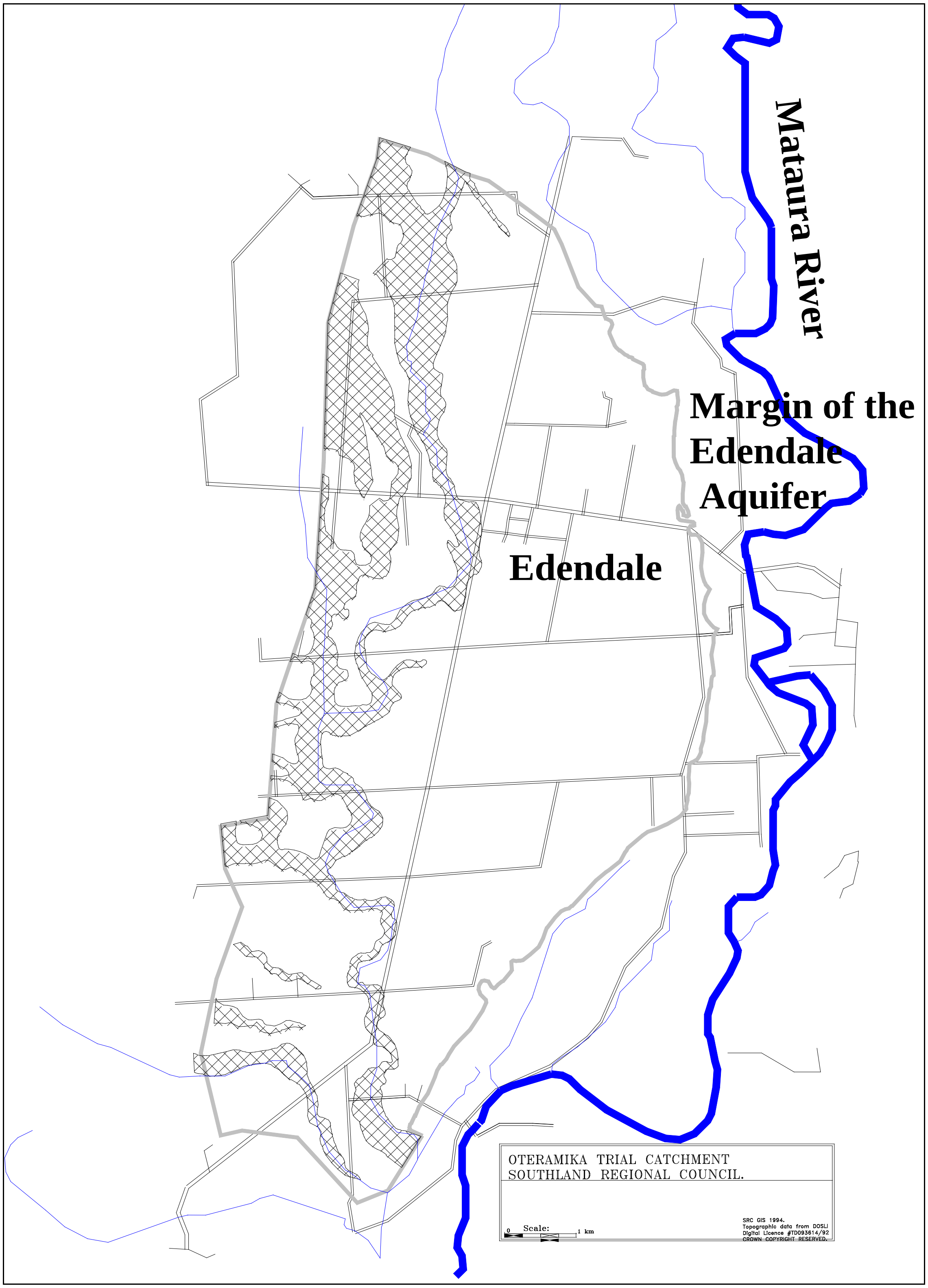

Figure 9 Contrasting soils on the Edendale Terrace. Hatched area marks Otikerama silt loam (slow draining), while most of the remaining area within the grey boundary of the Edendale aquifer is Edendale silt loam (rapid draining).

The eastern part of the Edendale terrace surface lacks any form of surface watercourses. This is also the area of the terrace entirely Edendale silt loam, and presumably very free draining. In such parts of the terrace, percolation of excess soil water will be the only form of land drainage, bypassing any involvement of surface water until the groundwater emerges at springs.

Slow soils such as the Otikerama silt loam are more likely to promote lateral interflow and even overland runoff which enters water bodies in the west of the terrace. Slow soils are also closely associated with the present-day watercourses.

2.3 Surface Water Hydrology.

Surface water hydrology has some relevance to the consideration of the Edendale Aquifer due to the interactions between groundwater and surface water. Some of these interactions have already been described and quantified in Hydrogeology. A summary of the principal hydrological mechanisms identified for the Oteramika Catchment and Edendale terrace is given below:

- The hill parts of the Oteramika catchment, largely those to the west, are dominated by surface water processes namely overland flow and shallow land drainage (interflow). However, shallow, lower permeability unconfined aquifers are believed to exist in the hill country. These provide baseflow to Oteramika Creek and tributaries,
- The terrace parts of the catchment, particularly those with rapid draining soils, are dominated by sub-surface drainage. Percolation of soil – water excess to the Edendale Aquifer is the predominant form of land drainage in these portions of the catchment,
- The majority of groundwater does not re-enter the Oteramika catchment after percolation. Instead there is a net export of water to springs and creeks (Ota Creek, Halls Pit, Shields Road springs and Ives Creek) out of the catchment directly to the Mataura River,
- Oteramika Creek appears to be perched above the Edendale Aquifer for most of its course across the Edendale Terrace. A significant separation in elevation between the base of the creek and the water table is maintained through most of the creek’s length.

2.3.1 Hydrological Data.

Oteramika Creek has had a hydrological recorder site since only December 1995. Prior to this, only spot gaugings have been made at the State Highway crossing near Edendale, on an irregular basis. The present hydrological recorder is located on the Howden’s property near the locality of Seaward Downs. The recorder logs creek stage and bore water level simultaneously. Creek stage is converted to instantaneous flow rate by fitting to the rating curve. The hydrological flow statistics for the period 16 December 1995 to 20 May 1998 are shown in the table below.

Hydrological Statistics for Howdens Recorder (16 Dec. 1995 – 20 May 1998)	m^3/s*
Mean Flow	0.441
Median Flow	0.184
Standard Deviation	0.770
Lowest Daily Mean Flow	0.001
Maximum Daily Mean Flow	10.181
Range of Flow Rates	10.18

* 1 m^3/s = 1,000 l/s

2.3.2 Specific Runoff & Water Balances.

Specific runoff is the catchment surface water yield specific to the surface area of the catchment. It is usually expressed in terms of litres per second per square kilometre of the catchment. Where it has been possible to delineate the catchment boundaries and areas, the flow statistics can be converted into a specific runoff.

Previous hydrologic assessments have estimated specific runoffs for catchments and sub-catchments bounding the Oteramika Creek catchment. Given similar precipitation and evapotranspiration rates of these surrounding areas, the specific runoffs should be broadly comparable. An assessment of the Mataura catchment (Riddell, 1984) made sub-catchment water balances of a number of gauged rivers and river reaches. In the lower catchment the Mimihau River and the Mokoreta / Wyndham River have been assigned specific runoffs of 21.6 and 22.4 $l/s/km^2$, respectively, for the period 1974 - 1984. While the Mokoreta / Wyndham River catchment has an annual precipitation about 30% greater than the Oteramika, the Mimihau River catchment is only 5 - 10% higher. Therefore, comparisons can be made with the Mimihau River catchment.

The Waihopai River has a specific runoff of 23.2 $l/s/km^2$ for the period 1994 -95 (Rekker, 1996). The Waihopai is a 'sister' catchment to the Oteramika, being of a similar soil type, altitudinal range, precipitation, geology and land use as the Oteramika. The specific mean annual runoff of Oteramika Creek can be estimated using the mean annual flow for 1996 and dividing the sub-catchment area inferred for the catchment 'seen' by the recorder site. As mentioned above in relation to baseflow, the sub-catchment area is uncertain due to the bi-modal nature of hydrology on the Edendale terrace, contributing to both groundwater export and creek streamflow. One means of calibration for estimating the surface water catchment area would be to calculate specific runoff using different possible areas and compare these with specific runoffs measured in surrounding catchments.

The total area forming the Oteramika Catchment incorporates the surface water catchment and the Edendale aquifer as a groundwater catchment extension. Several sub-catchments are delineated according to the positions of gauging sites of creeks or the margins of the Edendale aquifer. The table below summarises the areal extents for the various sub-catchments planimetered.

	Areal Extent (ha)	
Edendale Aquifer	6,487	Discharges at springs on eastern margin
Howden's surface water catchment	6,318	Taken directly from SRC catchment data-layer and truncated for Ota Creek Rd blockage and Howden's position
Slow Draining Soils on the Edendale Terrace	1,025	The terrace is largely covered by Edendale silt loam, but is in places mantled by slower draining soils that direct excess water towards surface water.
Northern Hill Catchment (contributing to Howden's flow recorder)	2,489	Determined by taking the western catchment boundary and truncating against the aquifer margin
Southern Hill Catchment	1,389	Combined hill country south of Howden's influence
Morton's (Intermediate) Tributary	607	Truncated to gauging site on Seaward Downs - Gorge Road crossing
McCall's Road Tributary	1,132	Truncated to gauging site on Seaward Downs - Gorge Road crossing
Total Catchment	10,773	Includes areas not planimetered above.

Given the catchment areas it is possible to begin developing sub-catchment water balances, which are explicit estimates of the flux of water through each sub-catchment. A long term precipitation total for Edendale of 1,000 millimetres per annum covering the period 1962 - 1981 (Riddell, 1984) is used in these water balances.

In discussion of specific runoff in the sub-section above two principal uncertainties remained;

1. The areal extent of the a sub-catchment with paired surface water and groundwater drainage,
2. A lack of continuous record for the southern hill country catchments (McCall's Road Tributary and Morton's Tributary)

The presence of net export of catchment water *via* infiltration and outflow directly to the Mataura River causes difficulties in making a specific runoff estimate. The Howden's sub-catchment was estimated and a mean annual flow from measured data for 1996 is available. The resulting specific runoff is shown below.

	Area (km^2)	**Mean Flow (l/s)**	**Specific Runoff (l/s/km^2)**
Oteramika @ Howden's	63.18	355	5.6

The derived specific yield is well beneath the specific runoffs from neighbouring catchments. If the area over the Edendale aquifer is excluded, a more plausible specific runoff is derived.

	Area (km^2)	**Mean Flow (l/s)**	**Specific Runoff (l/s/km^2)**
Oteramika @ Howden's	24.89	355	14.3

This value lies closer to values of 20 - 23 l/s/km^2 derived for neighbouring catchments. This suggests that there is hydrological division between the hill country that appears to be dominated by surface water drainage, and the terrace that is dominated by sub-surface drainage.

The southern hill country tributaries are gauged regularly, but do not have a continuous flow record. Correlation of gauged flow on McCall's Road Tributary and the Oteramika at Howden's reveals a linear relationship. This relationship is applied to the 485 days of Howden's recorder station record from January 1996 to April 1997 to derive an estimate of the equivalent mean creek flow in the McCall's Road Tributary.

	Area (km^2)	**Mean Flow (l/s)**	**Estimated Specific Runoff (l/s/km^2)**
McCalls' Road Tributary	11.3	161	14.2

It is noteworthy that the specific runoff estimated in this fashion is close to the estimate made by a different method for the hill country catchment of Oteramika Creek at Howden's.

The specific runoff for McCall's Road Tributary is then applied to Morton's Tributary.

	Area (km^2)	**Estimated Mean Flow (l/s)**	**Specific Runoff (l/s/km^2)**
Morton's Tributary	6.07	86.2	14.2

In this manner, reasonable estimates of the mean annual flows of surface water sub-catchments in the Oteramika Catchment are derived.

2.3.3 Water Balances.

The table below shows the estimated water balances for the various surface and sub-surface sub-catchments in the Oteramika Catchment.

Sub-Catchment.	**Area (ha)**	**Fluxes (mm/yr)**			
		Precip.	**A.E.T.**	**Flow**	**Rech.**
Edendale Aquifer	6,487	1000	551	51	398*
Oteramika @ Howden's surface water catchment	2,489	1000	550	450	n/a
Southern Hill Country surface water catchments					
Morton's (Intermediate) Tributary	607	1000	552	448	n/a
McCall's Road Tributary	1,132	1000	551	449	n/a
Total Catchment (combined surface water / groundwater catchment)	10,773	1000	553	177	200

Precip. = Precipitation
AET = Actual Evapo-Transpiration,
Rech. = Recharge to Edendale aquifer,
* Calculated by multiplying mean annual springflow with the aquifer area.

Of the flow in surface water sub-catchments, about 46% of streamflow will be made up of baseflow and interflow. The remainder will be made up of storm-induced runoff. This leads to the irregular, asymmetric flow distribution as shown in the figure below.

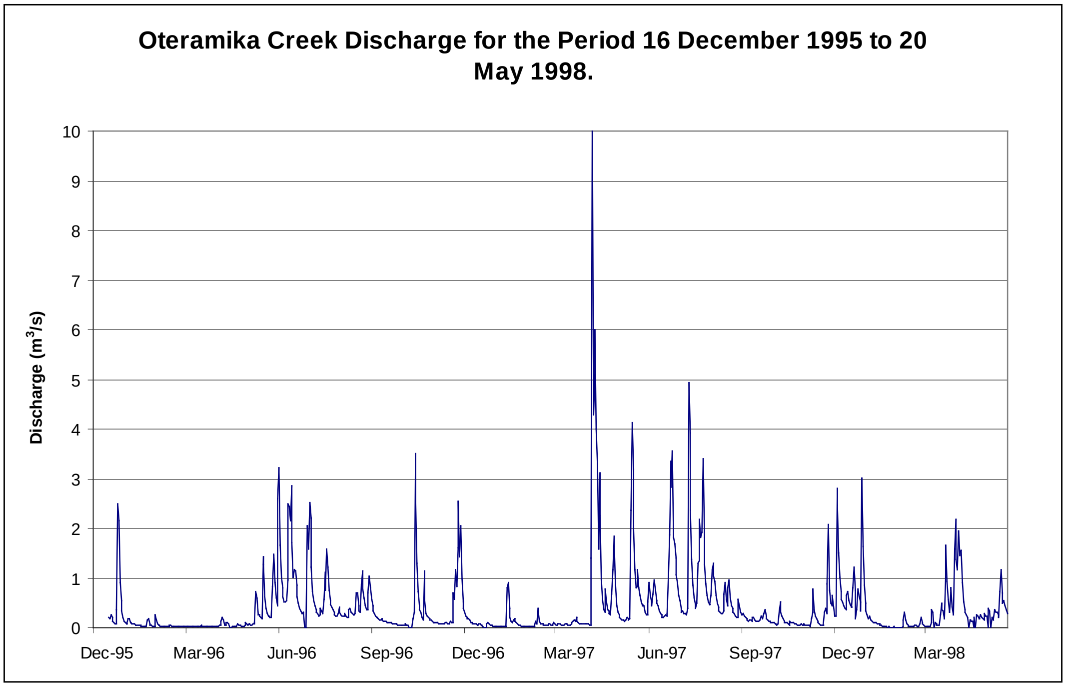

Figure 10 Hydrograph of Oteramika Creek at Howdens.

Base flow analysis of this record has estimated that about 46.5% of streamflow is baseflow and interflow occurring in the subsoils and shallow aquifers of the western hill country. The remainder is storm-induced runoff, as is suggested in the 'spiky' pattern of streamflow evident in the hydrograph above.

2.3.4 Recharging Groundwater Interaction.

The general model that the study has developed, is that Oteramika Creek is not in direct hydraulic communication with the underlying Edendale Aquifer. Instead, the base of Oteramika Creek as it crosses Edendale Terrace is separated from the underlying water table by several metres of unsaturated gravel. Only as the creek drops off the flank of Edendale terrace does the creek and water table intersect. Moderate amounts of groundwater seepage are measured in this transitional area.

Creeks perched in this fashion may still lose water to the aquifer at a rate dictated by the permeability of the 'clogging layer' underlying the base of the creek. This is a one-way connection only. No evidence of significant loss of groundwater has been found in simultaneous, multi-site, low flow gaugings of Oteramika Creek. The only evidence of seepage gain of groundwater into the creek has been downstream of the Howdens recorder site. Upstream of this point, the Howdens recorder logs the creek and bore water levels through time. The figure below compares the hydrographs.

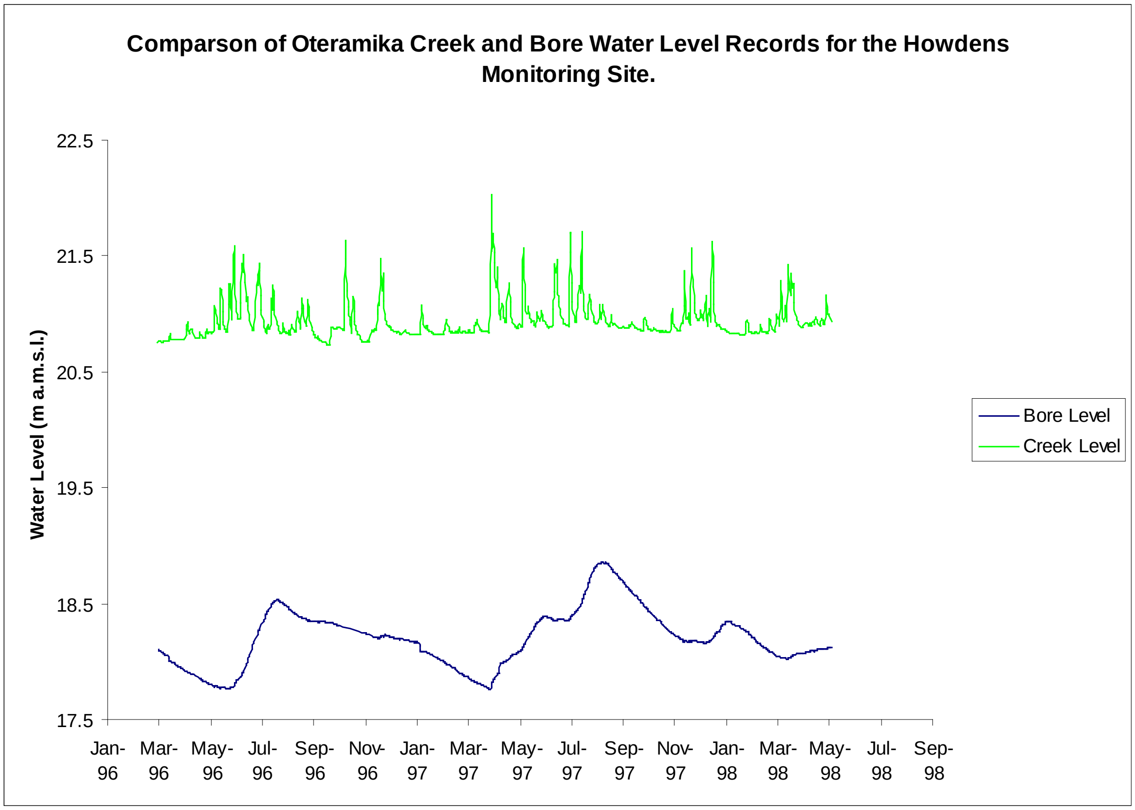

Figure 11 Graph showing separation and differing water level fluctuation for creek and water table at the Howdens recorder site. The bore water level is below creek level by a mean 2.7 metres.

It is evident that, in addition to the 2.7 metre separation in mean water level, that the mechanisms driving water level in creek and aquifer fluctuation are different. Creek flow is driven by the relatively rapid runoff of recent rainfall. Aquifer recharge, reflected in groundwater level, is driven by the slow percolation of water accepted by the soil and infiltrated through the base of the soil to the water table.

3. Groundwater Quality & Contaminant Loading.

3.1 Introductory Concepts on Groundwater Quality.

The study of non-point source water quality effects on groundwater is the sub-title of this report. The investigation of non-point source impacts on *surface water* is a relatively new technical discipline. Attention as to these effects on *groundwater* is even younger, and studies have often neglected the fact that surface and ground water are inter-connected. In past studies, surface water quality impacts were often largely or solely attributed to contaminants such as nitrogen "washing off the land" by dissolution in overland flow. In fact, in many humid regions with moderate pasture slopes the drainage of water is dominated by subsurface vectors, with overland flow making up a relatively minor part of a catchment's streamflow. Therefore, studies into eutrophication in the past have often wrongly assumed that controlling surface runoff was the best management practice in preventing nutrients entering sensitive water bodies.

A recent study into the baseflow characteristics indicated that up to 276 millimetres of precipitation that falls in Eastern Southland passes through the subsurface mode of land drainage to form baseflow in the region's creeks, streams and rivers (Rekker, 1997[8]). This is a significant proportion averaging about 50% of the river flow from the major catchments. Much of the region's freshwater nutrient load may in fact enter surface water *via* seepage of groundwater.

Groundwater is a water resource in its own right. Groundwater, where it is available, is the preferred source of raw water for private and community drinking water supply. Often because of the relative clarity and microbiological purity of groundwater, it is supplied to the consumer with minimal or no treatment. Non-point source contamination of groundwater can limit the utility of this resource for optimal resource management. The most common examples of groundwater contamination are the presence of nitrate or agricultural chemicals at concentrations higher than the safe level for human health protection. Such contamination from agricultural practices is more likely in the presence of freely draining soils over unconfined groundwater (Rekker, 1994).

Thus, contamination of groundwater, and water quality effects (such as eutrophication) on surface water, are interconnected aspects of agricultural land use effects. The Oteramika Creek catchment exhibits a relatively high intensity of agricultural land use for Southland, demonstrated presence of nitrate and agricultural chemicals in groundwater (sometimes at concentrations of health concern), dependence on unconfined groundwater for public and private drinking water supply, and large scale discharge of groundwater to sensitive aquatic environments. This makes the catchment appropriate as a case study of the processes and vulnerability with applicability over similar parts of the region.

3.2 Groundwater Quality Indices.

Groundwater from the Edendale Aquifer has been measured for a variety of basic water quality indices and substances since the end of the Second World War, principally from the Edendale School well and the Edendale cheese factory well. Records of water quality that have been preserved, go back only as far as 1982.

3.2.1 Primary Indices.

The indices that are of most value for providing benchmarks of effects on water quality and also for shedding light on groundwater contamination processes are listed in the table below:

Analyte / Parameter	Significance	Usual Resolution/ Detection Limit
pH	Indicates degree of pH shift from rainwater origin	± 0.1 pH unit
Electrical conductivity	Indicates dissolved solids, surrogates for chloride, indicates dairy factory wastewater influence	± 5 μS/cm
Nitrate nitrogen	Primary contaminant	± 0.2 gNO_3-N/m^3
Ammoniacal –N	Residual indicator as to denitrification, indicates redox state	± 0.01 gNH_3-N/m^3
Phosphorus (as DRP)	Secondary contaminant and promotes eutrophication in inland waters	± 0.005 gDRP/m^3
Chloride (Cl^-)	Conservative tracer and indicator of dairy factory wastewater influence	> 0.6 g/m^3
Total Iron	Indicates redox state and inhibition of nitrate accumulation	> 0.1 g/m^3

Other cations and anions are also of significance in assessing particular effects. For example sodium, although not as consistent and conservative as chloride, provides an indication of dairy factory wastewater influence on groundwater.

3.2.2 Guideline Values.

Nitrate, as the primary contaminant, has a number of toxicity or undesirable effect guide threshold values. In general, the human health guideline values are more conservative than for stockwater because of the higher notional cost of human mortality. The guideline limits of nitrogen for drinking, stock and dairy industry water uses are shown in the table below.

	NZ D.W. Standard[i]	**ANZECC Guidelines**[ii]
Nitrate in Drinking Water	50 g/m^3 as NO_3	11.3[iii] g/m^3as NO_3-N
Nitrite in Drinking Water	3 g/m^3 as NO_2	
Stock Water		30 g/m^3 as NO_3-N
Dairy Industry Water		< 20 g/m^3 as NO_3-N
Inland waters for Dissolved Inorganic Nitrogen (DIN)		0.04 – 0.1 $gDIN/m^3$

Nitrite is an accessory or transitional form of oxidised inorganic nitrogen. It has a lower toxicity threshold in humans, particularly in respect of methaemoglobinemia (so-called the Blue Baby Syndrome).

A secondary contaminant phosphorus, usually expressed as dissolved reactive phosphorus, has significance when it enters surface water as seepage. Groundwater has the potential to act as a vector for conveying phosphorus from beneath the soil profile to streams and rivers. Concentrations of dissolved reactive phosphorus (DRP) and dissolved inorganic nitrogen (DIN) in flowing fresh waters should be below 15 – 30 $mgDRP/m^3$ and 40 – 100 $mgDIN/m^3$, respectively for nutrients to exert any significant control (limitation) on periphyton biomass (Ryder, 1995a[9]).

3.3 Results of Long Term Monitoring of Bore and Spring Waters.

The Edendale Aquifer became the first area in Southland to receive State of the Environment (SOE or SEM) style monitoring of groundwater quality. Sampling began in September 1995 and has continued on a quarterly schedule until May 1998. The results of the monitoring as medians, minima and maxima are shown in the figures below.

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[i] Drinking Water Standards of New Zealand, 1995. Ministry of Health, Wellington.

[ii] Australian guidelines for fresh and marine waters, 1992. Australian & New Zealand Environment & Conservation Council.

[iii] The concentration of 50 g/m^3 as nitrate equals 11.3 g/m^3 as nitrate nitrogen. Public health guidelines commonly refer to nitrate concentrations, whereas resource management / water quality studies find it convenient to refer to nitrate nitrogen.

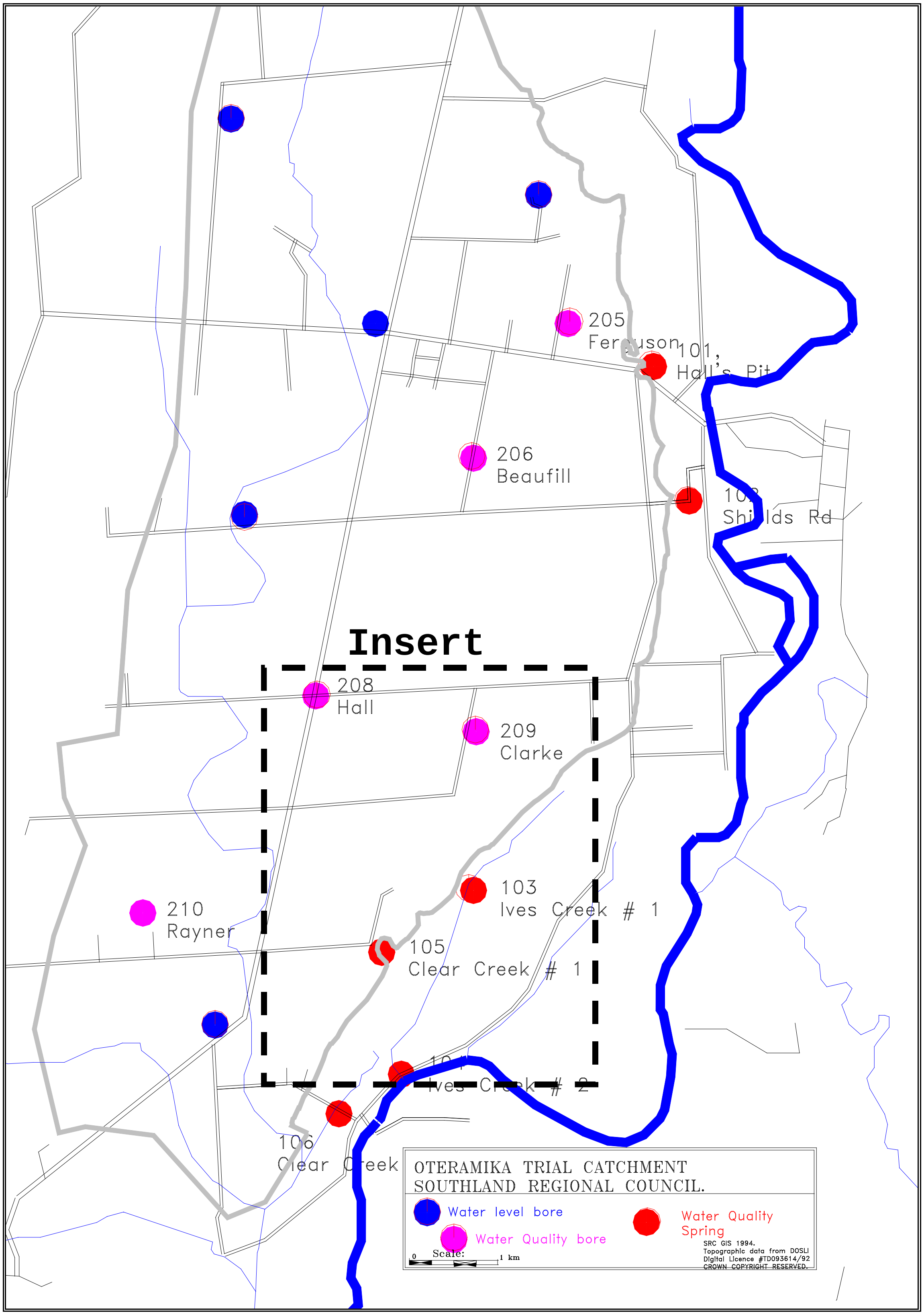


Figure 12 Location map of aquifer water level and water quality measurement sites.

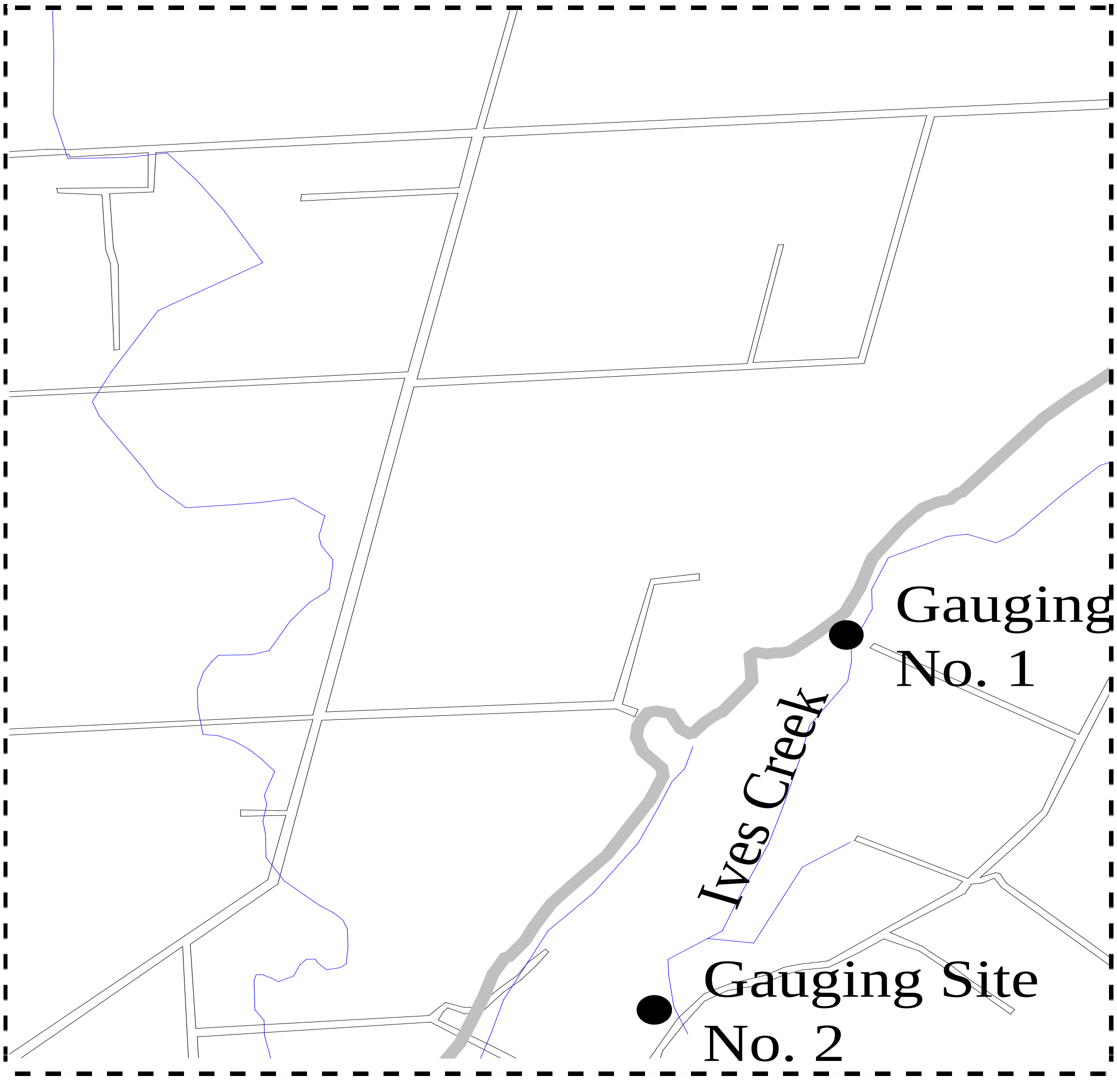


Figure 13 Insert of Ives Creek gauging / sampling points. The downstream site was sometimes not gauged during quarterly monitoring due to high flows in the Mataura River causing backwater effects at gauging site number 2.

3.3.1 Nitrate.

Nitrate is the primary contaminant of the Edendale aquifer. It is found at concentrations throughout the aquifer generally in excess of 50% of the Maximum Acceptable Value[iv] (MAV) for drinking water, the usually trigger for added vigilance of this parameter in public water supplies. The graph below shows the statistical parameters of concentration for several spring waters and bore waters monitoring as part of this study.

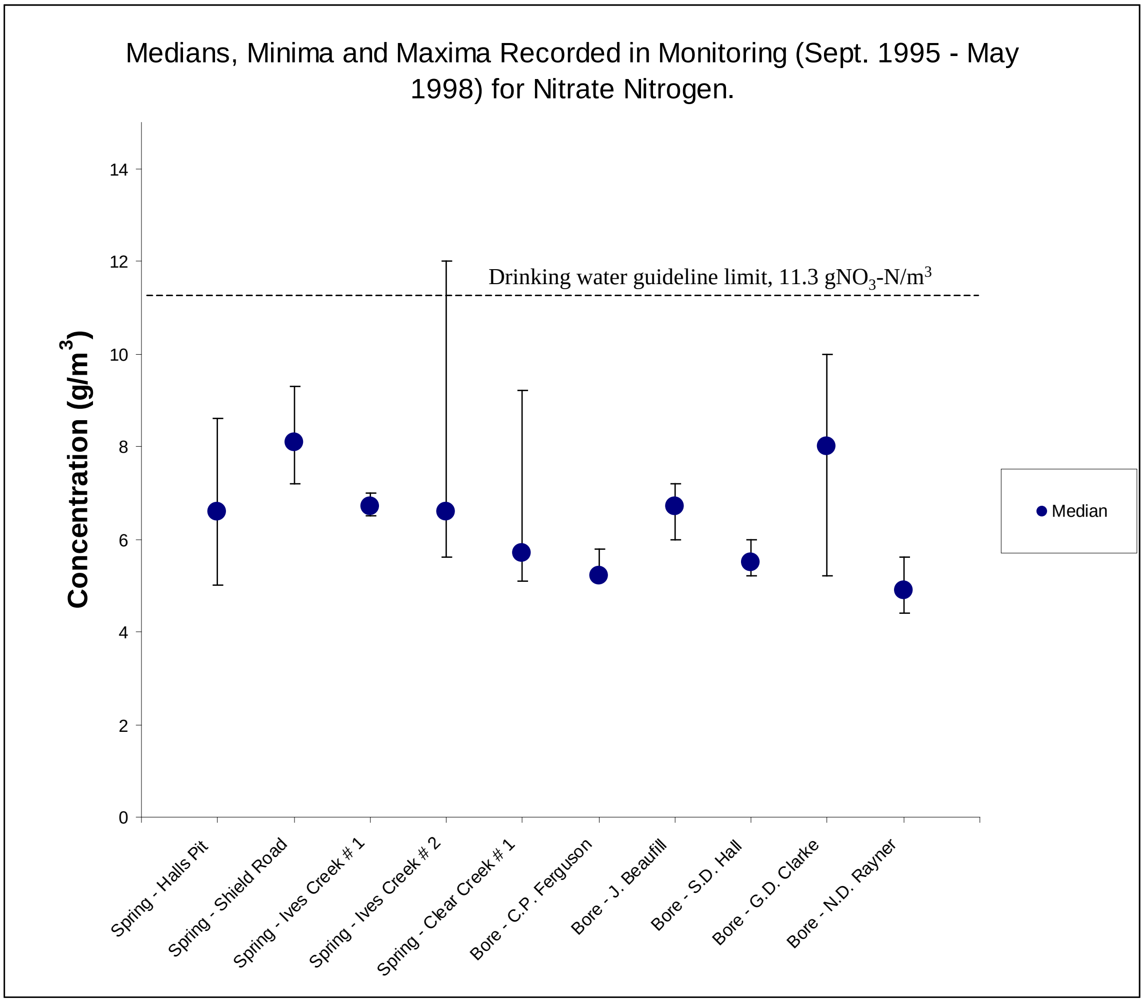


Figure 14 Groundwater concentration medians, minima and maxima for the nitrate nitrogen constituent. The median is represented as a dot bounded by the highest and lowest recorded concentrations.

Nitrate is expressed above as nitrate nitrogen. Only spring water in Ives Creek # 2 site breached the 11.3 gNO$_3$-N/m^3 guideline limit for drinking. With the exception of the Clarke bore, bore water tend to be less volatile in their minimum and maximum concentration bounds.

[iv] The Maximum Acceptable Value is the concentration of a determinand below which the presence of the determinand does not result in any significant risk to a consumer over a lifetime of consumption (NZ Drinking Water Standards. Ministry of Health, 1995).

3.3.2 Phosphorus.

Phosphorus is a secondary potential contaminant with significance for biotic degradation of surface water. It is expressed in analysis as either total phosphorus or dissolve reactive phosphorus. Dissolved reactive phosphorus (DRP) tends to quantify the labile and bio-available part of the phosphorus load. In general terms, DRP tends to make up $^2/_3$ of the phosphorus load in groundwater. The graph below shows the distribution of DRP in Edendale Aquifer groundwater.

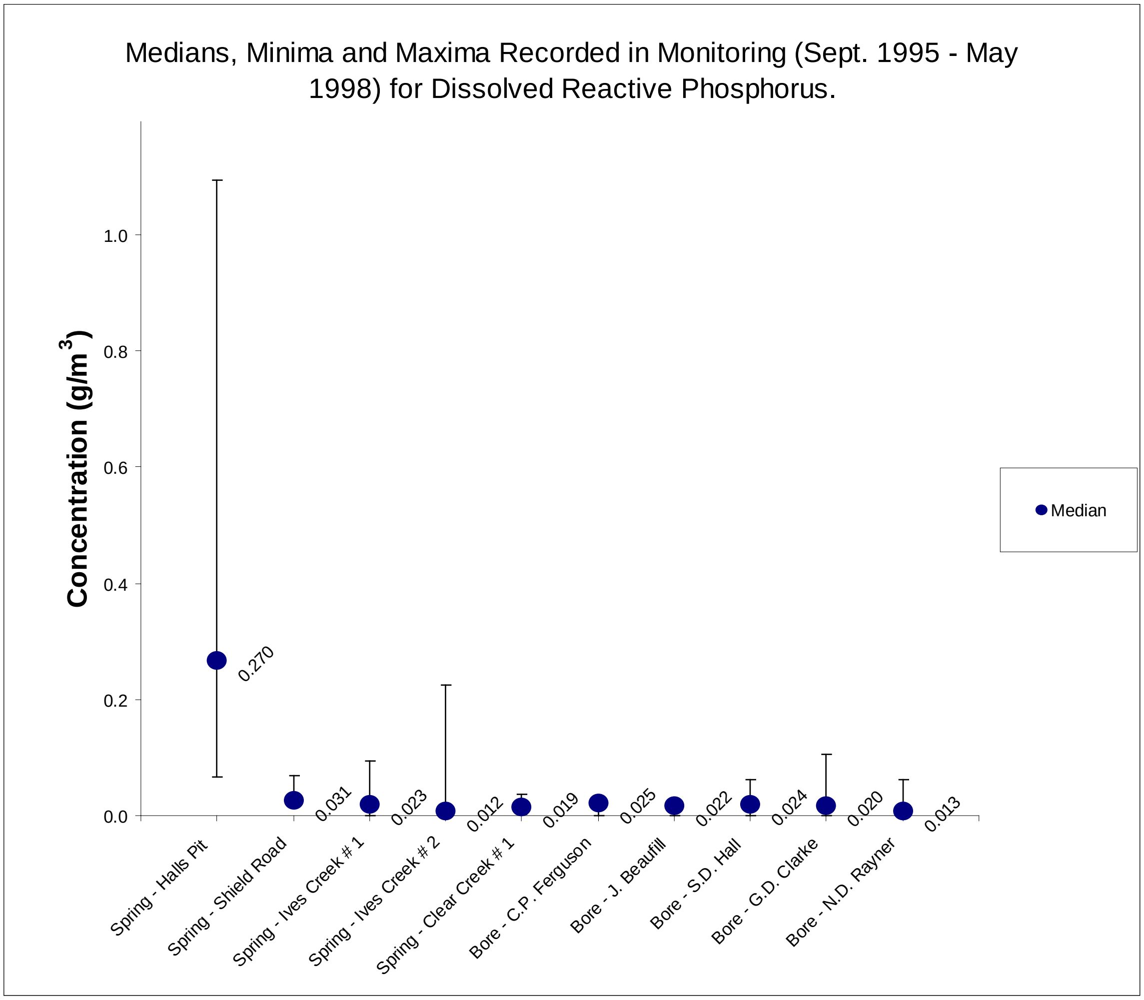


Figure 15 Groundwater concentration medians, minima and maxima for the DRP constituent. Values of the median for each site are labelled because of the wide range of values recorded.

Halls Pit groundwater stands out as an anomalously high DRP concentration. The minimum value for Halls Pit is higher than all other medians. It is also interesting to note that Ives Creek downstream (# 2) is lower in DRP concentration than the Ives Creek upstream sampling site (# 1). This could be attributed to stripping of the nutrient by aquatic macrophytes and periphyton. The detection limit for DRP is 0.005 g/m3. There were four bores with minima below this threshold, but their medians lie above.

3.3.3 pH Units.

The parameter of pH is an indicator of origin of water and of any prior oxidation – reduction reactions within the groundwater. Rainwater, because of its equilibrium with the atmosphere has a pH averaging 5.2. This value is closely reflected in soil pH. In the absence of any significant alkalisation of the soil / groundwater, the water within the Edendale Aquifer will reflect the range of pH 5 – 6. The graph below illustrates the range present in Edendale groundwater.

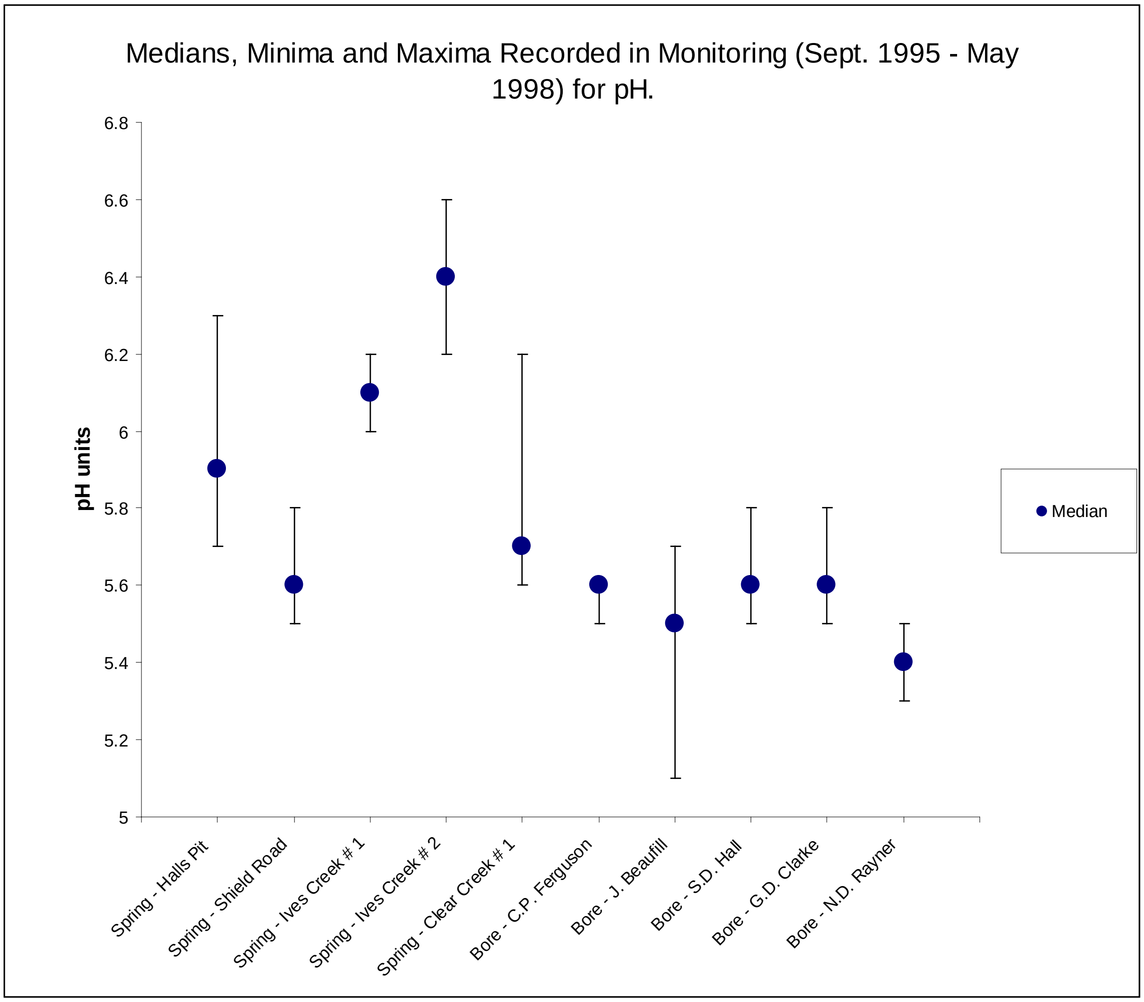


Figure 16 Groundwater medians, minima and maxima for pH.

Spring waters tend to have higher pH than bore waters. This could be attributed to reactions within the spring water following re-equilibration to atmospheric dissolved oxygen (DO) content from the depleted DO concentration of groundwater. There would not appear to be significant alkalisation of groundwater by chemical buffers such as calcite ($CaCO_3$) rich minerals or precipitates. The relatively low pH of Edendale groundwater is a slight limitation on its used in public and private water supply. Dissolution of copper or brass plumbing and fittings is reported by some residents.

3.3.4 Electrical Conductivity.

Electrical conductivity, strictly specking, is the measure of water to conduct electricity. It correlates with the total solute load of ionic compounds. The more dilute a water, the lower its electrical conductivity. The graph below shows the distribution of medians, minima and maxima for Edendale groundwater measured in long term monitoring.

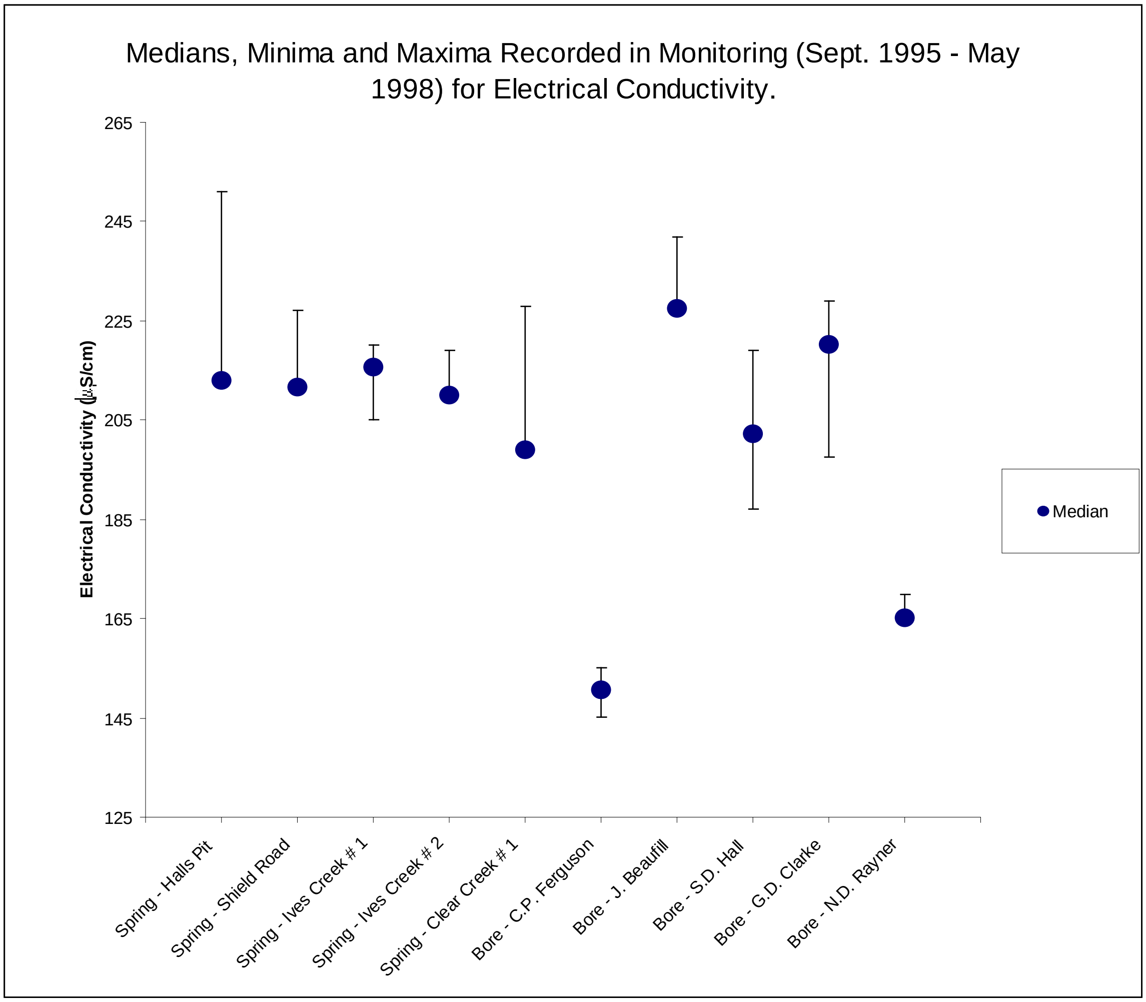
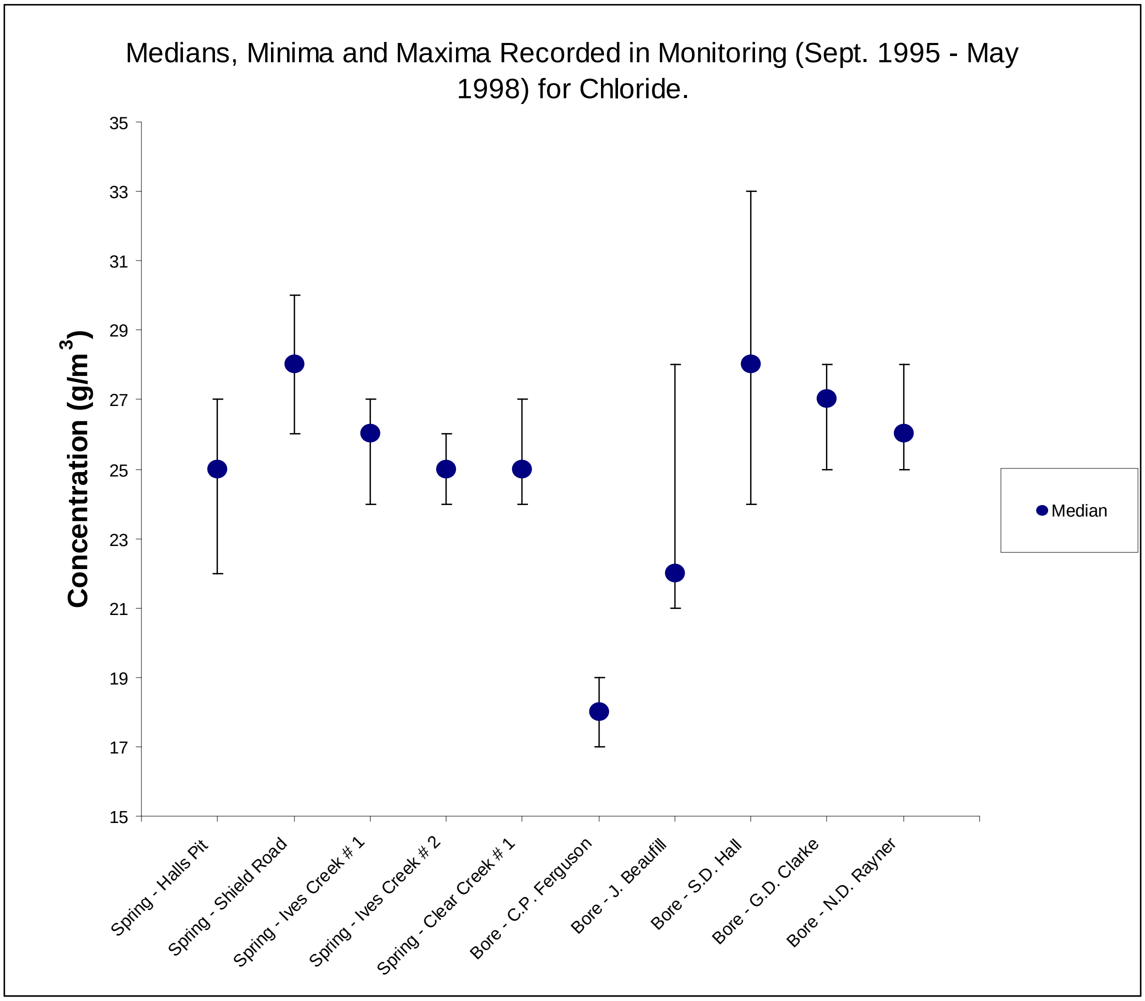


Figure 17 Groundwater concentration medians, minima and maxima for electrical conductivity.

The Ferguson bore water has the lowest electrical conductivity, and very little variability. Similarly, the Rayner bore that lies in a 'headwater' position in the aquifer has a low electrical conductivity. All spring waters have an electrical conductivity reflective of their 'downstream' position in the aquifer. The Hall and Clarke bore waters are thought to be influenced by the elevated ion load derived from the dairy factory discharge.

3.3.5 Chloride.

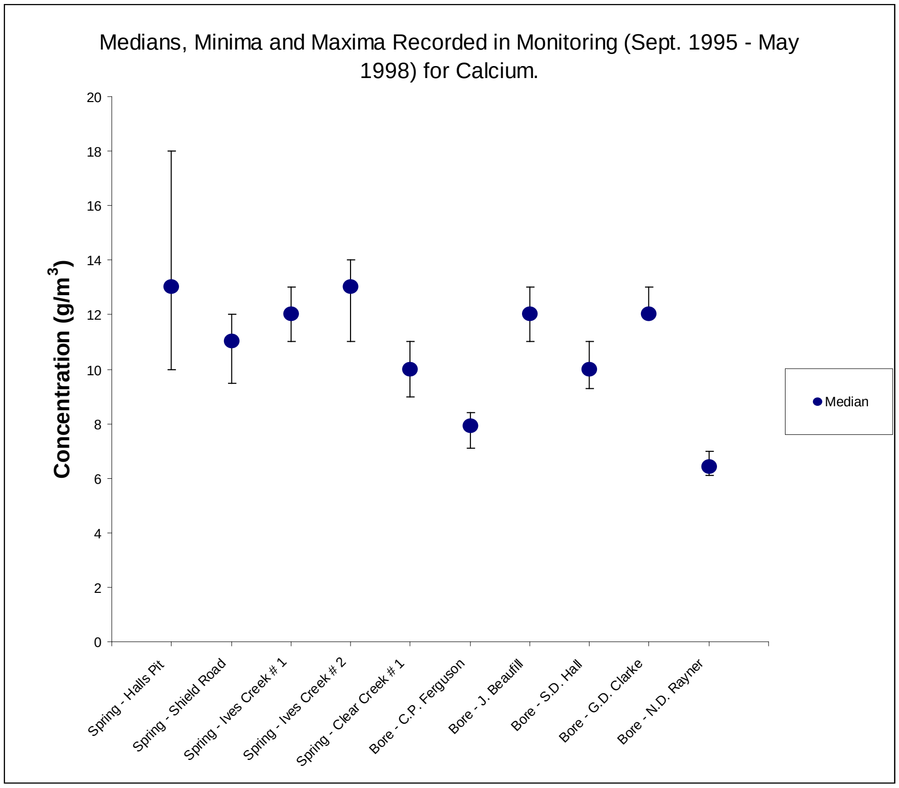
Chloride is a useful conservative of solute transport in soil and groundwater. Sources of chloride to the Edendale Aquifer include atmospheric inputs, KCL fertiliser and salt whey disposed to land as part of the dairy factory discharge. The mean chloride concentration of rain falling on the Edendale terrace is about 7 g/m^3 (Boswell *et al.*, 1992[10]). The graph below shows the ultimate chloride concentrations measured in monitoring.

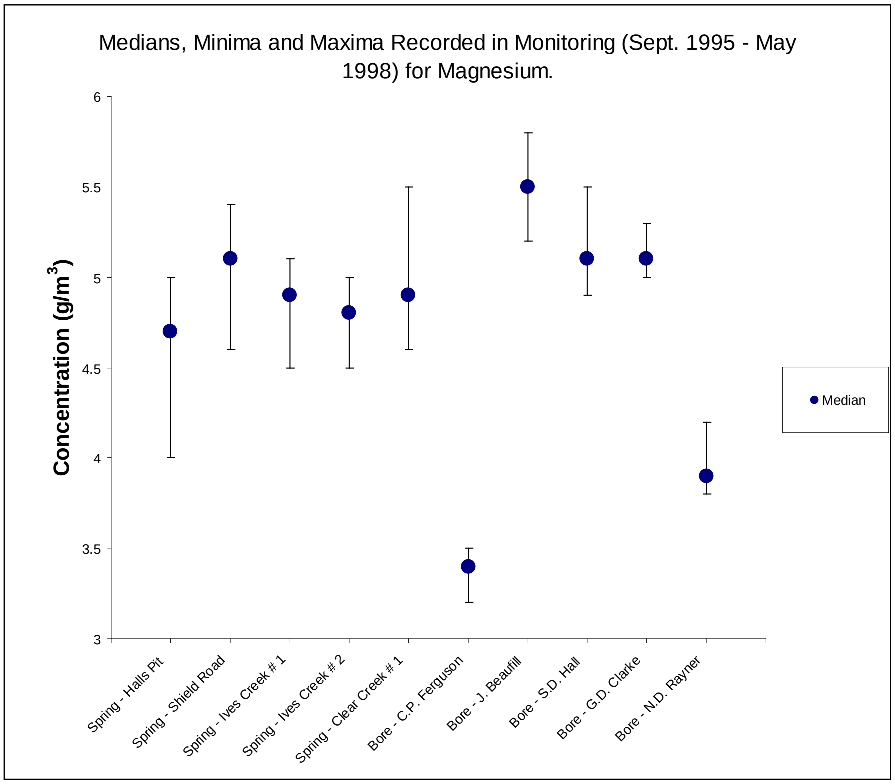


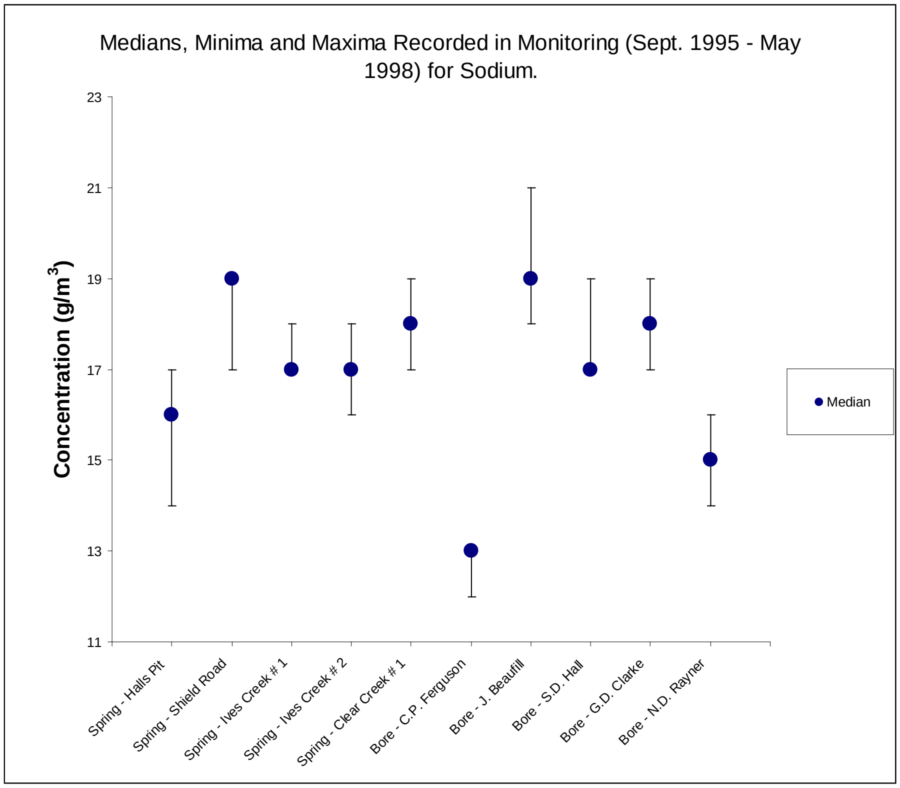
There is a significant range of values for groundwater chloride. All concentrations lie above that for mean rainfall, suggesting the effects of evaporative concentration, or artificial addition of chloride to the soil. The Hall, Clarke and Ives Creek # 1 sampling sites are believed to intercept a higher chloride groundwater plume originating from the dairy factory (Rekker, 1998[11]).

3.3.6 Other Cations and Anions.

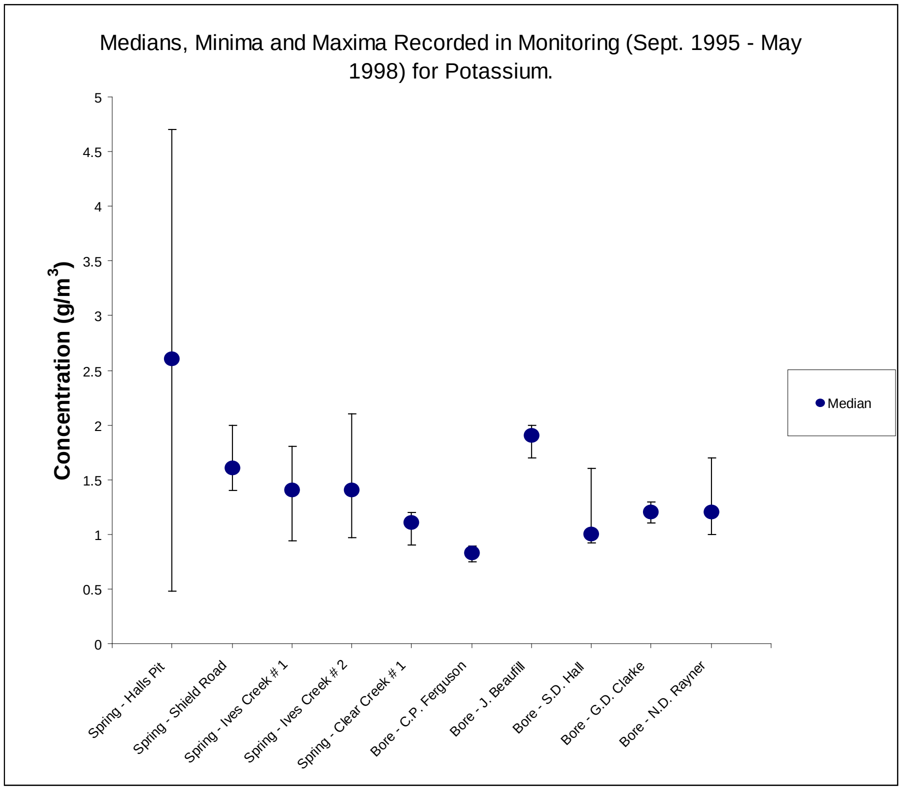
The graphs below show the results of monitoring for addition cations and anions.



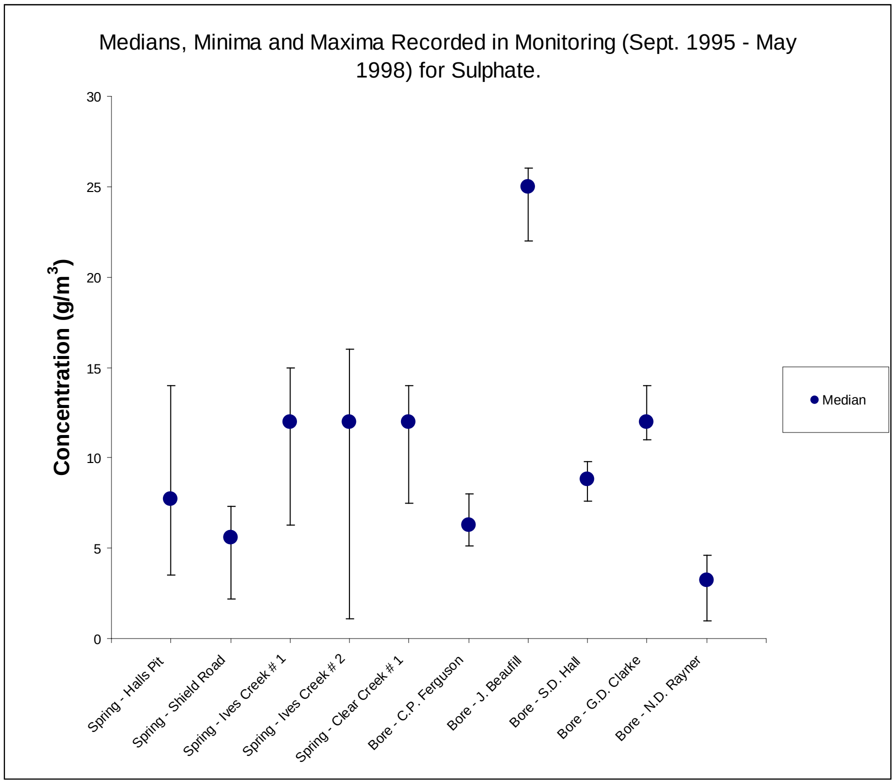


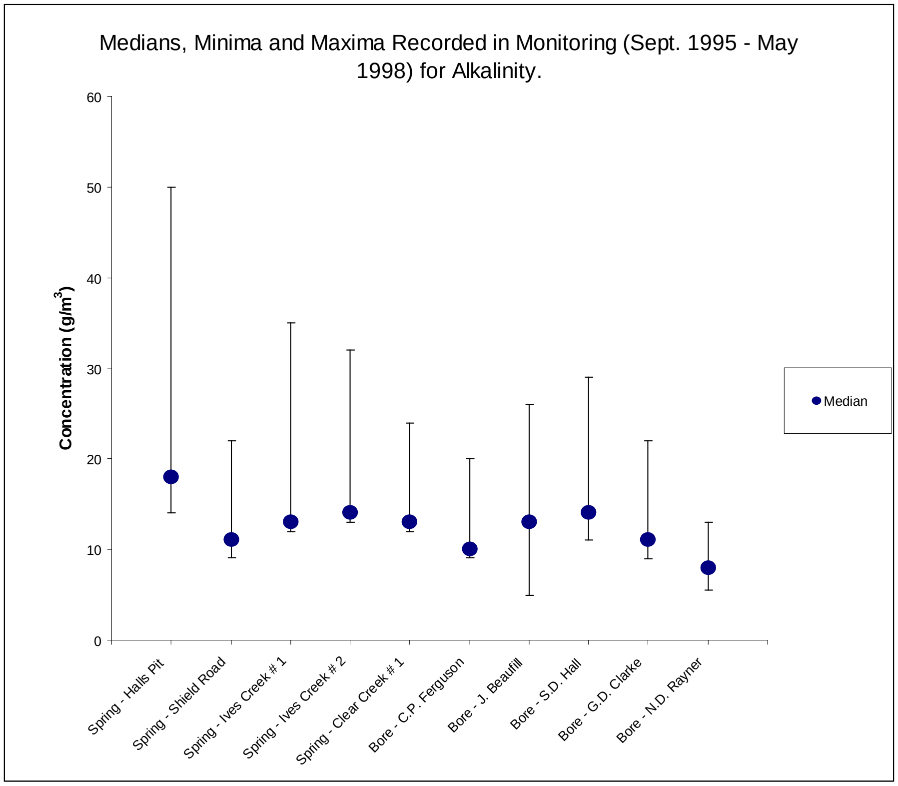


Medians, Minima and Maxima Recorded in Monitoring (Sept. 1995 - May 1998) for Sodium.
Concentration (g/m3)
23
21
19
17
15
13
11
Spring - Halls Pit
Spring - Shield Road
Spring - Ives Creek # 1
Spring - Ives Creek # 2
Spring - Clear Creek # 1
Bore - C.P. Ferguson
Bore - J. Beaufill
Bore - S.D. Hall
Bore - G.D. Clarke
Bore - N.D. Rayner
● Median



Medians, Minima and Maxima Recorded in Monitoring (Sept. 1995 - May 1998) for Potassium.
Concentration (g/m3)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Spring - Halls Pit
Spring - Shield Road
Spring - Ives Creek # 1
Spring - Ives Creek # 2
Spring - Clear Creek # 1
Bore - C.P. Ferguson
Bore - J. Beaufill
Bore - S.D. Hall
Bore - G.D. Clarke
Bore - N.D. Rayner
● Median


Medians, Minima and Maxima Recorded in Monitoring (Sept. 1995 - May 1998) for Sulphate.
Concentration (g/m^3)
0
5
10
15
20
25
30
Spring - Halls Pit
Spring - Shield Road
Spring - Ives Creek # 1
Spring - Ives Creek # 2
Spring - Clear Creek # 1
Bore - C.P. Ferguson
Bore - J. Beaufill
Bore - S.D. Hall
Bore - G.D. Clarke
Bore - N.D. Rayner
● Median


Medians, Minima and Maxima Recorded in Monitoring (Sept. 1995 - May 1998) for Alkalinity.
Concentration (g/m^3)
0
10
20
30
40
50
60
Spring - Halls Pit
Spring - Shield Road
Spring - Ives Creek # 1
Spring - Ives Creek # 2
Spring - Clear Creek # 1
Bore - C.P. Ferguson
Bore - J. Beaufill
Bore - S.D. Hall
Bore - G.D. Clarke
Bore - N.D. Rayner
● Median

Calcium Calcium shows relative consistency between spring water and bore water excepting the Halls Pit site. The calcium concentration of rainfall is about 0.3 g/m^3. Calcium is added to pasture in regular, large amounts in lime application (see quantification below). If the groundwater is under-saturated, calcium should also be available for dissolution in calcium minerals making up the aquifer material.

Magnesium Magnesium shows marked scattering of concentration depending on sampling site. The Ferguson and Rayner bore waters shows significantly lower magnesium concentration compared to all others. Magnesium has a rainfall concentration of about 0.5 g/m^3. It is also contained in some fertiliser applications.

Sodium Sodium shows a similar distribution to chloride. The chief potential sources of sodium are seawater and salt whey from the dairy factory discharge. As a cation, sodium has the potential to be bound, at least temporarily, into soil particles. Large loadings of industrial salt to dairy factory discharge in the 1996 – 97 dairy processing season had the effect of causing cation exchange in the wastewater irrigation farm soils, displacing calcium ions. Subsequent low-sodium wastewater application flushed some of the sodium ions out of the soil pool.

Potassium Potassium has a small natural range of concentrations in the Edendale Aquifer.

Sulphate Sulphate concentration has relative consistency in spring waters and variability in bore waters. The sulphate concentration of rainfall is about 1.2 g/m^3. Sulphate is added to pasture in gypsum application. Weathering of soil minerals is another source of sulphate, although the rate of weathering is slower than the loss of sulphur through leaching.

Alkalinity Alkalinity concentration is relatively consistent amongst spring waters and bore waters. Halls Pit shows some divergence from this pattern having an elevated median and maximum alkalinity concentration. Alkalinity as bicarbonate is a balance anion in any groundwater at equilibrium. The constituent elements of bicarbonate are largely derived from dissolved gases.

3.3.7 Cation / Anion Balances.

Any groundwater in ionic equilibrium will have a balancing cation / anion mass equation. The primary ionic constituents of significant weight are nitrate, chloride, sulphate, bicarbonate, calcium, magnesium, sodium and potassium. The concentrations of these ions is converted to molar equivalent concentration based on their respective atomic masses and summed for total cations and anions. The results of this for long term median ion concentrations are shown in the table below.

Balance of cations and anions in Edendale groundwater monitored 1995-1998.

	Cations (meq)	**Anions (meq)**	**Error %**
Spring - Halls Pit	1.81	1.63	9.8%
Spring - Shield Road	1.84	1.67	9.3%
Spring - Ives Creek # 1	1.78	1.67	5.8%
Spring - Ives Creek # 2	1.82	1.66	9.0%
Spring - Clear Creek # 1	1.71	1.58	8.0%
Bore - C.P. Ferguson	1.26	1.17	6.8%
Bore - J. Beaufill	1.93	1.83	4.9%
Bore - S.D. Hall	1.68	1.60	5.2%
Bore - G.D. Clarke	1.86	1.76	5.4%
Bore - N.D. Rayner	1.33	1.28	4.0%

The percentage errors fall within an acceptable range. The highest percentage error is found in the Halls Pit site, which is consistent with the degree of volatility evident in graphs above. Bore waters have significantly lower percentage error compared to spring water. This is probably explained by the inference that spring water is subject to incomplete inorganic and biotic processes having just emerged from the ground into a contrasting hydro-chemical environment, whereas groundwater is within a slow-moving, stable environment. The cation / anion balance is illustrated graphically in the figure below.

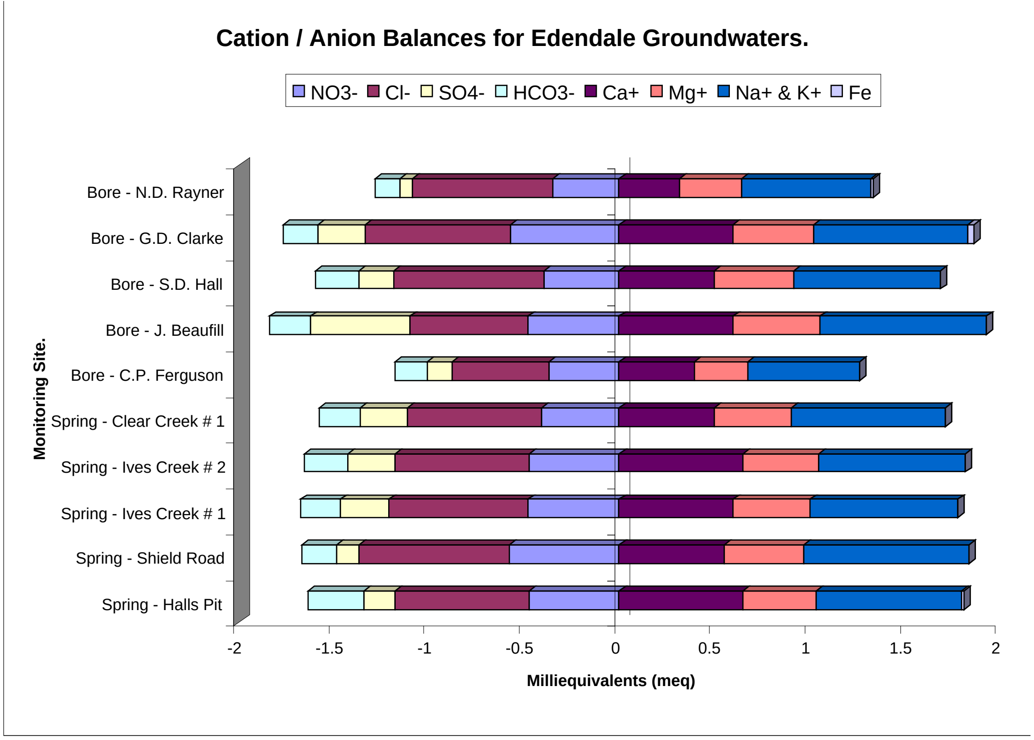


Figure 18 Graphical Cation / Anion balance of Edendale groundwater.

3.4 Mass Loading.

The preceding sections have provided details on the knowledge gained in this study on the rates of groundwater flow and groundwater concentration. Using these sets of parameters, a mass load for particular constituents can be developed. Particularly where mass loads averaged over an area (e.g., expressed as kg/ha), mass loads are useful in correlating the potential source masses and masses measured in groundwater.

The Edendale Aquifer contributing to groundwater recharge is believed to be 6,487 hectares in extent. The quantity of groundwater discharging from the aquifer is reliably estimated at about 820 litres per second or 25.8 million cubic metres per year. The table below develops this information, and combined weighted averages of spring water concentration into mass loading of the spring water discharging from Edendale Aquifer.

	Flow Weighted Average of All Springs Water Conc. (g/m^3)	**Mass Load** (Calculated using recharge of 25.8Mm^3/yr) (kg/yr)	**Areal Loading** (Calculated using an area of 6,487 ha) (kg/ha/yr)
Alkalinity	15.4	398,364	61.4
Calcium	11.1	285,686	44.0
Magnesium	4.9	127,017	19.6
Sodium	17.4	450,736	69.5
Potassium	1.3	34,281	5.3
Chloride	25.4	657,455	101.3
Sulphate	11.3	292,351	45.1
Nitrate-N	6.3	163,046	25.1
Nitrite-N	0.009	230	0.036
DIN	6.4	164,918	25.4
Ammonia-N	0.064	1,642	0.25
Total-P	0.073	1,879	0.29
DRP	0.048	1,244	0.19
Total iron	0.144	3,712	0.57

The mass loads developed above are highly pertinent to the study outcomes. They establish the global loading of contaminants such as nitrate and phosphorus. Localised areal loadings of these constituents will vary as a function of soil and land use factors. Spring water concentration will tend to reflect the general concentration after the effects of mixing with inflowing groundwater, while bore water concentrations will tend more to reflect localised inputs of potential contaminants. The table below shows the degree of difference between bore water and spring water concentration.

	Simple Average of Bore Water Conc. n = 5 (g/m^3)	**Flow Weighted Average of Spring Water Conc. (g/m^3)**	**Percentage Difference (±%)**
Alkalinity (HCO_3^-)[†]	12.0	15.4	22.0%
pH[†]	5.5	5.9	6.5%
Conductivity (μS/cm)	185.1	194.7	4.9%
Calcium	9.7	11.1	12.1%
Magnesium	4.6	4.9	6.0%
Sodium	16.5	17.4	5.6%
Potassium	1.3	1.3	4.9%
Chloride	24.3	25.4	4.4%
Sulphate	11.1	11.3	-2.1%
Nitrate-N	6.1	6.3	3.6%
Nitrite-N[†]	0.005	0.009	43.5%
DIN	6.1	6.4	4.4%
Ammonia-N[†]	0.013	0.064	79.3%
Total-P[†]	0.024	0.073	66.5%
DRP[†]	0.023	0.048	53.1%
Total Iron[†]	0.551	0.144	73.9%

[†] Non-conservative in the transition from groundwater to spring water.

It is noteworthy that conservative ions such as chloride and sodium show little difference between mean bore water and weighted mean spring water concentrations (4.4% and 5.6%, respectively). The primary contaminant of nitrate and dissolved inorganic nitrogen also show little difference (3.6% and 4.4%, respectively), which confirms the mass loadings for these constituents as being representative and of broad application. The secondary contaminant of phosphorus does not compare as well, perhaps as a result of low concentrations and nutrient stripping downstream of the spring outfalls. This discrepancy also points to the need to use areal mass load estimates for phosphorus with caution.

3.4.1 Mass Load for a Conservative Ion.

Chloride has also been discussed as having value as a conservative tracer. The principal source of chloride is from atmospheric fallout in rain falling on Edendale terrace. This input has been estimated as equating to 47 kg/ha/yr (Boswell *et al.*, 1990). Added to this should be the input of potassium chloride based fertiliser. The application of KCl fertiliser is largely restricted to dairy farms where about 100 kgCl-/ha/yr is added (Warwick Catto, *pers. comm.*, June 1997). Approximately 44% of the Edendale terrace land surface is used in dairy farming, so an estimate of 44 kgCl-/ha/yr over the whole aquifer recharge area is assumed. Chloride is also added in the cheese making process as has already been mentioned. However, significant addition of chloride has only been since the 1995 – 96 milk processing season. The rate of groundwater travel has resulted in the elevated chloride plume progressing only as far as mid-terrace without any discharge to springs. Therefore input of dairy factory derived chloride is neglected in the estimate made below.

Calculation table of chloride loading from known sources and comparison with measured concentration.

Atmospheric Input within rainfall*	47 kg/ha
Addition within KCl fertiliser	44 kg/ha
Total Chloride Areal Load	91 kg/ha
Total Chloride Load	565,292 kg as Cl^-
Recharge Rate based on spring discharge	3,980 $m^3 H_2 0$/ha
Or,	25,837,437 m^3
Calculated Chloride concentration	21.9 g/m^3
Measured Chloride concentration	25.4 g/m^3
Error, Calculated - Measured	-13.7% error

* Boswell *et al.*, 1990

The match between calculated and measured chloride concentration is reasonable given the accuracy of each of the terms going into the estimate. The negative error suggests either an under-estimate as to the chloride load or an over-estimate as to the recharge rate. Another interference may be the addition of salt whey chloride as dairy factory wastewater. This input is not included in the calculation above. The calculation above provides some measure as to the level of certainty for loading estimates for contaminants such as nitrate that appear to behave in a largely conservative fashion in the aquifer.

The soil percolate drainage trials conducted by AgResearch Ltd estimates an approximate chloride loading of 100 kgCl/ha/yr for a beef cattle property and measures loading of between 60 and 102 kgCl/ha/yr for 1996 (Ross Monaghan, pers comm., June 1997). The mean chloride concentration measured was about 19.4 gCl/m^3. These observations tend to confirm the validity of the estimates made above, and underline the variability that can still be expected.

3.5 Groundwater Typing.

Typing of groundwater chemistry has some utility in comparing patterns of recharge and chemical enrichment. The ionic composition of groundwater has a residual stability as is evident in the low cation – anion mass error in all hydro-chemical sites. This tendency of the hydro-chemistry to equilibrate can be exploited in evaluating geo-chemical processes.

An example is cross-plots of major ions against a conservative ion. The chloride – ion axis cross-plot is usually chosen with a seawater concentration – dilution line. An example is shown in the figure below.

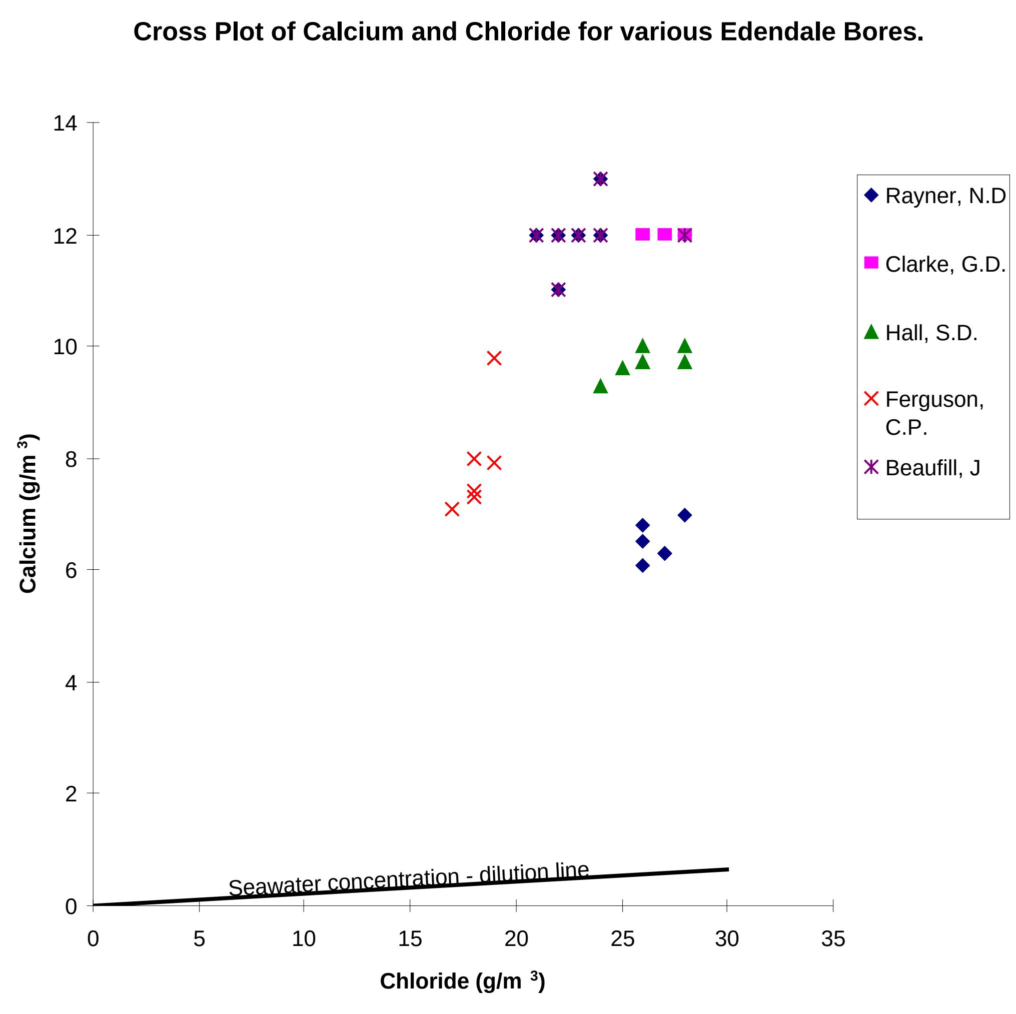


Figure 19 Cross-plot of calcium against chloride in Edendale bore water. The seawater concentration – dilution line indicates where points would plot were the sample diluted in the same proportions from seawater.

The cross plot shows the Edendale groundwater significantly enriched in calcium from sources other than seawater aerosols. The weathering of soils / sub-soils and dissolution of aquifer materials by acidic groundwater are the primary alternative sources of calcium in the groundwater. Calcium is added as lime to grazed pasture in order to correct tendencies towards acidification. A mean of approximately 900 kg/ha/yr is applied as lime according to the land managers whom replied to the Oteramika Landcare Group questionnaire. The calcium and other minerals within the lime joins the soil ion pool until weathering of soil particles displaces calcium into soil leachate. The soil store of calcium is estimated at approximately 3,000 kgCa$^+$/ha, equivalent to the application of 8,000 kg/ha of lime (McIntosh *et al.*, 1997[12]), accumulated over a number of years.

All other groundwater ions are enriched with respect of chloride to the seawater ion concentration – dilution ratio, indicating an elemental source other than seawater. The table below shows the degree of divergence from the concentration – dilution line.

	Theoretical chloride - ion seawater concentration – dilution ratio	**Chloride to ion ratio measured as mean concentration in Edendale groundwater**
Magnesium	15.00	5.51
Sodium	1.80	1.55
Potassium	48.50	20.63
Calcium	47.08	2.11
Sulphate	7.14	2.32

All measured groundwater displays some degree of enrichment with respect to the ions, calcium, magnesium, potassium, sodium and sulphate. This is not necessarily only a feature of impacted agricultural land subject to the application of fertiliser and soil treatments. Enrichment is also observed in ungrazed reserve areas (McIntosh *et al., ibid.*), especially in magnesium and sodium, which in fact lie at contents higher in reserve soils than actively grazed land. The figure below displays a cross-plot for sulphate.

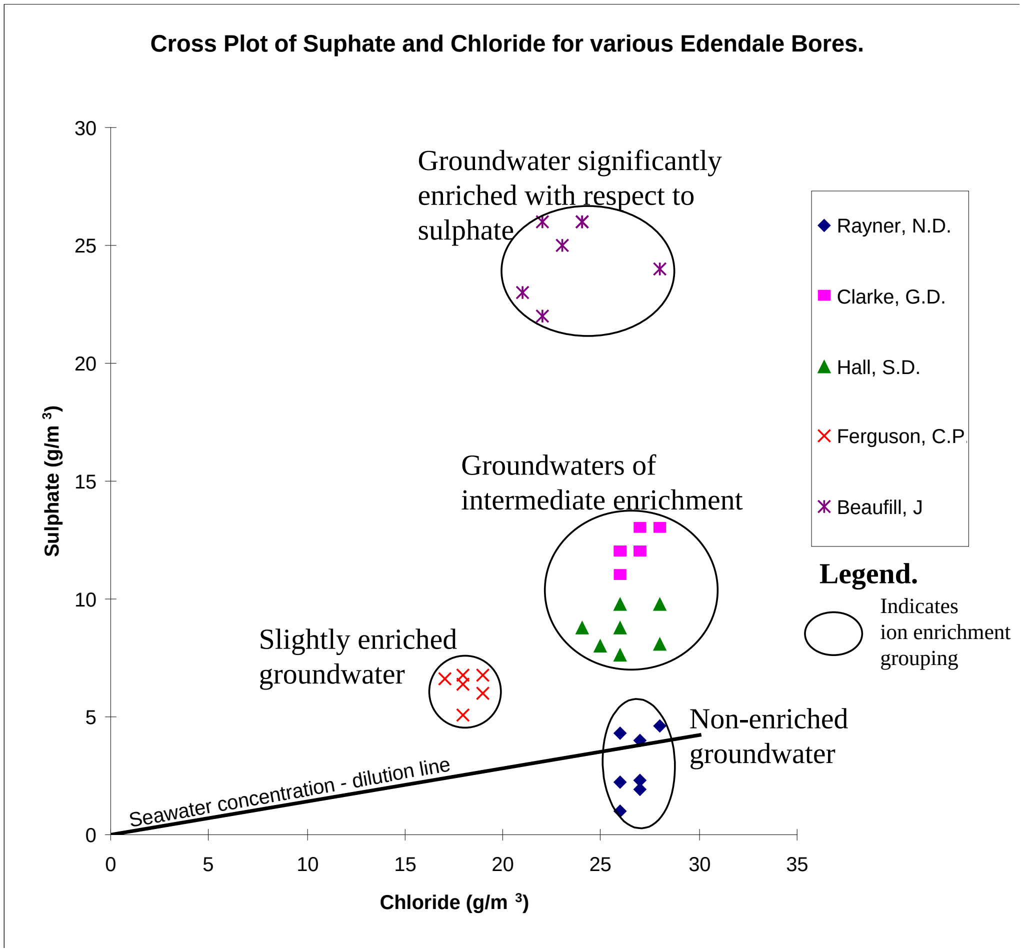


Figure 20 Cross plot of chloride and sulphate in Edendale bore water.

This cross plot reveals some of the variability between one bore and another. The Rayner bore straddles the seawater concentration dilution line. Rainfall has a chloride – sulphate ratio of between 1.7 to 18.1 as measured at Woodlands research station in 1991 (Boswell *et al*., 1992), but is believed to maintain an overall mean ratio of 7.1, which is the ratio of seawater. The Rayner bore water is not significantly different from that of rainwater. The Rayner bore is also one of the least concentrated bore waters, comparable with the Ferguson bore. This observation supports the typing of Rayner and Ferguson bore waters as reflective of 'headwater' groundwater quality. In contrast, the Clarke bore water is more concentrated and more enriched with respect to most ions. The Clarke bore proximity to the discharge of groundwater at Ives Creek support typing as a 'lower catchment' groundwater quality. All Edendale bore waters can be classed as 'sodium chloride' type.

Comparative groundwater typing is made with Edendale and the neighbouring upper Waihopai catchment. A tri-linear ion distribution plot is shown in the figure below.

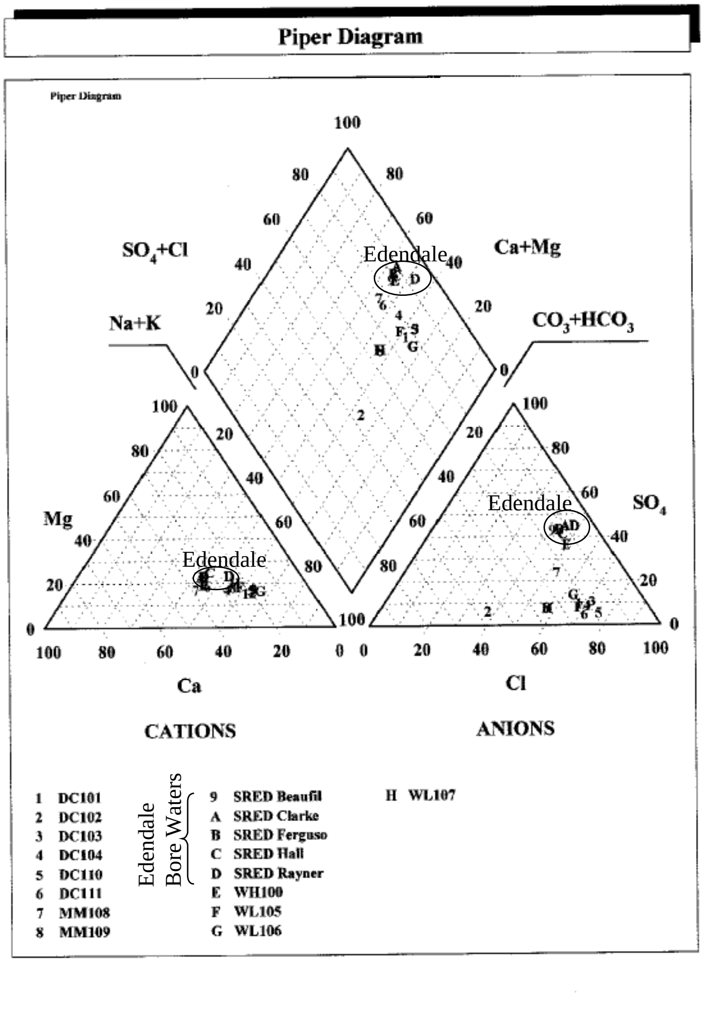


Figure 21 Piper plot for typing of groundwater ion chemistry of bore waters taken from the Edendale and Waihopai aquifers. Edendale bore waters are circled and plot in tight groups compared to Waihopai bore waters.

The comparison of the Edendale and Waihopai catchment ion balances suggests two inferences:

1. The Edendale aquifer groundwaters plot in a tight group compared to those of the Waihopai catchment. It is inferred that the Edendale aquifer water composition is more uniform, having a common origin and higher mixing rates.
2. The Edendale aquifer groundwaters have lower alkalinity concentrations allowing the inference that residence time is shorter than Waihopai groundwaters.

4. Groundwater Modelling.

4.1 Modelling Approach.

A groundwater model is a computer-based approximation of observed groundwater behaviour. In the case of the Oteramika study, the desire is to develop a groundwater model capable of simulating the hydrology, but also the hydro-chemistry of the Edendale Aquifer and mass loads of conservative nitrate dissolved within groundwater.

The optimal approach chosen was the formulation of a deterministic, physically based model. This requires the development of as good a simplification of the geometry, aquifer properties and source / sink terms as is achievable. The first parts of the modelling involve developing a groundwater model that adequately simulates the groundwater flow observed in long term monitoring. The chief calibration data sets are the water table elevations and spring discharges.

The second phase of model development is to couple the groundwater flow model with a pair of contaminant transport models. The first of such is the Basin New Zealand (BNZ) soil hydrology / contaminant loss model formulated by the NIWA – AgResearch model consortium. This model provides output as leaching or percolation rates for water and contaminant solutes dissolved in the water. The BNZ model is to be calibrated using field trials of soil percolation volumes and concentration. The second such model simulates the advection and dispersion of these contaminant solutes in the *saturated zone*, followed by lateral *transport in groundwater* outwards to the points of discharge from the aquifer. This model is to be calibrated using observed groundwater concentration from bores *in situ*, and mass loads developed from long term monitoring of effluent springs.

4.1.1 Groundwater Flow Model.

Initial efforts at producing a groundwater flow model employed the TWODAN analytical element method (AEM) model code. This model provided reasonable match to calibration targets, but lacked full integration of aquifer geometric factors. In addition, the coupling of TWODAN and the ultimate contaminant transport package proved less direct than desired.

Subsequently, a model was developed in the MODFLOW code under the Groundwater Vistas implementation (McDonald and Harbaugh, 1988[13]; and Environmental Simulations Inc., 1996[14]). This allowed fully discretised simulation of geometric variations and direct coupling with the contaminant transport package. MODFLOW is a block-centred finite difference numerical model, meaning that it calculates groundwater flow from one square cell to the next on a grid pattern. The BNZ model also used a 6¼-hectare cell size, so matches the layout used in MODFLOW. A single layer was specified in MODFLOW to replicate the unconfined single layer aquifer found at Edendale.

4.1.2 Groundwater Contaminant Transport Model.

Once the groundwater flow problem is adequately solved and calibrated to observed values, it becomes possible to simulate the transport of a single, dissolved contaminant (nitrate) within the aquifer. The model code used is called MT3D (Zheng, 1990[15]), which also uses a cell grid network such as BNZ and MODFLOW. The model implementation of MT3D under Groundwater Vistas is coupled directly with MODFLOW such that the results of the MODFLOW simulation are used in the subsequent MT3D simulation. The finite difference mode of contaminant transport is used in preference to the Method of Characteristics (MOC) due to greater stability.

4.2 Modelling Objectives.

The objectives in adding groundwater modelling to the Oteramika Trial Catchment study are spelt out below:

1. To provide a framework for further characterisation of Edendale Aquifer flow and contaminant transport processes in such areas as estimating groundwater velocities, flow directions, contaminant mixing rates and localised effects on groundwater concentration,
2. To provide a means of accounting for the net export of groundwater and contaminants out of the Oteramika Catchment by taking BNZ-model produced groundwater losses into an appropriate model environment for further analysis,
3. To provide quantification of groundwater concentrations and mass loads as a means of assessing the environmental impact of non-point source agricultural contamination.

4.3 Phases of Model Development.

All of the necessary steps in model development can be followed:

1. ***Model Framework Development***, involving selecting the model code, setting the geometric features such as basement boundaries, base of the aquifer, cell network size and orientation.
2. ***Model Stress Initialisation***, involving assigning flow boundaries such as the marginal springs and seepage creeks.
3. ***Parameter Assignment***, involving setting aquifer parameters such as hydraulic conductivity (permeability).

Following the assignment of parameters, the model is capable of being run. Initially, the model solutions can have large inaccuracy. A process of progressive calibration is undertaken employing a calibration data set. The further steps in model development follow the scheme below.

4. ***Model Calibration***, a set of measured water level is used to history-match the model results. Once complete, calibration of the model should result in the model water levels simulated, forming the same surface as the measured water levels.
5. ***Simulation***, or ***Scenario Modelling***, involves use of the model in the predictive mode. Certain sets of stresses or changed parameters may be used to test the response of the model aquifer.

In parallel with the steps above is the process of first developing the groundwater flow model, followed by the contaminant transport model. Independent calibration data sets are used for each. An indirect calibration of the BNZ model nutrient leaching predictions was also achieved using the MT3D model. Various predictions of the BNZ model as to nitrate leaching were run as input to the MT3D model to assess which provided the most plausible fit to recorded groundwater concentration and mass load data. Thus, indirect feedback as to the best approximation was provided. However, the primary calibration data set for the BNZ model leaching loss calibration remained the AgResearch soil drainage trails on the flank of Edendale Hill.

4.4 Model Framework Development.

This phase includes setting the geometric features such as basement boundaries, base of the aquifer, cell network size and orientation. The conceptual model has already been defined and the geometric aspects are taken from this.

4.4.1 Model Domain.

The model domain is specified by a uniform grid network with each cell having the dimensions of 250 by 250 metre, and an area of 62,500 square metres (6¼ hectares). The grid long axis is orientated parallel with north. The grid has 64 rows and 36 columns giving the domain an extent of 16 by 9 kilometres, or 14,400 hectares. This area covers the entire Edendale Aquifer with overlap. Of the 2,304 cells in the model domain, 1,997 cells are active. The remainder have been blanked as 'Head No Flow' cells, usually because they overlie land underlain by basement. The model includes the unconfined aquifers of the Wyndham terrace on both sides of the Mataura River, and parts of the Ota Creek Aquifer.

4.4.2 Base of Aquifer.

Elevation corrected heights of the base of the Quaternary aquifers are contoured and defined in the model explicitly. The base data of the elevation of the aquifer base was derived from drilling records of the lignite investigations of the late 1970's and 1980's.

4.4.3 Top of Aquifer.

The top of the aquifer does not require specification in an unconfined aquifer simulation. The water table is a free surface and one of the primary *outputs* of the model simulation.

4.4.4 Lateral Boundaries.

Lateral boundaries are specified only for the inferred contact between the Quaternary gravel deposits containing the Edendale Aquifer and the much less permeable lignite measures. 'Head No Flow' (HNF) cells are specified to impart lateral boundaries within the model domain.

4.5 Model Stress Initialisation.

This phase involves developing the source / sink boundaries such as recharge and discharge sites.

4.5.1 Aquifer Recharge.

Recharge of groundwater is entirely specified as diffuse soil percolation through the top of the aquifer to the water table. Recharge is applied at a uniform rate determined from long term monitoring, excepting the enhanced recharge through the soils of the Edendale dairy factory wastewater irrigation farm.

4.5.2 Spring Discharge Zones.

Discharge of groundwater at discharge zones is specified in the model as ‘drains’. Drains have a specified base elevation. When the water table is calculated in MODFLOW to rise above the base elevation, the drain will remove water until an equilibrium is established. The base elevation of the springs and seepage creeks receiving groundwater discharge from the Edendale and Ota Creek aquifers is estimated from topographic surveys. Lines of these drain cells are arranged in the positions of the several identified seepage zones.

4.5.3 River Discharge Zones.

The Mataura River is also inferred to receive seepage from the Quaternary unconfined aquifers, mainly from the Wyndham terrace aquifer. The length of the Mataura River with the model domain is specified as ‘river’ cells. The river cell is similar to the drain cell with some unique features. While recognising the river as a perennial receptor of groundwater, the ‘skin effect’ imparted by the bed of most rivers has an adjustable conductance term.

4.5.4 Wells.

Two industrial wells draw on the Edendale Aquifer at Edendale township for the dairy factory. These are simulated in one ‘well’ cell with a specified abstraction equivalent to the long-term mean for the factory groundwater take (approximately, 2,500 cubic metres per day).

4.6 Parameter Assignment.

The chief parameters for groundwater flow are:

- Hydraulic conductivity
- Specific yield (storage coefficient)

The chief parameters of contaminant transport are:

- Dispersivity (dispersion coefficient)
- Effective porosity

The range of these parameters has been described in the section of Hydrogeology. Absolute values for these parameters cannot be taken. Instead, plausible estimates as to the parameters are adopted in calibration. The effect and polarity of the parameters to calibration results are tested in sensitivity analysis. Following the process of sensitivity analysis and calibration, the ultimate best-fit parameters are derived.

4.7 Order of Simulation.

The groundwater quality model produces the primary outputs, such as the concentration of groundwater throughout the aquifer and the mass load of nitrogen in discharge. However, the MT3D simulations require a MODFLOW simulation of groundwater flow before concentration and mass loads can be modelled. Similarly, calibration of the MODFLOW groundwater flow model must be complete before calibration of the MT3D groundwater quality model can be calibrated and validated.

4.8 Linkage with Land Use.

The MT3D model is linked to overlying land use by the results of the BNZ model for the 12 different land use classes initialised in the BNZ model, and the specification of the corresponding recharge concentrations in MT3D. The contaminant modelled is nitrogen. Therefore, each of the active model cells lying within the boundaries of the Edendale terrace are assigned recharge nitrogen concentration value in the MT3D model.

This concentration joins the groundwater and is subject to two principal processes:

1. **Advection:** The nitrate injected into the aquifer by recharge is carried laterally with the flow groundwater.
2. **Dispersion:** The nitrate is the groundwater mixes laterally and transversely with surrounding groundwater in order to simulate the dispersion processes known to act within the aquifer.

Thus, the combined groundwater concentration is the sum of each of the contributing cell recharge concentrations in a process mediated by the advective – dispersive processes active in the aquifer.

The distribution of land uses is based on information collected in the Oteramika Landcare Group 1995 questionnaire. AgResearch Ltd has sorted the questionnaire responses and defined land use classes according to grazing system and land use intensity. This information has been codified and developed into a number of GIS data layers across the Oteramika catchment. This information has then been digitised within the Groundwater Vistas (MT3D) pre-processing software into 12 recharge zone databases. Each zone database specifies the rate of recharge and the concentration of the recharge. The recharge concentration values are specific to land use as modelled by the BNZ model for the Edendale terrace soils. The eastern third of the Edendale terrace was not explicitly considered in the BNZ model, so extension of the land use information has been undertaken to achieve full coverage of the Edendale aquifer extent. The map figure below illustrates the final land use distribution.

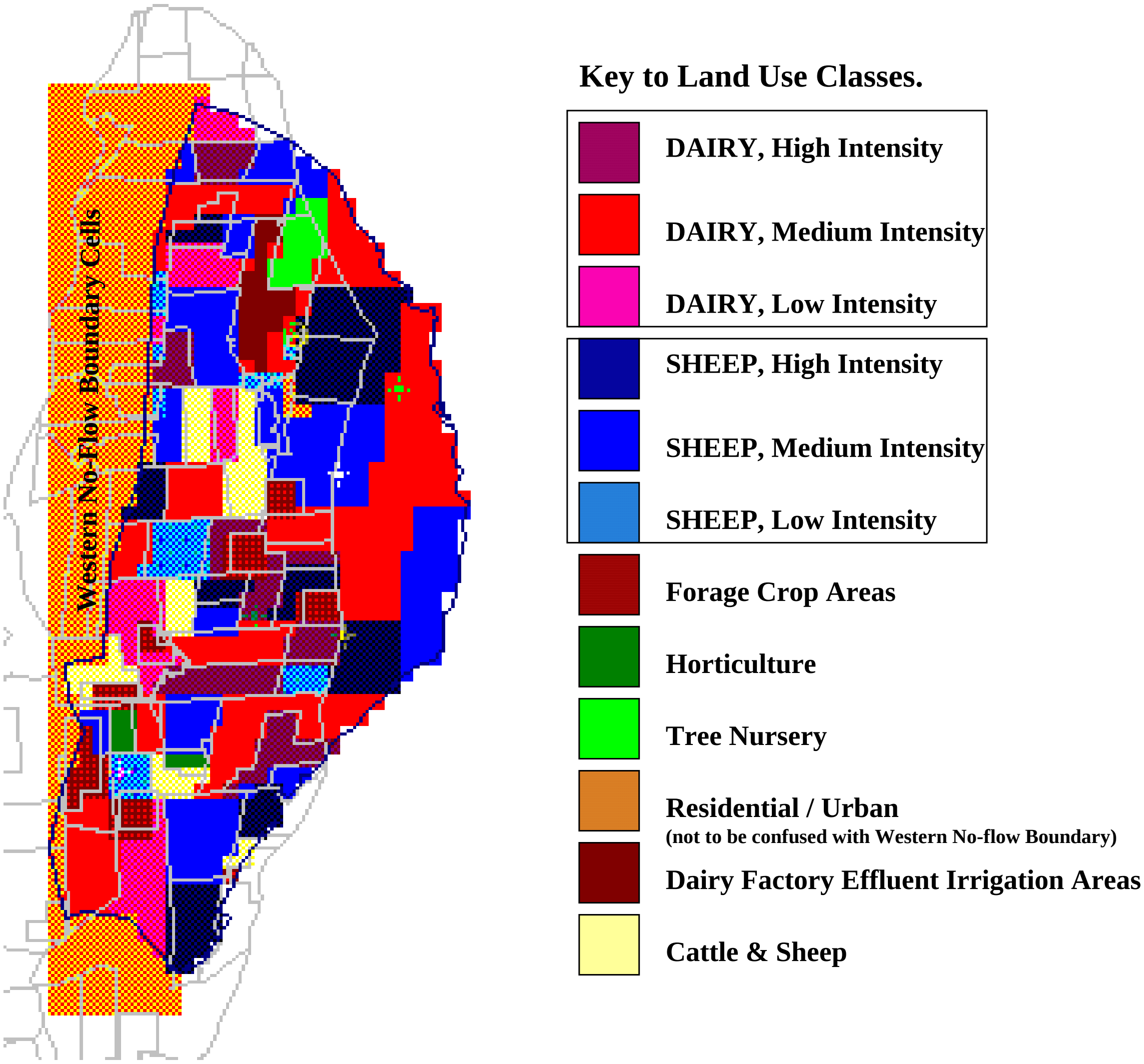


Figure 22 Distribution map of recharge zones used by MT3D model for the base scenario (Scenario 0).

This data set of land use specific recharge mass loads is the base scenario (Scenario 0) in scenario modelling. Subsequent scenarios consider significant changes to the land uses or intensity of land uses across the Edendale terrace.

4.8.1 Magnitude of Nitrate-N Losses.

Nitrate-N losses by leaching have been calculated by the BNZ –CREAMS simulations. On the Edendale terrace soils, the leaching rates are specific to land use. The mass load and recharge concentrations of these land uses are specified in the table below.

	Areal Mass Load (kg/ha/yr)	**Leachate Concentration (g/m^3)**
Dairy, High	53.3	13.7
Dairy, Medium	22.6	5.5
Dairy, Low	11.9	2.6
Sheep, High	10.8	2.4
Sheep, Medium	3.6	0.8
Sheep, Low	1.7	0.4
Forage Cropping	79.9	16.9
Horticulture	1.6	0.4
Tree Nursery	15.7	2.8
Residential / Urban	90.2	16.3
Effluent Irrigation	178.8	25.2
Sheep & Cattle	10.5	2.6

4.9 Scenario Modelling.

Several separate scenarios are defined. These are specified as lain out below:

- **Scenario 0**(Base Scenario) land uses as defined for the present day setting,
- **Scenario 1**Change all grazing land use to high intensity dairy,
- **Scenario 2**Change all dairy grazing to high intensity, all sheep and sheep & cattle grazing to high intensity sheep,
- **Scenario 3**Change all forage cropping to medium intensity sheep.

Each scenario is implemented by editing the land use specified recharge zone *distribution*. This entails re-digitising the distribution of the zones consistent to the scheme set out in the base scenario.

Because the boundaries of the land uses as defined in the property boundary map do not fall precisely on the rectilinear grid network of the model, an imprecise match in terms of boundary positions and absolute area is inevitable. The modelling pre-processor allows digitising of the property boundary by the user, and then assigns the cells that best match the ‘centre-of-gravity’ for the polygon. Both property boundary polygons and the cell network zones are displayed in the figures illustrating land use distribution.

4.9.1 Scenario 1: All Dairy, High Intensity.

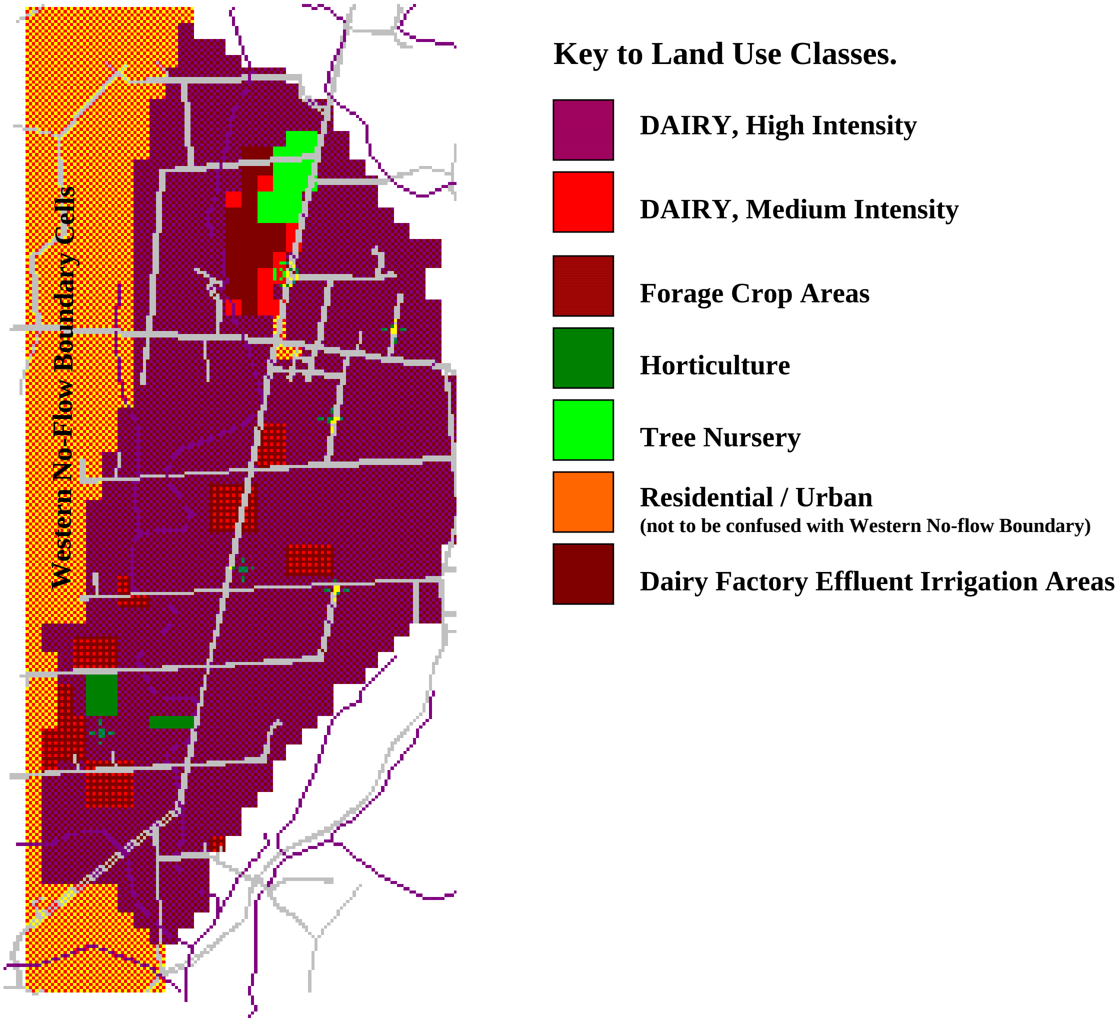


Figure 23 Scenario 1 Distribution of land use specified recharge zones following all grazing land uses changing to high intensity dairy farming.

This scenario requires that land use in all existing dairy, sheep and cattle/sheep grazing area is changed to high intensity dairy farming. The land uses of forage cropping, tree nursery, residential / urban and effluent irrigation are retained in their present form.

4.9.2 Scenario 2: High Intensity Grazing.

This scenario requires that grazing practices are changed from their existing intensity to highest intensity dairy or sheep farming. The land uses of forage cropping, tree nursery, residential / urban and effluent irrigation are retained in their present form.

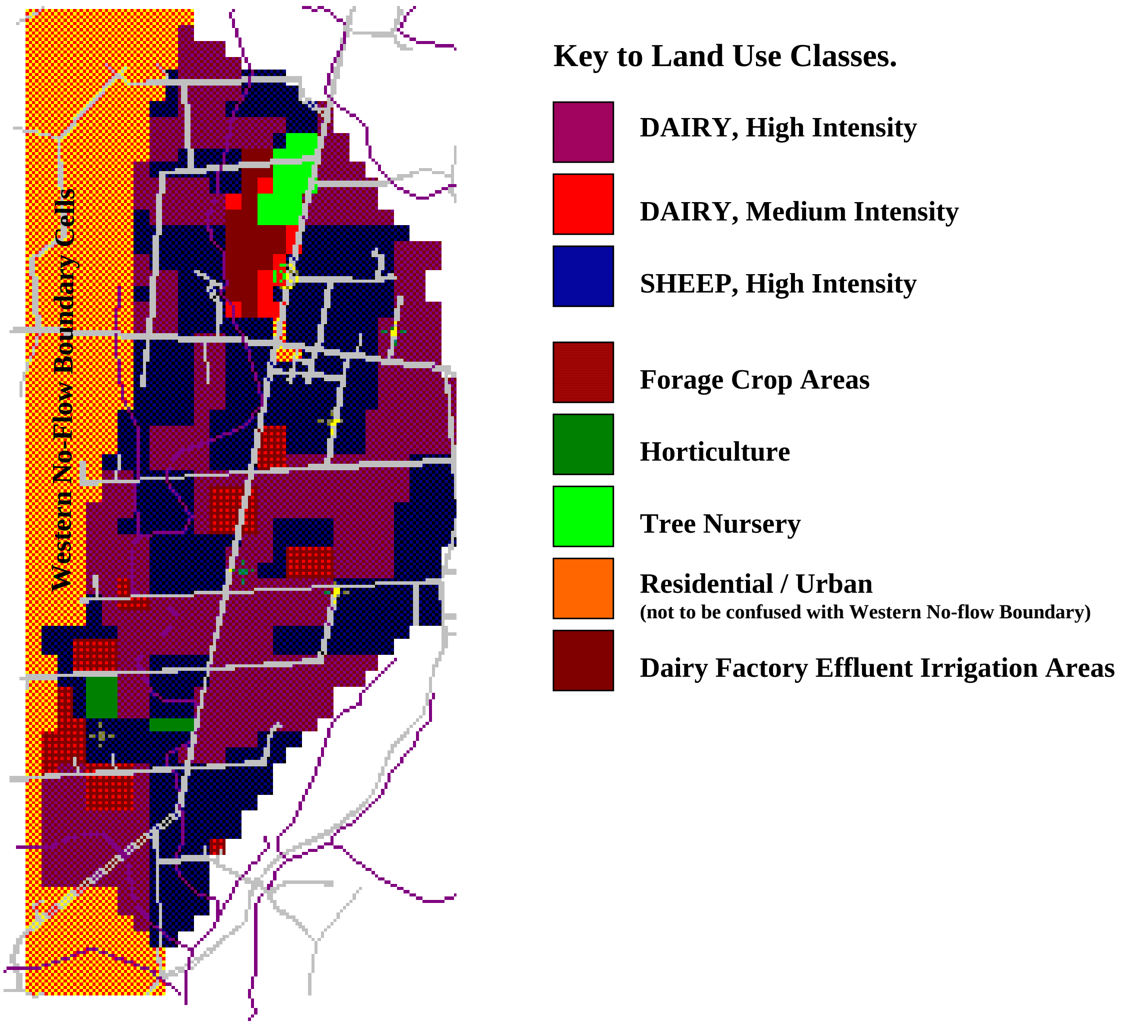


Figure 24 Scenario 2: Distribution of land use specified recharge zones following all grazing land uses changing to high intensity farming of either dairy or sheep, depending on the original land use.

4.9.3 Scenario 3: Replacement of Forage Cropping.

Forage cropping has been identified as a land use with high leaching losses of nitrate nitrogen. This scenario removes the forage cropping areas and replaces them with medium intensity sheep grazing. The purpose of this scenario is principally to test whether changes in forage cropping practice could be used as a Best Management Practice. It should be pointed out that the sites of forage cropping have been arbitrarily grouped geographically within the BNZ model in the *general* areas of highest concentrations of forage cropping practice. These areas do not lie on the exact locations of forage cropping, which on the whole are randomly distributed and shift around from year to year.

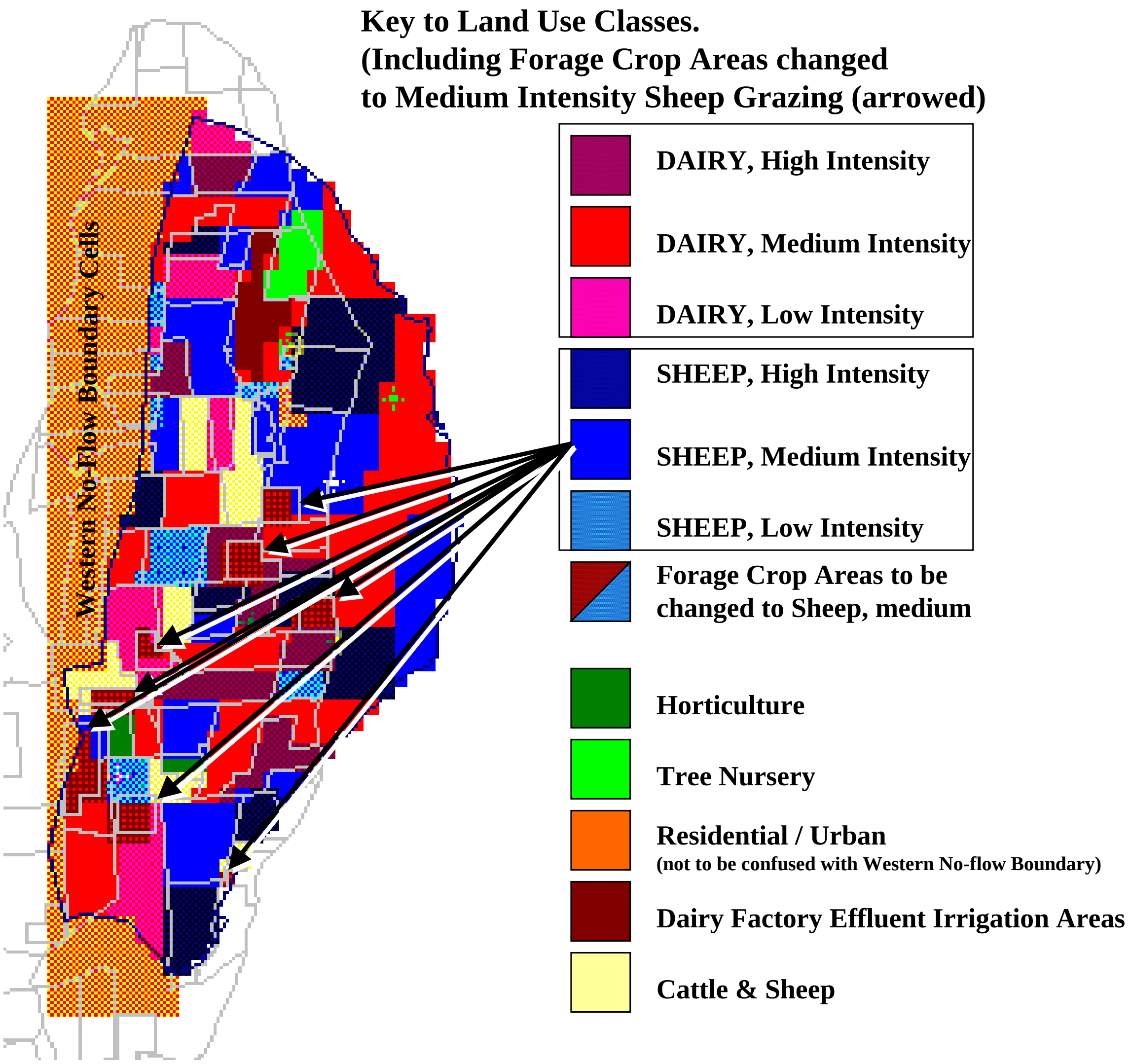


Figure 25 Forage cropping areas to be changed to medium intensity sheep grazing in scenario 3.

4.10 Results of Scenario Modelling.

The base scenario and three land use alteration scenarios have been described above. Scenarios 1 and 2 represent a net increase in recharge concentration across the Edendale Aquifer, while scenario 3 would be expected to result in a net decrease in the nitrate mass added in recharge. The scenarios are evaluated in the following fashion.

- Groundwater Concentration: The distribution of nitrate-N concentration throughout the aquifer can be illustrated with the use of contour maps,
- Mass Loads: The mass of nitrate-N entering and leaving the aquifer can be quantified as a rate,
- Differencing: The difference in nitrate-N mass and concentration between the base scenario and various scenarios of interest can be illustrated with overlain contour maps, mean concentrations and mass totals as measures of the net effect of changes made for each scenario.

In each case, the scenarios are run as entirely separate simulations: the initial conditions are identical from the base scenario, apart from the difference in land use specified recharge zonation. Each simulation is run over a hypothetical 17-year period in order to even out time-dependent effects towards a steady state solution. Every scenario is evaluated at the same time step.

4.10.1 Results of Scenario 1: Concentration.

The change in land use of all grazing to high intensity dairy grazing has a profound effect on the nitrate-N concentration distribution in the Edendale Aquifer. The figure below shows a contour map of base scenario and scenario 1 on nitrate distribution.

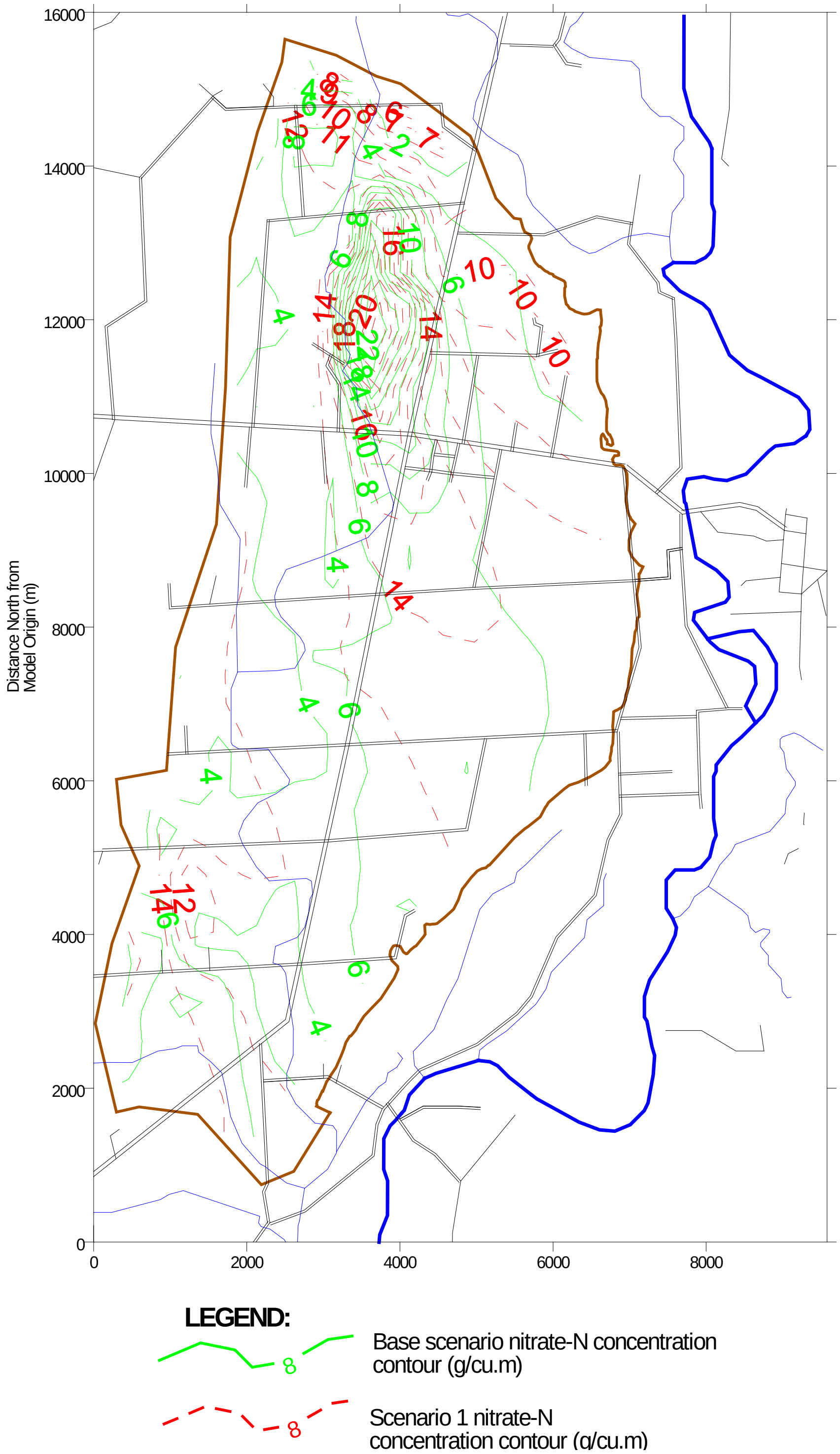


Figure 26 Modelled distribution of Scenario 1 nitrate-N concentration with base scenario for comparison.

The modelled effect is for the modelled nitrate-N concentration to be found at concentrations higher than 11.3 gNO_3-N/m^3 (drinking water standard) throughout almost the entire Edendale Aquifer. In the context of the drinking water standard, this would make Edendale Aquifer groundwater unpotable. The mean nitrate-N concentration of the Edendale Aquifer increases from 5.36 gNO_3-N/m^3 to 13.35 gNO_3-N/m^3, an overall increase of 7.82 gNO_3-N/m^3.

4.10.2 Results of Scenario 1: Mass Load.

The net increase in mass load for nitrate nitrogen is shown in the table below.

	N Mass (kg/yr)	**N Areal Mass (kg/ha/yr)**
Base Scenario	151,942	23.42
Scenario 1	367,044	56.58
Increment	215,102	33.16

4.10.3 Results of Scenario 2: Concentration.

The change in land use of all grazing to its respective high intensity form has a significant effect on the nitrate-N concentration distribution in the Edendale Aquifer. There is a general elevation in the groundwater nitrate-N concentration throughout the aquifer. The modelled effect is for larger areas of the aquifer to be found at concentrations higher than 11.3 gNO_3-N/m^3. The mean nitrate-N concentration of the Edendale Aquifer increases from 5.36 gNO_3-N/m^3 to 8.75 gNO_3-N/m^3, an overall increase of 3.2 gNO_3-N/m^3.

The figure overleaf shows a contour map of base scenario and scenario 2 nitrate distribution.

4.10.4 Results of Scenario 2: Mass Load.

The net increase in mass load for nitrate nitrogen is shown in the table below.

	N Mass (kg/yr)	**N Areal Mass (kg/ha/yr)**
Base Scenario	151,942	23.42
Scenario 2	240,579	37.09
Increment	88,637	13.66

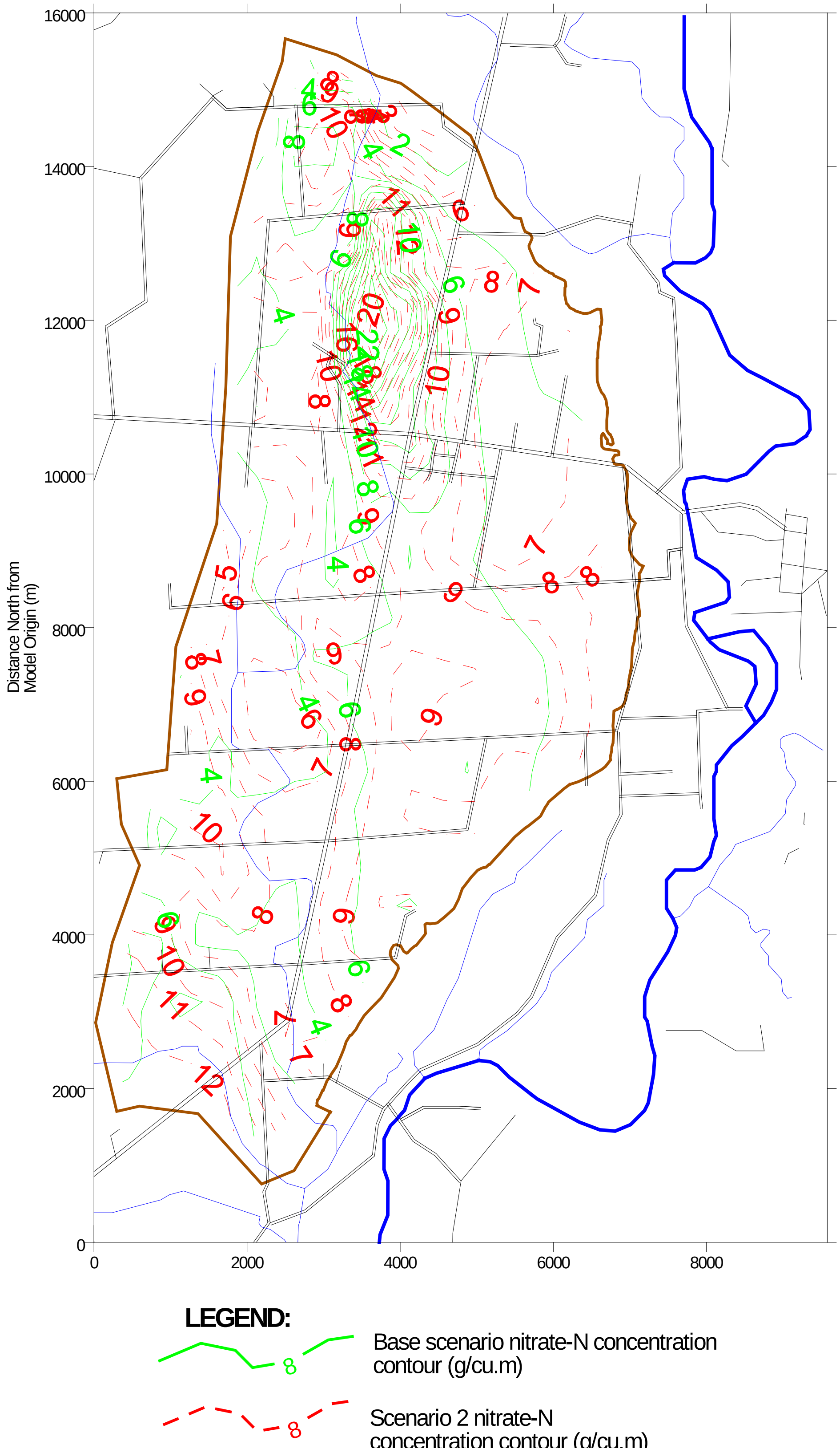


Figure 27 Modelled distribution of Scenario 2 nitrate-N concentration with base scenario for comparison.

4.10.5 Results of Scenario 3: Concentration.

The change from forage cropping areas to sheep farming of medium intensity in its place results in a net decrease in the groundwater nitrate-N concentration of the Edendale Aquifer as the contour map illustrates.

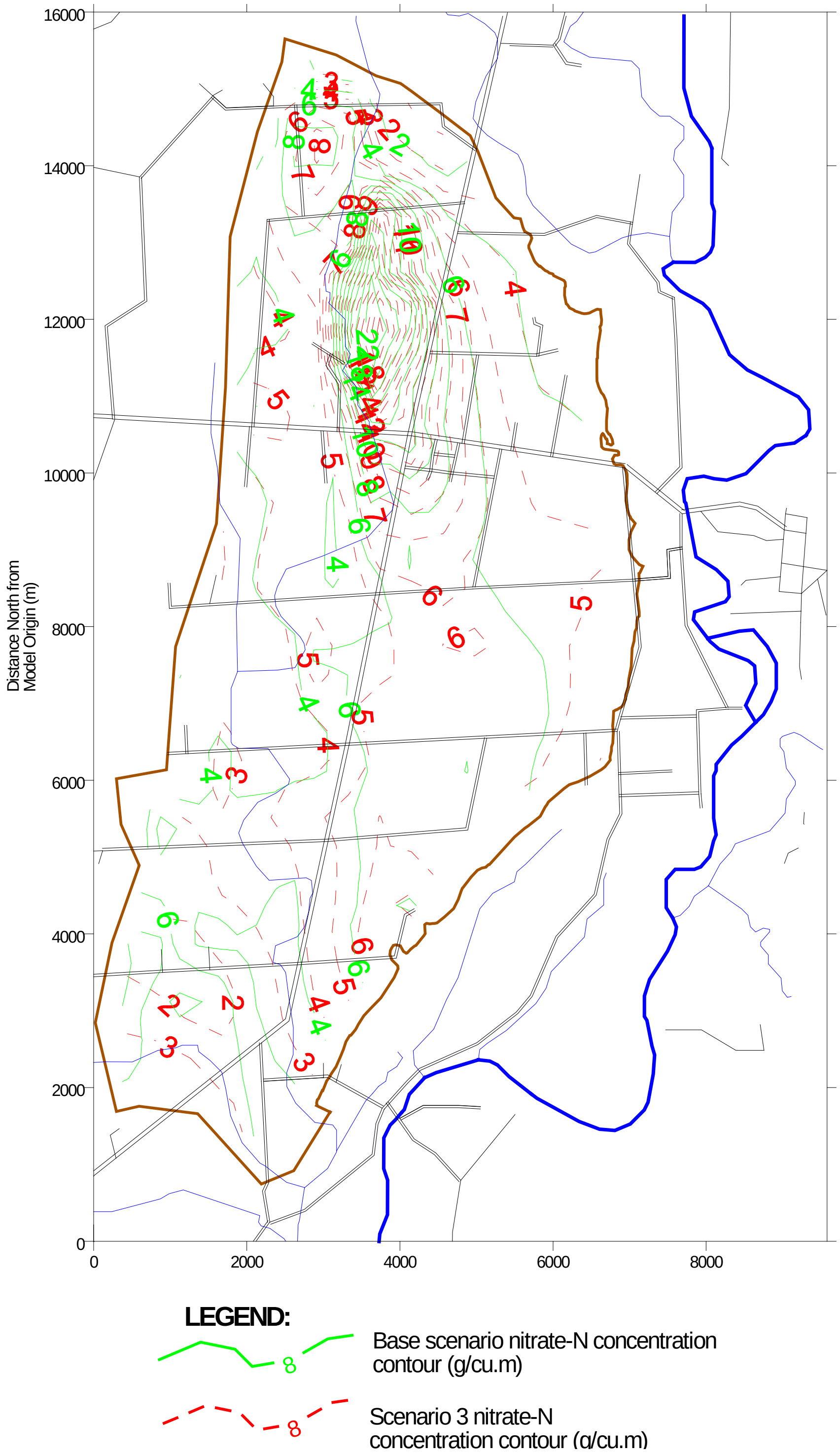


Figure 28 Modelled distribution of Scenario 3 nitrate-N concentration with base scenario for comparison.

The mean nitrate-N concentration of the Edendale Aquifer decreases from 5.36 gNO_3-N/m^3 to 4.63 gNO_3-N/m^3, an overall decrease of 0.9 gNO_3-N/m^3.

4.10.6 Results of Scenario 3: Mass Load.

The net decrease in mass load for nitrate nitrogen is shown in the table below.

	N Mass (kg/yr)	**N Areal Mass (kg/ha/yr)**
Base Scenario	151,942	23.42
Scenario 2	127,276	19.62
Decrease	24,667	3.80

4.10.7 Discussion.

Unsurprisingly, any intensification of the land use specified recharge zonation tends to lead to an increase in groundwater concentration / mass load. This is due to the BNZ modelling results specifying higher nitrate-N leaching rates for higher intensity land use. Results for scenario 1, the change of all grazing agriculture to high intensity dairy farming, reflect the disproportionately higher nitrate-N leaching losses from this land use.

The MT3D modelling demonstrates clearly the balance of assimilative capacity maintained in the aquifer by the presence of lower leaching rate land uses. The mix of these contrasting leaching rate land uses specified in scenario 2, the intensification of dairy and sheep grazing, reveals the value of the lower rate sheep farms being interspersed with dairy farms. In this scenario, there was only a marginal increase in the extent of aquifer affected by >11.3 gNO_3-N/m^3 concentrations, and then only downstream of the dairy factory wastewater irrigation farm.

Scenario 3 demonstrated the benefits of retiring forage cropping. While the potability of the aquifer's groundwater is not significantly improved, the total nitrogen loss from the Edendale Aquifer to the aquatic environment is decreased by over 16%. The 'freeboard' against transgression of the drinking water standard for nitrate-N is increased. Scenario 3 is perhaps achievable as a Best Management Practice by grazing stock, particularly dairy cattle, outside the Edendale Aquifer through the winter when forage grazing generally occurs.

Lastly, it is very important to state the limitations of the groundwater flow and nitrate contaminant modelling undertaken above.

1. A groundwater model is a simplification of a complicated system. The art of modelling is to frame the model in such a way that its results are underpinned by the best-understood information on the system. The weakest part of the model is probably the distribution of horizontal permeability and dispersion coefficients. These are very difficult and costly to determine physically.

2. The nitrate contaminant transport parts of the modelling are dependent on the quality of information used in its formulation. To this extent, the MT3D model leans heavily on the rates of nitrate-N leaching provided by the BNZ model project. In the absence of independent, physically determined information on these rates, it is difficult to validate the outcomes of the modelling.

3. The BNZ model appears to calculate an overly high nitrate-N leaching rate for the dairy factory effluent farm of 178 kgN/ha/yr. In MT3D modelling this results in significant areas of the aquifer down-gradient from the effluent farm transgressing the drinking water standard, whereas in reality transgression is found in sampling to be a patchy, occasional occurrence. Preliminary results of physical monitoring of effluent farm leaching rates suggest rates averaging about 80 kgN/ha/yr (Phil Greenwood, *pers. comm.*, July 1998). This is much more in line with observed groundwater nitrate-N concentrations near the effluent farm.

4. The split between the seepage from the Edendale aquifer into the eastern springs or Mataura River proved very difficult to replicate in the model. While the pattern of seepage matched a generalised pattern, problems were experienced in distinguishing fluxes from the river and springs. To circumvent these discrepancies, mass loads were drawn from the outflow across the aquifer boundaries rather than from the sum of river and spring nitrate fluxes.

5. Significance & Implications.

The preceding sections have concentrated on reporting the results of long-term measurements and data analysis. This section will emphasise the evaluation of that information in the context of the issues confronting the Oteramika catchment, particularly the Edendale Aquifer.

5.1 Oteramika Trial Catchment Project.

The Oteramika Trial Catchment Working Group was established on 28 September 1994. The Working Group's non-technical / client membership included:

- Southland Regional Council
- Oteramika Landcare Group, Steering Committee
- MAF Policy
- Southland District Council
- Southfert
- Fertiliser Manufacturers Research Association
- Southern Health, Health Protection Unit
- Department of Conservation
- Southland Fish & Game

A number of crown research institutes and private consultants also attended Working Group meetings, and later formed a Technical Working Group.

The Working Group coalesced as a loose group of organisations representing the community, regulatory agencies, crown research institutes and other interested parties. The idea of the Oteramika Landcare Group developed as a result of attention on water quality degradation in the Regional Council's dairy industry expansion EIA (Robertson Ryder & Associates, 1993). A steering committee was formed earlier in 1994 to investigate establishing a landcare group along the lines of similar Australian and New Zealand volunteer movements. One of its issues would be water quality, particularly groundwater, which was particularly valued by the local community. Ultimately, a set of objectives were agreed by the Oteramika Trial Catchment Working Party:

1. To characterise the natural and physical resources of the catchment,
2. To determine how current land use activities affect water quality,
3. To identify and promote land use practices which maintain high or desired standards, and mitigate adverse effects.

These objectives were developed from the issues confronting the Oteramika catchment, Southland Region, and rural New Zealand, generally. These issues relating to non-point source water quality degradation have been alluded to in the Introduction to this report. Eventually, the Working Group formed a consensus as to the component studies, reviews and investigations that would be directed towards meeting the stated objectives. A summary of this methodology is given below:

- Southland Regional Council technical / scientific studies:
    - Chemical and biological baseline studies and monitoring of aquatic environments in the catchment,
    - Trials of drain cleaning (mechanical versus chemical)
    - Storm runoff monitoring (data-sonde and ISCO sampler)
    - Edendale Aquifer characterisation studies (1995)
    - Long-term groundwater – springwater monitoring (1995 – 1998)
- Oteramika Landcare Group
    - Land user questionnaire
- AgResearch / NIWA consortium
    - BNZ model formulation and scenario modelling
    - Edendale Hill runoff trials
- AgResearch Ltd
    - Dairy farm soil compaction studies (Southland-wide)
    - Tile drain percolation studies comparing different fertiliser intensity effects on percolate nutrient load (1996-1998/9)
- Landcare Research Ltd
    - Detailed mapping of Edendale terrace soil classification
- Southland Fish & Game Council
    - Characterisation of fisheries in Oteramika Creek
    - Monitoring of fishery values through time

The sum of these investigations have contributed to the whole. The efforts by Southland Regional Council, AgResearch / NIWA and the Oteramika Landcare Group have been co-ordinated by Southland Regional Council and funded by Southland Regional Council, Ministry for the Environment and the Fertiliser Manufacturers Research Association.

The need to maintain or enhance groundwater quality crystallised as one of the key issues. The reasons for groundwater quality attaining such prominence as an issue may be as follows:

- The Southland Dairy Co-operative had made several applications over resource consents to discharge to land (affecting groundwater quality) and take of groundwater, in the years preceding 1994. These applications were subject to submissions by the community in some instances. A degree of awareness and controversy surrounded the issue of groundwater quality,
- Groundwater quality in the Edendale Aquifer was perceived to be high and vital to the resource base of the Edendale terrace,
- During 1992 – 1994, the issues of water quality impacts of pastoral intensification had gained particular currency with the community in Southland.

In 1994, the Oteramika Catchment, and the Trial Catchment Working Group was regarded as something of a microcosm or test-bench of the water quality issues, and how they would be tackled in Southland.

5.2 The Groundwater Nitrate Issue in Southland.

Nitrate nitrogen elevation in New Zealand's groundwater has been signalled as an impact of agriculture since at least the early 1980's (Burden, 1980[16]). At this time actual elevation of nitrate-N had been observed at a large scale in the Waimea Plains, Nelson and the Hawkes Bay. Subsequently, elevated nitrate-N has been reported in the Pukekohe basalt aquifers (Cathcart, 1994[17]), the Hamilton basin (Selvarajah *et al*., 1993[18]), and the Manukau Tertiary / alluvial aquifers in the Horowhenua (McLarin *et al.*,1996[19]). Overlying or upgradient land use has often been attributed as the cause of the fact that nitrate-N has become elevated, although soil and hydrogeological factors also have some influence.

Selvarajah et al., 1993 reported nitrate-N concentrations in a land use setting very similar to Edendale.
They found the majority of shallow bores on the Hamilton Basin, an area of grazing intensity similar to the Oteramika Catchment, to have nitrate-N concentration above the drinking water standard. They also estimated the mean nitrate leaching rate to be about 60 kgNO_3-N/ha/yr.

Nitrate-N elevation in groundwater in Southland aquifers become an issue drawing public attention since the mid-1980's. Routine monitoring of the nitrate concentration of the public water supply at Edendale (undertaken by Southland Area Health Board) had highlighted the fact of elevated nitrate-N in Edendale township in July 1985. An extensive area around the township having nitrate-N concentrations above the drinking water standard was encountered at this time. These elevated concentrations ultimately declined and stabilised to levels below the drinking water standard by 1990. The dairy industry expansion environmental impact assessment (Robertson Ryder & Associates, 1993) contained nitrate balance information which cast serious doubt over whether dairy herding and drinkable shallow groundwater could co-exist in the alluvial plains of Southland. Also in 1993, the Gore town water supply bores at Cooper's Wells became the subject of controversy when a change of ownership in overlying land use led to conversion to dairying (Rekker, 1994[20]). In early 1996, elevated nitrate-N were encountered in the Oreti Plains district, triggering a follow-up investigation into links with land use (Rekker and Greenwood, 1996). All of these events have served to place the issue in the public mind and initiate a variety of regional council investigations around the issue.

5.3 Non-point Source Groundwater Quality Effects in the Edendale Aquifer Context.

The Edendale terrace and underlying aquifer share a number of unique factors in its land use, soils and hydrogeology:

- The terrace is probably the most intensively grazed land in the Southland region,
- The terrace contains the Southland Dairy Co-operative dairy factory, with one 150 hectare wastewater application area and a second in planning,
- The terrace is mantled with free draining silt loam and loess soil / sub-soil which provides for high recharge rates (typically around 400 millimetres per annum),
- The Edendale Aquifer has a high hydraulic conductivity and saturated thickness when compared to many other unconfined aquifers in Southland.
- The Edendale Terrace unconfined aquifer water table does not intersect the water level of Oteramika Creek until it has passed the southern flanks of the terrace leading to the absence of interaction between the aquifer and terrace portion of the Creek,
- There is a net export of groundwater derived from the drainage of soil making up the majority of the catchment towards springs and seepage creeks discharging to the Mataura River, or lower Oteramika Creek,
- Much of the aquifer outflow can be measured by waded section gauging downstream of the most voluminous springs. Sampling and analysis of groundwater concurrent with flow gauging allows estimation of mass load.

The last factor is significant. In the absence of the ability to reliably measure flow rate and concentration, estimation of mass load is achieved by a ‘top-down’ approach, usually the approximation of rate from time variant data and the mean of concentrations measured from bores. This ‘top-down’ approach is vexed by a variety of inaccuracies, especially within a heterogeneous setting, such that the confidence of the estimate is undermined. So, given the ability to measure these components directly at the bottom end of the system, the accuracy of these estimates of Edendale aquifer mass load and concentration are significantly enhanced.

The Edendale Aquifer recharge and through-flow rates are high, due to the permeability of the soils, sub-soils and aquifer matrix. These high flow rates promote ready mixing and larger assimilative capacities to incoming contaminants. This means that larger mass loads of contaminants can be accommodated with groundwater following mixing before elevation to undesirable concentrations result.

Dilution of infiltrating contaminants such as nitrate-N is enhanced by a high aquifer flow rate. The higher the flow rate, the lower the contaminant concentration. This is analogous to a river, which is better able to cope with contaminant loads during periods of high flow.

To some extent the unique factors of the Edendale terrace and aquifer detract from the need for the catchment to be representative nature of other Southland catchments, in other ways they make the catchment groundwater more easily studied and understood. The Oteramika catchment still contains a cross-section of Southland's agricultural land uses, with the exception of grain, mixed cropping and deer grazing. The ability to extensively quantify overall nitrogen leaching loss and understand the dynamics of nitrate accumulation allow the transportation of the fruits of this study to other parts of the region.

5.3.1 Agricultural Nitrogen Losses.

The dairy industry expansion environmental impact assessment (Robertson Ryder & Associates, 1993) indicated and estimates of 80 kgN/ha/yr under dairying and 15 kgN/ha/yr under sheep grazing. In developing a nitrogen budget for the Oteramika catchment, Robertson Ryder & Associates (1993, page 99) inferred an overall nitrogen loss rate of about 33 kgN/ha/yr to the Edendale Aquifer.

This study has been able to refine this mass load estimate with physically derived data to a figure of 25.4 kgN/ha/yr for the years 1996 and 1997. The nitrogen loss results of the BNZ model (mean: 6.2 gN/m^3) accord well with the mean concentration measured physically (mean: 6.1 gN/m^3). The distribution of concentration derived through combined / sequential BNZ – MT3D modelling matched closely with those measured in long term monitoring for all but the area surrounding the wastewater irrigation and tree nursery sites. This provides more confidence that the linkage between nitrogen leaching losses and land use, and the relative values of mass load between the different land uses, are valid.

This would tend to suggest that the estimates of leaching made in 1993 can be revised downward somewhat. Below is a comparison of the areal mass loads of nitrogen developed using the BNZ model and those estimated using farm nitrogen budgets (Robertson Ryder & Associates, 1993).

	Areal Mass Load, BNZ Model (1998) (kg/ha/yr)	**Areal Mass Load, Robertson Ryder & Associates (1993) (kg/ha/yr)**
Dairy, High	53.3	95
Dairy, Medium	22.6	80
Dairy, Low	11.9	73
Sheep, High	10.8	15
Sheep, Medium	3.6	<15
Sheep, Low	1.7	<15
Effluent Irrigation	178.8	>80
Sheep & Cattle	10.5	35

Research commissioned by Southland Regional Council for reporting in the 1998/99 financial year using soil moisture sampling under these different land uses will be able to shed further light on the actual relative and absolute values of nitrogen leaching losses for different pastoral land uses and effluent application.

5.3.2 Phosphorus Losses.

Phosphorus may become problematic in Southland's freshwater waterways at concentrations significantly lower than that of nitrogen. This is because of the phosphorus is more likely to be the limiting nutrient in periphyton and macrophyte growth. Ratios of dissolved inorganic nitrogen to dissolved reactive phosphorus (DIN:DRP) between 8:1 and 15:1 are optimal for algal growth (Ryder, 1995a).

The Edendale Aquifer contains groundwater at annual mean concentrations between 0.026 and 0.017 gDRP/m^3. Elsewhere in aquifers fringing the Mataura River upstream of Wyndham, riparian groundwater concentrations lie in the range 0.024 – 0.010 gDRP/m^3, and averaging 0.014 gDRP/m^3 (Southland Regional Council, unpublished data). Thus, groundwater concentration in alluvial aquifers generally, is enriched with respect to that of the Mataura River. In order to limit periphyton growth during low flows in the lower Mataura River, the bio-available phosphorus (e.g.; DRP) concentration should not exceed 0.005 gDRP/m^3 (Ryder, 1995b[21]). Thus, groundwater concentration in alluvial aquifers generally, is enriched with respect to that of the Mataura River. The river is especially vulnerable to excessive periphyton growth during low summer flows, when stream temperature is elevated, water clarity is high, and sunlight levels are also elevated. It is also during low flows in the Mataura River when baseflow and seepage will assume a larger proportion of total river discharge, providing less dilution capacity for seepage inflows enriched with respect to phosphorus.

5.3.3 Residential Septic Tank Losses.

The township of Edendale has a population of about 500 persons. The sewage waste of the dairy factory is trucked to Invercargill for disposal. The quality of septic tank effluent at discharge to tile drains or soak-holes is shown below.

Septic Tank Effluent Characteristics (Robertson Ryder & Associates, 1995[22])	
Septic Discharge (litre/day/person)	180
Biological Oxygen Demand [BOD_5] (mg/l)	150 (median)
Suspended Solids [SS] (mg/l)	100 (median)
Ammoniacal nitrogen [NH_4-N] (mg/l)	30 - 35
Total nitrogen [TN] (mg/l)	40 - 50
Total phosphorus [TP] (mg/l)	4 - 9
Faecal Coliforms [FC] (MPN per 100 ml)	10^6 - 10^8

The effluent undergoes significant chemical transformation and filtration in the soil and unsaturated zone, which leads to nitrification of the organic and inorganic nitrogen in the effluent. Phosphorus tends to be adsorbed and precipitated to soils and sub-soils with only low concentrations persisting in the saturated zone. However, significant concentrations of dissolved inorganic nitrogen enter the saturated zone from septic tank discharges.

In the modelling of the BNZ model, the areal mass load of nitrogen loss from residential areas was calculated to be 90.2 kgN/ha/yr at a percolate concentration of 16.3 gN/m^3. In the BNZ and MT3D model, these rates of nitrogen loss were applied over 18.8 hectares near Edendale township. This is equivalent to a septic effluent mass load of 1,690 kgN/yr.

Planning of the waste management in Edendale township have advanced to the point where sewage reticulation and off-site treatment / disposal are a real possibilities. Southland District Council have put a proposal for servicing each property in the township to the community. Were this to take place, the nitrogen losses to groundwater within the township would be significantly reduced. The BNZ model land use equivalent would change from residential / urban to sheep low.

This can be estimated as a simple mass balance change from 90.2 kgN/ha/yr or 1,690 kgN/yr, to 1.75 kgN/ha/yr or 32.8 kgN/yr. This is equivalent to a decrease of 1,657 kgN/yr, or 98% over 18.8 hectares. The net decrease in aquifer-wide nitrogen loading is less significant, at only a 1-% reduction in the 164.9 tN/yr lost from the Edendale Aquifer. The impact on groundwater nitrate-N concentration is shown in the figure below.

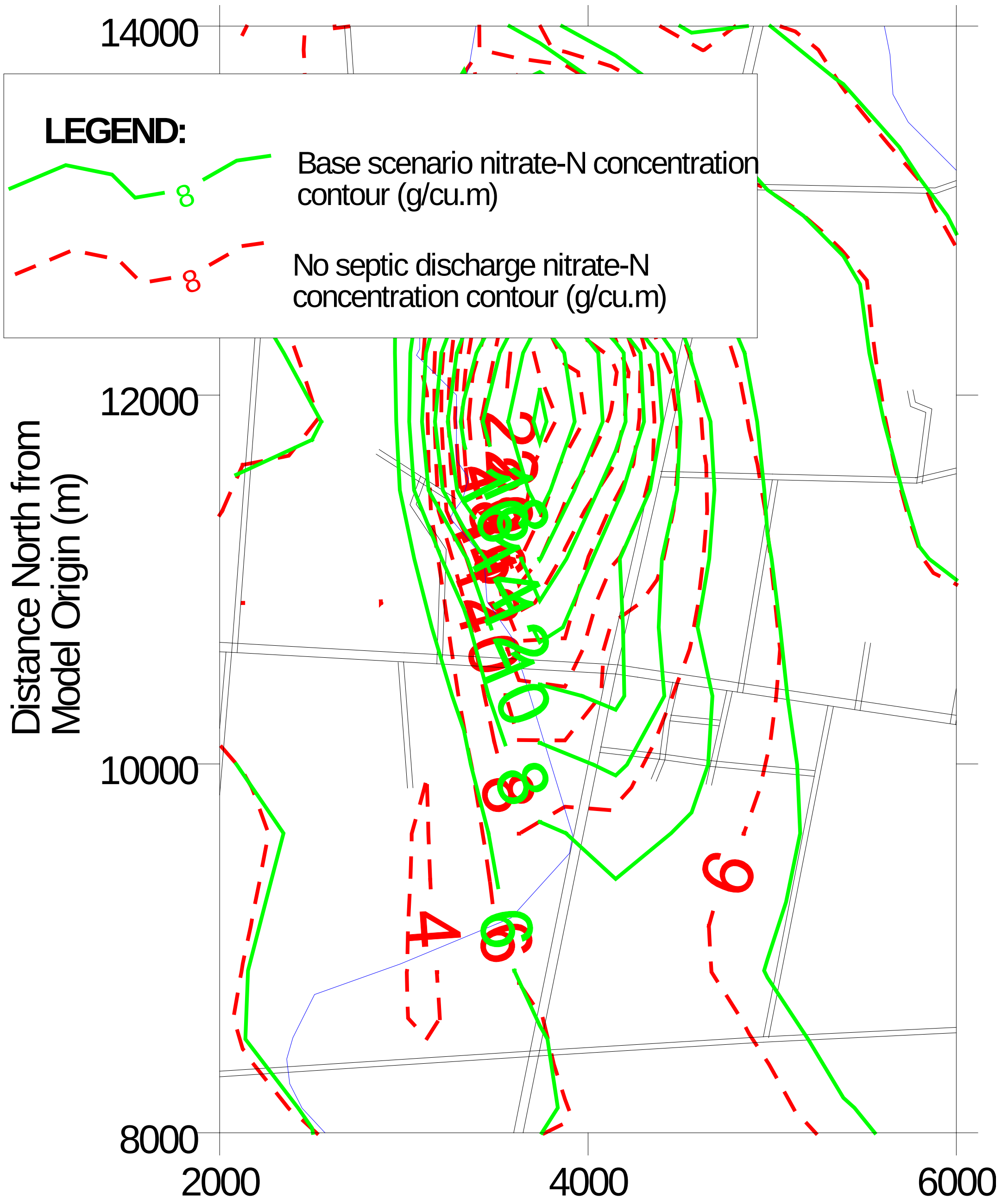


Figure 29 Contour overlay of nitrate-N concentrations in aquifer with and without septic discharge in Edendale township.

The difference in groundwater nitrate concentration is not great due to the predominance of other land uses modelled at high mass loads. Residents of Edendale township could expect a nitrate-N decline in their water bores of perhaps 1 gN/m^3. One needs to bear in mind the scale dependence of such an assessment. The mass load and modelling of the change in concentration assumes full mixing within and between model cells of 6.25 hectares extent. In reality, localised reductions in nitrate-N concentration may be greater.

5.4 Non-point Source Groundwater Quality Effects in the Regional Context.

An important motivation in Southland Regional Council initiating the Oteramika Trail Catchment Project was to learn from intensively studying non-point source effects of agriculture. The knowledge gained from the studies could then be applied extensively to similar settings elsewhere in the Southland. This sub-section examines the applicability of the study to other aquifers in the region.

5.4.1 Previous Regional Studies.

There have been few region-wide studies of Southland. The regional groundwater scoping study (Rekker, 1994) took a highly preliminary 'broad-brush' approach to characterising the region's groundwater resources. The scoping study drew on geological information and a scattering of data on hydrologic properties and water quality. The regional baseflow study (Rekker, 1997) used existing hydrographic records to estimate recharge and discharge of Eastern Southland's alluvial aquifers. The baseflow study made the overall conclusion that an estimated 276 millimetres per year forms the overall mean baseflow rate in Eastern Southland. The regional groundwater nitrate snapshot survey (Keith Hamill, 1998[23]) reports sampling of several hundred water bores drawing on the unconfined alluvial aquifers. The nitrate snapshot survey found groundwater nitrate elevation not to be extensive, with only six bores in a handful of areas manifesting with concentrations above the drinking water standard.

5.4.2 Extent of Similar Settings.

The Edendale Aquifer is contained within an alluvial terrace, which correlates as rank 2-3 in the scheme of terrace flights of the Mataura Valley. The terrace surface is mantled with the Edendale / Otikerama silt loam soils and thick measures of loess (aeolian silt). This configuration is repeated across the plains and downlands of Southland. These alluvial veneers cover extensive areas of southeastern and southwestern Southland. The Quaternary alluvium is typically only 5 to 25 metres in thickness. It is unusual to encounter Quaternary alluvial basins any deeper than 30 metres.

Alluvial soils form on the alluvial surfaces with a variety of hydrologic and chemical properties, but they are generally well drained and non-reactive. Several general groups of alluvial soils are recognised:

- Recent soils, found on the younger terraces,
    - Mataura
    - Tuatapere

- Yellow-brown Earths, found on higher terraces:
    - Waikiwi
    - Edendale

- Yellow-grey Earths, e.g. Kaweku
- Yellow-grey / Yellow-brown Earth Intergrades
  - Pukemutu
  - Aparima
- Gley / Gley Recent Soils
  - Dacre
  - Makarewa (Cutler and Wright, 1964[24])

All of these broad soil types are utilised in downland agriculture, generally in the more intensive grazing and cropping activities. To varying degrees, infiltration of precipitation excess forms part of the drainage system of these soils. The underlying alluvium is usually permeable enough to receive infiltrating groundwater and conduct it away to a down-gradient drain, creek, marsh or river, maintaining an unsaturated zone between the base of the soil and the water table. This is the broad pattern of groundwater replenishment and contribution to freshwater baseflow.

The figure below shows the extent of most of the alluvial aquifers underlying agricultural land in Southland.

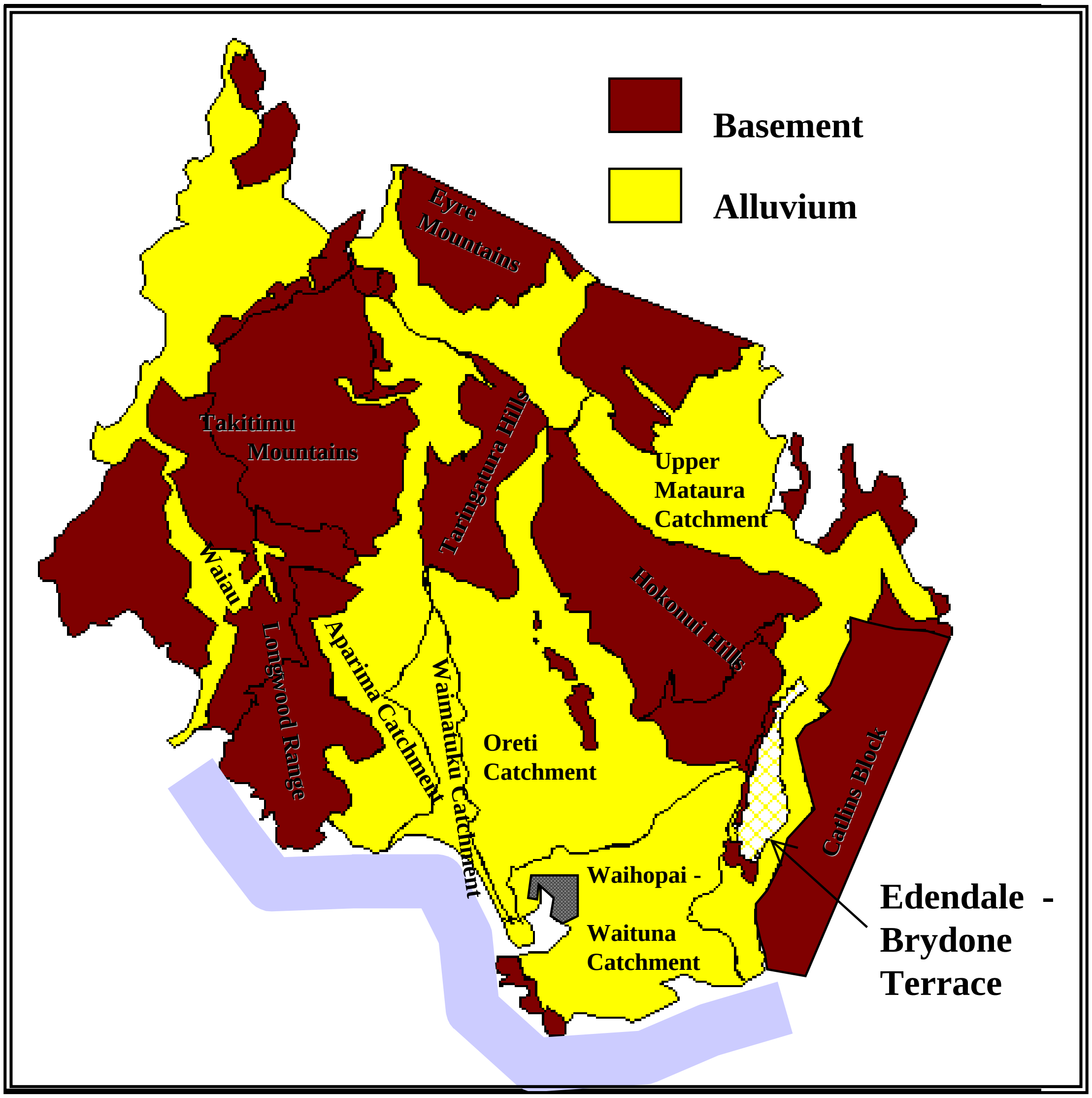


Figure 30 Distribution of Alluvial Aquifers in settled Southland. The yellow area represents the land underlain by alluvium. The brown areas represents the basement blocks of consolidated rock or, in minor cases, low permeability sediment which form the geo-hydrological basement for any significant unconfined groundwater flow. The position and size of the Edendale Terrace is shown for comparison. The information portrayed in the map above is drawn from the Geology module of the digital Land Resource Investory (NZLRI), maintained by Landcare Research / Manaaki Whenua Ltd. A licence to the NZLRI is retained by Southland Regional Council for inclusion in the ArcInfo GIS system. AquaFirma Ltd has manipulated the data within MapInfo to the form presented above.

5.4.3 Applicability of Edendale Information in other Regional Settings.

Soil / sub-soil properties, aquifer properties, land use and climate all impart variability on the processes controlling the non-point source contamination of unconfined groundwater in Southland. However, some generalisations can be made:

- *The presence of low dilution capacity increases maximum and mean concentrations.* This may manifest as high nitrate-N concentration within lower permeability aquifers. The Edendale Aquifer has a high recharge rate (~400 mm/yr) and is well mixed by merit of its generally high permeability. Consequently, high intensity land use causing percolate concentrations higher than the drinking water standard tend to be diluted to concentrations below the drinking water standard by more dilute groundwater in through-flow. In lower recharge / flow rate aquifers, this assimilative capacity (by dilution) may not be as high.

- *The presence of elevated iron correlates with decreased nitrate-N concentration.* In some alluvial aquifers, especially those containing a significant organic component, low flushing rates and reduced hydro-chemical conditions consume incoming nitrate.

For example, an investigation of elevated nitrate-N at Oreti Plains (Rekker and Greenwood, 1996[25]) found the relatively unique soil-water percolation properties of the Pukemutu soil to be a significant factor. Percolation by-pass *via* shrinkage cracks admitted fast percolation of high nitrate-N soil-water directly to the water table. This was borne out by the high ∂N^{15} values indicating relatively direct percolation of urine and dung breakdown products encountered in stable nitrogen isotope analysis undertaken for Oreti Plains groundwater. By comparison, stable nitrogen isotope studies undertaken as part of the Edendale Aquifer characterisation study found medium ∂N^{15} values suggesting longer soil-water residence for fractionation in percolating nitrogen solutes. The low permeability aquifer at Oreti Plains does not possess the same assimilative capacity against nitrate-N elevation as does the Edendale aquifer.

Despite these generalised differences, other alluvial aquifers are likely to be broadly applicable for transportation of the broad impacts observed and characterised in the Oteramika Trial Catchment Project. Tempering this statement, are points contained in the two paragraphs, below.

The Edendale Aquifer and the overlying Edendale silt loam are robust resources for intensive agriculture. The Edendale silt loam has good to excellent properties for tolerating high stock treading, hydraulic loads and nutrient loads. The silt loam retains soil-water and nutrients, but still has a high soil drainage rate to the underlying aquifer. The high flow rate of the underlying aquifer allows dilution of infiltration under areas of elevated contaminant leaching and amelioration of the high concentrations that would otherwise be generated. On a semi-quantitative hydrogeological assessment of the other alluvial aquifers of Southland (e.g.; source data for Rekker, 1997), the Edendale Aquifer has among the highest dilution capacity for infiltrating contaminants. It is highly probable that less robust alluvial aquifer settings are found elsewhere in Southland. Given the information developed in this study, were agriculture to intensify across downland Southland to the same extent as the Oteramika catchment, significant areas of the underlying alluvial aquifers would become elevated with respect to nitrate.

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28 August 1998.

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Appendix 1

Base Data of this Report.

In many such scientific / resource management reports, the detailed base data that have gone into the assessment made in the parent document are appended. In this case the base data used encompasses an extensive, multi-agency, 3-year project. Southland Regional Council has co-ordinated the various investigations.

Inquiries as to the availability of base data referred to in the report can best be made directly to Southland Regional Council:

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Appendix 2

Groundwater Model

The groundwater model referred to in this report comprises a model developed in two codes: MODFLOW and MT3D. Due to the unnecessary length that would be added to the report in appending the model code initialisation, the reader wishing to review the model or obtain a copy for whatever purpose is referring to the report author:

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