CHAPTER 1. INTRODUCTION TO RESEARCH

1.1. INTRODUCTION

The unconfined aquifer that exists throughout the South East region of South Australia provides much of the water that is necessary to support the variety of industries and communities within the region, and is therefore of significant economical and social importance to the region and the State. Since the 1970s, elevated levels of nitrates in this aquifer have been observed across the region and were first comprehensively reported by Waterhouse (1977) and later Harvey (1979). These reports and a variety of later works have identified that these elevated concentrations may limit the current and future uses of this groundwater resource.

The necessity to protect this unconfined aquifer from contamination with nutrients (mainly nitrogen) has been identified as one of the primary water quality issues facing resource managers in the region (SECWMB 2003, SENRCC 2003, BLMC 2006). Elevated nitrogen within groundwater has the potential to limit its use, particularly as a potable water supply.

A number of research and investigative studies have been undertaken within the region to assess and model the nature and extent of this contamination, and the behaviour of nitrogen within the sub-surface environment. It remains apparent that in many instances, the source of the nitrogen is not well understood.

The area around the township of Coonawarra (approximately 60km north of Mount Gambier) is an example where elevated nitrate concentrations have been identified within the unconfined aquifer for nearly thirty years, but there has been insufficient information to ascertain the source of this contamination.

This research project improves the level of knowledge regarding the sources of nutrients into the unconfined aquifer across the region through the investigations of the sources and pathways of nitrate to groundwater around the township of Coonawarra.

1.2. PURPOSE

The aim of the research project was to explain the sources of nitrogen into the unconfined aquifer in the South East region so as to provide added knowledge for groundwater management and protection.

1.3. OBJECTIVES

The research project tested the hypothesis that;

> *"The elevated concentrations of nitrate detected in the unconfined aquifer in the study area are not the result of human activity."*

1.4. REGIONAL DESCRIPTION

The research project is focused at addressing the water quality degradation issues that are apparent in the South East region of South Australia. Figures 1.1 and 1.2 show the regional scale context for the project, and the investigation area where the assessment was undertaken.

The South East region is defined by the South Australian/Victorian border to the east, the Southern Ocean to the south and west, and encompasses the Kingston and Tatiara District Council areas to the north (SENRCC 2003). The region is approximately 350 km from north to south, 200 km from east to west, and covers an area of approximately 21,000 km^2.

Throughout the majority of this region there exists a shallow aquifer (often less than five metres below ground level) that was the primary water resource investigated in this project. This aquifer occurs mainly within the coarse-grained, fossiliferous zones of the Gambier Limestone stratum (Holmes and Waterhouse 1983). The aquifer is generally unconfined throughout the region, and is recharged locally through diffuse infiltration

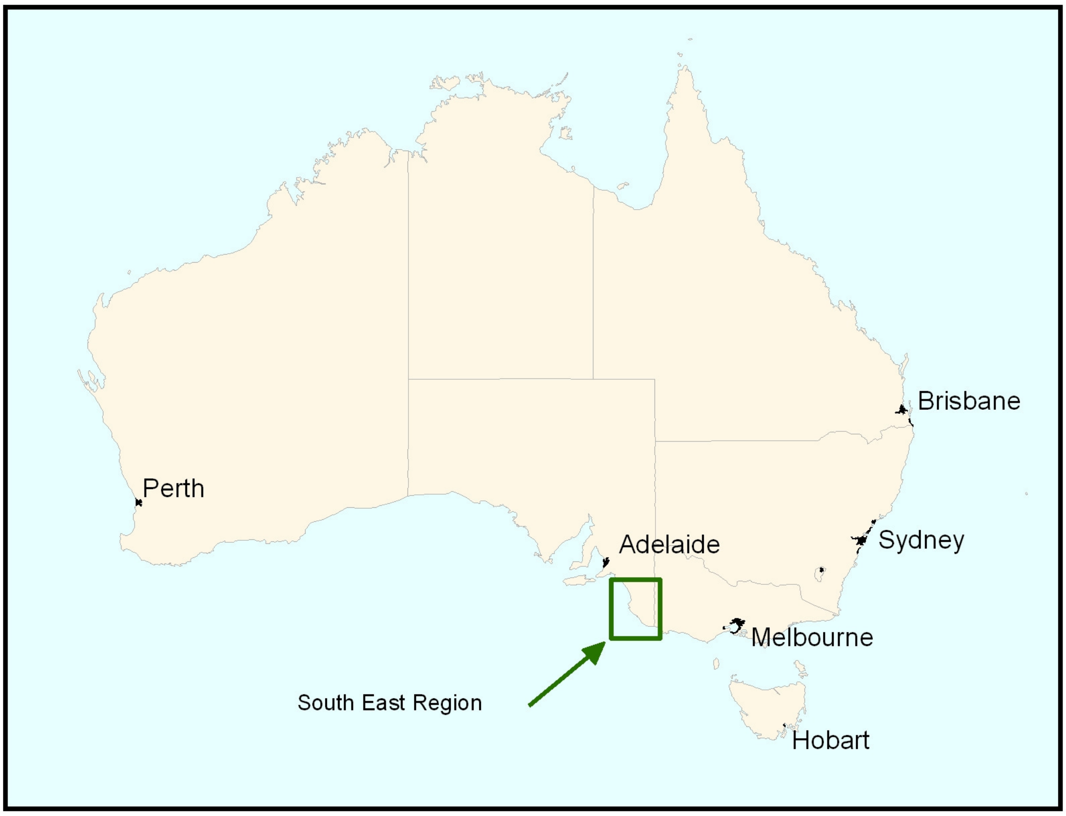

Figure 1.1: The South East Region of South Australia

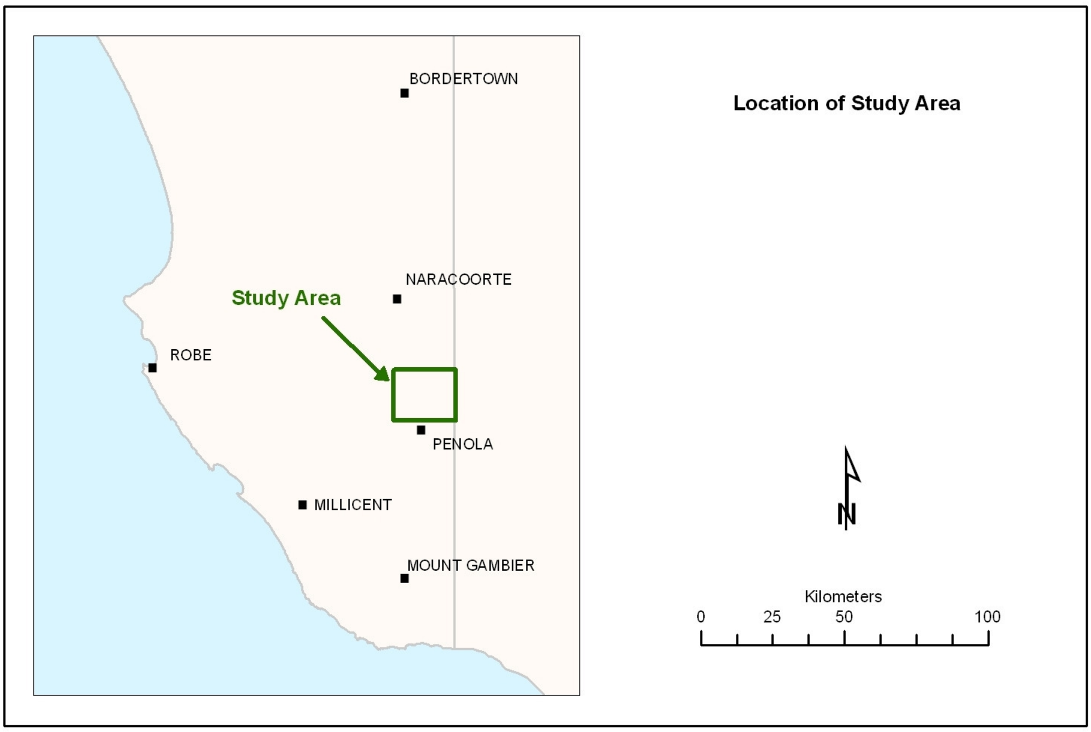

Figure 1.2: The location of study area within South East region

from the landscape, as well as through natural (sink holes) and constructed (drainage bores) recharge points.

Although elevated concentrations of nitrate occur within the unconfined aquifer throughout the South East region, this research project focused investigation on a small project area (approximately 400 km^2). This particular site location was selected as elevated concentrations had been identified in the shallow unconfined aquifer (Harvey 1975, MacKenzie 1980, MacKenzie and Stadter 1981, Schmidt et al. 1998), but there was uncertainty and local dispute regarding the source of this contamination.

1.5. SIGNIFICANCE OF THE RESEARCH

1.5.1 Regional Setting and Human Settlement

The South East of South Australia is a region of significant economic and agricultural growth. This growth has, to a large extent, been advanced through the availability of large volumes of high quality groundwater from the shallow unconfined aquifer. Although it is difficult to quantify the economic benefits to the region through the utilisation of this resource, it has been estimated that the farm gate value of irrigation activities alone is in excess of $200M/yr (Binks 2000). The majority of the 60,000 residents in the region also rely upon this aquifer to provide a domestic water supply.

Within the study area is the Coonawarra grape growing area which produces high quality varieties of wines and therefore the proportional contribution within the study area is likely to be well above the estimates of Binks (2000). Maintaining the water quality of this resource is therefore important to sustain the regional population and economy.

The municipal and economic development of the unconfined aquifer has been due to the resource's high water quality, the often high yields obtainable (up to 300 L/s) and the shallow nature of the aquifer (SECWMB 2003). Throughout the majority of the region, the infrastructure costs associated with the access and extraction of water from the unconfined aquifer is therefore relatively small. As a result it is not surprising that an estimated 30,000 groundwater extraction bores are registered in the region for accessing this aquifer.

These attributes of the aquifer (shallow, widespread, permeable, locally recharged) that have made it such an attractive resource for exploitation, have also meant that water within the aquifer is highly susceptible to degradation through the same landuse activities that it supports. Local experience has identified that point source discharges into this aquifer can result in groundwater contamination and the limitation of future use (Richardson 1990, Emmett and Telfer 1994). Additionally, there is wide regional recognition that landuses and land management activities in the South East region result in a significant diffuse nitrogen contamination of this unconfined aquifer. This is supported through a range of local, national and international research projects that have investigated the relationship between landuse practices and the diffuse impacts upon surfaceous aquifers (Lawrence 1983, Exner and Spalding 1990, Bolger and Stevens 1999, Pakrou and Dillon 2000, Böhlke 2002, Oren et al. 2004).

The region supports a range of diverse agricultural and industrial activities, including broad-acre agriculture (cropping and grazing), plantation forestry, irrigated agriculture, dairying, horticulture, vineyards and associated processing industries. These industry sectors are generally clustered in localised areas of the region, and are often locally dominant with respect to landuse. All of these industries rely upon accessing good quality water (generally) from the unconfined aquifer, and all of these landuses have the potential to contaminate the aquifer with the diffuse recharge of nutrient-rich water.

In addition to the use of water from the unconfined aquifer for agriculture and industries, the unconfined aquifer also provides the majority of source water to the Blue Lake (Ramamurthy et al. 1985). Beyond being the primary municipal water supply for the city of Mount Gambier, this unique water body is world famous due to its remarkable colour change from grey in winter to deep blue in summer, and is the primary tourist attraction for the Mount Gambier area (Turoczy 2002).

1.5.2 Nitrogen in the Environment

Nitrogen and its oxidized forms are ubiquitous in the environment and occur throughout the air, water, soils and organisms that live on the planet. Nitrogen is a major component of proteins that are the essential building blocks of life. The development of nitrogen as a fertilizer has had the direct result of significantly improving crop yields that have allowed the expansion of the human population (Kolenbrander 1977, Duke et al. 1978). For these reasons, nitrogen in the environment is essential for the survival of humans as well as introduced livestock and crops. However, in both natural and altered environments, severe problems can arise when there is an imbalance in the nutrient cycle. The nitrogen cycle is described in detail in Chapter 6 and is presented in Figure 6.1.

1.5.3 Impact on Human Health

Concern regarding nitrogen in potable groundwater systems was first highlighted in the review by Comly (1945) that linked the presence of nitrate in drinking water to the condition of methemoglobinemia in infants. In the years since this article, there have been a variety of publications that continue to investigate the potential sources of nitrate in the diet of humans, and the linkages to human illnesses, including methemoglobinemia, respiratory illness and cancer (Johns and Lawrence 1973, Deeb and Sloan 1975, Mirvish 1977, Shuval and Gruener 1977, Hill 1991, Knobeloch et al. 1993, Fan and Steinberg 1996, Gupta et al. 2000, Knobeloch et al. 2000, Gupta et al. 2001). This work has included studies that have reported upon serious health impacts on the population of the South East region as a result of elevated nitrate concentrations in groundwater (Scragg et al. 1982, Dorsch et al. 1984). It is now accepted by policy makers that elevated nitrate concentration in drinking water has the risk of resulting in nitrate-induced methemoglobinemia. A variety of countries have established guidelines and standards based upon this risk (Fan et al. 1987, Hill 1991, MAFF 1992, NHMRC and ARMCANZ 1996, Kendall 1998, Schubert et al. 1999).

It is arguable that this health risk, particularly to infants, has also been a driving factor in the prioritisation of research into nitrate contamination of groundwater resources.

L'hirondel and L'hirondel (2002) have recently reviewed much of the research that has linked elevated nitrate levels in drinking water to human health impacts. Their review provides a strong argument against the presumption of both a chronic and toxic effect of nitrate upon the human body. The views are supported by the acceptance of high dose uses of nitrate in medical treatment (Winbury 1981), and the recognition that methemoglobinemia in children is likely to be caused by other common food items (Sanchez-Echaniz et al. 2001).

The debate on the health effects of elevated concentrations of nitrate in drinking water is a medically-based argument, and therefore outside the scope of the research described in this thesis. Given the unresolved nature of this debate, it is appropriate that resource managers and environmental researchers continue to adopt a cautious approach that elevated nitrate levels are likely to impact upon human health.

1.5.4 Impact on Natural Biodiversity

The impact of elevated nitrogen levels on natural aquatic systems has been the focus of considerable research both nationally and internationally. The occurrence of algal blooms in natural water bodies, the altering of species abundance or direct toxicity to native species are likely to be the result of elevated nitrogen concentrations in surface waters in Australia (Marco et al. 1999, ANZECC and ARMCANZ 2000, Buhl and Hamilton 2000).

In respect to groundwater, the impact of increased nitrogen concentrations on natural ecosystems could either be through the direct impact on natural biodiversity that exist underground (stygobiotic), or to those ecosystems that access groundwater (phreatophytic) at either discharge sites, or where the aquifer is close to the surface.

There has been little investigation undertaken in the South East region to collect data on either the distribution of stygobiotic or phreatophytic ecosystems, or the likely impact of elevated nitrogen concentrations upon these systems (URS 2000). However other studies have identified stygobite species within Australian groundwater systems (Bradbury and Williams 1997, Bradbury 2000), and the evolutionary geology of the South East region appears favourable to their presence (Holsinger 1993). Stygobite species have already been found within cenotes in the region, and in 2004, a survey recovered a new species of blind amphipod from a borehole within the region (R. Leijs, SA Museum, pers. comm. 2004).

Given the stable nature of any groundwater ecosystem environment it is expected that subtle changes in groundwater quality may result in changes to these ecosystems (SKM 2001). Considering the knowledge of nitrogen impacts upon surface water ecosystems in Australia, it is reasonable to suggest that elevated groundwater nitrate concentrations will cause detrimental impacts to stygobiotic or phreatophytic ecosystems.

1.5.5 Impact on Productive Systems

In productive agricultural systems, nitrogen is an important input that is widely used in Australia to replace nutrients that are removed through the export of livestock or production crops. However, there is evidence to suggest that the application of nitrogen in certain circumstances may be detrimental to production. It is suggested that nitrate poisoning of stock, through access to feed or water with high (non-protein) nitrogen, may be widespread yet undiagnosed (Knott 1971, Carrigan and Gardner 1982, Egyed and Hanji 1987, Schneider et al. 1990, Antoine et al. 1993, Bruning-Fann and Kaneene 1993, Burritt and Provenza 2000, Scott 2001).

Additionally, some production plant crops, particularly grape vines, may be detrimentally affected by increased input of nitrogen such as through the irrigation of groundwater with high nitrogen concentrations. It is identified that nitrogen application to vines can increase vine vigour, and potentially reduce the quality of the final product (Spayd et al. 1995, Bell and Robson 1999, Choné et al. 2001). In some growing regimes, vineyard managers will not want vine vigour to occur. This is the case in the Coonawarra area where high quality red wines are characteristic of the region. Vineyards are a dominant landuse within the investigation area.

1.6. PREVIOUS RESEARCH

1.6.1 Regional Studies

There has been significant research undertaken within the South East region, Australia and internationally to understand the extent and nature of nutrient contamination into groundwater systems. Within the lower South East region, the existence of elevated nitrate concentrations in the unconfined aquifer have been noted since the early 1970s. The first comprehensive assessments that documented the level of nitrate contamination, and potential risks associated with this contamination in the lower South East, were by Waterhouse (1977) and Harvey (1979). Both of these works undertook a broad assessment of the groundwater quality in the region and both identified elevated nitrate concentrations across the catchment. Other nutrients such as phosphorus and potassium were also investigated, however, these nutrients were often undetectable and therefore considered not of primary concern to water quality protection.

Both Waterhouse (1977) and Harvey (1979) identified that the likely sources of the elevated nitrate concentrations were landuse related, most likely the result of diffuse infiltration of nitrogen-rich water from agricultural activities and/or effluent disposal practices. In some instances, point sources were also considered as being possible sources of nitrogen contamination to the unconfined aquifer. Waterhouse (1977) observed that given the absence of nitrate from the Gambier Limestone geology, it was unlikely that the nitrate observed in the unconfined aquifer originated from the aquifer matrix. Although this observation suggests that the nitrate appears to have entered the aquifer from another source, it does not preclude the potential that the nitrate is of a natural source. In some areas, including central Australia, elevated nitrate concentrations in groundwater are believed to be from natural processes in the environment (Bolger and Stevens 1999, Harrington 1999).

Later, a study undertaken by Dillon (1988) sought to review and model nitrate concentrations in the unconfined aquifer in the lower South East. This study identified that up to 27% of the study area displayed groundwater nitrate concentrations above the 10 mg/L (as N) drinking water standard. This study, which identified that point sources have impacted groundwater quality locally, concluded that the dominant source of nitrogen to the unconfined aquifer was through the fixation of nitrogen by leguminous pastures and the uneven redistribution by grazing livestock.

The sources of the elevated nitrate concentrations in groundwater across the lower South East region were further investigated by Schmidt and his colleagues (1998). This study reviewed existing groundwater data, and attempted to correlate elevated nitrate concentrations in the groundwater with landuse data (and other environmental attributes). Their study identified that the variability in nitrate concentrations in groundwater could be correlated with soil associations, soil permeability and landuse, however these factors combined accounted for less than 40% of the total variation in the nitrate concentrations. In this study, it is relevant that the spatial correlation was based upon data of an accuracy of 1:100,000, that only broad landuse classifications were available, and that limited field proofing of the data was possible. Schmidt and his co-workers observed from their study that localised factors were likely to influence nitrate concentrations in the unconfined aquifer.

Given the recognition of elevated nitrate concentrations in groundwater in the region, a variety of other studies have been undertaken to investigate particular landuse activities and the resulting pathways of nitrogen input to the underground aquifer (Richardson 1990, Leaney and Herczeg 1995, Pakrou and Dillon 1995, Schmidt et al. 1996, Herczeg et al. 1997, Pakrou 1997, Dillon et al. 2000, Pakrou and Dillon 2000, 2000, 2004). These studies provide useful evidence to support the previous findings of Waterhouse (1977), Harvey (1979), Schmidt et al. (1998), Dillon (1988) and Lawrence (1983) that point sources will impact locally upon the nitrate concentration in groundwater, but that contamination from landuse practices is likely to be a major contributor to elevated nitrate concentrations in the unconfined aquifer at the regional scale.

1.6.2 Previous Studies in the Coonawarra Area

The first study undertaken to specifically investigate nutrient contamination in the Coonawarra area was by Harvey (1975). This work sought to assess the contamination risks to the groundwater around the Coonawarra area and did not include any review of the groundwater quality, instead focusing upon the liquid waste disposal practices of the wineries. Harvey however stated that at the time there were no major water quality problems in the area.

By 1980 groundwater contamination with nitrate had been identified in the study area and attributed to the wastewater disposal practices by wineries (MacKenzie 1980). The subsequent study by MacKenzie and Stadter (1981) was the first to specifically report upon the groundwater quality of the unconfined aquifer in the study area. This work identified that a large plume of elevated nitrate was present around the township of Coonawarra. Given the extent of the plume it is unlikely that this contamination occurred in the intervening years since the 1975 study by Harvey.

A review of regional groundwater data by Schmidt and his colleagues (1998) again reported elevated nitrate concentrations in groundwater in the vicinity of Coonawarra. The studies by MacKenzie and Stadter (1981) and Schmidt and his colleagues (1998) are the only two that have attempted to map nitrate concentrations in the unconfined aquifer within the study area.

Although this area of elevated nitrate concentrations is acknowledged through a variety of studies, there remained considerable uncertainty as to the source of this nitrogen to the aquifer. The continual presence of this 'plume' in the vicinity of the township indicated that the contamination to the unconfined aquifer was ongoing.

Figure 1.3 shows the study area with the elevated nitrate concentrations that were determined by both the MacKenzie and Stadter (1981) and Schmidt and his colleagues (1998). The figure illustrates the similar extent of elevated nitrate concentrations over the 17 year timeframe.

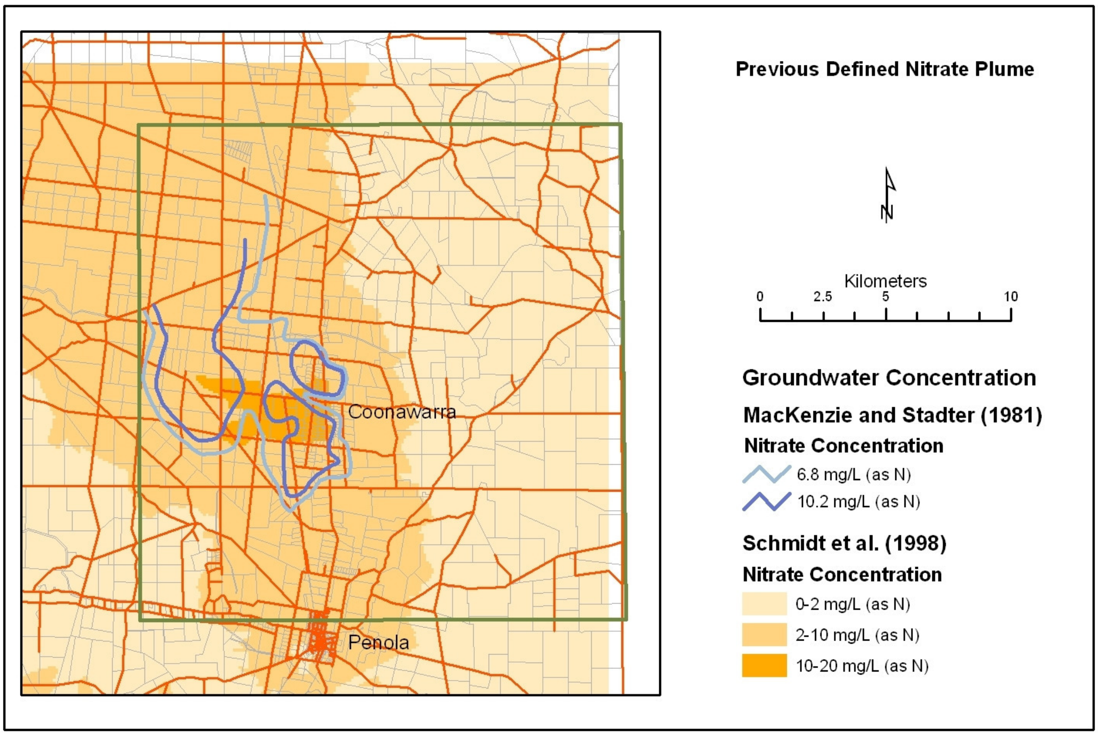

Figure 1.3: Previously defined plume of elevated nitrate concentration in groundwater

1.7. UNDERSTANDING THE CAUSE OF NITRATE CONTAMINATION IN THE STUDY AREA

Although the presence of elevated nitrate concentrations in groundwater in the vicinity of Coonawarra had been documented through the above studies, the source of this nitrate had not been established. Unlike other areas in the lower South East region, the Coonawarra area has very few landuse activities that are considered high risk sources of nitrate contamination to groundwater. For instance there are, comparatively, very few dairies, piggeries, agricultural processing industries (e.g. abattoirs, plant processing), large unsewered populations or intensive irrigated leguminous pastures established in the area.

The obvious distinction of this area is the dominance of vineyards and the associated wine production facilities. However, established vineyards are generally not fertilised, and grape vines do not fix atmospheric nitrogen. Additionally, the vineyard areas are not subject to regular or broad cultivation, and therefore it is not expected that tillage will significantly influence the leaching of nitrate downwards from the soil profile. Tillage has been demonstrated as being a mechanism for accelerating nitrate leaching (Lawrence 1983, Keeney 1986, Knight and Tuckwell 1988, Keeney 1989, Thomas et al. 1989, Worrall and Burt 1999, Dillon, et al. 2000, Worrall and Burt 2001).

Although vineyards have been implicated in some assessments of landuse and nitrate leaching (Schmidt, et al. 1998, Zhang et al. 1998), there does not appear to be any clear explanation for this suggested association.

It has been proposed that the source of the nitrate contamination may include the inappropriate disposal of winery effluent (MacKenzie 1980, MacKenzie and Stadter 1981). However, winery wastewater is not nitrogen-rich compared to other effluents (Chapman et al. 2001, Di Berardino et al. 2001). A preliminary mass-balance assessment undertaken in the early 1980s suggested that wineries could not be a major contributor to the elevated nitrate concentrations in the groundwater (Ochota 1982). The question therefore remained unanswered as to the likely source of the reported plume of nitrate within the unconfined aquifer under Coonawarra.

A difficulty for natural resource managers and the community is the absence of a clear understanding of the source(s) of nitrate contamination in this area.

Without an understanding of the cause, there is reduced confidence that the current land management regimes are sustainable in respect to groundwater quality.

The research project was therefore to investigate the origin and fate of nitrate into the Gambier Limestone aquifer in the vicinity of Coonawarra, and assess the impacts of this outcome upon water quality management opportunities for the study area and the South East region.

1.8. STUDY AREA DESCRIPTION

The study area encompasses the township of Coonawarra and extends from the South Australian/Victorian border, approximately 20 kilometres west. The study area is approximately 20 kilometres from north to south, and so covers an area of around 400 km^2 (Figure 1.2). Figure 1.4 details the physical landscape within the study area.

The area has a Mediterranean climate with warm dry summers and cool wet winters and an average rainfall of 640 mm/yr (Penney 1983).

The population of the study area is focused within the township of Coonawarra, which has a population of around 200 people. The surrounding landscape includes small allotments with many houses for vineyard workers and farming families further away from Coonawarra township.

There are four main landuses within the study area, with each of these being locally dominant. The vineyard areas are within the centre of the study area and generally reflect the distribution of the terra rossa soils that are sought for high-value wine production (Mee et al. 2004). The eastern side of the study area is dominated by plantation forestry and native forests, and the western side of the study area is dominated by broad-acre farming (cropping and grazing).

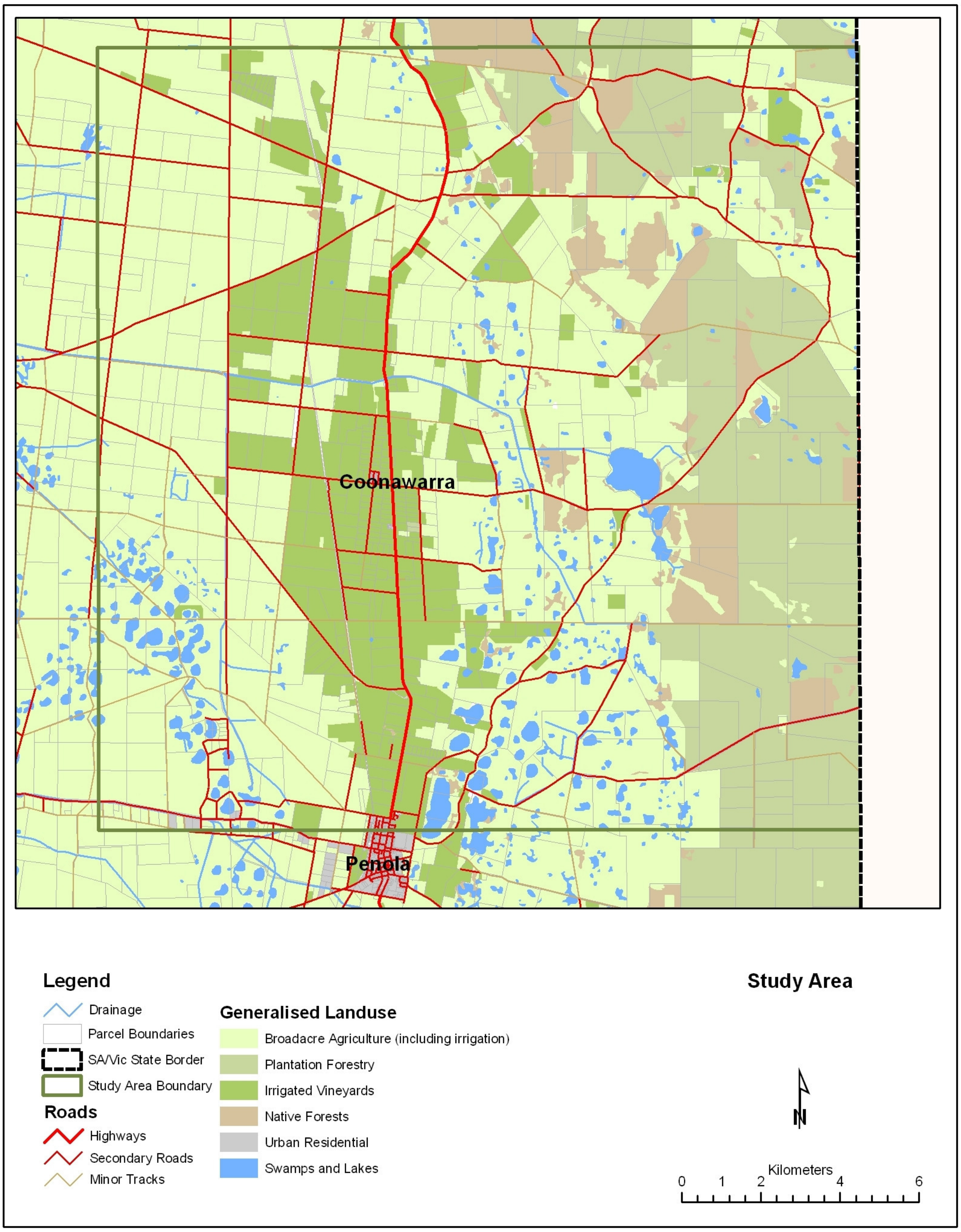

Figure 1.4: Study Area Map

Most of the study area is flat, with topography varying only a few metres. This flat landscape is contrasted by an elevated ridge diagonally crossing the north east corner of the study area. This ridgeline is the result of uplift along the Kanawinka Fault.

Given the generally flat terrain, there are no natural drainage features within the study area, and surface drainage is controlled through constructed surface drains. Prior to the construction of these drains, the surface water is likely to have ponded in much of the study area (Shepherd 1966).

The geology of the study area is dominated by marine and lacustrine deposits of Eocene to Pleistocene age. The surface geology is a mixture of bryozoal limestone, sandstone and clays. The limestone and sandstone deposits contain the regionally extensive unconfined aquifer that is recharged primarily through vertical surface infiltration.