DISTRIBUTION OF NITRATE-N CONCENTRATIONS IN GROUNDWATER BENEATH INTENSIVELY GRAZED PASTURELAND IN THE NGATARAWA VALLEY, HAWKES BAY

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ABSTRACT

Nitrate-N concentrations in groundwater of the central and lower regions of the Ngatarawa Valley, Hawkes Bay, New Zealand, exceed 10 g/m^3 and range up to 57.2 g/m^3. Nitrate leaching from non-irrigated and surface-irrigated pastures is extensive. The spatial distribution of concentrations is principally controlled by high groundwater velocities, an extensive subsoil hardpan, an impermeable silt layer that locally confines groundwater, seasonal changes in drainage volume and groundwater level, and seepage of low nitrate-N river-water.

INTRODUCTION

The Ngatarawa Valley encloses 1450 ha of agricultural land about 10 km west of Hastings City in Hawkes Bay (Fig. 1). Groundwater in the valley is unconfined and is, therefore, susceptible to contamination from man's activities on the land surface. Contamination of groundwater is potentially a serious problem because the valley overlies a zone of river recharge to the extensive Heretaunga Plains aquifers which constitute the source of domestic water for a regional population of 130,000.

This paper identifies the source and evaluates the distribution of nitrate-N concentrations in ground water of the Ngatarawa Valley in relation to geology and land-use. Previous analyses of domestic well-water indicated widespread nitrate-N contamination with concentrations in some wells approaching or exceeding 10 g/m^3 (Burden, 1979).

Excessive amounts of nitrate in water supplies are hazardous to human health (Shuval and Gruener, 1977). The New Zealand Department of Health has adopted the recommendation of the World Health Organisation for an upper limit of 10 g/m^3 nitrate-N for drinking water fed to infants (WHO, 1971). At present the department informs users of contaminated domestic water of the potential health risk and then conducts a monitoring program on the families affected.

DESCRIPTION OF STUDY AREA

Geology

Bedrock in the Hawkes Bay region consists of intercalated mudstones and limestones of marine origin deposited in the East Coast Geosyncline

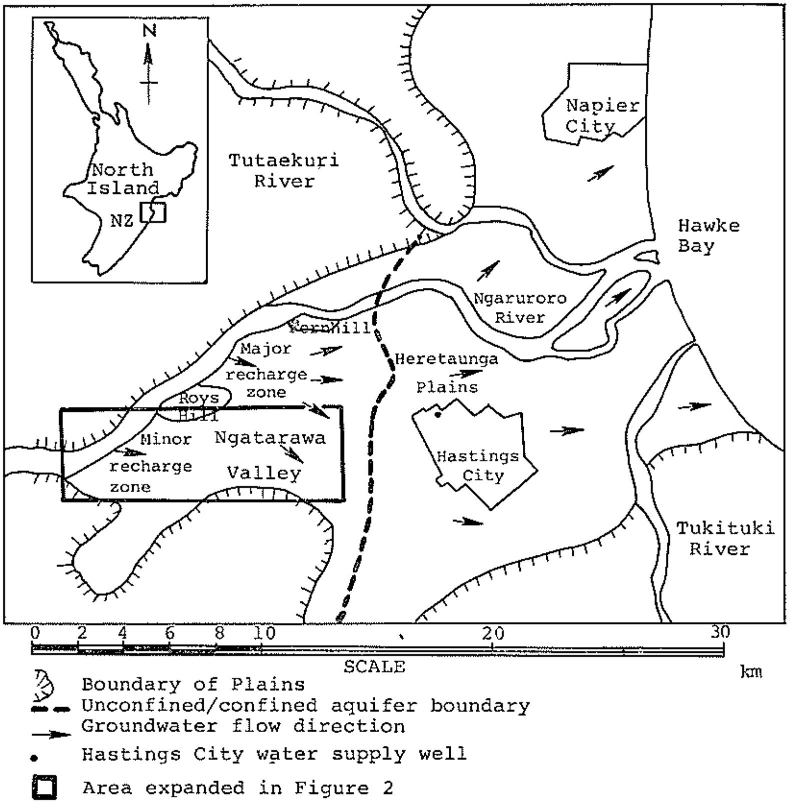

FIG. 1—Location and hydrology of the Heretaunga Plains.

(Kingma, 1971). During the early Pleistocene the syncline was infilled by coarse sediment derived from the rapidly eroding greywacke mountains of the Main Divide. During orogenic and climatic fluctuations in sea-level inter-bedded layers of clay, silt and sand were deposited and some beds now form aquicludes throughout the eastern portion of the Heretaunga Plains aquifers (Fig. 1).

The Ngatarawa Valley is infilled to a depth of about 40 m by alluvial terrace and flood-plain sediments deposited when the Ngaruroro River flowed between Maraekakaho and Roys Hill (Hawkins, 1978).

The gravel substrata is overlain by sandy loams (Ngatarawa, Poporangi and Takapau series) and silt loams (Pakowhai series) (Griffiths, 1975). The soils are shallow (30 to 60 cm), have moderate to high infiltration rates (20 to 130 mm/h) and, with the exception of the Poporangi series, are well drained. An extensive hardpan restricts vertical drainage from the Poporangi soils (Fig. 2).

Hydrology

Mean annual rainfall is 814 mm and rainfall exceeds evapotranspiration by 200 to 250 mm. Groundwater is also recharged by seepage from the Ngaruroro River at a low-flow rate of about 0.7 m^3/s (Grant, 1972). There is a further unknown contribution to ground water by run-off from the surrounding hills.

Depth to water table increases from 3 m to 12 m down valley. Seasonal fluctuation in static water-level is in the range ±1.5 m. Groundwater in the Heretaunga Plains aquifers generally flows west to east from the Ngauroro River above Fernhill to the coastline (Fig. 1). Flow velocities of shallow groundwater in the valley are variable (5 to 40 m/day) but mean groundwater flow rate is probably close to 5 m/day (Ministry of Works and Development, 1981).

Land-Use

The Ngatarawa Valley is almost exclusively intensively-stocked pastoral farmland. Approximately 1450 ha is sown in grass-clover pasture, 1300 ha of which is not irrigated. In the absence of irrigation annual pasture growth is 7000 to 10,000 kg dry matter per hectare allowing sheep to be grazed at a rate of 11 to 18.5 livestock units per hectare (King and Orsman, 1975). The remaining area (150 ha) is surface-irrigated by a border-dyke scheme. Water is applied at a rate of 700 to 1000 mm per irrigation season. Irrigation stimulates annual pasture production to 10,000 to 15,000 kg dry matter per hectare and permits the stock carrying capacity to be increased to about 29 livestock units per hectare.

METHODS

Soil and gravel samples were collected from beneath two surface-irrigated and three non-irrigated pastures in the Ngatarawa Valley (Fig. 2). Boreholes were drilled by dry augering with a 1 m diameter auger. Samples were taken at 0.5 m intervals to a depth of 5.5 m, or to the water-table when groundwater was encountered above 5.5 m. Duplicate samples were shovelled directly from the auger flights and immediately sealed in airtight containers. Samples were manually split. One fraction was weighed, oven dried and weighed again. The loss in weight was used to calculate the water content of the field sample. The second fraction was made to a saturated paste by adding distilled water, and saturation extracts were then obtained by suction filtration. Each saturation extract was analysed for nitrate-N and concentration was expressed in terms of soil moisture.

Groundwater was sampled approximately monthly over the period May 1978 to June 1979 from seven wells in the Ngatarawa area (Fig. 2). Observation wells were fitted with slotted PVC screens (100 mm i.d.) which extend about 10 m below maximum waterlevel. Samples (300 ml) were collected manually using an in-situ pressure-vacuum device (Martin, 1976). Groundwater samples were analysed for nitrate-N and calcium.

Saturation extract and groundwater samples were frozen within 48 hours of collection. Samples for nitrate-N analysis were preserved with mercuric chloride added to a final concentration of 40 to 60 g/m^3.

Nitrate-N was determined by an automated colorimeter (Downes, 1978) and calcium by flame emission (American Public Health Association, 1975).

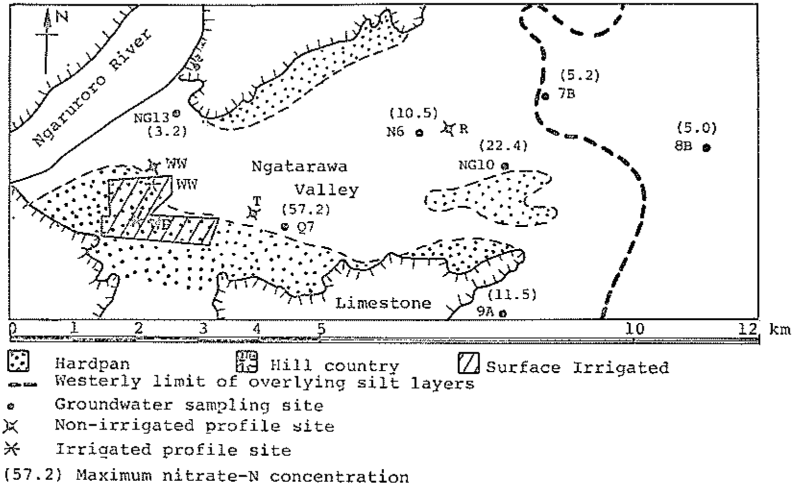

FIG. 2—Land-use, soil-type, sampling locations and maximum nitrate-N concentrations of groundwater in the Ngatarawa Valley.

RESULTS AND DISCUSSION

Source of Nitrate

Maximum nitrate-N concentrations in groundwater of the Ngatarawa Valley are shown in Figure 2. In the central and lower regions of the valley nitrate-N concentrations exceed 10 g/m^3, a recommended safe limit for drinking water (WHO, 1971), and range up to 57.2 g/m^3. The median value of all the maximum concentrations is 10.5 g/m^3.

The widespread distribution of high nitrate concentrations indicates extensive groundwater contamination. This contamination may emanate from numerous point sources or from a distributed (non-point) source. Septic tanks may be discounted as potential sources because the population of the valley is sparse. Nitrate-N concentrations in the local precipitation (<0.2 g/m^3) and in the Ngaruroro River (<1.0 g/m^3) are too low to be of significance. Nitrate is, however, leached from intensively-grazed pastureland in the valley.

The relationships among nitrate-N concentration, moisture content and depth into the unsaturated zone beneath two non-irrigated pastures in the Ngatarawa Valley are shown in Figure 3. The data represent the average of two samples per depth per profile. Nitrate-N concentrations were similar in both profiles and ranged from 4.2 to 12.6 g/m^3.

In intensively stocked pasture nitrogen is returned to the soil in urine at a rate of about 300 to 600 kg $ha^{-1}a^{-1}$ (Doak, 1952). Urea, which constitutes about 80 percent of urine-nitrogen, is converted to nitrate at a much faster rate than a pasture can utilise. As a result a considerable quantity of nitrate may be leached when the water storage capacity of a soil is exceeded by precipitation or irrigation (Ball et al., 1979; Quin, 1979). The elevated nitrate-N concentrations in drainage water indicate that substantial quantities of nitrate are leached from non-irrigated pastures in the Ngatarawa Valley. Grazed pasture appears, therefore, to be the principal source of nitrate in groundwater.

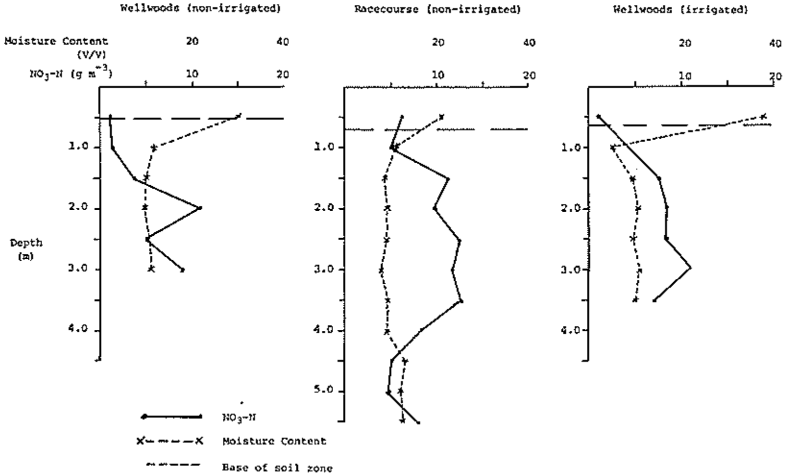

FIG. 3—Distribution of nitrate-N concentration and moisture content beneath Ngatarawa pastures in August 1979.

Nitrate-N concentrations in drainage water beneath surface-irrigated and non-irrigated pastures in the valley are similar (Fig. 3). This finding was unexpected because surface irrigation of intensively grazed pastures in Mid-Canterbury substantially increased nitrate-N concentrations in drainage water (Quin and Burden, 1979). There appear to be two possible explanations for the low nitrate levels in the irrigated-pasture drainage at Ngatarawa. Up to 100 mm of water is applied during an irrigation season. Each application of about 100 mm results in deep drainage and therefore nitrate leaching from the shallow (~ 50 cm) Ngatarawa soils. The excess water may, however, also cause appreciable dilution of drainage nitrate-N concentrations. In contrast, only 600-700 mm irrigation water is applied in Mid-Canterbury and dilution is therefore correspondingly less. An alternative explanation is related to the disturbance of the soil profile by land recontouring during border-dyke construction. The soil organic matter nitrogen pool, which is disrupted and in some places removed during contouring, takes from 10 to 40 years to re-establish equilibrium (Kolenbrander, 1977). Because the Ngatarawa pasture has been irrigated for only five years some of the nitrate normally available for leaching may be immobilised in the soil organic matter, thereby reducing the nitrate-N concentration of drainage water.

Although nitrate-N concentrations of non-irrigated and surface-irrigated drainage are similar (Fig. 3) a larger volume of drainage and therefore a greater quantity of nitrate is leached from the irrigated pastures. At Ngatarawa, annual drainage is about 225 mm from non-irrigated pasture and about 800 mm from a surface-irrigated pasture (Ministry of Works and Development, 1981). Mean subsoil nitrate-N concentrations for the profiles depicted in Figure 3 are 8.2 g/m^3 (Wellwoods surface-irrigated), 7.1 g/m^3 (Wellwoods non-irrigated), and 8.8 g/m^3 (Racecourse non-irrigated). Data for the soil was omitted because rapid changes in field-water content close to the soil surface affect measured nitrate-N concentrations (Pratt et al, 1972). Combining mean subsoil concentrations and drainage volumes indicates that nitrogen is leached at a rate of 16.0 kg N $ha^{-1}a^{-1}$ from the Racecourse non-irrigated pasture, 19.8 kg N $ha^{-1}a^{-1}$ from the Wellwoods non-irrigated pasture, and 65.6 kg N $ha^{-1}a^{-1}$ from the Wellwoods irrigated pasture. These values closely agree with estimates from Mid-Canterbury pastures (Quin, 1979).

Spatial Distribution of Nitrate-N Concentrations

Nitrate-N concentrations near the water-table in wells N6 and 9A (Fig. 2) were similar to concentrations in drainage beneath non-irrigated and irrigated Ngatarawa pastures (Fig. 3) indicating that drainage constitutes a significant proportion of the shallow groundwater. However, appreciably higher concentrations were recorded in wells Q7 and NG10 and in the unsaturated gravel substrata near Q7 (Fig. 4) suggesting that more nitrate is leached in these areas. Evapotranspiration may progressively increase the nitrate-N concentration of drainage as it flows across a hardpan that extends away from the hills that form the southern

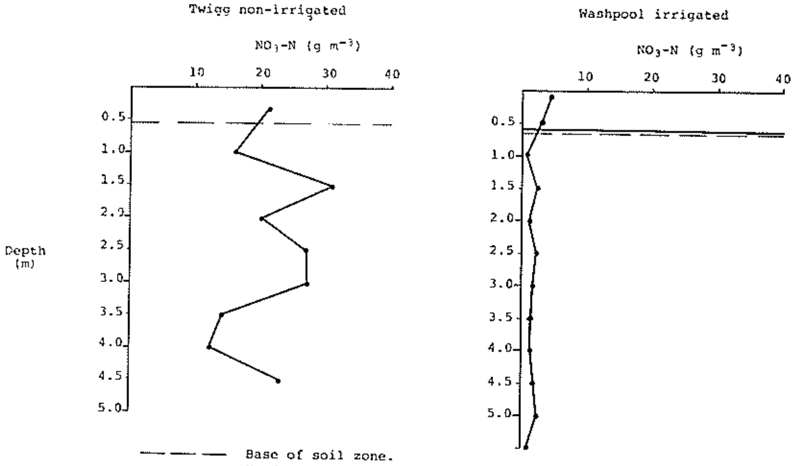

FIG. 4—Distribution of nitrate-N concentration beneath an irrigated (Washpool) and a non-irrigated (Twigg) pasture in the Ngatarawa Valley in August 1979.

boundary of the valley. Vertical drainage through this hardpan is negligible (Griffiths, 1975). The restricted vertical drainage is illustrated by the nitrate-N concentration profile beneath an irrigated pasture on the Washpool Station (Fig. 4). Nitrate-N concentrations decrease sharply immediately below the hardpan and remain at a low level (<2.0 g/m^3) to a depth of 5.5 m.

Calcium concentrations in wells Q7 and NG10 were markedly higher than those in the other observation wells. There was a close correlation between calcium, nitrate-N and water-table elevation in Q7 and NG10 throughout the twelve month sampling program (Table 1). The correlation between groundwater composition and water-table elevation indicates that the high calcium and nitrate-N concentrations are derived from drainage from the overlying unsaturated gravels. The limestone hills to the south of the valley appear to be the only possible source of calcium. For calcium to be present in the unsaturated gravels adjacent to wells NG10 and Q7 therefore, drainage must move a considerable distance across the hardpan. The hardpan terminates close to well Q7 but is less well defined near well NG10 which may account for the lower nitrate-N concentrations recorded in well NG10.

TABLE 1: Calcium concentrations and correlations between time series of nitrate-N and calcium and between nitrate-N and change of water-level in Ngatarawa wells.

	Well number					
	Q7	NG10	NG13	N6	7B	8B
Mean Calcium conc. (g/m^3)	41.3	91.2	27.8	25.0	29.4	31.1
Correlation (r) nitrate-N vs calcium	0.78*	0.70*	—0.03	0.13	—0.11	0.39
Correlation (r) nitrate-N vs change of of water-level	0.86*	0.71*	0.10	0.81	—0.12	—0.38

* Significant at 99% confidence level.

The low nitrate-N concentrations in wells NG13, 7B and 8B are associated with the recharging of groundwater by low nitrate-N water (0.2 to 0.9 g/m^3) from the Ngaruroro River. Well NG13 lies close to the minor river-recharge zone (Fig. 2) and its low nitrate-N concentration indicates that drainage water makes up only a small proportion of the shallow groundwater at the head of the valley. Nitrate-N concentrations increase down the valley because high nitrate-N drainage constitutes a progressively greater proportion of the total groundwater flow.

Groundwater from the major river-recharge zone flows, in part, across the bottom of the Ngatarawa Valley and has a uniformly low (<1.0 g/m^3) nitrate-N content (Burden, 1979). Groundwater is replenished from the major and minor river recharge zones in an approximately

8:1 proportion (Grant, 1972). Clearly, therefore, the low nitrate-N concentrations in wells 7B and 8B are the result of the rapid dilution of high nitrate-N groundwater flowing from the Ngatarawa Valley. The municipal water supply of Hastings City is drawn from two well-fields the closest of which is 6 km north-east of Ngatarawa Valley (Fig. 1). Because the regional flow pattern dilutes contaminated Ngatarawa groundwater and constrains it to move south of the city area it appears unlikely that any future changes in land-use within the Ngatarawa Valley will affect the potability of Hastings City domestic water.

Temporal Fluctuation of Nitrate-N Concentrations

The monthly distribution of nitrate-N concentrations in groundwater of the Ngatarawa Valley is shown in Figure 5. Nitrate-N levels in all wells, except 7B and 8B, exhibited a similar seasonal trend. Concentrations were highest over the winter months (May to August) peaking in August 1978. Through spring and summer (September to February) concentrations decreased to a minimum in February 1979 but then rose sharply through March and April.

The seasonal variation in groundwater nitrate-N concentration coincides with temporal variation in the amount and concentration of nitrate leached from the root zone of grazed pastures (Quin and Forsythe, 1978). The groundwater nitrate-N concentrations may result therefore from seasonal variation in the nitrate-N concentration of drainage water or from seasonal variation in the volume of contaminated drainage entering groundwater or from a combination of both factors.

In the soil zone of two non-irrigated Ngatarawa pastures (Fig. 3) nitrate-N concentrations were low but moisture contents were high. Below the soil zone, moisture contents were uniformly low but nitrate-N concentrations generally increased with depth down to about 3.5 m. Throughout winter (May to August) input of inorganic nitrogen to the soil zone by organic matter mineralisation and from stock urine is low (Quin and Forsythe, 1978). Over the same period, however, precipitation exceeds evapotranspiration by 200-250 mm. If the equilibrium moisture content of the gravel substrata is about 10 percent by volume (Fig. 3), and drainage directly displaces water previously held in the gravel, then the drainage front would have moved 2.0-2.5 m below the soil zone by the end of winter (when the unsaturated profiles were sampled). The top 3.0-3.5 m of the unsaturated profiles (Fig. 3) document, therefore, the progressive depletion and redistribuion of soil zone nitrate over winter. The low nitrate-N concentrations at depths greater than 4.0 m in the Racecourse profile probably represent the previous winter cycle of soil nitrate depletion. The more variable nitrate-N concentrations between 2.0 and 3.5 m depth in the profiles may be due to the partial mixing of successive drainage events caused by uneven vertical flow rates which result from the textural heterogeneity of the gravel substrata (Quin, 1978). Although the nitrate-N concentrations in drainage retain their seasonal pattern in the gravel substrata, when the drainage enters groundwater the concentration pattern will be out of phase with the season at the land surface because depth to water-table varies from 3 m to 12 m throughout the valley. The seasonal trend in groundwater nitrate-N concentration must, therefore, be due to temporal variation in the volume of drainage entering groundwater.

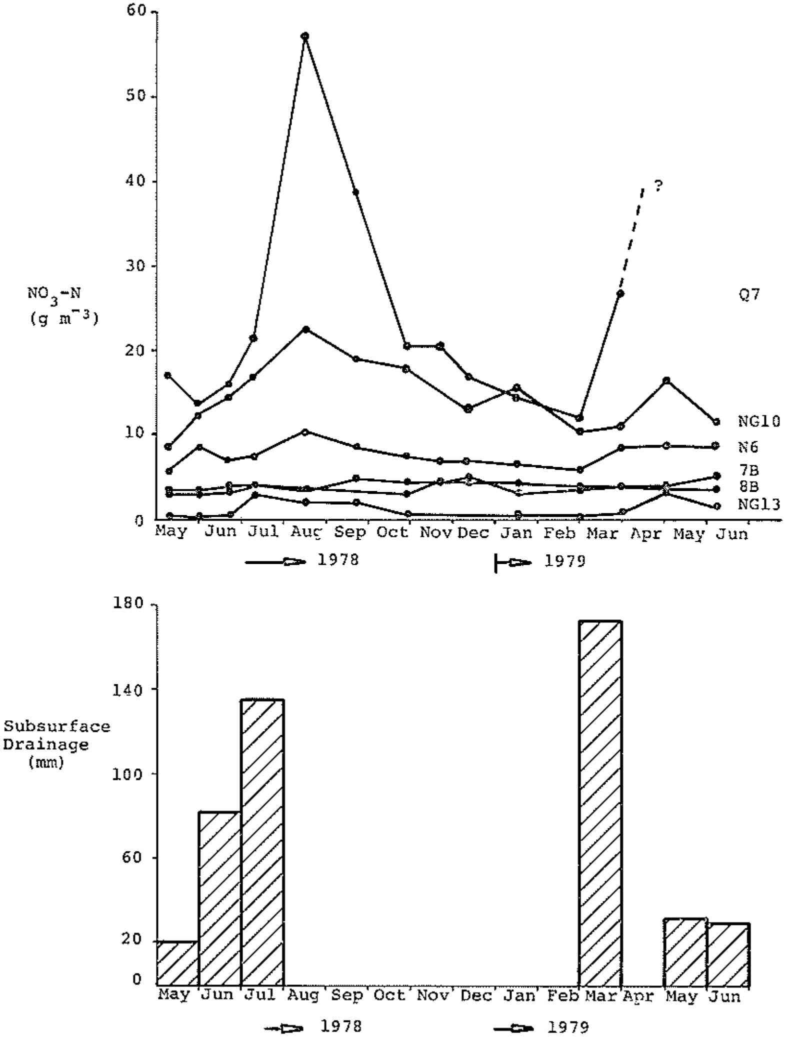

FIG. 5—Comparison of nitrate-N concentrations in Ngatarawa wells with monthly estimates of subsurface drainage for the period May 1978 to June 1979. Monthly drainage was computed from daily precipitation and evaporation data. Havelock North pan evaporation was converted to potential evapotranspiration by multiplying by 0.74 (Ministry of Works and Development, unpublished data).

Two processes control the volume of drainage that mixes with groundwater at any given time. First, drainage held in the unsaturated gravels percolates to groundwater when precipitation or irrigation exceeds soil water storage capacity. Secondly, groundwater rising in response to a rainfall or river-recharge event, incorporates water held in the previously unsaturated gravels. The annual pattern of drainge from non-irrigated Ngatarawa pastures is compared with the monthly distribution of nitrate-N concentrations in wells N6, Q7 and NG10 in Figure 5. There is close correlation between winter drainage and high nitrate-N concentrations. However, groundwater levels also rise during winter in response to rainfall and river recharge.

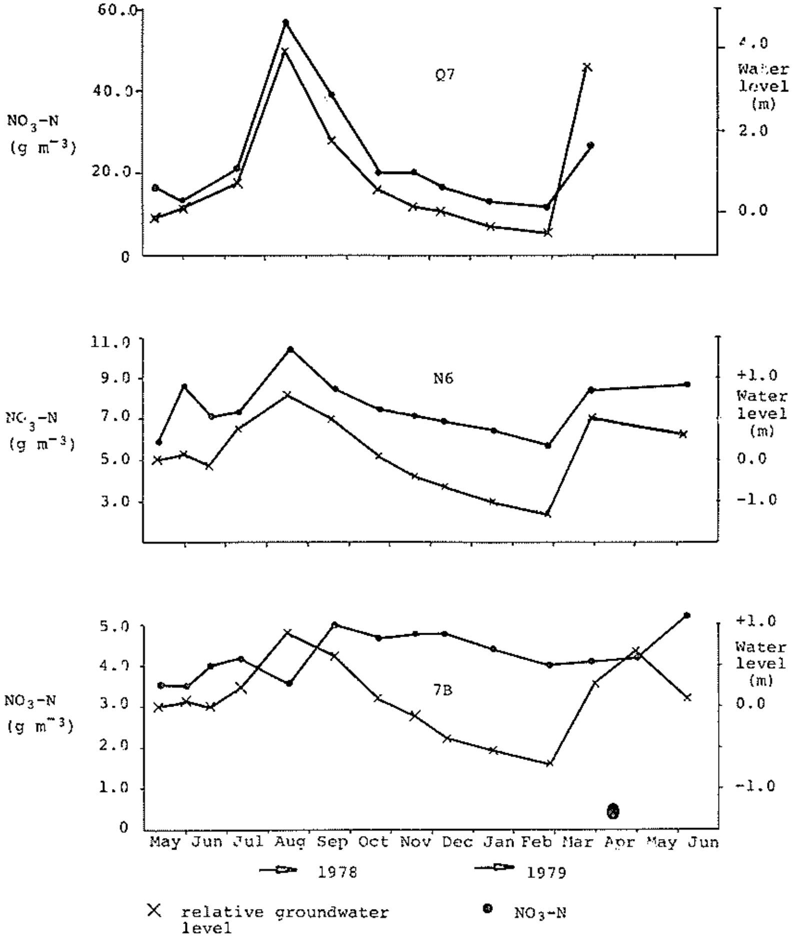

FIG. 6—Nitrate-N concentrations and changes in groundwater level in Ngatarawa wells for the period May 1978 to June 1979.

Groundwater nitrate-N concentration and change in water-level in wells N6 and Q7 (Fig. 6) are closely correlated (Table 1). A rise in water-level produces an increase in groundwater nitrate-N concentration and the greater the groundwater rise the larger the increase. Clearly, therefore, the seasonal variation in nitrate-N concentration of shallow groundwater results from temporal changes in the volume of drainage water mixing with groundwater, due to both percolation and incorporation, and not from changes in drainage composition.

Previously the small surface-irrigation scheme (150 ha) at the head of the Ngatarawa Valley was thought to be principally responsible for high groundwater nitrate-N concentrations throughout the valley. However, the rapid response of these concentrations to changes in water-level indicates that the drainage from immediately adjacent pastureland is the principal source of nitrate in groundwater, except where the drainage flows across the hardpan on the south side of the valley.

Nitrate-N concentrations in wells 7B and 8B exhibited neither a clear seasonal pattern nor a direct correlation with change in water-level (Fig. 5 and 6). The lack of predictable response arises because groundwater in the vicinity of these wells is overlain by an extensive silt layer(s) that prevents vertical drainage to groundwater (Fig. 2). Nitrate-N concentrations in wells 7B and 8B are therefore not related to drainage from adjacent land but instead probably reflect the ratio of mixing of groundwater from major and minor recharge zones.

CONCLUSIONS

The results of this study illustrate the need to analyse geological and hydrological as well as land-use factors in order to interpret the distribution of nitrate-N concentrations in groundwater subject to contamination. In the Ngatarawa Valley the principal source of nitrate-N in ground-water is drainage from intensively grazed pastureland. Nitrate-N concentrations in the central and lower regions of the valley exceed 10 g/m^3 and range up to 57.2 g/m^3. The spatial distribution of concentration is principally controlled by a high groundwater velocity, an extensive subsoil hardpan, an impermeable silt layer that locally overlies groundwater, seasonal changes in drainage volume and groundwater level, and seepage of low nitrate-N river-water.

Because nitrate-N concentrations in shallow groundwater exceed 10 g/m^3 and, in view of possible detrimental effects to public health, an alternative water supply for Ngatarawa should be given consideration.

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