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Hydrogeology, water quality, and nitrate movement in the unconfined gravel aquifer beneath the Maraekakaho sheep feedlot, Hawke's Bay, New Zealand

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Abstract

The geology, hydrogeology, and hydrochemistry of the Maraekakaho area, Hawke's Bay, New Zealand, have been studied to construct flow directions, and determine hydrochemical trends and nitrate concentrations in the groundwater directly below a sheep feedlot.

The geology of the Maraekakaho area consists of greywacke boulders, gravels, and sands forming Holocene and Pleistocene terraces of the Ngaruroro River. The terrace deposits are highly porous and permeable but are intermixed with clay and bentonite stringers that may produce perched water tables and reduce permeability in some areas. Water levels in multi-level piezometers and stream elevations indicate that the groundwater flow direction is almost due east.

Limestone bedrock to the south of the feedlot area is a major source of alkalinity (HCO_3^-) to the Maraekakaho River. Piezometric mapping indicates that groundwater flows from the Maraekakaho River to the Ngaruroro River, so that high- HCO_3^- Maraekakaho River water mixes with low-HCO_3^- groundwater under the feedlot area. The low HCO_3^- groundwater is a mixture of rainwater, groundwater derived from non-limestone areas, and Ngaruroro River water.

Nitrate concentrations are highest down-gradient of the feedlot site (range 15 - 40 g/m^3 NO_3^--N) and the distribution of the high concentrations are consistent with the calculated groundwater flow directions originating from the feedlot. However, some nitrate concentrations measured before the feedlot was in operation were 3 times the current background concentration (0.7 - 3.0 g/m^3), suggesting that other factors affect nitrate concentrations. Elevated nitrate and lower HCO_3^- concentrations in bores and streams coincide with rainfall events with less than one month lag time, indicating

that rainwater infiltration is the main short-term process for washing accumulated soil nitrate into the aquifer.

Introduction

Sheep farming has had little impact on groundwater quality in New Zealand except within localised areas on farms, related to overgrazing or fertilising. Recent changes to farming practices brought about by international market pressures have led to the introduction of cattle and sheep feedlots in New Zealand to grain-feed animals before slaughter or live shipment overseas. Because of this, water quality issues related to the livestock industry now include feedlot waste runoff and its impact on groundwater.

In New Zealand, the concentration of nitrogen as nitrate (NO_3^--N) in groundwater is of general concern (Burden, 1980). It has been demonstrated that methaemoglobinaemia in infants may be caused by excessive concentrations of nitrate in water (Comley, 1945). If untreated this disease may cause death. Nitrate is therefore considered to be a health risk to children under the age of 6 months at concentrations over 10 g/m^3 as N (NO_3^--N). This concentration had been adopted by the World Health Organization (1984) and the U.S. Environmental Protection Agency (1992) as the maximum permissible for drinking water consumed by humans. However, new World Health Organization (1993) guidelines now set the maximum permissible concentration of nitrate in drinking water as 50 g/m^3 as NO_3^-. This value equates to a NO_3^--N concentration of 11.3 g/m^3. Recently, the 50 g/m^3 NO_3^- concentration limit has been adopted in New Zealand as the maximum permissible concentration in drinking water (Drinking Water Standards for New Zealand, 1995).

In addition to the problems associated with human consumption, high concentrations of nitrate will also kill cattle, at nearly the same concentrations as those that affect human infants (Kreitler and Jones, 1975). Furthermore, excess nitrogen may cause adverse environmental impacts such as algal blooms in rivers and lakes, promote changes in the invertebrate fauna of rivers, and cause fish kills related to ammonia toxicity.

The proper management of feedlot wastes has been an issue in the U.S.A. and Australia for a number of years (Gilbertson *et al.*, 1981; Young, *et al.*, 1982; Young *et al.*, 1994), but this problem is relatively new to New Zealand. To my knowledge no studies have been published on sheep feedlots in New Zealand. The effluent wastes carry both nitrogen and phosphorous, as well as some heavy metals such as copper, zinc, and iron. Beef-cattle feedlots have been shown to have greater impact on the groundwater than other types of feedlots (Miller, 1980). Gilbertson *et al.* (1981) estimated that for an unpaved sheep feedlot, 5 percent of the nitrogen in manure is transported annually from the feedlot in runoff. This is a significant amount of contaminant transport in an area where there may be over 35,000 sheep.

The present study addresses the effects of feedlot operations on groundwater quality by examining nitrate migration in groundwater beneath the Maraekakaho sheep feedlot in Hawke's Bay (Fig. 1). New hydrologic and geologic information was gained from drilling 14 observation bores at 6 sites around the feedlot area (Fig. 1). Existing hydrogeological and water chemistry information were reviewed to identify the effects of the feedlot on the concentrations and distribution of nitrate in groundwater.

Previous work and background

The Maraekakaho sheep feedlot is situated west of Hastings near the confluence of the Maraekakaho and Ngaruroro rivers, northwest of the town of Maraekakaho (Fig. 1). The feedlot is an approximately 1 km^2

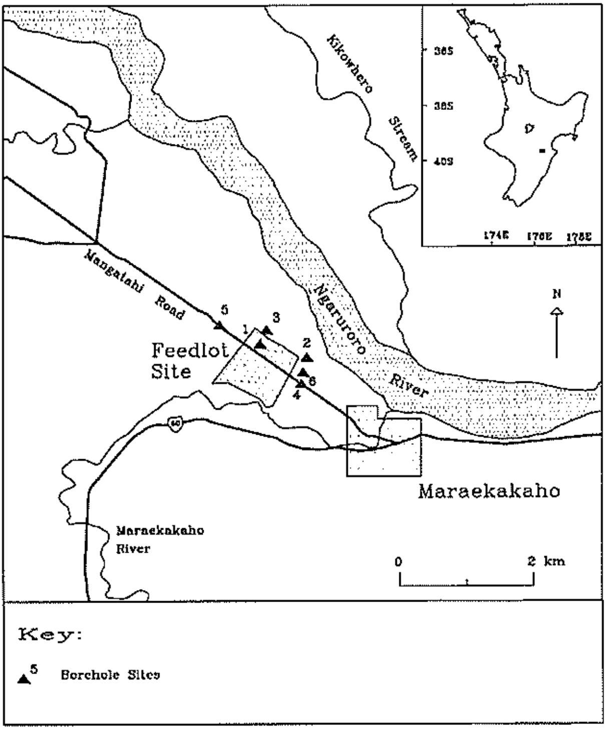


Figure 1 - Map of the Maraekakaho area showing the location of the feedlot and bores drilled for this study.

unpaved area with no control of run-on or run-off of surface water. There is no vegetation where the sheep are kept and the soil cover is relatively thin (less than 0.2 m deep). When in full operation, approximately 35,000 sheep may be on the site for up to 10 days at a time.

The township of Maraekakaho, which uses shallow groundwater wells for its drinking water supplies, is roughly down-gradient of the feedlot. The present study was, in part, initiated to determine the risk of contamination to the township drinking water supply.

The feedlot began operation in July 1986. One month prior to operation, the Hawke's Bay Regional Council (HBRC) collected groundwater quality data from farmers' existing bores and surrounding rivers in the area of the feedlot. After the feedlot opened, groundwater quality data was collected sporadically until 1990. Hooper (1989) reported on the major and minor ion composition (including nitrate) of bores and the Maraekakaho and Ngaruroro rivers from 1986 to 1989; she was unable to clearly identify the source of high nitrate values (up to 27 g/m^3 NO_3^--N) in some groundwater bores. However, these data were limited in distribution across the aquifer due to the positions of the bores and provided little information on groundwater flow direction. In addition, information on the construction of the bores, depth of aquifer penetration and hydrogeological data are scarce.

Thorpe (1990) reviewed the geohydrology of the Ngaruroro River terraces at Crownthorpe, an area approximately 6 km upstream from the Maraekakaho feedlot site. He found that the site was not suitable for another sheep feedlot because the permeable nature of the river gravels underlying the site made contamination of the shallow unconfined aquifer likely (Thorpe, 1990). However, these terraces are on the opposite side of the Ngaruroro from the Maraekakaho feedlot and may not be representative of the hydrogeologic conditions under the Maraekakaho site.

Geology of the Maraekakaho area

A detailed description of the regional geology of the area can be found in Rosen *et al.* (1995) and references therein. The feedlot lies within a triangular area bounded by the Ngaruroro River to the north and the Maraekakaho River to the south and east (Fig. 1), underlain by Pliocene to Holocene age sedimentary fluvial and marine deposits. The township of Maraekakaho lies just north from the centre of this block. Ngaruroro River terrace deposits are greywacke gravel from the Ruahine and Kaweka ranges. Near the confluence of the Ngaruroro and Maraekakaho rivers, the Maraekakaho River and nearby streams are currently degrading the older terraces in response to tectonic uplift of the Puketapu Fault Zone. The Ngaruroro River also eroded the river terraces before the establishment

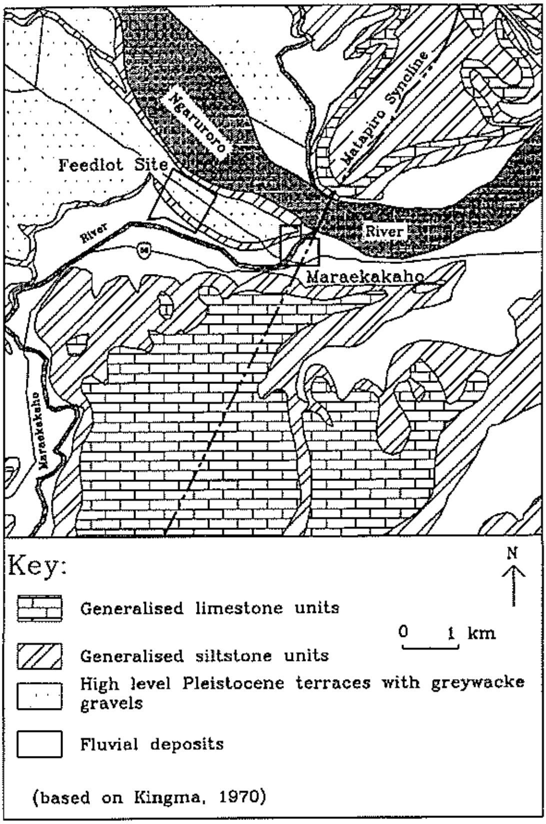


Figure 2 - Geologic map of the Maraekakaho area (based on Kingma, 1970). Generalised limestone units include the Pentane Limestone (Beu, 1980), Mason Ridge Limestone and interbedded mudstones (Kelsey *et al.*, 1993), and the Matapiro Limestone (Beu, 1992). Generalised siltstone units include: the Okanawa Formation (Kelsey *et al.*, 1993), the Makaretu Mudstone (Kelsey *et al.*, 1993), Taradale Mudstone (Beu, 1992), and the Moteo Mudstone (Beu, 1992).

of flood control works in the early 1980's.

Fluvial deposits mapped as Pleistocene in age (Hawera Series) underlie the feedlot site (Fig. 2). These are the Pigsty terrace (Kingma, 1971) deposits, which probably accumulated during the late, last (Otiran) glaciation (L.T. Brown, *pers. comm.*, 1995). A terrace of up to 10 m height above the Ngaruroro River marks the northern boundary of the feedlot, as well as the boundary between the Hawera Series gravels and the Holocene gravels. Boulders up to 0.3 m in diameter are exposed in this terrace, which was formed as a result of degradation as the Ngaruroro River adjusted to tectonic uplift at the Puketapu Fault Zone and shortening of river course as sea level rose and transgressed over the Heretaunga Plains prior to 6500 years B.P. Kingma (1970) records pumiceous Pleistocene (Wanganui Series) siltstone as cropping out in the gravel cliff, but this contact was not found in the terrace nor intersected by the bores during this investigation. This Pleistocene siltstone may underlie the Hawera Stage fluvial terrace deposits. To the south of the feedlot is a hill of Neogene Petane limestones that may influence the chemistry of the groundwater and river water.

Methods

Hydrogeology

Preliminary measurements from groundwater wells drilled before this study and river levels indicated that the groundwater gradient was to the east. However, there was no information directly down-gradient from the feedlot site. Six groundwater monitoring sites were drilled in collaboration with HBRC (Fig. 3). Four of these sites (GMK94 - 01 through 04) have piezometers at three depths, and two sites (GMK94 - 05 and 06) have single level piezometers. One site (GMK94 - 05) was located up-gradient from the feedlot as a control well. The remaining sites were placed to better define the migration of any contaminants from the feedlot site (sites GMK94 - 02, - 03, - 04), and to monitor the groundwater directly underneath the feedlot (GMK94 - 01). The 6 sites provided information on the geology of the area, more water levels for the piezometric surface map, and sampling points to trace the migration of nitrate in the groundwater.

The holes were drilled by the cable-tool method (Rosen *et al.*, 1995) to allow collection of bailed sediment samples and therefore did not introduce drilling muds into the formation. A small amount of water was used to facilitate bailing sediment from the hole, but this water was pumped out of the holes when the piezometers were developed. The lithology of each hole was logged on site and sediment samples were collected at 1 m intervals.

Boreholes were drilled to depths of 27 m, 17.5 m, 12.7 m, 22.5 m, 21 m and 13.8 m for sites GMK94 - 01 to GMK94 - 06 respectively. Boreholes GMK94 - 05 and 06 had one 75 mm P.V.C. piezometer installed to 3 m below the groundwater surface. All other boreholes had three 75 mm P.V.C. piezometers placed to 3 m (a), 7 m (b), and 12 m (c) below the groundwater surface. All piezometers have a 1 m deep sump at the bottom. Piezometers (b) and (c) then have a 1 m screened interval directly above the sump. Piezometer (a) has a 5 m screened interval above the sump to allow for groundwater level changes. Each piezometer was packed with grout below and above the screened interval using a tremi device, and grout was used around the well-head to seal the aquifer from the surface. The piezometer sites were surveyed to New Zealand height datum along with the other bores and water levels in the rivers.

Water quality sampling

Groundwater samples were collected by staff of the HBRC at fairly regular intervals from 1986-1990 from farmers' bores and the Ngaruroro and Maraekakaho rivers (Fig. 3). Some of these data were interpreted by Hooper (1989) and more recently by Rosen *et al.* (1994, 1995); this information forms the background for the present water quality assessment. In addition to groundwater and river water data, daily rainfall has been measured by the HBRC Ohiti Pa, approximately 8 km north-east of the feedlot, for the last 5 years. The average rainfall over the period 1989 -1993 was 741 mm, with a standard deviation of 123 mm. This average rainfall is less than the 30 year averages at Keruru (approximately 1200 mm) and Paritu (approximately 900 mm), which are c.15 km southwest and northwest of the feedlot respectively.

Water quality samples were collected in June 1994 from the Maraekakaho

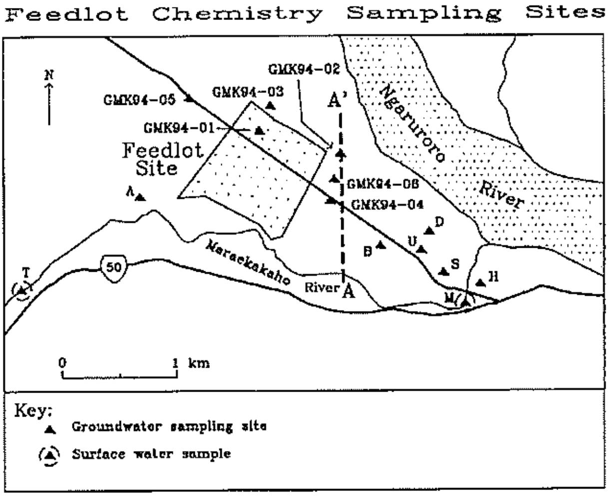


Figure 3 - Map of Maraekakaho area showing sample collection points for the historic data and the present collection points for this study. B= Barley's bore, U = Urban's bore, D = Dean's bore, S = School house bore, M = Maraekakaho River sampling site, H = Hunt Club bore, A = Simmond's bore, T = Tait Road Bridge gauging site. GMK94 - 01 through 06 are piezometers installed for this study. Line A - A' corresponds to cross-section line in Figure 5.

River, selected farmers' bores, and the recently drilled piezometers. Samples from bores were collected after pumping the piezometers for 15 minutes to allow a representative sample to be collected. The pH of water samples was measured in the field. 500 ml water samples were collected and stored in ice until analysed. Alkalinity titrations to determine bicarbonate (HCO_3^-) were performed immediately upon receipt in the laboratory. The remainder of the samples were filtered through 0.45 mm membrane filter paper and analysed for chloride (Cl^-) and nitrate (NO_3^-) on a Technicon Auto Analyzer using Standard Methods for the Examination of Water and Wastewater (1985) within a month of sample collection. Results of analyses are presented in Rosen *et al* (1995).

Results and discussion

Hydrogeology of the aquifer

The cable-tool drilling method used made it difficult to determine grain sorting. All holes penetrated rounded, blue-grey greywacke gravels and boulders with brownish sandstone pebbles. Sites GMK94 - 01, 04, 05, and 06 were drilled through the highest terrace, the sediments are largely Pleistocene in age (Fig. 2). Sites GMK94 - 02 and 03 were drilled near the Ngaruroro River, below the high terrace, and penetrate mostly Holocene gravels (Fig. 2). It was not possible to determine the contact between Pleistocene and Holocene gravels in the strata penetrated.

Clast size varied from hole to hole, from sand to boulders. In GMK94 - 05 a brown clay-rich layer at a depth of 10.7 m - 14.7 m is interpreted to be an altered tephra layer (bentonite), possibly with admixtures of loess. X-ray diffraction (XRD) analyses indicate the layer is composed of smectitic clays mixed with quartz and feldspar sand and silt. The smectitic nature of the clays suggest that the unit is a bentonite clay derived from the weathering of volcanic ash. Although bentonitic clay-rich sediments were plentiful throughout the gravels as a matrix surrounding boulder and gravel clasts, this was the only place it appeared as a distinctive layer.

The range in matrix grain-size and clast-size is extreme. Boulders in the order of 0.3 m in diameter are not uncommon in the sediments (Fig. 4). Conversely, clay-size matrix is also present. Local drillers indicated that the clast size decreases toward the east, down gradient from the feedlot (R. Baylis, *pers. comm.*, 1994). The high permeability of the area was emphasized by the loss of water during drilling.

With the exception of small lenses of perched water, the main aquifer is unconfined. The total thickness of the gravel units overlying the Pleistocene siltstone and Neogene limestone is unknown but is greater than 27 m thick under the feedlot.

Outcrops show much the same variation in grain-size as the drill holes. However, the stream bank outcrops show sedimentary structures such as imbrication of the boulder clasts, cross-bedding, lensing, channelisation, and varied clast size (Fig. 4). Filling of the pore spaces by altered ash units can also be seen in outcrop.

The outcrops demonstrate that highly permeabe units are discontinuous, so pathways for migration of fluids and potential contaminants may be laterally and vertically variable. Channelisation, packed boulder lag deposits and pore plugging by clays are the main hindrance to water movement in the aquifer. However, as a whole the gravels are exceptionally permeable, so infiltration and water movement are rapid.

Figure 4 - Cross-bedded channel deposits are exposed in an outcrop near site GMK94-05, the person in the photo has his hand on the bottom of a channel; imbricated boulder clasts are also visible in the lower right. Water was flowing to the right at the time of sediment deposition. Notice the sorting of grain-sizes and the scouring of the material below the hand of the person.

The stratigraphy of the bore holes and outcrops indicate that the Maraekakaho area is underlain by river channel and overbank deposits of a braided stream system similar to the present-day unrestricted Ngaruroro River. The channelisation of the deposits causes a variability in grain size that in turn controls the permeability of the aquifer. The permeability is also affected by fine clayey mixtures of eroded tephra and loess transported to the area by wind.

The average gradient of the Maraekakaho River is approximately 0.005 m/m in the study area. This compares with the average Ngaruroro River gradient of 0.004 m/m in the same distance above the confluence with the

Maraekakaho River. The steeper gradient of the Maraekakaho River means that its water levels are above those of the Ngaruroro River upstream of their confluence. Piezometric contours estimated from river and well water levels indicate that groundwater is moving generally towards the Ngaruroro River and away from the Maraekakaho River in the study area (Fig. 5). Any water leaking from the active channel of the Maraekakaho River would tend to travel underground to emerge in the Ngaruroro River channel.

Stream gaugings measured in January 1994 on the Maraekakaho River

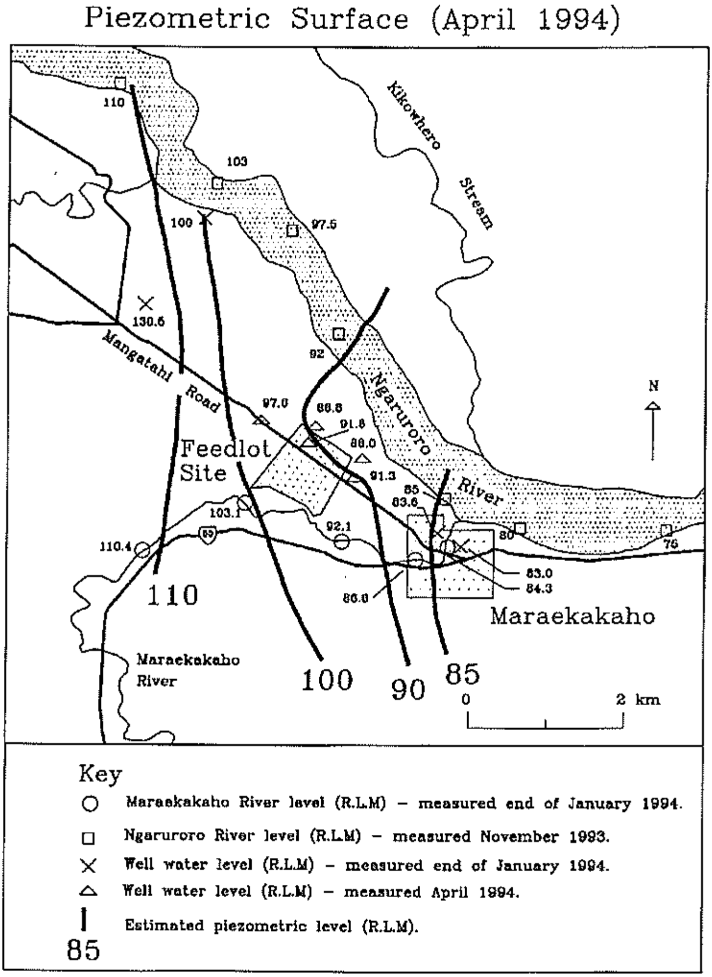


Figure 5 - Piezometric contour map of the Maraekakaho area. Groundwater flow in the vicinity of the feedlot is east-northeast, away from the Maraekakaho River towards the Ngaruroro River.

show that a flow of 177 l/sec at the Tait Road Bridge site (Fig. 3) is reduced to 100 l/sec at Maraekakaho Township. Surface flow is completely lost between the Tait Road Bridge and a location near the gauging site. A significant amount of this water is probably travelling as stream underflow, as flow re-emerges at Maraekakaho Bridge. If approximately 80 l/sec are lost from the Maraekakaho River below Tait Road Bridge then this water, assuming no extraction, will travel through the gravels towards the Ngaruroro River.

Two aquifers are observed for GMK94 - 03, based on the water levels and the stratigraphy. The first is a perched, probably ephemeral, boulder-gravel aquifer 0.2 - 4.5 m below ground surface whose source of water is surface flooding and direct runoff recharge. This is contained below by a tightly packed gravel, sand and clayey layer between 4 m - 6 m depth. The second, lower gravel aquifer below 6 m is probably a permanent groundwater aquifer; no water was encountered when drilling between 4.7 - 6.7 m, artesian flow occurred when the hole was 7 m deep, and static water levels for the piezometric holes differ.

At GMK94 - 04 the water level in the shallow hole appeared to rise much higher after a rainfall event in mid July than in the intermediate and deep holes. This is interpreted as the rain infiltrating and filling a shallow perched water table before reaching the static water table. Heterogeneities in the terrace sediments caused by scouring and filling during deposition are the likely cause for the development of local, small lenses of perched aquifers in the area.

Surface run-off

The ground surface of the feedlot is essentially barren soil with a paved road running through the middle of the site. Surface run-off has not been measured, but farmers in the area indicated that surface run-off from the feedlot site occurs after major storms. The feedlot site has no collection ponds or barriers to surface flow. Infiltration of surface run-off that has flowed downhill from the feedlot will make water with elevated nitrate concentrations more readily accessible to the groundwater.

Water quality

From measured alkalinities, Hooper (1989) established that groundwater in the study area is recharged by the Maraekakaho River. The Maraekakaho River water is more alkaline (average of 226 g/m^3 as HCO_3^-, from 1981-1989; depending on the site) than the Ngaruroro River (average alkalinity as HCO_3^- of c. 61 g/m^3, from 1981-1989; depending on the site). This relatively large difference in alkalinity is because the Maraekakaho River catchment is mostly in limestone that reacts with rain water to produce

CO_3^{2-} and HCO_3^-, while the Ngaruroro River water is derived from different lithologies, many with low alkalinities. In general, the alkalinity of the groundwater from the unconfined aquifer varies within the limits set by the recharging rivers. Only one bore (Barley's bore) has an alkalinity lower than 100 g/m^3. This well is shallow (approximately 8 m deep) and may have direct rainwater recharge.

Elevation differences between the Maraekakaho and the Ngaruroro rivers cause a chemical and hydraulic gradient from the Maraekakaho to the Ngaruroro. The mixing-zone between the high alkalinity Maraekakaho River water and low alkalinity Ngaruroro River water varies in position depending on rainfall recharge and Maraekakaho River flow (Fig. 6). Sodium and chloride concentrations (both conservative ions) in the bores and river demonstrate that all of the wells plot as a mixture between the two river end-members (Fig. 7a). Barley's bore is closest to the Ngaruroro River. A plot of HCO_3^- versus chloride shows a similar pattern to the sodium, although Barley's bore is depleted in HCO_3^- relative to the other bores (Fig. 7b). This may be due to direct rainwater recharge of this shallow well. However, direct rain water recharge cannot account for long-term

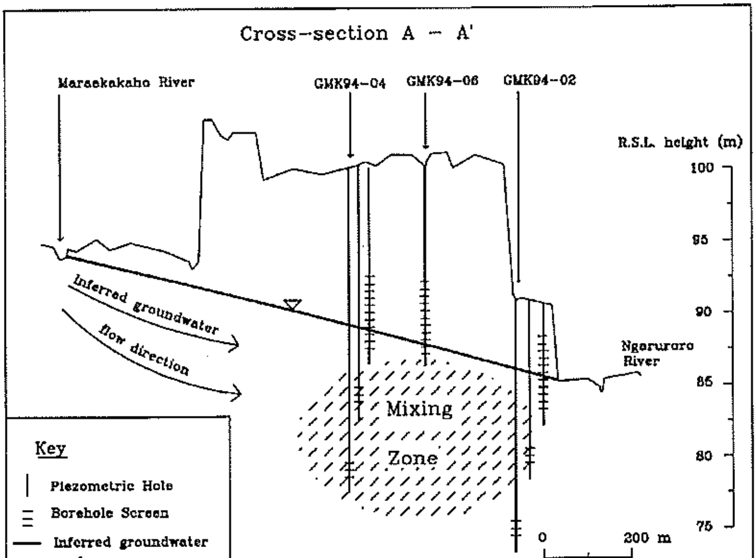


Figure 6 - Cross-section of the Maraekakaho area showing the groundwater mixing-zone between Maraekakaho and Ngaruroro river water. The ground surface was surveyed by the HBRC. The Maraekakaho River is topographically higher than the Ngaruruo River, indicating a hydraulic gradient between the two rivers.

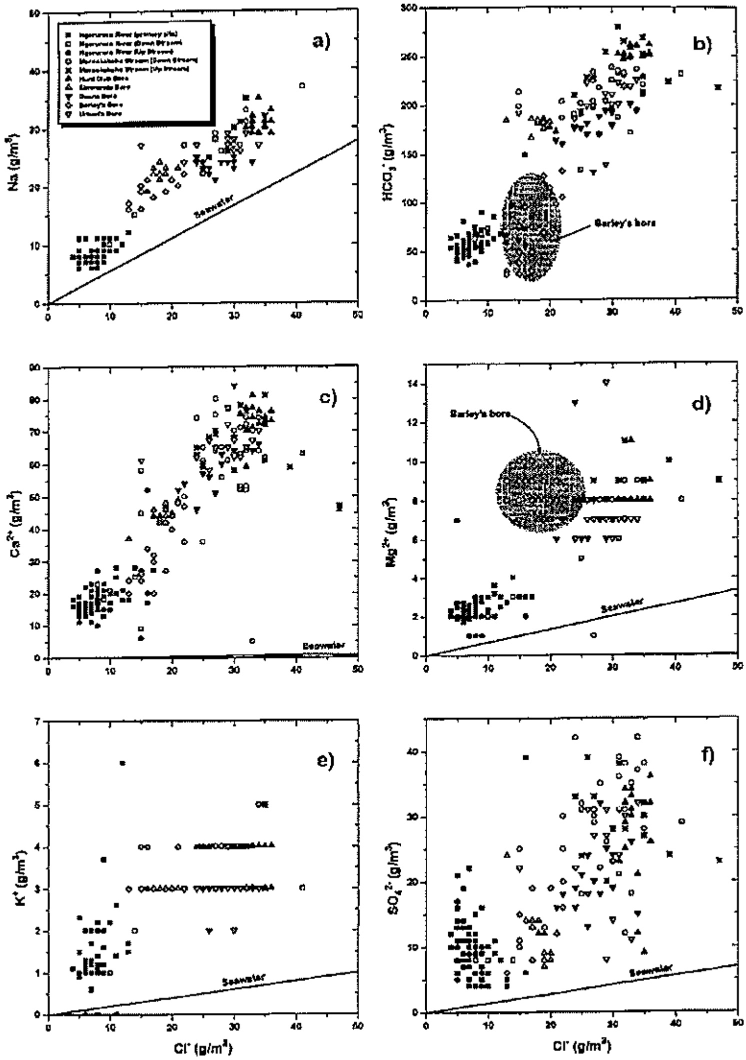


Figure 7 - Cross-plots of: a) sodium, b) bicarbonate, c) calcium, d) magnesium, e) potassium, and f) sulphate, versus chloride for chemical data from 1986 - 1990. The chemistry of the Ngaruroro River plots as the freshwater end-member and the Maraekakaho plots as the concentrated end-member solution. Groundwater bores plot in between these two end-members. Samples from Barley's Bore appears to be enriched in Mg^{2+} but more depleted in HCO_3^- than other bores (Fig 8 b), but still plots in a position representing mixing between two end-member river waters. Primary sites in the legend refer to HBRC long-term river monitoring sites.

variations in bore chemistries in the area. This is because the concentrations of sodium and chloride for all bores in the area plot between Maraekakaho and Ngaruroro river water in a straight line (Fig. 7a). Although rain water recharge may change the composition of an individual bore for a short while, the average composition of the bore relative to the two rivers remains constant, indicating mixing of water with different compositions.

It can be seen in Fig. 7a that rain water recharge is insufficient to greatly affect the position of an individual bore on the mixing line. Thus, mixing of at least two groundwaters with different chemical compositions must be called upon to explain the chemical patterns in the bores. Most of the bores plot closer to the Maraekakaho composition rather than the Ngaruroro, indicating that a significant portion of the groundwater comes from the Maraekakaho River.

Plots of Ca^{2+}, Mg^{2+}, K, and SO_4^{2-} versus Cl^- also show the same general mixing trend between Ngaruroro and Maraekakaho river water (Figs. 7c - f). However, potassium values are not sufficiently precise to determine the slope of the mixing line. Barley's bore appears to be depleted in HCO_3^- and enriched in Mg^{2+} relative to Cl^- compared to all other wells. The reason for the Mg^{2+} enrichment is not known. All ions in the groundwater are enriched relative to a theoretical concentration - dilution line for seawater. This indicates that weathering of the surrounding rocks and soils contribute significantly to the composition of the river and groundwaters.

Saturation indices (SI) were calculated using the computer programme WATEQF (Plummer *et al.* 1976). This programme calculates mineral saturations based on thermodynamic equilibria equations and data. In general, the ground and river waters are sufficiently fresh that they are undersaturated with respect to most common minerals. However, groundwater samples from Simmond's Bore (A in Fig. 3), which is up-gradient of the feedlot and near the Maraekakaho River, is saturated with respect to calcium carbonate minerals. The reason the groundwater in this bore is saturated is because large amounts of Ca^{2+} and HCO_3^- ions are produced by the weathering of the limestone in the hills south of the river, influencing the composition of the groundwater surrounding the Maraekakaho River.

The bore with historically high nitrate concentrations is Barley's bore (B in Fig. 3), which is located down slope from the feedlot. Bores that are down-gradient from Barley's bore are also high in nitrate, but are diluted by low-nitrate Maraekakaho and Ngaruroro River water. However, these bores also plot in a mixing zone between Barley's bore and river water (Rosen *et al.*, 1994). Bores that are up-gradient from the feedlot, the Ngaruroro River, and the Maraekakaho River have relatively low nitrate values (< 1 g/m^3 NO_3^--N), although depending on the time of year, the Maraekakaho River (both upstream and downstream of the feedlot) may have up to 4.1 g/m^3 NO_3^--N.

There is an inverse correlation between alkalinity values and nitrate values in both bore (Fig. 8) and river water (Rosen *et al.*, 1995). This suggests that nitrate is flushed from the surrounding soils and infiltrates to the groundwater after periods of rain. Bore water chemistry is affected by higher alkalinity Maraekakaho River water during droughts or low-flow events when the water table is lower. High nitrate values correlated with rainfall events (Fig. 8), further substantiating the relationship between recharge events and alkalinity. The inverse correlation between alkalinity and nitrate values also substantiates the idea of a mixing zone between high and low alkalinity water under the terrace.

Groundwater from Barley's bore can be high in nitrate (up to 27 g/m^3

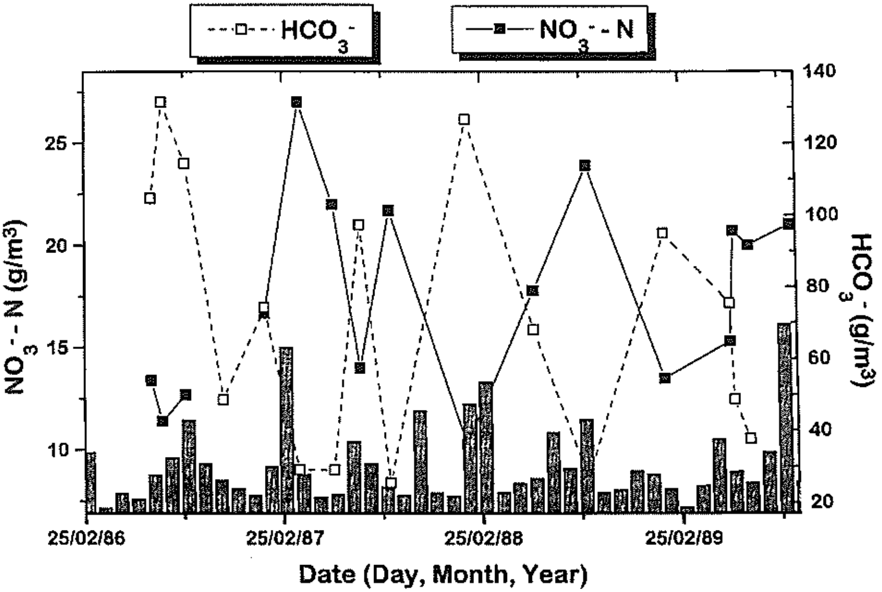
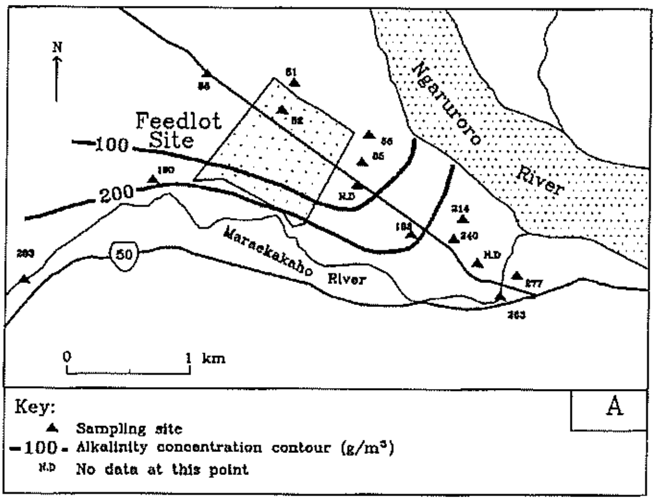
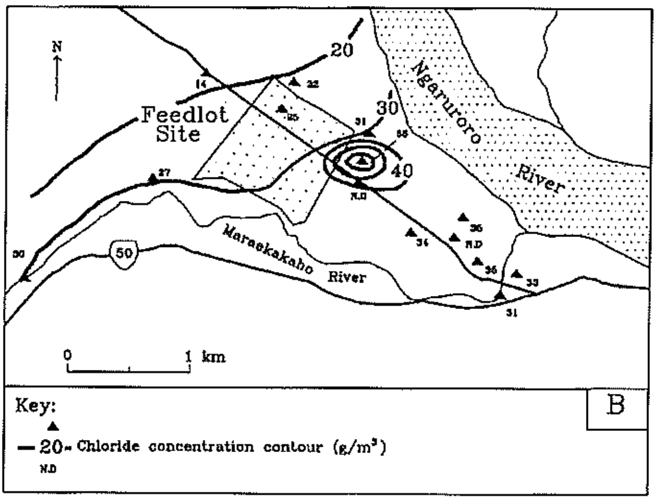


Figure 8 - Time-series plot of HCO_3^- and NO_3^--N for groundwater from Barley's bore. Notice the inverse relationship between HCO_3^- and NO_3-N for groundwater from this bore. Other bores plot in a similar manner. Monthly rainfall from HBRC collection stations (grey bars at base of diagram) near Maraekakaho at Keruru shows a strong correlation between high rainfall events and high nitrate values in the groundwater at this site. A low nitrate value in early 1988, which appears to correspond to a high rainfall period, was from a sample collected before the start of the rainy period.

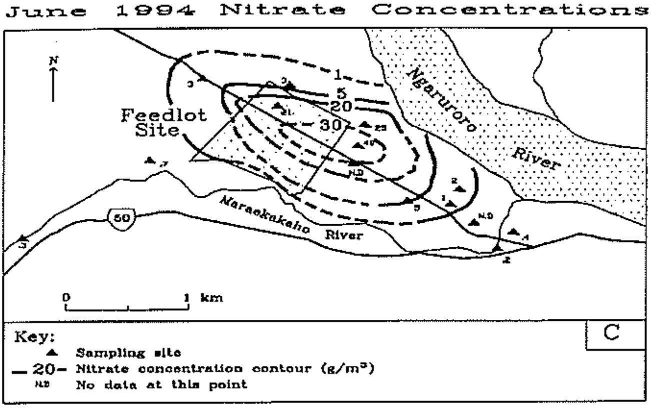


June 1994 Alkalinity Concentrations



June 1994 Chloride Concentrations

Figure 9 - Concentration contours of groundwater for a) HCO_3^- , b) Cl^- and c) NO_3^--N for June 1994 plotted on the Maraekakaho base map. Resampling of bores after the feedlotwas used in October, 1994 (Rosen, unpublished data) showed the same trends, although nitrate concentrations were greater than 80 g/m³ NO_3^--N in bore GMK94 - 01 and 06, more than double the values measured in the June 1994 sampling.



NO$_3^-$-N). Hooper (1989) suggested that the source of nitrate may be local, possibly a leaking septic tank that is within 7 m of the bore, but she could not rule out the possibility of additional nitrate from the feedlot. Samples taken just before the feedlot began operations and shortly after it opened (Fig. 8) indicated that the water in the bore was already high in NO$_3$ (11.4-13.4 g/m^3 NO$_3^-$-N). Subsequent analyses of the bore up to 1990 show no marked overall increase in nitrate over time (Fig. 8), although the nitrate concentrations do increase to high values during the year. As the background nitrate concentrations in the area of Barley's bore are high, remediation of the feedlot site may not lower the nitrate concentration in Barley's bore to below the Drinking Water Standards for New Zealand (1995) guidelines (11.3 g/m^3 NO$_3^-$-N).

Chemical data collected in June, 1994 (Rosen *et al.*, 1995) show trends that are similar to the historic data, but provide information on Cl$^-$, HCO$_3^-$, and NO$_3^-$ in areas lacking previous data (Figs. 9a,b,c).

Concentration contour maps of both Cl$^-$ and NO$_3^-$-N show considerable enrichment under or down-gradient of the feedlot (Figs. 9b and c) that are consistent with transport of contaminants in the direction of groundwater flow. Chloride concentrations increase down-gradient, with values as low as 14 g/m^3 at the control site increasing to an average of about 33 g/m^3 near the confluence of the Maraekakaho and the Ngaruroro rivers (Fig. 9b). Bore GMK94 - 06, located just down-gradient of the feedlot, shows an elevated chloride concentration of 66 g/m^3. Some of this enrichment may be due to clearing of vegetation around the site. This area is being prepared for orchards and has barren areas that may accelerate the leaching of adsorbed soil ions into the groundwater.

Concentrations of NO$_3^-$-N are also high (40 g/m^3 NO$_3^-$-N) in groundwater from GMK94 - 06 bore, and in bores GMK94 - 01 and GMK94 - 02. Groundwater from the control site bore (GMK94 - 05) has a concentration of about 3 g/m^3 NO_3^--N (Fig. 9c). Groundwater from Barley's bore, which has historically been enriched in nitrate, contained 5 g/m^3 NO_3^--N at the time of sampling.

Both the Cl^- and NO_3^--N results indicate that the feedlot affects the groundwater quality of the immediate area down-gradient from the feedlot. Other land uses may contribute to changes in groundwater quality, but as bores up-gradient of the feedlot (control sites) and further down-gradient from the feedlot (near the Maraekakaho township) all have lower nitrate and chloride concentrations, the main source of elevated nitrate and chloride in the down-gradient area immediately east of the feedlot is likely to be the feedlot. The Maraekakaho township bores have low nitrate concentrations because the high nitrate groundwater from the feedlot intersects the Ngaruroro River northwest of the township. However, any substantial pumping (possibly for irrigation) of the groundwater down-gradient of the feedlot, and up-gradient of the township, may change the groundwater flow directions, affecting nitrate concentrations of the township bores.

Conversely, concentration contour maps of HCO_3^- show smooth contours that are influenced by the hydrochemistry of the Maraekakaho and Ngaruroro rivers and are related to the position of the limestone units south of the Maraekakaho River. Higher HCO_3^- concentrations occur closest to the Maraekakaho River, which drains from the limestone hills, and the lower values are near the Ngaruroro River (Fig. 9a).

Conclusions

The geology under the Maraekakaho area feedlot area consists of greywacke boulders, gravels, and sands forming Holocene and Pleistocene terraces of the Ngaruroro River. An unconfined shallow aquifer occurs where the terrace deposits are highly porous and permeable. Perched water tables develop where intermixed clays and bentonite stringers reduce permeability. Drilling of multi-level piezometers in the area of the feedlot has defined the groundwater flow direction as being north east.

Limestone hills to the south of the feedlot area provide a major source of alkalinity (HCO_3^-) and calcium (Ca^{2+}) to the Maraekakaho River and to the groundwater. The groundwater flow direction is eastward from the higher elevation Maraekakaho River to the lower elavation Ngaruroro River. Flow measurements along the Maraekakaho River indicate that the river loses water to the ground before it reaches the confluence with the Ngaruroro River. The groundwater derived from the Maraekakaho mixes with water from the Ngaruroro River and direct rainfall recharge under the feedlot area. The degree of mixing depends on flow in the Ngaruroro River and rainfall in the area.

The chemistry of the groundwater under the Maraekakaho area indicates:

1. Elevated NO_3^--N concentrations are highest under the feedlot and the distribution of the high concentrations are consistent with calculated groundwater flow directions down-gradient of the feedlot.
2. Groundwater from Barley's bore shows elevated NO_3^--N concentrations through time, the concentrations in the bore just before the feedlot began operation were approximately 3 times the background concentration for the area. Therefore, feedlot operations alone may not explain the high NO_3^--N concentrations in this bore.
3. Elevated nitrate and lower HCO_3^- concentrations in bores and streams coincide with rainfall events with very little lag time. This suggests that rainwater infiltration is the main processes for washing accumulated soil nitrate into the unconfined groundwater aquifer. However, because infiltration is rapid, direct rain water recharge alone cannot account for the long-term spatial variations in water chemistry of the groundwater bores in the Maraekakaho area.
5. Chloride concentrations are also elevated above background down-gradient of the feedlot. However, there may be some contribution from orchards in the area.

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