CHAPTER 5. STATISTICAL AND PROFILING METHODS FOR DETERMINING PATHWAYS

5.1. INTRODUCTION

The primary purpose of this study was to investigate the sources of nitrogen into the unconfined aquifer in the Coonawarra area to assist in environmental protection of groundwaters both within the study area and in other similar environments.

The earlier parts of this thesis have described the magnitude and trends of elevated nitrate concentrations in groundwater, and properties of the physical environment that may significantly contribute to the elevated nitrate concentrations. This chapter considers both the characteristics of the nitrate concentrations and potential causal factors to provide guidance on likely sources and pathways for nitrate contamination.

5.2. METHODS

A review of the temporal trends of nitrate concentrations in groundwater has been reported in Chapter 3. A spatial assessment of this data was also undertaken to further examine their variability. The decadal periods 1994-2003 and 1974-1983 were chosen to investigate spatial patterning.

For bores that reported a groundwater nitrate concentration, landuse classifications within these periods, soil texture classes and bore details were collated. Classifying landuse for a period of 10 years is problematic due to possible changes in landuse during this time (particularly the expansion of vineyards in the study area). Therefore the years 1980 and 2002 were used to generalise landuse classifications. Landuse data for 1980 was compiled from historical aerial photography, and published landuse mapping was used for 2002 (DWLBC 2004). Soil texture classification was developed from 2004 Soil and Land Information Mapping (DWLBC 2004) and is shown in Figure 2.7. Based upon field inspections, historical records and aerial photography, each bore was also classified by type.

Multiple regression analysis was undertaken using SPSS (SPSS 2003) to determine the degree of relationship between these factors and nitrate concentrations observed in groundwater.

A consideration of the vertical stratification of the nitrate concentrations in groundwater was also undertaken using historical geochemistry profiles.

5.3. RESULTS

5.3.1 Spatial Nature of Nitrate in Groundwater

Chapter 3 provides an account of a number of analyses that indicate that the concentration of nitrate in groundwater was elevated during the late 1970s and early 1980s with an overall decrease in concentrations since this time. A possible explanation for this is that there has been a decrease in the flux of nitrate entering the groundwater since this time (it is not possible, however, to draw conclusions regarding any change in nitrate loadings to the soil surface).

Because of the non-random nature of the sampling locations (described in Chapter 3), and the potential that the nitrate sources may be point sources, the measured nitrate concentration data should not be used to describe conditions throughout the aquifer. Instead the data has been analysed to show results of point samples. Figures 5.1 and 5.2 are the spatial distribution of nitrate concentrations for the two clustered reporting periods of 1974-1983 and 1994-2003.

Figures 5.1 and 5.2 indicate that there is a spatial patterning of the nitrate concentrations that is similar to the spatial distributions described by MacKenzie and Stadter (1981) and Schmidt and his colleagues (1998). The spatial extent of these elevated nitrate concentrations are within the area of current vineyard plantings, the Coonawarra township and the inferred area of

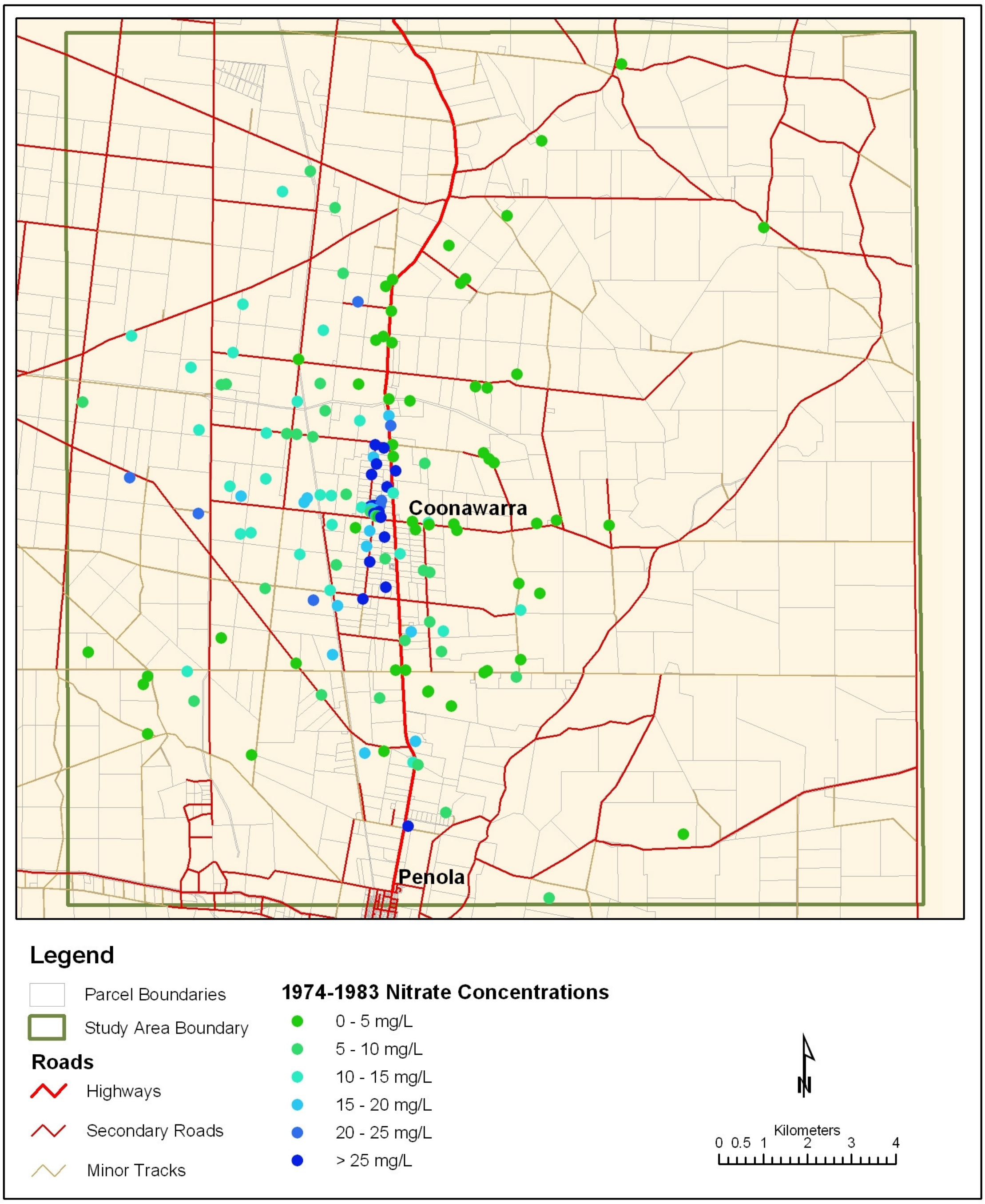

Figure 5.1: Nitrate concentrations of groundwater in the study area collected between 1974 and 1983

high recharge described in Figure 4.11. Any or all of these factors may have contributed to elevated nitrate concentrations.

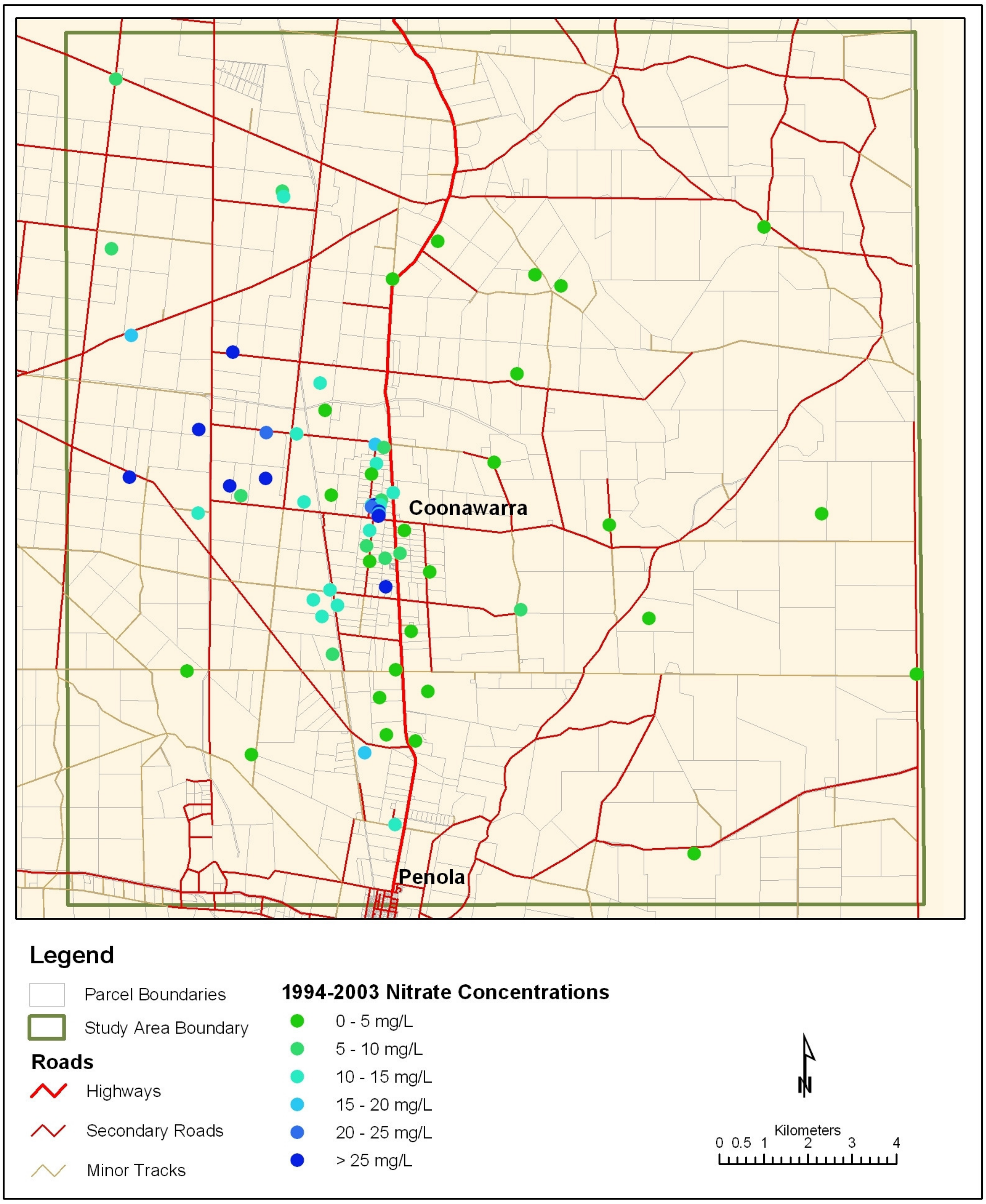

Figure 5.2: Nitrate concentrations of groundwater in the study area collected between 1994 and 2003

It was not possible to determine the environmental causes of the higher recharge rates estimated for the centre of the study area. A kriging method was unsuccessfully used to model recharge rates over the study area. Recharge is controlled by physical aspects in the catchment that were not considered in the kriging method. A multiple regression analysis was undertaken on nitrate concentrations based on geographic information system classification (ESRI 2002) but did not show a strong correlation with soil texture, landuse or a combination of these factors.

A simple comparison between observed nitrate concentrations and estimated recharge rates was undertaken. The area of higher recharge was defined spatially by the bores that reported a recharge estimate greater than the median estimate (of all bores). This approach provides further evidence that the higher recharge rates correspond to the higher nitrate concentrations in groundwater (Figure 5.3).

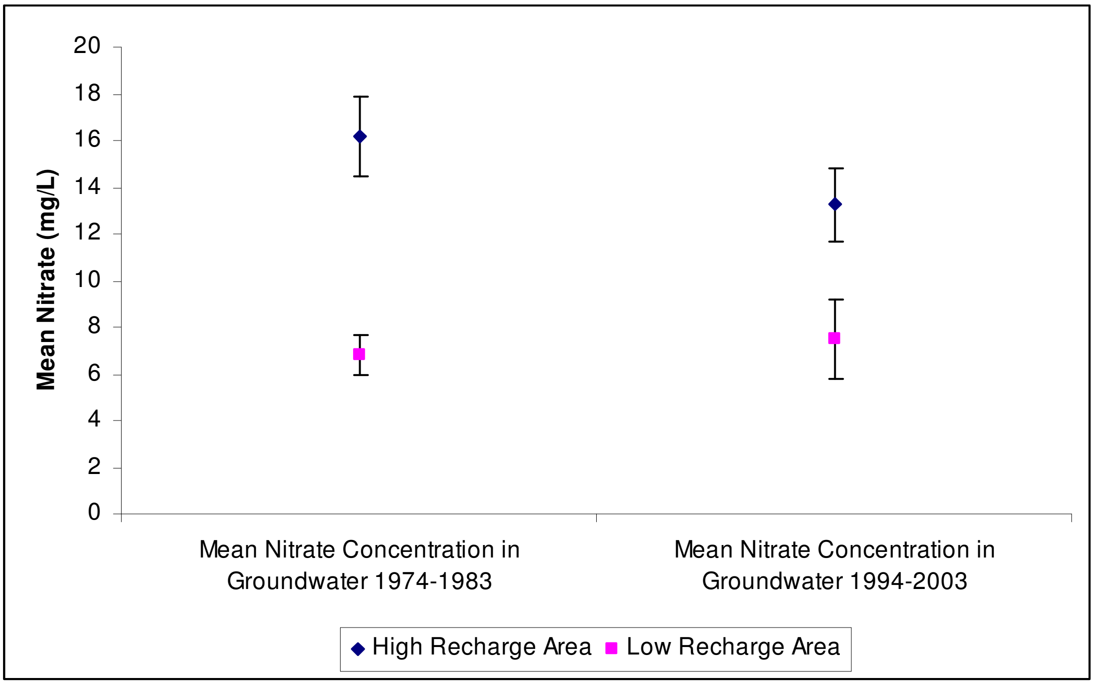

Figure 5.3: Mean nitrate concentrations (with standard error bars) for the calculated higher and lower recharge areas

Whether the higher recharge rates in the centre of the study area contributed to elevated nitrate concentrations in groundwater was investigated. Regression analysis (of the 1974-1983 groundwater nitrate data and the inferred recharge area) showed that this higher recharge area only explained 9.9% ($p<0.05$) of the variability in groundwater nitrate concentrations (i.e. 90.1% of the total sum of the squares was in the residual). This result is supported by leaching modelling of the vineyard land system (Chapter 7).

The result suggests that other physical or management issues contribute to the elevated nitrate concentrations in groundwater.

5.3.2 Landuse and Nitrates in groundwater

Landuse classifications, well types and soil texture descriptions were investigated to determine whether these were able to explain the spatial variability of nitrate concentrations. The summary of the multiple regression analysis is shown in Table 5.1, where *B* are the beta values, and β are the standardised beta values (Field 2005).

Table 5.1: Multiple regression analysis of nitrate concentrations 1974-1983 and environmental variables

Stepped Analysis	*B*	*SE B*	β	Sig.
Step 1*				
Constant	6.941	1.676		.000
Other bore vs House bores	13.861	2.390	.467	**.000**
Other bore vs Windmills	1.330	3.291	.032	.687
Other bore vs Observation Bore	-2.771	5.184	-.040	.594
Other bore vs Industrial Bore	7.963	4.885	.123	.105
Step 2*				
Constant	4.449	1.729		.011
Other bore vs House bores	8.483	2.377	.286	**.000**
Other bore vs Windmills	3.148	3.007	.075	.297
Other bore vs Observation Bore	-2.303	4.689	-.033	.624
Other bore vs Industrial Bore	5.436	4.423	.084	.221
Grazing vs Vineyards	8.031	2.228	.251	**.000**
Grazing vs Township	20.239	3.433	.441	**.000**
Grazing vs Irrigation	-1.894	6.034	-.021	.754
Grazing vs Structural Veg.	-3.640	8.386	-.029	.665

* R^2 = .21 for Step 1; R^2 = .39 for Step 2 (*ps*<0.001)

The classification of wells is based upon their primary use. Bores coded as "Other bore" include irrigation wells or private wells that do not fit other codes. Step 1 reports the statistical relationship between the bore types; step 2 includes step 1, and therefore the R^2 reported is a combination of both steps. Soil texture data was incorporated in step 3 of the analysis but did not result in any significant improvement in the model and so this step has been excluded from reporting.

The analysis shown in Table 5.1 indicates that 39% of the variability of nitrate concentrations can be explained by considering the landuse classification and the type of bore, and that significant variability ($p<0.05$) between bores at houses (regardless of the house location) and other types of bores, and between grazing landuses and both vineyards and Coonawarra township. The contribution of some of the other comparisons needs to be considered in context, as some landuses and bore types had few paired samples to consider (Table 5.2).

Table 5.2: Number of wells classified for multiple regression analysis of nitrate concentrations 1974-1983 and environmental variables

Bore Classification	Number of bores
Bore type	
Other bore	69
House bores	58
Windmills	23
Observation Bore	8
Industrial Bore	9
Landuse type	
Grazing	100
Vineyards	44
Township	17
Irrigation	4
Structural Vegetation	2

The most apparent relationship from this assessment is that bores within the township area, and house-bores throughout the study area are significantly correlated with nitrate in groundwater. The positive β value also implies that, when compared to either grazing or other bore types, house bores have significantly higher nitrate concentrations. Figure 5.4 provides the comparison of mean nitrate concentrations based upon the type of bore.

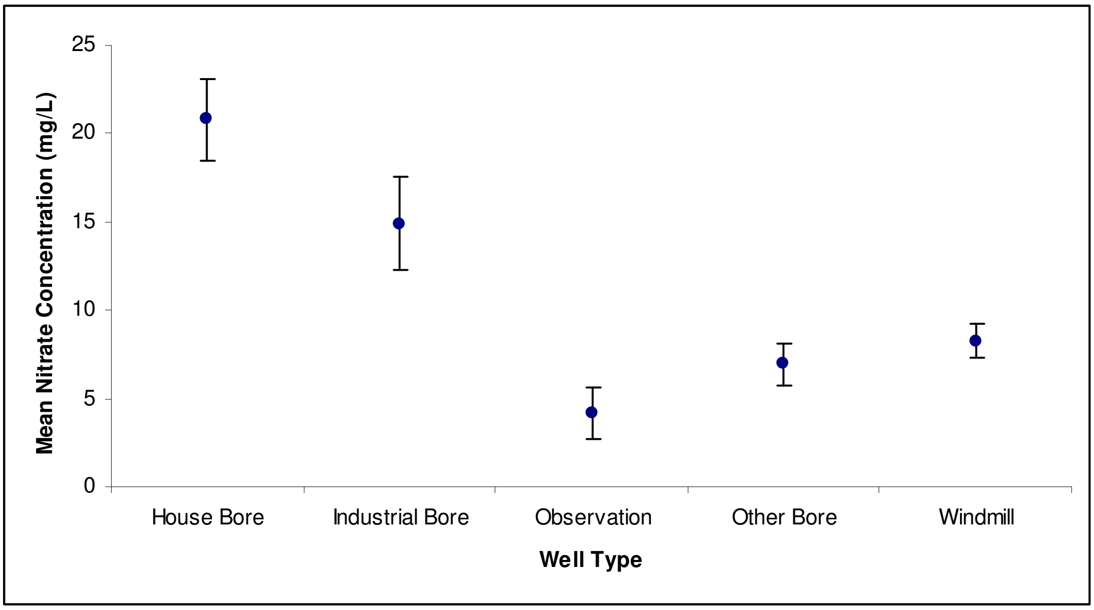

Figure 5.4: Mean nitrate concentrations of different well types for period 1974-1983

The only other comparison of significance is that the vineyard areas display a significantly greater nitrate concentration than grazing areas. Grazing areas contained the greatest number of bores with nitrate records and includes areas that may also be used for leguminous cropping. Figure 5.5 demonstrates the variability of nitrate in groundwater under each of the landuse types for the study area for the period 1974-1983.

Other studies have indicated that bores in rural areas are often located close to point sources for nitrate leaching and so this bore type can be an indicator of elevated nitrate concentrations in groundwater (Spalding and Exner 1993, Kitchen et al. 1997).

5.3.3 Sub-surface Inputs of Nitrate into Groundwater

The nitrate concentrations summarised above, and those discussed in Chapter 3 are for samples taken from the surface of the aquifer, or samples

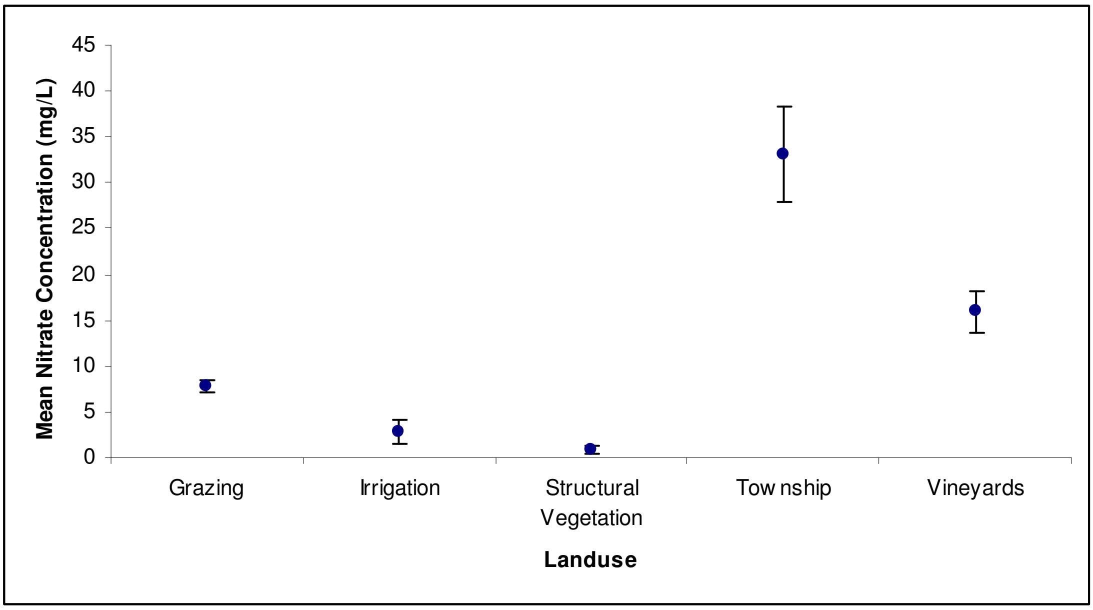

Figure 5.5: Mean nitrate concentrations of different landuses for period 1974-1983

of the entire aquifer penetrated. In 1976, as part of a study of groundwater quality in the Coonawarra area, discrete sampling was undertaken through the upper portion of the unconfined aquifer at two bores, 702303762 and 702303675. In addition, a number of other observation wells were sampled at the phreatic surface and at least at one other depth in order to identify any nitrate stratification within the aquifer (see Figure 5.6).

The depth profiles of nitrate concentration from these bores are shown in Figure 5.7. The profile for bore 702303762 shows the behaviour expected for nitrate input into a homogeneous aquifer from the surface, where the concentration of nitrate decreases with depth. This general profile is also shown for the majority of bores in Figure 5.7. A different profile is shown for 702303765, and this could be explained by nitrate entering the well at sub-aquifer levels as well as from the surface. The bores 702302827, 702302828 and 702302829 also show nitrate profiles which do not decrease with depth.

Although the bores 702302827, 702302828 and 702302829 are located centrally within the study area, the bore 702303675 is further south with well 702303762 located in between. If sub-aquifer inputs of nitrates were

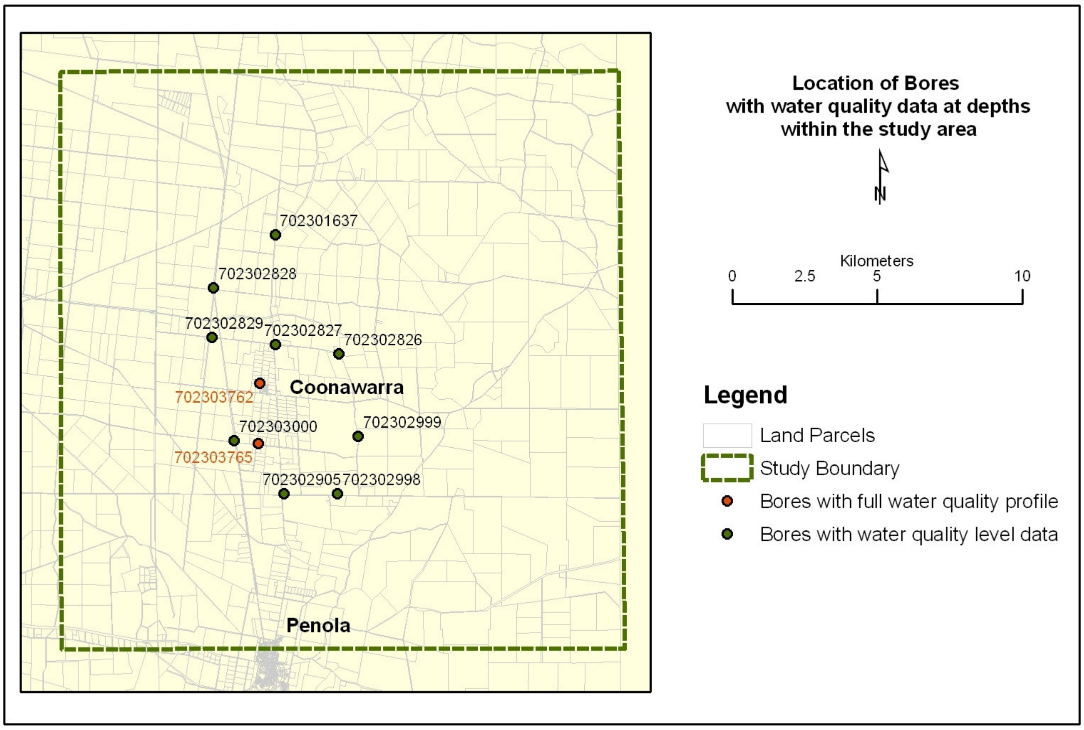

Figure 5.6: Bores where geochemistry profiles are available

occurring throughout this central area, then it would be expected that well 702303762 would display similar characteristics to 702303765 (and 702302827, 702302828 and 702302829). That this is not the case could indicate that there are multiple sources of sub-surface nitrate into the aquifer throughout this area. The study was unable to identify the source(s) of this sub-surface input.

Figure 5.7 for the bore 702303675 indicates that within the interval of 17 m to 19 m the nitrate concentration decreases substantially from the concentrations above. This depth corresponds to the unnamed clay unit described in Figure 2.4 that is between the Gambier Limestone and the Coomandook-Bridgewater Formation. The very low concentrations are likely to be the result of the low permeability of this clay aquitard and the potential denitrification that is occurring within this unit (in Chapter 6 analysis of residual nitrate in the groundwater demonstrates that denitrification has occurred).

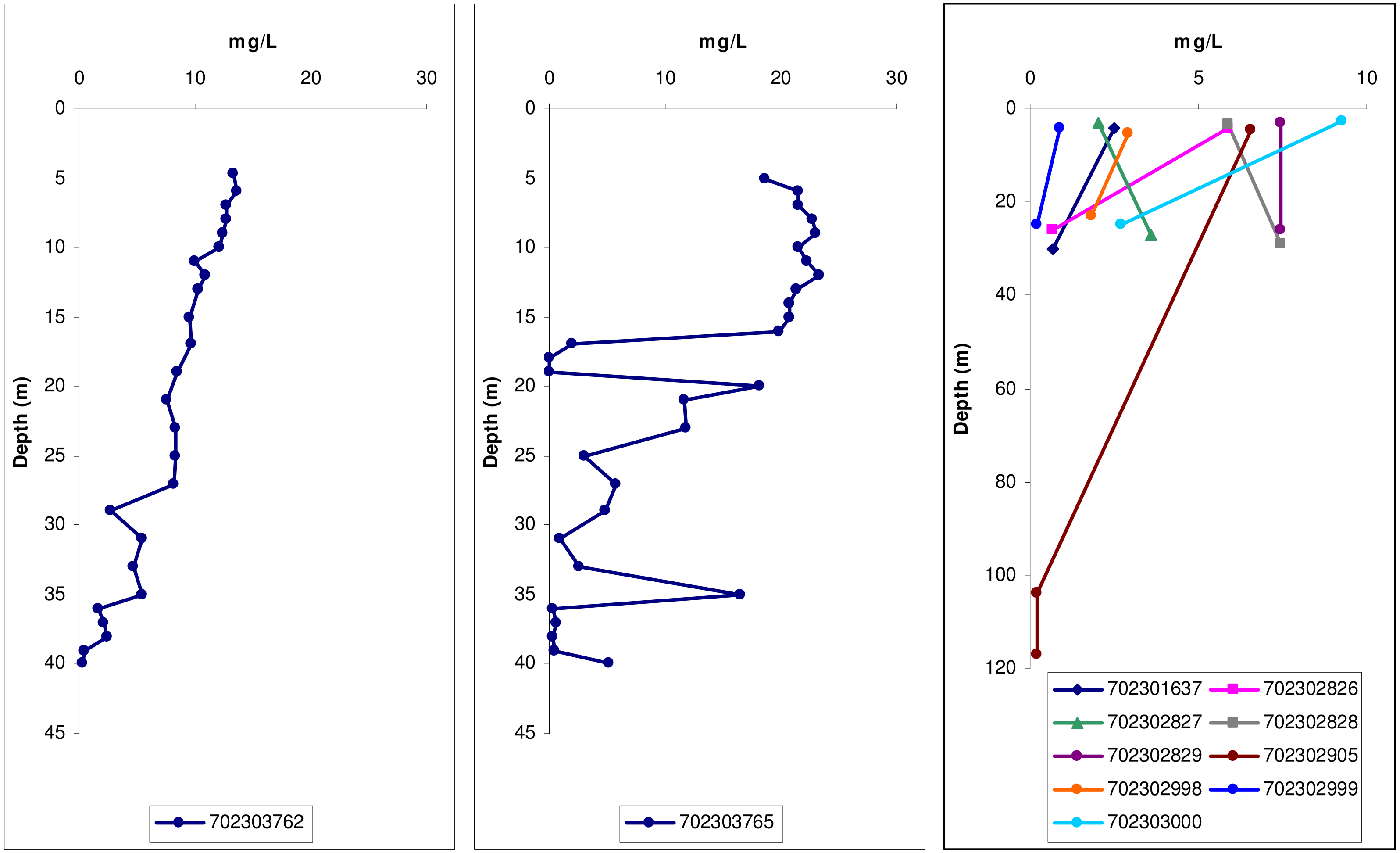

Figure 5.7: Nitrate profiles and nitrate concentrations at the water table and at least at one depth for selected bores

Figure 5.8 shows the profile of all available water quality data for this borehole and indicates the presence of a reductive zone of potentially older water (indicated by higher TDS and low sulphate concentrations). That there is elevated nitrate concentrations below this level, and particularly that non-oxidised nitrogen exists suggests that there is an organic source of nitrogen below this confining level, or that the unnamed clay unit is discontinuous in the area and vertical mixing is occurring within the aquifer. However, the lower chloride levels indicate a potential input of a different water source. This pattern is repeated at approximately 35 m. It is suggested that this could also be the result of differing geological units within the Gambier Limestone with differing hydrologic characteristics.

A localised source of nitrate at depth could not be identified. Within a five kilometre radius of this borehole, only 12 bores with a depth greater than 20 metres have been recorded as existing at that time (other than dedicated observation bores). Only one of these was classified as a drainage well (702302694), however it is 3.3 kilometres to the north east. This well is not up-gradient of 702303765 and is unlikely to be a source. Unrecorded drainage bores (or unrecorded bores used for discharge of wastewater) or preferential flow-paths to depth in the aquifer may be responsible.

The water quality data for the profile depths illustrated in Figures 5.7 and Figure 5.8 are presented in Appendix 6. Included in that appendix is the complete hydrogeochemistry profile for bore 702303762 although this is not presented graphically in this thesis.

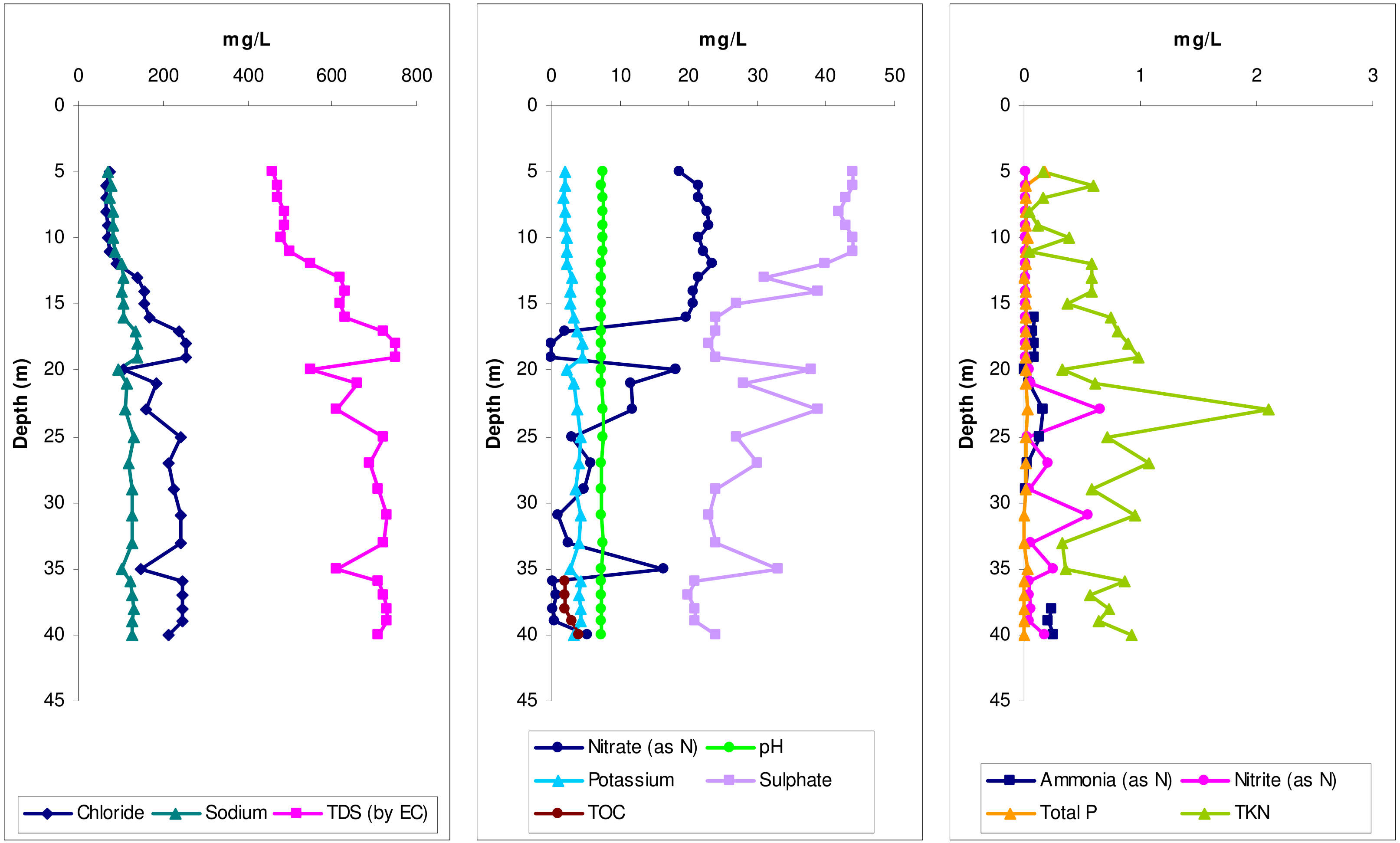

Figure 5.8: **Geochemistry profiles of bore 702303765 showing possible unnamed clay unit aquitard at 17-20m**

5.4. DISCUSSION

5.4.1 Nitrate Sources and Pathways

This spatial and statistical analysis failed to comprehensively explain sources of nitrate. Spatially, elevated nitrate concentrations appear to be grouped within the centre and spread towards the north west of the study area. However the correlation undertaken for the decade 1974-1984 could only explain approximately 40% of the groundwater samples based upon predicted physical characteristics.

The research has shown that the nitrate is unlikely to be related to a single source within the study area, nor a single pathway. Nitrate contamination of groundwater in the South East region has been attributed to both point and diffuse sources (Waterhouse 1977, Harvey 1979, 1983, Holmes and Waterhouse 1983, Lawrence 1983, Dillon 1988, Schmidt, et al. 1998, Pakrou and Dillon 2000, SECWMB 2003, SENRCC 2003, GHD 2005), and groundwater within the study area appears to be impacted by both processes as well.

The statistical analysis indicates that domestic sources (the township of Coonawarra and isolated residences) and vineyard operations both explain some of the spatial variability of nitrate.

The high correlation of nitrate concentrations in groundwater with domestic activities has not previously been reported for the area, however it is suggested that localised loadings of nitrogen from domestic activities (primarily onsite domestic wastewater disposal) has resulted in localised elevations of nitrate concentrations.

There is no centralised domestic wastewater disposal scheme within the study area, and all residences rely upon onsite disposal; primarily soakage trenches from septic tanks. Septic tanks have been reported in numerous studies as contributing significantly to localised nitrate contamination of unconfined aquifer systems (Hantzsche and Finnemore 1992, Hallberg and Keeney 1993).

The field inspections undertaken confirmed that both within the township of Coonawarra, as well as at isolated farming residences, there is often very little separation between septic tanks and bores (often less than 20 metres). Fortunately in these circumstances there were no occurrences where a land owner reported using bore water for more than garden water or for toilet flushing.

While the net nitrogen loading to the unconfined aquifer is low compared to other sources, the proximity of septic tanks to domestic bores highlights this as a likely source. This outcome demonstrates the inappropriateness of extrapolating measured nitrate concentrations from such bores to generalise about nitrate concentration in regional groundwater.

Another potential point source investigated was nitrogen from winery wastewater disposal. While inappropriate winery effluent discharge in the past may have resulted in some localised impacts, this source itself cannot be responsible for the elevated nitrate concentrations observed across the study area. A simple mass balance of the nitrate in groundwater for the centre of the study area for the mid 1970s (when elevated nitrate concentrations were being reported) reinforces this view. Given that the volume of winery wastewater produced in 1975 was 16,000 kL (Emmett unpublished), and had an estimated nitrogen concentration of 37 mg/L (TKN) (Harvey 1979), the resulting annual nitrogen production in the centre of the study area was only 592 kg. At the scale of the study area, this input would not be detectable, but like the domestic sources, this input may significantly impact upon localised groundwater quality.

A relationship was found between the vineyard landuse and elevated concentrations of nitrate in groundwater. The conclusion that vineyard landuse is a contributing factor must be considered with care as vineyard locations are closely related to the extent of the terra rossa soil type in the study area. The multiple regression analysis found that inclusion of soil textures did not improve the accuracy of predictions, however it is not possible to distinguish between whether the causal factor is the vineyard landuse or the terra rossa soil type (or a combination of both). For this reason this landuse-soil type association was considered together.

Within the study area, vineyards generally do not receive fertiliser applications after establishment (two years), and irrigation applications to vineyards during the growing season are now limited in order to produce higher quality grapes. However mineralisation of organic nitrogen in vineyards resulting from the management of intra-vine areas is a possible source. Also, although vineyards do not receive (comparatively) heavy irrigation during the growing season, significant quantities of irrigation water are applied through frost protection each year. A recent study has estimated that during the winter months (June–September) significant volumes (6.7 ML/ha) are applied which, given the flat topography of the study area, percolates through the soil zone and into the unconfined aquifer (Pudney 2007). This significant increase in winter infiltration has the potential to further leach any oxidised nitrogen into the aquifer, and an investigation into this is reported in Chapter 7.

The inability to account for 60% of the variability in nitrate concentrations could be due to several reasons. It is considered unlikely that the nitrate concentrations are influenced by a predictable factor not included in this study. It is more likely that there is significant variability in the local influences that control nitrate concentrations in groundwater. The pursuit of statistical analysis to identify these factors is therefore unlikely to improve understanding of the source(s) of nitrate. Instead it is necessary to consider environment factors at a finer scale and focus upon discriminating localised impacts from diffuse sources.

While this study highlights that point sources contribute significantly to the variability of nitrate contamination in groundwater, it also indicates that diffuse nitrate contamination is likely to be occurring within the study area.

There are a number of examples, particularly on the western side of the study area where no local nitrate point source could be identified, and moderate nitrate concentrations (more than 5 mg/L) are regularly detected.

This study does not discount these diffuse sources, however it does highlight that point sources appear to have considerably influenced reported ambient groundwater quality.

5.4.2 Relevance to Future Research

This study has also shown that within the scale of the study area, there may be substantial variability in recharge (Chapter 4), and although recharge rates are likely to be a confounding issue, they were not able to explain more than 10% of the variability of nitrate concentrations in groundwater. This low correlation is believed to be partly due to the inability to adequately explain the causes for the variability of recharge within the study area.

The reasons for this unexplained variability in nitrate concentrations are considered to be significant local variability in land management, recharge rates and soil structures as well as compounding effects of localised point sources. Therefore at the scale of this study area, it is considered that the correlation of nitrate sources statistically to environmental factors may not be possible given the variability unable to be properly considered in feature mapping.

At the regional scale Schmidt and his colleagues (1998) achieved a similar level of correlation as this study. This indicates that statistical methods will not achieve confident predictions of nitrate concentration where both point and diffuse sources exist.

5.5. CONCLUSIONS

An investigation of the spatial distribution of groundwater nitrate concentrations found that less than 40% of the variability was related to the broad landuse category and location of the well. Only a small amount of the variability was able to be explained by the elevated recharge rates modelled (Chapter 4), or the soil textures for the study area.

This outcome indicates that there may be significant variability in the landscape environment and/or recharge rates, and that wells located close to residences generally have higher nitrate concentrations. While these higher nitrate concentrations are of concern, it is expected that the nitrogen loadings from these sources is comparatively low when considered at the study area scale. However these wells result in reported levels which are likely to over-estimate the regional groundwater quality. Considerable care needs to be taken when using these values to describe regional water quality. This data can be used in trend analysis however (as described in Chapter 3).

It appears that the sources of nitrate to the groundwater in the study area are varied and include both point and diffuse sources. It is not possible to differentiate between sources as 60% of the variability of nitrate in groundwater remains unexplained.