EVALUATION OF NITRATE CONTENT OF GROUNDWATER ON THE NEPEAN PENINSULA

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INTRODUCTION

The area considered in this report is a triangular strip of land boundered by the ocean on the south, by the tranquil waters of Port Phillip Bay on the north and by the scarp of Selwyn's fault in the east. The peninsular forms an ismith that narrows to "Point Nepean" at the entrance to Port Phillip Bay.

The Nepean peninsular attains a maximum width from Cape Schank in the south to Tootgarook in the north of 8 kilometres and the peninsular extends 15 kilometres from Selwyns fault scarp to Point Nepean.

The Nepean Peninsular has a low topographic relief rising from sea level to a maximum elevation of around 100m as it abuts Selwyn's fault scarp in the east. The central spine of the peninsular consists of humpy undulating dune terrain. Locally known as "The Cups" landscape. Elevation in the central spine of the peninsular seldom exceeds 30m with local relief in the swell and swale topography of "The Cups" being as much as 20m.

The peninsular has become a popular holiday resourt and now boasts a considerable number of permenant residents. The coastal fringe along Port Phillip Bay from Rosebud to Sorrento has been heavily developed with urban housing. The distribution of urban areas has been outlined on figure 7. A dual zoning of urban development has been identified; zone 1 as densely settled areas with permanent residences, and zone 11 the outer urban areas with less dense development and more holiday homes. The interveining areas are largely rural; grazzing and with some groundwater irrigation and market gardening around Boneo.

Hydrogeology

The geological succession in the upper 200m of the sedimentary sequence is represented by an accumulation of shallow water calcarenites and carbonate rich aeolian dune sands referred to as the Wannaneue Formation. These sediments are of Upper Pliocene to Pliestocene in age. The upper aeolian dune sequence may be brocken by as many as five palaeosoles, which may provide local perching of the water table or confinement of groundwater flow. Although the sands in the dune sequence are carbonate rich secondary cementation is only readily evident in soil calcretes and in some of the exposed coastal sections.

The calcareous dune sands are usually fine to medium sands and have been found to have hydraulic conductivities within the range 5-15 m/d, refer to Geological Survey Unpublished Report 1980/7.

A reticulated water system services a large proportion of the Nepean Peninsular, however, reticulated sewerage at present does not extend beyond Rosebud. Householders use septic tanks and infiltration systems for the disposal of household liquid wastes.

Due to the porous and permeable nature of the sandy sediments many of the residents have availed themselves of groundwater supplies. The Department of Industry, Technology and Resources has more than 600 bores registered in the parishes of Fingal, Nepean and Wannaneue on the Nepean Peninsular. Although this is not a complete inventory of bores, departmental analyses, which include data up to the end of 1982, indicate that around 10% of bores have recorded more than 45 mg/l nitrate (as NO_3), and that the average nitrate concentration for waters with less than 2500 mg/l of total dissolved salts is 15 mg/l nitrate (as NO_3). The highest recorded nitrate level up to the end of 1982 was 190 mg/l nitrate (as NO_3).

Groundwater on the Nepean Peninsula has been used for stock water supplies, irrigation purposes and farm water supplies. In the suburban and residential areas, it has been widely used for garden watering and other allied domestic purposes. Recharge in the urban areas of the peninsula has been augmented by the ground infiltration of storm water and road side culvert drainage. The use of ground infiltration systems with domestic septic tanks further accentuates the accession of water to the groundwater system in the urban areas.

The hydrological equilibrium of the arenaceous aquifers of the peninsula has undergone a considerable change since pre-european conditions. Farm land clearing, ploughing of pastures, sowing of crops and use of improved grasses have had their corollary in the urban areas as pavement, buildings, drainage pits, domestic waste systems and suburban gardens.

It is the combined impact of these aspects of the hydrology and their affect upon the nitrate content of the groundwaters that will be discussed in the following passages.

Apart from these significant sources of nitrate some smaller insignificant occurrences have often been referred to. They are the old landfill sites. The migration of nitrate rich leachates from landfills has not been observed. The Department of Industry, Technology and Resources has two monitoring bores in the middle of the Shire of Flinders tip, the present site south of the football ground. The nitrate (NO_3) levels in these bores has been less than 0.1 mg/l, refer to Geological Survey Unpublished Report 1985/56.

Occurrence of Nitrate in Groundwater

The occurrence of rather large amounts of nitrate in groundwater in certain locations has attracted a large amount of interest. There is evidence from temperate climates that the most widespread source of nitrate in groundwater is from cultivation which has led to the decomposition of organic matters in the soil and the mineralisation of nitrogen compounds, including the nitrofication of ammonia and nitrate (Lawrence 1983, Nitrate - rich groundwater of Australia. AWRC Technical Paper No. 79).

In the soil nitrogen is transformed to organic matter by nitrogen fixing bacteria (Rhizobieum species), which live in symboitic relationship with leguminous plants (clovers, peas, beans etc.,) in nodules on the plant roots. Some non legumes are also able to support nitrate fixing bactria.

Also some algae (blue-green) that live on in the soil after rain, upon dying decay and add ammonia and nitrate to the soil. A similar attribute has been identified with some species of lichen in central Australia (P McDonald pers com.). The path to fixation is to ammonia then under aerobic conditions in the soil it is converted to nitrate by nitrifying bacteria.

Nitrate may find its way into the groundwater system by solubilisation and hydrolyis of organic nitrogen to ammonia, by nitrification of ammonia to nitrite then nitrate it can also be reduced by natural processes. Firstly by biochemical transformation ie., plants consuming it and secondly by being reduced to gaseous nitrogen in low dissolved oxygen waters with low redox potentials.

Natural levels of nitrate may be in the order of 1-50 mg/l (NO_3) with "atmospheric" nitrogen being the main source (Bouwer, 1978). The nitrate ion is mobile in groundwater systems and usually unaffected by anion exchange or absorption.

Shallow groundwater in rural areas may be subject to pollution from farm yards and similar sources. In some areas of the United States high nitrate concentrations occur so extensively that they do not seem to be logically explained by either farm yard pollution or fertilization (Hem 1959). Relatively high concentrations occur in groundwater in certain areas where an explanation seems difficult, some of these areas are in desert basins where groundwater occurs at considerable depth, where simple native plants may fix nitrate in the soil.

VARIATION OF NITRATE CONCENTRATIONS WITH DEPTH

The decrease in the nitrate concentration in groundwater with increasing depth below the water table is a commonly observed phenomena. At depth the nitrate ion is reduced and nitrogen released into solution. The reduction of nitrate concentrations with depth has been identified by Lawrence (1983) in the following table.

Table 1 Nitrate concentrations in bores, Nepean 10 045 and 10 075.

	Depth	NO_3 (mg/l)
Nepean 10 045	3.6 - 6	62
	12.4 - 18.8	58
	18.8 - 24.9	38
Nepean 10 075	3 - 4.1	73
	14.1 - 15.9	53
	18 - 22.8	48

If this data is fitted to a linear regression curve then the groundwater may be expected to be free of nitrate at depths of around 30-40m. If a logarithmic regression is used zero nitrate concentrations may not be expected above a 80-100m depth.

NITRATE OCCURRENCE IN GROUNDWATER ON THE NEPEAN PENINSULA

Nitrate occurs as a natural constituent of groundwater. Nitrate in groundwater may also originate from sources of contamination or as a result of the alteration of the hydrological equilibrium.

Nitrate concentrations on the Nepean Peninsular vary from below the limits of detection to 200 mg/l and have an average around 15 mg/l. If zero values are excluded, the average is 25 mg/l. Concentrations of less than 10 mg/l nitrate are assumed to be naturally occurring in groundwater of the area. Nitrate at low concentrations probably originates from such sources as precipitation and the decomposition of organic materials in the soils. Siem et al. (1972) and Junge (1958) indicate that precipitation may supply ammonium and nitrate-nitrogen componds ranging from 5 to 10 mg/l per year nitrate to the land surface.

The distribution of unsewered urban development on the Nepean Peninsula has been plotted on figure 1. Two zones of urban development have been identified, the older more densely settled areas on the Port Phillip side of the peninsula; including Rosebud, Tootgarook, Rye and Sorrento and the second zone including subdivisions on the ocean side of the peninsula and also the Buckingham Park area north of Boneo. Ground infiltration of domestic waste is utilised by urban and farm dwellings alike on this position of the peninsula.

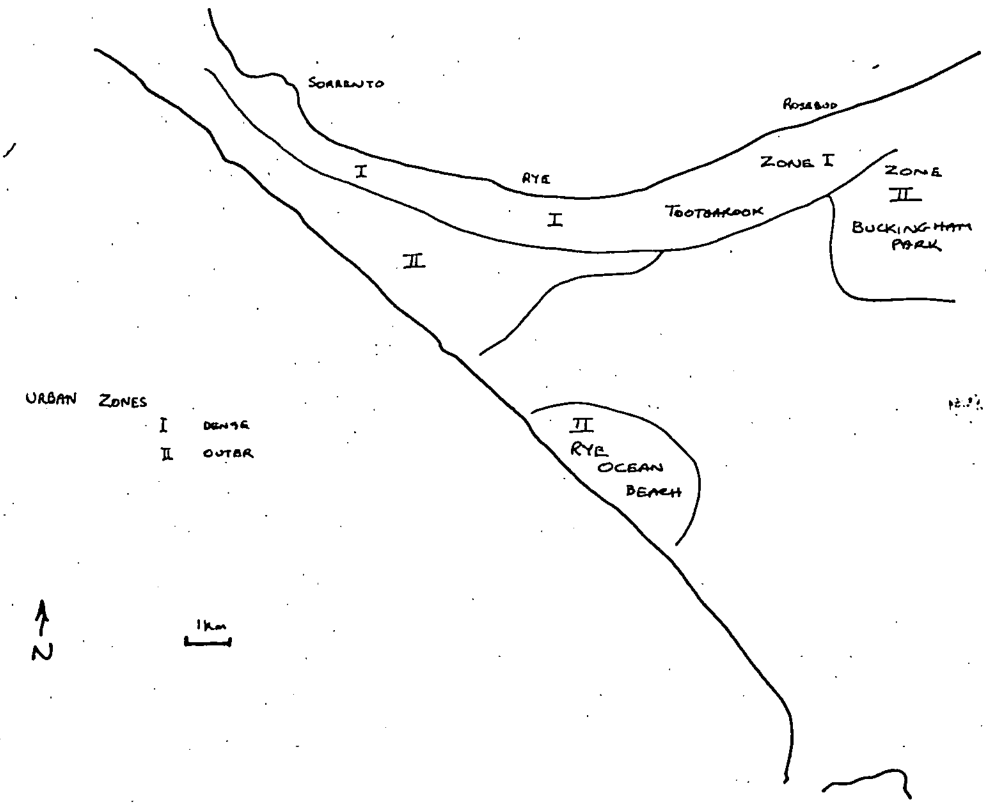

Figure 1 Location of Urban areas on the Nepean Peninsula.

The widespread occurrence of nitrate in the groundwater on the peninsula and its sysmpathetic correlation to the special distribution of the unsewered urban developments indicates a causal relationship. Contours of the nitrate concentrations in the groundwater have been presented as figure 2. The data contoured on figure 2 represents analyses of groundwater from over 600 bores. This data has been collected and analysed by the Geological Survey (of the Department of Industry, Technology and Resources) and is part of the Geological Surveys database. The analyses were performed at the time of or shortly after drilling. They include samples from both government (Department Industry, Technology and Resources) and private bores.

Nitrate was included in the Geological Surveys standard analysis from around 1968 onwards. The data therefore includes a temporal component. This aspect will be discussed further.

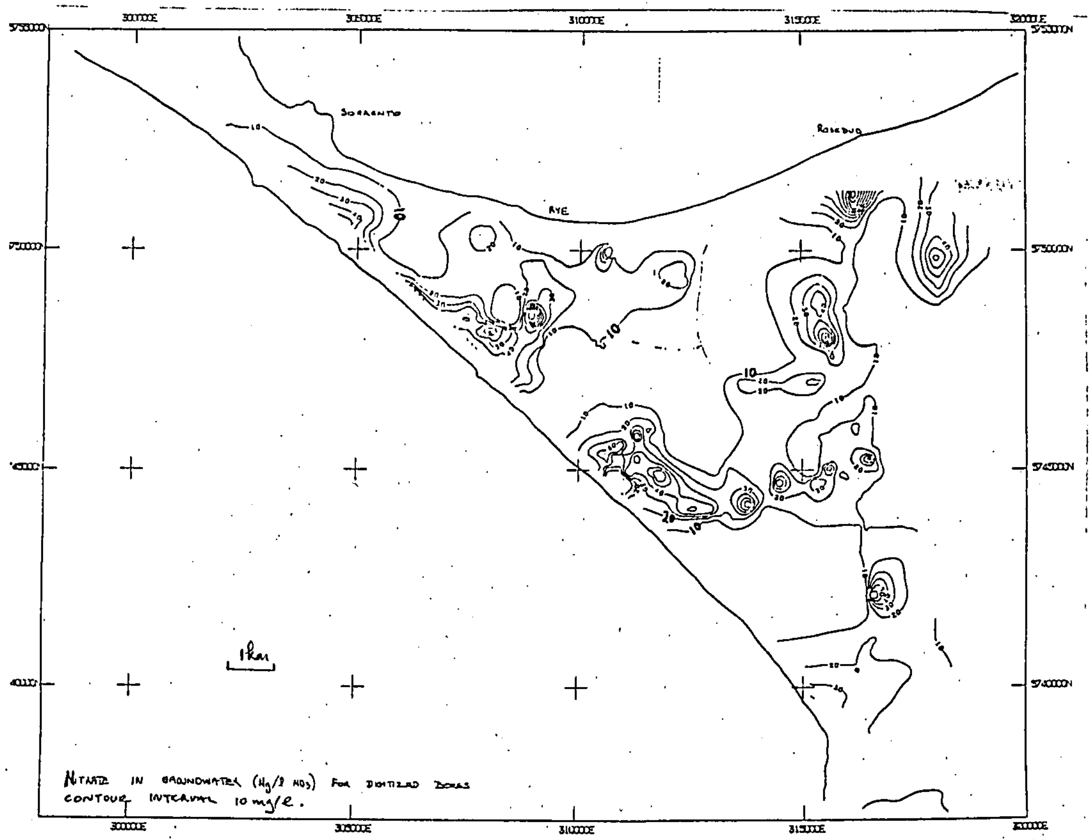

Figure 2 Contours of the nitrate concentrations in the shallow aquifers on the Nepean Peninsula.

A comparison of figures 1 and 2 illustrates that the nitrate "highs" occur generally in the vicinity of the urban unsewered zones. The large areas on figure 2 with nitrate levels of less than 10 mg/l are grassed farm lands of the "Cups".

The Cups area is also an area of high recharge and low salinity groundwater (refer to figure 3).

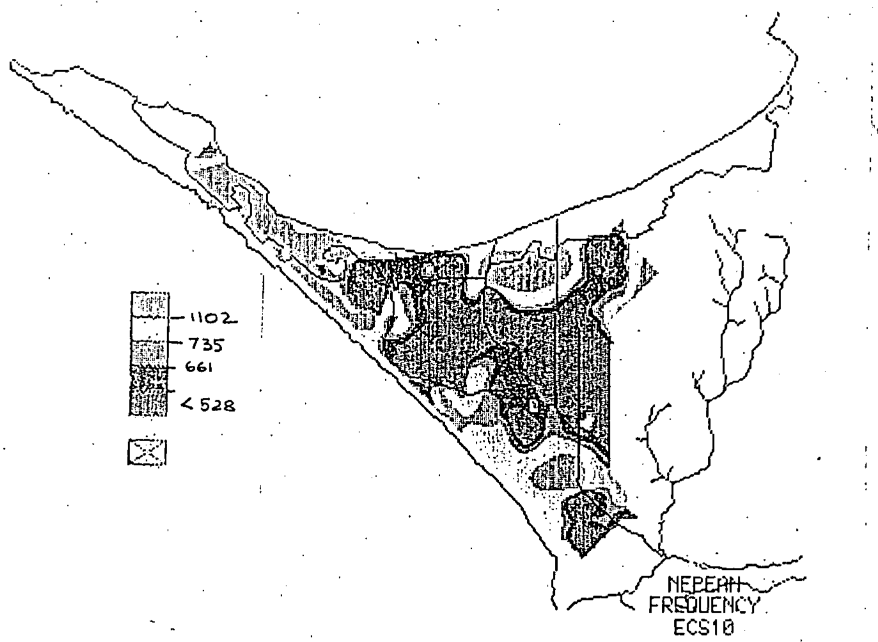

Figure 3 Salinity contours for the shallow unconfined aquifer of the Nepean Peninsula.

The salinity contours illustrate demonstrate that the best quality groundwater occurs under the central portion of the peninsula and quality falls of towards the ocean and bayside discharge zones. There is not a strong correlation between the groundwater salinity and its nitrate concentration.

The groundwater conditions on a large part of the peninsular have been significantly modified by the encroachment of urban development. Although no studies have been conducted to quantify the precise changes, some rudimentary observations may be made regarding the effects of urban hydrology. The establishment of culverts, pavement, rooves and roadways have an almost self evident modifying effect upon the hydrology of the landscape. However, the superposition of unsewered settlement has a more subtle effect. On a gross scale pre-urban landforms may have achieved between 10% and 20% recharge of annual rainfall, i.e, a depth of around 150mm. This value may vary over the peninsular, however, estimates close to this may be obtained by comparing groundwater quality with precipitation chemistry, by companying recharge rates obtained on similar sandy aquifers with the same climatic conditions (Geological Survey Unpublished Report 1984/73), or from the application of hydrogeological principles to the groundwater hydrographic records collected by the Groundwater Branch of the Geological Survey i.e, examination of the groundwater hydrographs and aquifer storativity.

The close clustered unsewered urban developments with reticulated water supply may attain discharge depths in excess of twice the "natural" recharge rate; depending upon household size and water usage patterns. It might, therefore, be speculated that in the urban areas this discharge of imported waters after passing through the domestic cycle swamps the natural recharge processes.

Before discussing the temporal observations of nitrate concentration in groundwater on the Nepean Peninsula, the loading potential of the domestic waste cycle should be outlined.

CONTRIBUTIONS FROM SEPTIC TANKS AND SEWERAGE

The contribution made by septic tank systems to the nitrate load in the groundwater varies quite significantly. The nitrate increment found in the domestic cycle from tap water to domestic waste water may be further magnified or reduced in the ground infiltration processes. The average increment or increase in the domestic cycle tap water to waste water is indicated in the following table (Bouwer 1978).

	average increase (mg/l)
phosphate	8
TDS	320
Ammonim-N	16
Nitrate-N	2

Gehm (1976, table 11-13) indicated the following characteristics of combined sewerage waste water.

	range	mean mg/l
COD	80 - 1760	382
BOD	10 - 470	71
total phosphate	0.8 - 9.4	3.0
total nitrogen (N)	1.0 - 16.4	3.5
Ortho phosphate	0.1 - 5.0	2.0
Ammonim nitrogen (N)	0 - 4.7	1.5
pH	5.6 - 6.7	6.3
Bacteria		
Total coliform	420 000 - 5800 000	2800 000
fecal coliform	240 000 - 5040 000	2400 000
fecal streptococci	1 000 - 49 000	17 200

The infiltration of effluent from which nitrogen has not been completely removed is associated with many sewerage systems. In Perth 120 000 house holds discharge an estimated 2200 tonnes/yr of inorganic N from septic tanks to the unconfined aquifer. Discharge from the soak wells contains about 100 mg/l NH4-N. (Lawrence 1983).

Table 2 Typical composition of domestic sewerage (US EPA)

Constituent	Concentration* Strong	Medium	Weak
Solids, total	1 200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids, (ml/l)	20	10	5
Biochemical oxygen demand, 5-day, 20°C (BOD_5 20°)	300	200	100
Total organic carbon (TOC)	300	200	100
Chemical oxygen demand (COD)	1 000	500	250
Nitrogen, (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chlorides [a)]	100	50	30
Alkalinity (as $CaCO_3$)[a)]	200	100	50
Grease	150	100	50

* all values except settleable solids are expressed in ppm.

Examining the nitrate concentrations recorded in groundwater on the Nepean Peninsular some magnification of the nitrate increment in the domestic waste water cycle would be necessary to attain the maximum recorded levels of around 200 mg/l. The domestic waste water cycle producing an average nitrate increment of only around 20 mg/l.

GROUNDWATER CHEMISTRY

The groundwater chemistry of the peninsula is dominated by the influence and proximity of the sea. Although the aquifer contains considerable amounts of calcium carbonate the groundwater is dominated by the sodium chloride ions. Groundwater in the unconfined aquifer has a salinity range from under 300 mg/l to 36 000 mg/l of total dissolved salts. The comparative importance of the cations sodium and calcium in the groundwater is illustrated in the following diagrams.

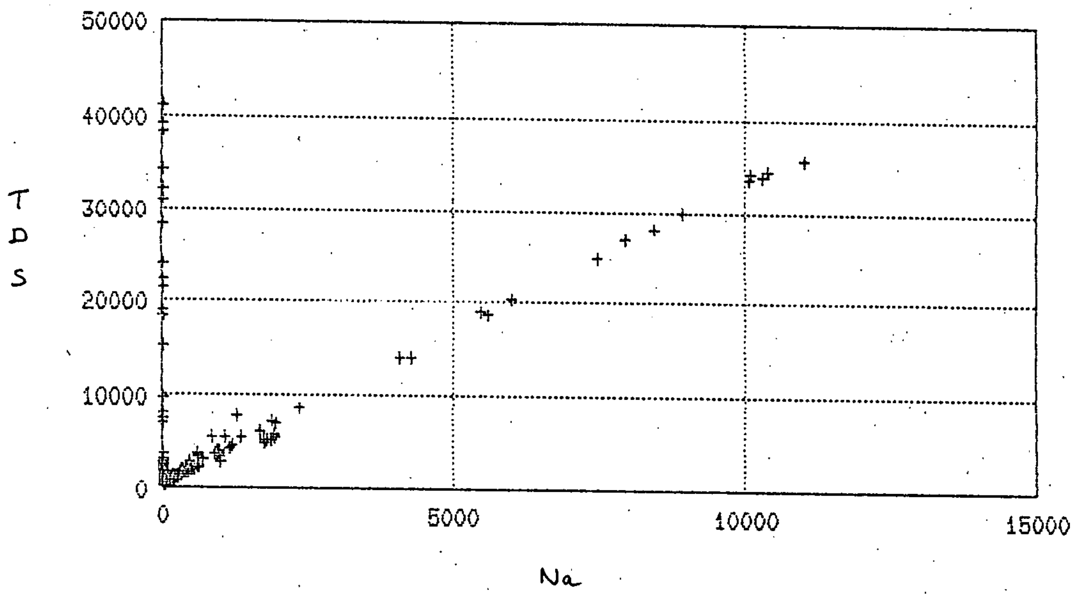

Figure 4 Plot of Sodium versus total dissolved salts for the shallow unconfined aquifer of the Nepean Peninsula.

This plot demonstrates an almost linear relationship between the salinity and the sodium ion. Sodium accounting for about a third of the total dissolved salt species (mg/l).

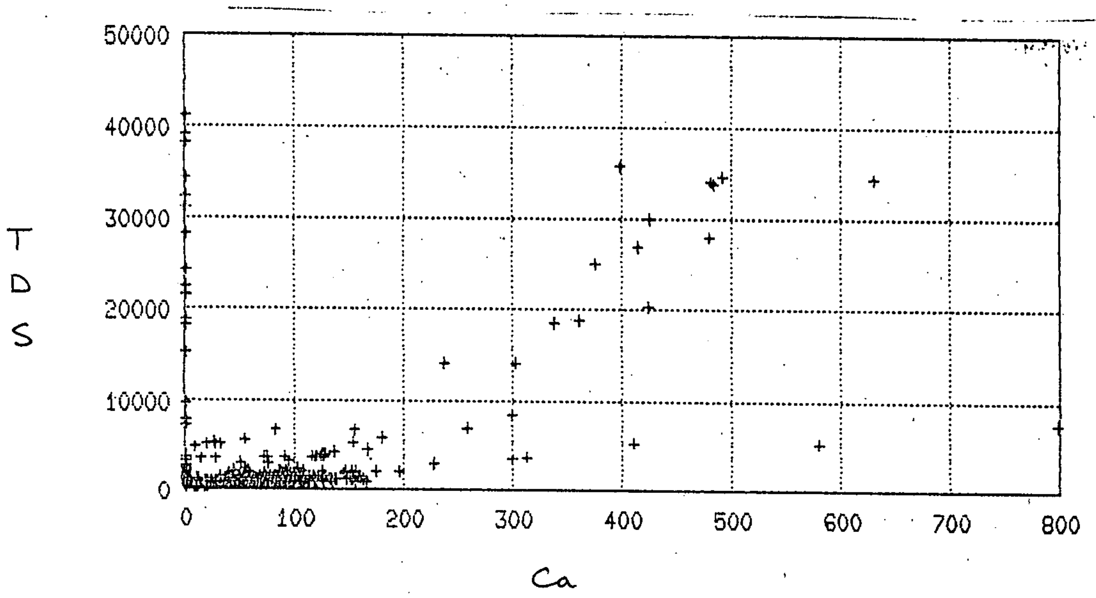

Figure 5 Plot of calcium versus total dissolved salts for the shallow unconfined aquifer of the Nepean Peninsula.

Chemical equilibria involving carbonates are a major factor in limiting the solubility of calcium. The solubility of calcium may be determined by the ionic strength of the solution, the partial pressure of CO_2 and by carbonate complexing. Nethertheless calcium concentrations in the waters of the Nepean Peninsula are usually below 200 mg/l, except in the saline waters of the salt water interface.

The distribution of the major cations in the groundwater; sodium, calcium and magnesium have been plotted versus total dissolved salts for the groundwater with salinities of less than 2 500 mg/l. Sodium concentrations over the salinity range indicate that it is the dominant cation when the salinity exceeds 1 000 mg/l, that the concentrations of calcium and magnesium are governed by their solubility in these waters.

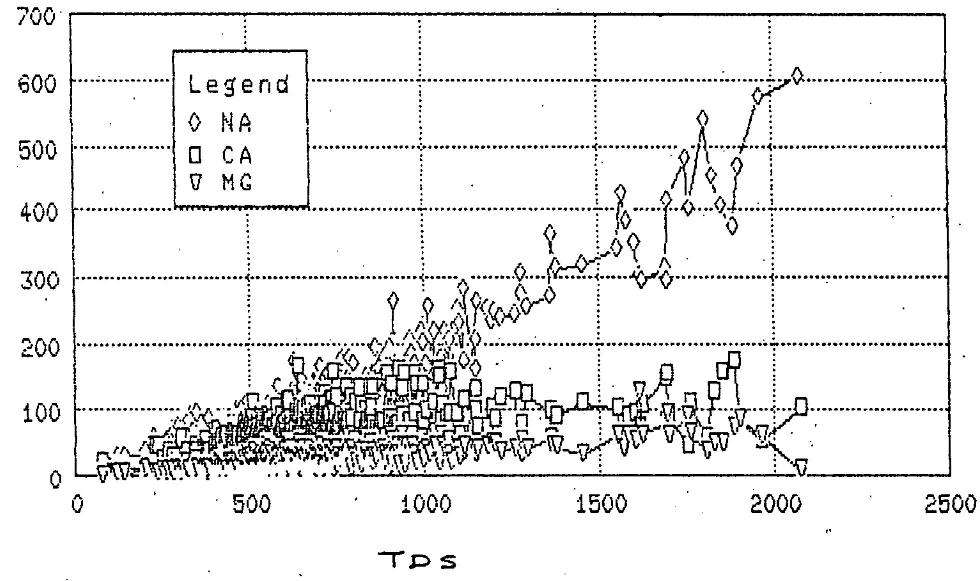

Figure 6 Plot of major cation species versus total dissolved salts for the shallow unconfined aquifer of the Nepean Peninsula.

TEMPORAL FLUCTUATIONS IN NITRATE CONCENTRATIONS IN THE SHALLOW UNCONFINED AQUIFER

As outlined previously in this report the samples of groundwater on the peninsula collected by the Geological Survey (DITR) have certain sample population idiosyncracies. The sample population of 600 is large enough to be a smooth and random collection of groundwaters from the peninsula. However, there are geographical biases as the bores have a tendancy to be clustered in the urban areas. Also the collection represents a sample collection period of several decades.

If the groundwater samples are assumed to come from a random population a dot frequency diagram may illustrate the type of population distribution. In figure 7 the zero values have been ommitted, the frequency function indicates a logarithmic or skewed distribution.

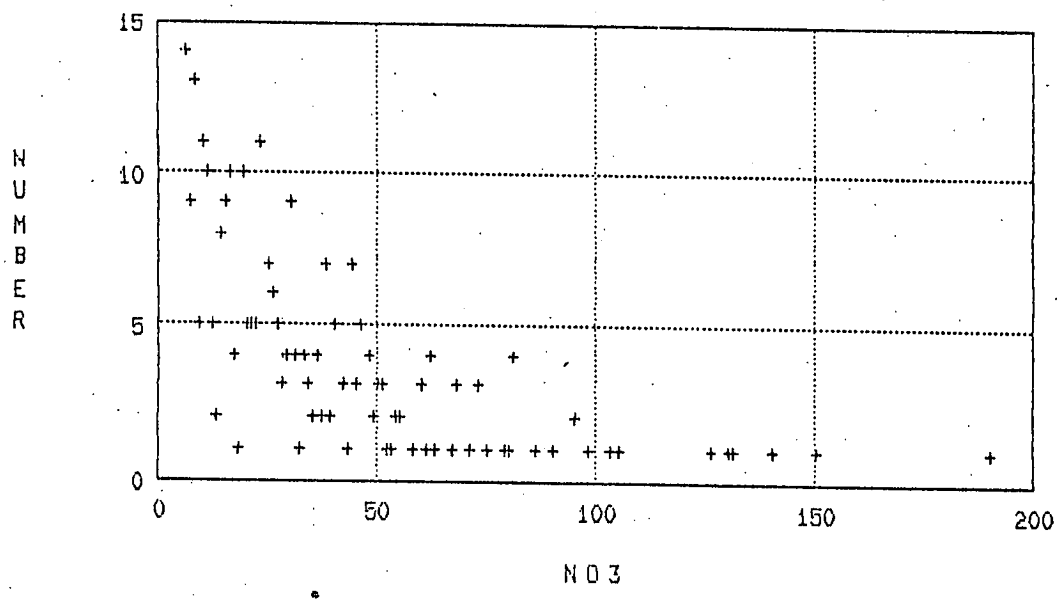

Figure 7 Frequency dot diagram for nitrate (as NO_3) in the unconfined aquifer of the Nepean Peninsula.

The frequency diagram illustrates lthat about 5% of the population exceed 50 mg/l of nitrate (as NO_3) and around 1% of the sample population have nitrate concentrations of greater than 100 mg/l nitrate (as NO_3).

The "random" population of groundwater samples has a time component and the following figure is a plot of the concentration of nitrate in groundwater versus time. The zero values have been ommitted. The time plot of nitrate concentrations shows a decline in average concentration of nitrate over the period 1970-1984. The decline may reflect that samples include new bores in areas unaffected by urban waste disposal. Notwithstanding this apparent purtubation a surprising negative trend for the average value of nitrate is demonstrated. If water samples were retaken from these bores at a period of ten years after drilling an alternate positive trend might be established.

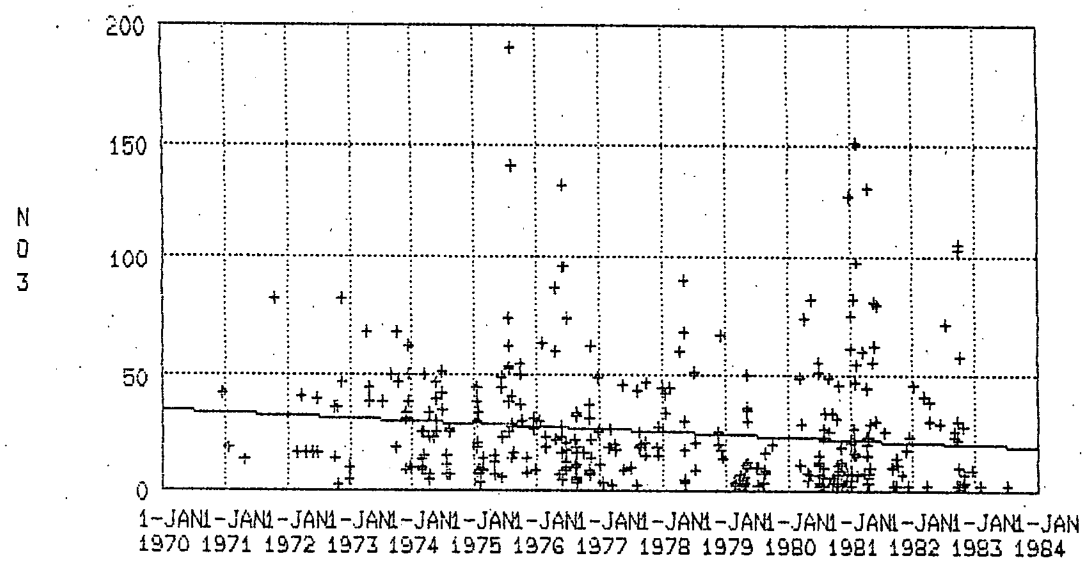

Figure 8 Time versus nitrate (as NO_3) concentration for the unconfined aquifer of the Nepean Peninsula.

OVERVIEW

1 In the data there exists an apparent special relationship between the urban unsewered areas and the occurrence of the higher concentrations of nitrate in the groundwater on the Nepean Peninsula.

2 The trend in time for a decline in nitrate levels in analyses of water from new bores may reflect that new bores are being constructed mainly in areas without a history of domestic waste disposal. It may also reflect the Shire of Flinders urban water management policy for runoff to be channeled into infiltration pits and galleries.

3 The overall significance of nitrate concentrations in the groundwater must be expressed in view of the data available. The average nitrate (as NO_3) level is 15 mg/l. Less than 10% of the sample population (n greater than 660) exceed the arbitary recommended drinking water standard of 45 mg/l (nitrate as NO_3). It would be falaceous for a water authority to apply drinking water standards to undisinfected groundwater from a shallow unconfined aquifer in an unsewered urban area.

4 In view of the data presented in this report resampling of the bores cannot be objectively entertained. To resample the bores on the Nepean Peninsula would require a budget of exceeding $200 000. This would include analytical costs, collection costs, data processing and reporting costs. The Geological Survey has an ongoing monitoring program on the Nepean Peninsula.

The Geological Survey's groundwater monitoring program includes water level monitoring and water quality monitoring on the Nepean Peninsula.

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