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MODELLING THE IMPACTS OF DARFIELD AND KIRWEE WASTEWATER
DISCHARGES ON GROUNDWATER QUALITY

Modelling the Impacts of Darfield and Kirwee Wastewater Discharges on Groundwater Quality

✧ Prepared for
Selwyn District Council

✧ May 2011



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Executive Summary

This report considers the impacts of the existing and future wastewater discharges from the townships of Darfield and Kirwee on groundwater quality, with a particular focus on nitrate-nitrogen.

At present, there are no reticulated community wastewater schemes servicing Darfield and Kirwee. Wastewater generated in the houses is treated and discharged on-site, mostly via single chamber septic tanks and boulder holes.

The large thickness of unsaturated gravelly strata beneath the towns offers the underlying groundwater good protection from many contaminants in the wastewater, via attenuation processes that occur within that zone.

Nitrogen is one of the few contaminants in the wastewater that is not expected to be attenuated in the unsaturated zone. Nitrogen concentrations in groundwater are also becoming of increasing concern in Canterbury, due to intensification of land use. Groundwater monitoring indicates that current nitrate-nitrogen levels are elevated from land use in this area and are close to the Maximum Allowable Value in the Drinking Water Standards.

Comparison with other land uses in the area suggests the expected nitrogen leaching (mass of nitrogen leached per area) beneath Darfield and Kirwee from the wastewater discharges is comparable to irrigated arable land uses and low intensity dairy farming but is much higher than sheep grazing and unirrigated arable land use in this area.

Modelling has shown that the existing discharges from Darfield and Kirwee are likely to be causing a small increase in the nitrate-nitrogen concentrations in the groundwater beneath the townships. This effect decreases with distance from the townships due to dispersion. While the individual impact is expected to be small, the cumulative impact of the mass of nitrogen originating from the wastewater discharges in combination with the mass of nitrogen leaching from other land uses needs to be considered, with particular consideration of potential future land development, both residential and agricultural.

A reticulated wastewater treatment system that collected, treated and discharged wastewater from each town would not provide benefit in terms of reducing the nitrogen leaching to groundwater unless it could achieve significantly more nitrogen removal. Alternatives to a reticulated scheme are available to reduce the nitrogen leaching from each town, such as on-site treatment and disposal systems that provide better nitrogen removal than the current systems.

The groundwater quality impact is one of a number of environmental and economical factors that must be considered in any decisions on the method of wastewater treatment and disposal in Kirwee and Darfield. Ongoing groundwater quality monitoring and analysis to determine trends is important. Land use trends both within the townships and the surrounding areas should also be monitored, to assess changes in the overall mass of nitrogen entering groundwater.

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1.0 Introduction

This report outlines the potential impacts of the existing and future wastewater discharges from the townships of Darfield and Kirwee on groundwater quality, with a particular focus on nitrate-nitrogen.

At present, there are no reticulated community wastewater schemes servicing Darfield and Kirwee. Wastewater generated in the houses is treated and discharged on-site. Most houses are serviced by single chamber septic tanks and boulder holes (MWH, 2004). The permitted activity rule for the discharge of wastewater (Rule WQL9) in Environment Canterbury's (ECan) Proposed Natural Resources Regional Plan (NRRP) does not permit the use of boulder holes for the discharge, therefore, any wastewater from new houses in Darfield and Kirwee will need to be discharged via an alternate system, if the discharge is to be permitted under this rule. Consents granted for properties in some of the more recent subdivisions require treatment and disposal systems that offer a higher level of treatment than the traditional septic tank/boulder hole systems.

Previous reports have been undertaken by others on the potential impacts of these discharges on groundwater quality (e.g. Lewis and Barlow (1999) and MWH (2004)). This current study considers the potential impacts on groundwater quality in light of more recent information, such as the groundwater quality monitoring undertaken by Selwyn District Council (SDC) and ECan and recent census data.

This information has been prepared to assist SDC in their planning for future wastewater management in Darfield and Kirwee.

This report focuses on the potential impacts arising from the nitrogen contained within the discharged wastewater. The reason for this is that nitrogen is one of the few contaminants in the wastewater that is not expected to be attenuated in the unsaturated zone (Section 3.0 of this report), is frequently monitored in groundwater and has limits set in a number of regulations (Section 4.0 of this report). The concentrations of nitrogen in groundwater are also becoming of increasing concern in Canterbury, due to intensification of land use.

A map showing the study area is provided in Figure 1.

2.0 Local Hydrogeology

The Canterbury Plains comprise a series of large coalescing fluvio-glacial fans built by the main stem rivers (e.g. the Rangitata, Rakaia and Waimakariri). During successive glaciations when glaciers partly occupied the inland valleys and extended to the eastern foothills, great quantities of material eroded from rapidly rising mountains. Gravel with sand and silt material was transported eastwards and deposited to form the fans of gravel-dominated sediments that extend beyond the present day coastline. During these glacial periods, some re-sorting of the gravel deposits occurred due to alluvial processes (Brown 2001). During the warmer interglacial periods, the glaciers retreated up the

valleys and less new gravel material was transported out onto the plains. However, alluvial processes continued to re-work the gravels.

Beneath Darfield and Kirwee there are zones of better sorted, more permeable gravels created by alluvial re-working processes, inter-mixed with zones of poorly-sorted gravel. Depositional processes have created a high degree of anisotropy in the deposits, where the horizontal hydraulic conductivity is higher than in the vertical direction. The gravels are expected to be several hundreds of metres thick in this area and overlie the basement rock (Torlesse greywacke). They are saturated with groundwater over most of their thickness, although unsaturated conditions are present above the water table. ECan records indicate the depth to the water table is around 80-90 m beneath Darfield and around 75 m beneath Kirwee. Rain, irrigated water and wastewater drains through this unsaturated zone until it reaches and mixes with the underlying groundwater.

Soil maps for the area indicate that Darfield and Kirwee are built on Lismore shallow silt loam, which has an average profile available water of 95 mm. This falls into the category of a light, shallow soil (PAW of 75-110 mm).

Groundwater flows in a south-easterly direction at Darfield and a more southerly direction at Kirwee, as shown by the piezometric contours available on the ECan GIS database and reproduced in Figure 2. These contours were checked as part of this study through a review of concurrent water level measurements and for wells with similar depths. A very similar groundwater flow pattern was obtained through that review. Based on the contours in Figure 2, the average slope of the water table (the hydraulic gradient) across Darfield is about 15 m/km and about 4 m/km across Kirwee.

Any contaminants that drain through the large unsaturated zone and into groundwater beneath Darfield and Kirwee will be transported horizontally in the direction of groundwater flow. The average rate at which contaminants will be transported through the pore space in an aquifer is described by the average pore velocity. This can be calculated based on the hydraulic conductivity, hydraulic gradient and the effective porosity of the aquifer. The hydraulic conductivity of the aquifer can be derived from an estimate of transmissivity.

The calculation of the pore velocity is detailed in Appendix A. Based on the calculations, the average pore velocity beneath Darfield is expected to range between around 2 and 40 m/day while at Kirwee it is expected to range between around 0.5 and 10 m/day.

The average pore velocity describes the average rate at which contaminant transport is expected to occur. At small scales, there will be large variation in the actual velocities due to variation in pore size and shape and hydraulic conductivity, such as preferential flow paths through buried river channels (as shown in Dann et al. (2008)). For this study area, the average pore velocities are likely to be representative of contaminant transport over the scale of this study (a scale of around several hundred metres). Over this range, local variability in hydraulic conductivity (such as in channels) is less significant. There are no wells used for water supply within a kilometre down-gradient of Darfield and Kirwee.

3.0 Contaminants Present in Wastewater

Wastewater contains a number of different chemicals and microbes that can be harmful to human health and the natural environment. These originate from sources including human excrement, food waste and products such as pharmaceuticals, detergents, disinfectants and other household personal care and cleaning products.

The large unsaturated zone that exists beneath both Darfield and Kirwee is expected to provide for significant reduction in the number of microbial contaminants (bacteria, viruses and protozoa) due to filtration and the microbial decay that will occur over the long infiltration time through this zone. As a result, microbial contamination of the groundwater due to the discharges from Kirwee and Darfield is not expected.

A number of organic and inorganic chemicals are also likely to be attenuated by strata within the unsaturated zone (for example by filtration and adsorption), including most of any heavy metals present and phosphorous.

Nitrogen is one of the contaminants that is not expected to be retained or attenuated through the unsaturated zone. This is partly because the underlying strata are low in organic carbon, which does not provide a suitable environment for denitrifying bacteria. Some denitrifying bacteria may occur directly beneath the disposal systems, where organic carbon is available within the infiltrating wastewater. Overall, the mass of nitrogen entering groundwater is expected to be similar to that leaving the disposal systems.

Most houses in Darfield and Kirwee are currently serviced by single chamber septic tanks and boulder holes. Septic tanks offer a basic level of wastewater treatment and provide little in the way of nitrogen removal. Boulder holes are not expected to provide any nitrogen removal.

The expected concentrations for some of the constituents present in raw wastewater are presented in Table 1 below.

Table 1: Typical raw wastewater constituents	
Constituent	Typical Raw Wastewater
Total Suspended Solids (mg/L)	250
Total Nitrogen (mg/L)	50
Nitrate – Nitrogen (mg/L)	0
Total Phosphorous (mg/L)	10
Dissolved Reactive Phosphorous(mg/L)	8
Carbonaceous Biochemical Oxygen Demand (g.O₂-m³)	250
Faecal coliforms (cfu/100ml)	5 x 10 ⁶

Consents granted for properties in some of the more recent subdivisions require treatment and disposal systems that offer a higher level of treatment than the traditional septic tank/boulder hole systems. For example, effluent discharge consents for the 75 lot subdivision owned by Buttle Properties on Kimberley Rd require a sand filter disposal system rather than a boulder hole and the effluent discharge consents for the 59 lot subdivision owned by Stanwood Holdings on Mathias St require a membrane bioreactor treatment system (MBR), or an alternative wastewater treatment system that provides the same or better quality treatment. Sand filters are expected to remove 42% of nitrogen (ARC, 2004). Monitoring of MBR systems by Oasis Clearwater Environmental Systems Ltd has shown that they are capable of reducing nitrogen concentrations to a level that achieves an effluent concentration of around 13 mg/L, which is much less than the typical nitrogen concentration in septic tank effluent.

Drip-line irrigation systems are becoming a popular method of disposing wastewater for lifestyle blocks and in some subdivisions around Canterbury. Drip-line irrigation systems provide a high level of microbial removal but are also highly effective in removing nitrogen due to nitrogen uptake by plants covering the drip-line irrigation area. The nitrogen discharged to the environment for new properties with drip-line systems installed will be less than for properties with septic tank/boulder hole systems.

4.0 Groundwater Quality

A review of the latest groundwater quality monitoring results collected by SDC from wells in the Darfield/Kirwee area and a comparison with previous sampling results since 2006 has been undertaken by Liquid Earth (2011). Their findings are discussed in this section.

The report concluded that the sample results indicate groundwater quality in the Darfield/Kirwee area is high with few indications of contamination likely to be associated with on-site wastewater disposal in the Darfield/Kirwee townships. It is noted that areas of elevated major ion and nutrient concentrations are observed east of Darfield and along Station Road. The report attributed the poorer water quality in those areas to general land use activities across the contributing recharge area rather than existing wastewater disposal.

In the latest sampling round (January 2011), nitrate-nitrogen concentrations between Darfield and Kirwee ranged between 4.5 and 10.1 mg/L, while down-gradient of Kirwee concentrations of between 2.4 and 7.2 mg/L were observed. Hanson and Abraham (2009) suggested that concentrations of less than 2.9 mg/L suggest little or no influence from human activities. The recorded concentrations are above that expected for natural groundwater and indicate an impact from land use in the area.

Evidence for the poorer water quality east of Darfield and along Station Road not being directly attributable to wastewater discharges from Darfield or Kirwee, includes:

- ✦ Nitrogen isotope data analysed in previous sampling rounds suggested that the major nitrogen inputs into groundwater in the area result from agricultural sources

(fertiliser or soil mineralisation) rather than animal sources (e.g. wastewater discharge);

- ✧ A number of groundwater quality parameters (including electrical conductivity, chloride, nitrate, sodium, calcium and potassium) were found by Liquid Earth to be moderately to well correlated between individual wells suggesting common influences on groundwater quality across the study area with no obvious indications of localised contamination from existing wastewater discharge activities;
- ✧ Previous samples analysed for fluorescent whitening agents (FWA) do not indicate the presence of these compounds (directly associated with on-site wastewater disposal) within the study area.

An analysis of the available data has found statistically significant trends in individual water quality parameters in a total of ten wells. At these sites, variations in nitrate-nitrogen was the most frequently identified temporal trend, with six sites showing an increasing trend and one site exhibiting a declining trend.

The groundwater monitoring is carried out in wells with a range of screened depths below the water table. In general, contaminant concentrations would be expected to decrease with depth below the water table, as illustrated in Hanson and Abraham (2009). A review of the nitrate-nitrogen data for the Darfield/Kirwee area suggests that there is not a strong relationship between nitrate-nitrogen concentrations and screen depth below the water table in this monitoring data.

The January 2011 monitoring round included an additional deep well (L35/0806, 250 m deep) located immediately west (up-gradient) of the Darfield township. Given this well is screened around 100 m below the water table, it is unlikely to provide a good representation of the quality of the shallowest groundwater up-gradient of Darfield. The 54 m deep well L35/0171, which is about 5 km up-gradient of Darfield, has records of nitrate-nitrogen and other determinands dating back to the early 1980's. This well provides some information on the up-gradient quality and shows that recorded nitrate-nitrogen concentrations have ranged between 1.5 and 3.6 mg/L. These concentrations are lower than the typical measurements down-gradient of Kirwee and Darfield, which indicates a general deterioration in groundwater quality with distance down-gradient of L35/0171.

The Drinking Water Standards for New Zealand (MoH, 2005 revised 2008) specifies a maximum acceptable value (MAV) for nitrate-nitrogen of 11.3 mg/L for drinking water supplies. Objective WQL2.1(2)(a) of the NRRP states that the maximum concentration of nitrate-nitrogen in semi-confined, unconfined, and other confined aquifers shall not increase by more than 1.5 mg/L every ten years, if, during the life of the NRRP, the overall maximum nitrate-nitrogen concentration exceeds 5.6 mg/L in an aquifer. The rate is based on the overall maximum concentration measured or reasonably deduced in an aquifer in the three years prior to 1 November 2010. Objective WQL2.1(2)(b) states that the overall maximum nitrate-nitrogen concentration in any aquifer shall not exceed 11.3 mg/L.

Although there is insufficient evidence to suggest that the major ion and nitrogen concentrations observed east of Darfield and along Station Road are directly attributable to the wastewater discharge from Darfield and Kirwee, the nitrogen concentrations are of concern given that increasing trends have been observed and the concentrations are close to the MAV. It is important for this reason that nitrogen inputs to the groundwater system in this area are managed carefully.

Given that wastewater is rich in nitrogen, most nitrogen discharged to ground is expected to reach groundwater, there are good monitoring records of nitrogen concentrations and these records indicate current levels are close to the MAV, nitrogen has been chosen as the key contaminant for this modelling study. As nitrate-nitrogen is the form for which nitrogen is of most concern for groundwater drinking quality and the discharge is far from surface water bodies (which are more sensitive to other forms of nitrogen), this study focuses on nitrate-nitrogen.

Despite this focus on nitrogen, monitoring for the other contaminants associated with wastewater discharge should be continued in order to detect if any issues arise with those contaminants.

5.0 Comparison with Existing Nitrate-Nitrogen Sources

In this section of the report, the wastewater discharges are compared to the existing sources of nitrate in the Darfield/Kirwee area, to better understand their potential effects on groundwater nitrate concentrations.

Information on the type of systems and on the population and area of the each township was required to assess the amount of nitrate-nitrogen that could enter groundwater from the existing wastewater discharges.

The population of Darfield was obtained through the NZ 2006 census data for the town available on the Statistics NZ website (www.stats.govt.nz). The 2006 census is the most recent census, as the 2011 census that was due to take place on the 8 March 2011, was cancelled due to the 22 February 2011 Port Hills Fault earthquake.

The 2006 census data showed that there were 1482 people living in 567 households in the Darfield area. This gives an average of 2.6 people per household. Based on a typical wastewater generation rate of 200 L/person/day (ARC, 2004), the average predicted wastewater generation volume for the Darfield township is expected to be 296 m³/day.

Wastewater in Darfield is generally treated in individual septic tanks and discharged directly to soakage holes. The nitrogen loading and the degree of nitrogen removal provided by the system need to be estimated to assess the amount of nitrogen leaving each system. ARC (2004) quotes a number of sources that suggest the total nitrogen in raw wastewater can range between 8-13 grams per person per day (g/p/d). USEPA (2002) suggests a range of 6-17 g/p/d, while USEPA (1992) suggests an approximate value of 11.2 g/p/d. ARC (2004) also includes a reference to a report where 12 g/p/d is considered a conservative estimate of the total nitrogen per person contribution to

wastewater. Based on these ranges and recommendations, a value of 12 g/p/d has been adopted for this study, which is considered an appropriate typical value for Darfield. This treatment and disposal process consisting of septic tanks and boulder holes usually offers negligible removal of nitrogen, so no allowance has been made for any nitrogen reduction through the system.

Based on these figures, a total of 6500 kg of nitrogen could reach groundwater each year beneath the 248.4 ha area of Darfield as a result of the wastewater discharges. This is equivalent to a leaching rate of 26 kg nitrogen/hectare/year (N/ha/year), assuming that all the wastewater enters the groundwater directly below the township.

It is noted that the area of 248.4 ha that is classed as the "Darfield area unit" by Statistics NZ excludes some houses that appear on the 2010 satellite imagery (refer Figure 3). This may in part be due to growth that has occurred since that time. For this reason, the total amount of nitrogen reaching groundwater may be underestimated from the 2006 census. However, the mass of nitrogen leached per hectare is unlikely to have increased as the properties outside the zone appear to be larger in area.

While there is 2006 census information available for Kirwee, this refers to the general area (including Darfield) rather than the township itself. The ECan Online GIS system and the latest satellite imagery for Kirwee has been used to estimate that there are 350 dwellings in the township over an area of 129 ha. Assuming that the average number of people per household is roughly the same as Darfield (2.6 people per house) the estimated current population for Kirwee is around 900 people. Based on the typical wastewater generation rate of 200 L/p/day, the average predicted wastewater generation volume for the Kirwee township can be expected to be 180 m³/day.

Based on these estimated figures for Kirwee, a total of 3940 kg of nitrogen could enter groundwater each year beneath the 129 ha area. This equates to a leaching rate of 31 kg of N/ha/year, assuming that all the wastewater enters the groundwater directly below the township.

A soil moisture model was also set-up to calculate the range in expected nitrogen concentrations in the drainage water entering groundwater beneath each town, allowing for dilution with rainfall infiltration. This soil moisture modelling is outlined in Appendix B. The modelling showed that the concentration in the drainage water at the point it enters groundwater beneath Darfield will range from approximately 5 to 60 mg/L over the different months of the year, depending on the contribution of rainfall recharge. For Kirwee, the modelling indicated that the nitrate-nitrogen concentration in the drainage water will range from approximately 6 to 60 mg/L.

It should be noted that no sources of nitrogen other than wastewater have been included in the modelling for Darfield or Kirwee. In reality, it is likely that some people may use fertilisers in their gardens or have grazing animals on the larger lifestyle blocks which would increase the total amount of nitrogen leaching to groundwater. Bidwell et al. (2010) present a nitrogen leaching figure of 16 kg N/h/year for a lifestyle block in the

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Darfield area on a light soil (such as a Lismore shallow silt loam). It is not clear from the report what lot size this is for and what nitrogen sources are included in the calculation.

The Bidwell et al. (2010) report presents nitrogen leaching figures for a range of other land uses. These are summarised in Table 2 together with the predictions for Darfield and Kirwee.

From aerial photos and visits to the area, the most common land use in the Darfield/Kirwee area appears to be unirrigated sheep grazing and cropping (arable), although there are a number of irrigated properties. Comparison with the expected nitrogen leaching from Darfield (26 kg N/ha/year) and Kirwee (31 kg N/ha/year) indicates that the towns contribute much more nitrogen to groundwater, on an areal basis, than sheep grazing of the land. The nitrogen leached from the towns, per area, is comparable with irrigated arable land use but is still much higher than unirrigated arable land use. A similar areal leaching rate is expected for low intensity dairy farming, but higher intensity dairy farming is expected to leach much more nitrogen, per area, than the townships. On the basis that the surrounding area is still predominantly unirrigated, it could be expected that nitrate-nitrogen concentrations directly beneath the townships might be elevated above concentrations in the surrounding area. This could change with an increase in the area of irrigated land.

Table 2: Comparison of nitrogen leaching for different land uses¹			
Land -Use	Concentration in Drainage Water	Nitrogen Loading Rates	
Darfield Township	5 - 60 mg/L (wastewater only source of nitrogen accounted for)	26 kg/ha/year	
Kirwee township	6 - 60 mg/L (wastewater only source of nitrogen accounted for)	31 kg/ha/year	
Sheep	6.3 mg/L	No irrigation	8 kg/ha/year
		With irrigation	16-42 kg/ha/year
Arable	8-13 mg/L	No irrigation	8 – 19 kg/ha/year
		With irrigation	20 – 24 kg/ha/year
Dairy	9 -16 mg/L	With irrigation	24– 109 kg/ha/year
1. Sheep, arable and dairy values are from Bidwell et al. (2010) and vary based on type of irrigation (spray versus border dyke), number of cows/ha and seasonality of land use.			

6.0 Potential Nitrate Transport in Groundwater

When the nitrogen reaches groundwater, mixing will occur with the groundwater and the nitrogen will tend to migrate laterally in the direction of groundwater flow. The nitrogen concentrations will be reduced by dispersion effects, as it moves away from the point of discharge, provided the surrounding groundwater has a lower nitrogen concentration. To affect any down-gradient wells, the nitrogen will need to disperse (mix) over a vertical distance that is at least the distance between the lowest water level and the shallowest well screen.

The modelling described in this section has been carried out to assess the potential nitrate-nitrogen concentration changes in groundwater caused by the wastewater discharges in Darfield and Kirwee. The potential impacts of an increased population and reticulated systems are also considered. For the modelling, it has been assumed that all nitrogen in the drainage water could have undergone nitrification and therefore be in the form of nitrate when it eventually enters groundwater.

6.1 Base-case Scenario

A three-dimensional analytical model developed by Dr Bruce Hunt of the University of Canterbury (Hunt, 2008) has been used to model the transport of the nitrate-nitrogen through groundwater. The equation is based on the assumption that groundwater flows through a homogeneous and isotropic aquifer. The equation models a continuous discharge at a constant concentration from a line source. To model the discharges from Darfield as a line source, the entire mass flux of nitrogen (as determined in Section 5.0) was distributed along a 1400 m long line, which is the approximate width of Darfield perpendicular to the groundwater flow direction. This same approach was used for Kirwee, with the entire mass flux of nitrogen distributed along a 600 m long line, which is the approximate width of Kirwee perpendicular to the groundwater flow direction. The groundwater pore velocity and effective porosity were based on the values discussed in the local hydrogeology section of this letter.

A general relationship between dispersivity, which controls how the plume spreads in groundwater, and travel distance has been established from a number of international tracer tests. The test results show that the value of longitudinal dispersivity is generally in the order of one tenth of the travel distance, as illustrated in Fetter (1999) and Domenico and Schwartz (1990). As the dispersion is not scale dependent in the model used, the dispersivity was set iteratively to one tenth of the distance to the nitrate-nitrogen concentration of interest. The transverse and vertical dispersivities were set to typical ratios of 10% and 1%, respectively, of the longitudinal dispersivity.

The model was used to investigate over what extent the wastewater discharges may be increasing nitrate-nitrogen concentrations by 11.3 mg/L (the MAV). The model was also used to investigate over what extent an increase of 1.5 mg/L might be occurring as per Objective WQL2.1(2)(a) of the PNRRP. This objective is relevant as nitrate-nitrogen concentrations above 5.6 mg/L have already been observed in the area, although the

1.5 mg/L change from the wastewater discharges could be considered a part of the current environment.

The model results are summarised in Table 3. The predicted extents of the 1.5 mg/L change in nitrate-nitrogen are also illustrated in Figure 4. The modelling for Darfield is based on the expected possible range in groundwater pore velocities of 2 to 40 m/day. For Kirwee, the modelling is based on the expected possible range in groundwater pore velocities of 0.5 to 10 m/day. The modelled extents are for the changes that occur at the water table. The concentrations are highest at the water table, where the wastewater enters groundwater, and decrease with depth.

Table 3: Contaminant transport model results (base case)		
Scenario	Darfield	Kirwee
Distance from township with concentration increase > 11.3 mg/L (MAV)	Up to 15 m	Up to 70 m
Distance from township with concentration increase > 1.5 mg/L (PNRRP Objective)	20 to 100 m	110 to 550 m

Table 3 shows that the predicted extent of the nitrogen impact is greater for Kirwee than Darfield. This is because the calculated groundwater velocity is lower at Kirwee, which means that there is slower dilution of the wastewater, and the wastewater discharges are more concentrated than Darfield (more discharges per hectare).

6.2 Sensitivity Analysis

The model results provided in Table 3 incorporate uncertainty in the groundwater pore velocities. Further modelling was carried out to assess the sensitivity of the model to various dispersivity values. Over the scale of the modelling (several hundred metres), dispersion is primarily controlled by variations in hydraulic conductivity values (Domenico and Schwartz, 1990). While the longitudinal dispersivity is generally expected to be in the order of one tenth of the travel distance, there is a range in reported values. Figure 10.11 in Domenico and Schwartz (1990) shows that the reported range in longitudinal dispersivity values for international tracer tests ranges from around 1% to 100% of the travel distance over the scale of interest for this study. Table 4 presents the model results for this range in dispersivity values. These reported ranges in extents are for the same range in pore velocities and transverse and vertical dispersivity ratios used for the base-case scenario.

Table 4: Contaminant transport model results (sensitivity analysis)		
Scenario	Darfield	Kirwee
Distance from township with concentration increase > 11.3 mg/L (MAV)	Up to 40 m	Up to 225 m
Distance from township with concentration increase > 1.5 mg/L (PNRRP Objective)	10 m to 300 m	30 m to 1700 m

The predicted concentrations and their extents are not particularly sensitive to the values used for transverse dispersivity as the plume is already distributed in the direction perpendicular to groundwater flow due to the dispersed nature of the on-site wastewater discharges. The sensitivity of the predicted concentrations for the vertical dispersivity, which controls vertical mixing, has not been considered for values less than 1% of the longitudinal dispersivity as smaller values typically result in less than 10 m of vertical mixing over the scale of interest. Most wells will be screened more than 10 m below the water table.

Most of the distances that have been predicted are smaller than the scale for which the model can be expected to provide realistic results (several hundred metres). In reality, the nitrate will be dispersed over a wider area (the area of the township) rather than a line, and therefore the concentration changes will be less. Local variation in hydraulic conductivity will cause some variation in the travel distance of the nitrate.

What the modelling does show is that the expected impact of Darfield and Kirwee on nitrate-nitrogen concentrations, when considered in isolation of other nitrogen sources, is small and limited in extent. This is consistent with the lack of an observable impact from Darfield and Kirwee townships in the groundwater monitoring data.

6.3 Increased Population

An increased population in Darfield and Kirwee will result in an overall increase in the mass of wastewater-derived nitrogen reaching groundwater, but the characteristics of the resulting nitrogen plume would depend on where the new development is located. For example, if the new development in Darfield occurred to the northeast and southwest of the current township (in the direction perpendicular to groundwater flow), this would result in a wider nitrogen plume but would not increase the peak concentrations. Alternatively, if the new development was located northwest and southeast of the current township (parallel to the groundwater flow direction), the width of the plume would not increase but the peak nitrogen concentrations and distance of elevated nitrogen concentrations would increase.

As an example, a model has been set-up to replicate what might occur if the population of Darfield doubled in size to around 3000 people (from 1482 people in 2006) and all new development occurred to the northeast and southwest of the existing town. This was modelled by doubling both the mass of nitrogen discharged and the length of the line

source. The modelling showed that, as expected, the plume would double in width (to 2800 m) but the down-gradient extent of the plume would not change.

6.4 Reticulated System

Consideration has also been given to the nitrogen impacts from a single reticulated wastewater treatment system that collected, treated and discharged wastewater from each town. Over the scale of interest for this study, the wastewater discharges would effectively change from an areal source (a number of discharges spread across each town) to a point source. If there was no change in the amount of nitrogen removed via the reticulated system, higher nitrate nitrogen concentrations would be expected to occur in the groundwater beneath and directly down-gradient of the discharge point than for the existing case of on-site treatment and disposal. The nitrogen plume would be narrower but would be more concentrated and extend over a larger distance down-gradient.

If a reticulated system was considered solely with respect to nitrogen concentrations, there would be no reason to change to such a system unless it could provide significantly more nitrogen removal than a standard on-site system. Consideration would also need to be given to the benefit of using a reticulated system over upgrading the on-site systems. For example, wastewater on larger sections could be discharged via drip line irrigation systems, which provide good removal of nitrogen. Alternatively, more advanced on-site treatment systems that provide for nitrogen removal could be used for existing system upgrades or new houses.

6.5 Mass-mixing Model

The model described in the preceding section is useful for looking at the impacts of the wastewater discharges in isolation. Far from the source, the predicted concentrations can be viewed as the likely increase in nitrate-nitrogen concentrations at the water table caused by the wastewater discharges. However, directly beneath the town the predicted change of 11.3 mg/L is only relevant if the background concentrations are 0 mg/L. If not, then a mixing calculation is required. For example, if wastewater containing 60 mg/L of nitrogen enters groundwater that has a background concentration of 10 mg/L, the resulting concentration is not 70 mg/L, it is somewhere between 10 mg/L and 60 mg/L depending on the mixing that occurs.

Because the background concentrations are greater than zero, a mass-mixing model has also been set-up to calculate the resulting concentration after mixing over a depth of 10 m. A value of 10 m has been chosen, as most wells will be screened more than 10 m below the water table. The nitrogen from the wastewater discharges would need to mix over at least this depth to cause a change in the well water nitrogen concentrations.

For Darfield, the background nitrogen concentration was set to the average nitrate-nitrogen concentration over the last 10 years in the up-gradient bore L35/0171. For Kirwee, the background nitrogen concentration was set to the average nitrate-nitrogen concentration over the last 10 years in the up-gradient bore L35/0191, the public supply well. The same groundwater flow velocity and town widths as used in the plume model

(previous model) were used. The same mass flux was applied (12 g/pp/day) and the calculate rainfall recharge and wastewater recharge (described in Appendix B) were used in the mixing calculation. Table 5 summarises the results.

Table 5: Mixing Model Results		
Scenario	Darfield	Kirwee
Background concentration (up-gradient)	3.0 mg/L	3.7 mg/L
Down-gradient concentration (after complete mixing over 10 m)	4.2 mg/L	8.2 mg/L

Table 5 shows that the concentration changes are larger for Kirwee than Darfield. This is because the calculated groundwater velocity is lower at Kirwee, which means that there is less dilution of the wastewater, and the wastewater discharges are more concentrated than Darfield (more discharges per hectare).

The mass mixing model is useful for considering the nitrogen concentrations that may occur directly beneath the townships, after mixing with the groundwater. As the nitrogen travels away from the town, the concentrations will decrease due to dispersion, which is not accounted for in the mass mixing model. The plume model (the previous model) is more useful for considering those changes that occur down-gradient of the town, as it incorporates dispersion.

6.6 Nitrate Transport Summary

To summarise, the existing discharges from Darfield and Kirwee are expected to be causing a small increase in the nitrate-nitrogen concentrations in the groundwater beneath the townships. The increase in nitrate-nitrogen decreases with distance from the townships due to dispersion. The effects of an increased population will depend on the location and density of the new development. A reticulated system would result in a more concentrated discharge of nitrogen with a more extensive plume in the groundwater flow direction, unless the reticulated system was efficient in removing nitrogen.

Whilst the nitrogen in Darfield and Kirwee's wastewater does not appear to be causing any widespread groundwater contamination, the wastewater does contribute to the overall mass of nitrogen entering the groundwater system, although at a lower rate than some other land use activities. Nitrogen concentrations in the area are already elevated above typical concentrations for unaffected groundwater. Consideration of the cumulative mass of nitrogen entering groundwater catchments is an emergent issue in Canterbury.

7.0 Localised Effects on Community Supply Wells

A review of the individual and community water supplies in the area was carried out to assess whether the wastewater discharges from Darfield or Kirwee could affect any water supplies. The Darfield community supply is sourced from areas up-gradient of the proposed project site and off the Waimakariri River, and therefore the wastewater discharge from Darfield will not affect the quality of the existing Darfield community supply. If wells are to be used for future supply, it would be preferable to use a deep well to avoid elevated nitrogen concentrations arising from general land use in the area.

Kirwee is supplied by the only community supply well listed on the ECan Online GIS database in the Darfield/Kirwee study area, which is the 115 m deep well L35/0191. This well is located about 7.5 km east of Darfield, just up-gradient of Kirwee (the location is shown in Figure 5). The well has experienced nitrate-nitrogen concentrations of between 3 and 5 mg/L, with no obvious increasing trend. Based on the piezometric contours, this well is more cross-gradient than down-gradient from Darfield, although lateral dispersion of the nitrogen plume could possibly result in nitrogen from Darfield entering this well. However, the modelled area of elevated nitrogen concentrations from the Darfield wastewater discharges does not extend to this well and therefore the Kirwee community supply well is not likely to experience any direct effect from wastewater discharges in Darfield.

The measured water levels in the Kirwee supply well L35/0191 and the surrounding area suggest that the well screen is around 30 m below the water table. For nitrogen derived from the Kirwee wastewater discharges to enter this well, mixing would need to occur over a 30 m depth. It is possible that drawdown of the water table with pumping and vertical flow could result in some of the wastewater-derived nitrogen entering the well, although the concentrations to date are not of concern for drinking water quality. Dilution that would occur with groundwater mixing between the water table and the well screen will reduce the concentration of nitrogen from that at the water table. Regular water quality monitoring should continue to assess whether an increased population in Kirwee is impacting on the quality of the water in terms of nitrate-nitrogen.

Other wells recorded as drinking water supply wells down-gradient of each town are listed in Table 6. Although the wells are not shown as community supply wells on the ECan GIS systems, the well cards for two other wells, L35/0527 and L35/0528 (refer Table 6), suggest these wells are used as public supply wells.

The locations of the wells listed as being used for drinking water supply in the study area are also shown on Figure 5. The distances to the nearest supply wells are greater than the expected extent of the area where the wastewater discharges will cause nitrate-nitrogen to increase above the MAV (11.3 mg/L), so are not expected to be directly adversely affected by the current wastewater discharges.

Table 6: Closest wells down-gradient of towns

Well	Distance	Depth	Comment on ECan well card
L35/0282	~1.5 km from Darfield	No recorded depth	Well unlikely to exist
L35/0598	~2 km from Darfield	125 m	Well not used. Water level range 94 to 97.4 mbgl.
L35/0729	~4 km from Darfield	125 m	Uses: Domestic Supply, Stockwater and Irrigation
L35/0527	~4 km from Darfield	101 m	Uses: Domestic Supply, Irrigation, Public Water Supply
L35/0528	~4 km from Darfield	109 m	Uses: Domestic Supply, Irrigation, Public Water Supply
L35/0813	~1.7 km from Kirwee (in southwest direction, not directly down-gradient)	125 m	Uses: Domestic Supply, Stockwater and Irrigation
L35/0219	~2.9 km from Kirwee	105 m	Uses: Domestic Supply, Stockwater and Irrigation
L35/0818	Adjacent to new development to north of township	120 m	Proposed well. Proposed use: Domestic supply

8.0 Cumulative Effects

As outlined in Section 6.0, while the wastewater discharges from Darfield and Kirwee are not expected to directly affect the drinking water quality in down-gradient wells, the amount of nitrate-nitrogen leached to groundwater in the area will contribute to cumulative nitrate-nitrogen changes from land use in the area. The existing nitrogen concentrations in some of the monitoring wells are of concern given that increasing trends have been observed and the concentrations are close to the MAV, indicating that groundwater quality in the area is being impacted by land-use. If more nitrogen is released to groundwater as a result of an increase in housing around Darfield and Kirwee or from land in this area being used for more intensive purposes such as for irrigated dairying or cropping, then the nitrate-nitrogen concentrations in groundwater can be expected to increase. It is possible that the nitrogen concentrations in drinking water supplies in the area could increase above the MAV with land use development.

The groundwater passing through this area will eventually make its way to the sea or emerge in spring-fed streams near the coast. Some of the groundwater will be abstracted for irrigation, industrial use or for domestic and public water supplies along the way. The way development in the wider area around Darfield and Kirwee is managed will have a direct effect on the downstream groundwater quality and the viability for down-gradient groundwater derived drinking water supplies to continue to be used. It is important for

this reason that nitrogen inputs to the groundwater system in this area are managed carefully.

The Canterbury Water Management Strategy (CWMS) is currently working towards setting catchment load limits for nitrates to control the total volume of nitrogen discharged in Canterbury catchments to protect the quality of the water resource. The targets include:

- ✧ Setting catchment load limits for nitrates consistent with drinking water quality targets for each zone.
- ✧ Achieving a demonstrable decrease in nitrate concentrations in shallow groundwater in priority areas.
- ✧ Average annual nitrate levels in all groundwater wells to be below 50% of maximum allowable value for drinking water.
- ✧ Achieving nutrient efficiency targets on all new irrigated land and 100% of other rural properties (and properties within urban boundaries that apply nutrients over significant areas). It is envisaged that this would involve specifying the total mass of nitrogen that could be applied in a catchment and/or specifying a maximum leaching rate from land use on a mass per area basis.

The mass of nitrogen originating from wastewater discharges in the townships of Darfield and Kirwee and other residential properties in the area will need to be accounted for in the future calculations for the Selwyn-Waihora Zone (the relevant CWMS catchment) and controlled in line with this strategy.

9.0 Conclusions

The large thickness of unsaturated gravelly strata that exists beneath Darfield and Kirwee offers the underlying groundwater good protection from a number of contaminants in wastewater discharges, particularly microbial contaminants, due to filtration, adsorption and microbial decay processes that occur within that zone.

Nitrogen, however, will reach groundwater as it is transported in infiltrating wastewater and rain through the unsaturated zone and is not likely to be retained or attenuated within that zone. This study has focused on the nitrogen because:

- ✧ the nitrogen discharged to ground is expected to reach groundwater
- ✧ wastewater is rich in nitrogen
- ✧ there are good monitoring records of nitrogen concentrations in groundwater
- ✧ the monitoring records indicate current levels are elevated from land use in the area and are close to the MAV

As nitrate-nitrogen is the form for which nitrogen is of most concern for groundwater drinking quality and the discharge is far from surface water bodies (which are more sensitive to other forms of nitrogen), this study has considered the case where all nitrogen is in the form of nitrate-nitrogen.

Wastewater in Darfield and Kirwee is treated and discharged on individual lots, typically via a septic tank and boulder hole. This system provides little in the way of nitrogen removal.

Comparison with other land uses in the area suggests that the expected nitrogen leaching (mass of nitrogen leached per area) beneath Darfield and Kirwee from the wastewater discharges is comparable to irrigated arable land uses and low intensity dairy farming but is much higher than sheep grazing and unirrigated arable land use in this area.

Modelling has shown that the existing discharges from Darfield and Kirwee are likely to be causing a small increase in the nitrate-nitrogen concentrations in the groundwater beneath the townships. The increase in nitrate-nitrogen decreases with distance from the townships due to dispersion.

While the individual impact of Darfield and Kirwee on nitrogen concentrations in groundwater is expected to be small, the cumulative impact of the mass of nitrogen originating from the wastewater discharges in combination with the mass of nitrogen leaching from other land uses needs to be considered, particularly with changing land use.

The Canterbury Water Management Strategy is currently working towards setting catchment load limits for nitrates to control the total volume of nitrogen discharged in Canterbury catchments to protect water quality. The mass of nitrogen originating from wastewater discharges in Darfield and Kirwee and other residential properties in the area will need to be accounted for in the future calculations for the Selwyn-Waihora Zone (the relevant CWMS catchment) and controlled in line with the strategy.

10.0 Recommendations

When considered in isolation, the impacts of the Darfield and Kirwee wastewater discharges on groundwater quality are expected to be small and limited in extent. However, the impact of the nitrogen leaching when considered in combination with other land use in the area and potential future land development, both residential and agricultural, is a potential concern given that nitrogen concentrations in the area are already elevated.

A reticulated wastewater treatment system that collected, treated and discharged wastewater from each town would not provide benefit in terms of reducing the nitrogen leaching to groundwater unless it could achieve significantly more nitrogen removal. In fact, if the nitrogen removal offered was no greater than for a septic tank/boulder hole system, the resulting nitrogen plume arising from the discharge of the each town's treated wastewater at a single location would be more concentrated (higher nitrogen concentrations) and extend over a larger distance down-gradient.

Alternatives to a reticulated scheme are available to reduce the nitrogen leaching from each town. These include discharging wastewater on individual properties via a drip-line

irrigation system rather than a boulder hole or sand filter or treating the wastewater on-site via a more advanced system that achieves a higher degree of nitrogen removal.

The groundwater quality impact is one of a number of environmental and economical factors that must be considered in any decisions on the method of wastewater treatment and disposal in Kirwee and Darfield. The cost to the community of installing and maintaining a reticulated system or more advanced on-site systems will need to be considered. At present, the typical system of treating via a septic tank and discharging to a boulder hole or sand filter has some environmental benefits over a reticulated system and more advanced on-site treatment systems. The materials used typically have a low environmental impact in their sourcing and manufacture (for example concrete septic tanks and boulder holes), they require little or no energy to run (depending on whether the system is gravity run or run with a pump) and very little pipework is required. A reticulated system would require a significant network of pipes to be installed and maintained and energy to pump and treat the wastewater.

Ongoing groundwater quality monitoring and analysis to determine trends is important. Furthermore, current land use trends both within the townships and the surrounding areas should be monitored, with reference to the overall mass of nitrogen entering groundwater.

References

- Auckland Regional Council (ARC). (2004). On-site Wastewater Systems: Design and Management Manual, Technical Publication No.58 (TP58), Third Edition.
- Bal, A. A. (1996). Valley fills and coastal cliffs buried under an alluvial plain: evidence from variation of permeabilities in gravel aquifers, Canterbury Plains, New Zealand. *Journal of Hydrology (NZ)*, 35(1), 1-27.
- Bidwell, V., Lilburne, L., Webb, T., Ford, R. (2010) Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury. Environment Canterbury Report No. R10/127. September 2010
- Brown, L J. (2001). Canterbury; In *Groundwaters of New Zealand*, M R Rosen and P A White (eds) New Zealand Hydrological Society Inc, Wellington. p 441-459.
- Dann, R., Close, M., Pang, L., Flintoft, M. and Hector, R. (2008). Complementary use of tracer and pumping tests to characterize a heterogeneous channelized aquifer system in New Zealand. *Hydrogeology Journal*. Volume 16. Number 6.
- Domenico, P. and Schwartz, W. (1990). *Physical and Chemical Hydrogeology*. John Wiley and Sons.
- Fetter, C.W. (1999). *Contaminant Hydrogeology*. Second Edition. Prentice-Hall, New Jersey.
- Hanson, C. and Abraham, P. (2009). Depth and spatial variation in groundwater chemistry - Central Canterbury Plains. Environment Canterbury Report R09/39
- Hunt, B. 2008. Groundwater analysis using FUNCTION.XLS. Available online at <http://www.civil.canterbury.ac.nz/staff/bhunt.shtml> . Last Update: 15 August 2008
- Lewis and Barlow Ltd. (2004). The Potential for Adverse Effects on Groundwater Quality due to Cumulative Effects of On-Site Effluent Disposal at West Melton, Kirwee and Darfield. Prepared for Selwyn District Council. May 1999.
- Liquid Earth. (2011). Darfield/Kirwee Groundwater Monitoring February 2011 Update. Prepared for Selwyn District Council. February 2011.
- Ministry of Health (MoH). (2005). *Drinking-water Standards for New Zealand 2005*. Ministry of Health, Wellington, New Zealand.
- Montgomery Watson Harza (MWH). (2004). Darfield Sewage Options Technical Appraisal. Prepared for Selwyn District Council. 19 January 2004.
- USEPA. (1992). *Wastewater Treatment/Disposal for Small Communities Manual* EPA/625/R-92/005. September 1992.
- USEPA. (2002). *Onsite Wastewater Treatment Systems Manual* EPA/625/R-00/008. February 2002

Appendix A – Average Pore Velocity Calculation

A review of specific capacity data, step test data and constant rate pumping test data was undertaken with the purpose of obtaining an estimate of the transmissivity of the aquifer to use to calculate the average pore velocity.

To obtain an estimated transmissivity from specific capacity data near Darfield, specific capacity values were selected for wells up to 135 m deep within 5 km of the Darfield centre, as the specific capacity values from these wells were considered to be more representative of the permeability of the material at the water table than values from deeper wells. A geometric mean transmissivity of 760 m²/day was calculated from the 15 specific capacity values using the Bal (1996) equation.

To obtain an estimated transmissivity from specific capacity data near Kirwee, specific capacity values were selected for wells up to 135 m deep within 4 km of Kirwee. A lesser radius was required to obtain sufficient data as there are more wells in this area than around Darfield. Values from shallow wells near the Waimakariri were also excluded as these were not considered representative of the material at the water table beneath Kirwee. A geometric mean transmissivity of 830 m²/day was calculated from the 30 specific capacity values using the Bal (1996) equation.

There are some transmissivity estimates available on the ECan database derived from step-test data and constant-rate test data in this area of Canterbury. These are shown in Table 7. The values for the wells up to 131 m deep are considered most representative of the strata at the water table.

To convert the estimates of transmissivity to hydraulic conductivity values, it was assumed that the transmissivity estimates were representative of a 10 m thickness of strata. Based on the values described above, most calculated hydraulic conductivity values fall within a range of 50 to 250 m/day.

The effective porosity values for the gravel strata are likely to fall within the range of 0.1 to 0.4.

Based on these values and the piezometric gradients at Darfield and Kirwee, the average pore velocity beneath Darfield is expected to range between around 2 and 40 m/day while at Kirwee it is expected to range between around 0.5 and 10 m/day.

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Table 7: Transmissivity (T) estimates from step-test data and constant-rate test data¹

Well	Step test T (m ² /day)	Constant rate test T (m ² /day)	Depth (m)	Distance from Darfield (km)	Distance from Kirwee (km)
L35/0557		1094 ⁴	59	8.0	15.4
L35/0185	65 ²		111	10.0	1.8
L35/0191	1950 ³		115	8.1	0.6
L35/0522	1100		118	5.3	3.1
M35/9628	500	1210 ⁵	120	12.3	3.9
L35/0685		2500 ⁶	131	6.3	2.2
L35/0687	1200		212	11.0	3.9
L35/1067	2750	2500	218	11.6	4.7
L35/0277	200		265	2.6	10.9
1. ECan consider reliable aquifer tests and analyses are those with Reliability <=2 and Parameter Accuracy <=3) 2. The ECan aquifer test card notes that this is a very low reported T for the area and a T of 1500 m²/day would be expected. 3. Parameter accuracy 3, Reliability 3 4. Reliability 1 5. Parameter accuracy 3, Reliability 2 6. Parameter accuracy 4, Reliability 3					

Appendix B – Soil Moisture Calculations

Soil moisture modelling was carried out to calculate the range in expected nitrogen concentrations in the drainage water entering groundwater beneath Darfield and Kirwee, allowing for dilution with rainfall infiltration.

To calculate daily drainage rates, daily records of rainfall at the nearest rainfall station (Christchurch Airport) and evapotranspiration recording station (Lincoln) were obtained from the beginning of January 1967 to the end of April 2006 (around the time of the 2006 census). The profile available water of the soil was set to the average value for the Lismore shallow silt loam of 95 mm. A daily soil moisture balance model was then created which incorporated the rainfall and evapotranspiration to calculate the daily drainage to groundwater. This was then used in conjunction with loading rates of nitrate-nitrogen to assess the nitrate-nitrogen concentrations in the drainage water reaching to groundwater.

The soil moisture balance model for the townships was set up in two parts. Firstly, the amount of recharge per hectare was calculated without the wastewater recharge using the rainfall and evapotranspiration data. The purpose of this was to assess how much rainfall recharges the groundwater beneath each town. It is recognised that this number may be less than the actual recharge as rainfall that lands on hard standing areas and roofs is likely to be directed directly to groundwater via boulder holes without passing through the surface soils. Secondly, a soil moisture balance model was set up to assess the total flow through the boulder holes. The area of the boulder holes was set to 4 m² (based on information from a local septic tank cleaner reported in MWH (2004)), although the area of this has little influence on the soil moisture balance modelling. As the application rate will be much greater than the water holding capacity of the gravels (or any other material used in the soak holes), the water holding capacity of the soils has no effect on the calculated recharge through the boulder holes as it will always be exceeded (there will be no storage). It was convenient to incorporate the boulder holes into the soil moisture model, although as evaporation and rainfall rates were much lower than the wastewater application rate, this was not strictly necessary. For Darfield, the modelling was carried out on the basis that there are 2.3 boulder holes per hectare (the count of 570 occupied dwellings was for an area of 248.4 ha that is classed as the "Darfield area unit" by Statistics NZ). The ECan Online GIS system and the latest satellite imagery for Kirwee was used to estimate that there are 350 dwellings in the township over an area of 129 ha (which gives 2.7 boulder holes per hectare).

It was assumed that by the time the wastewater enters groundwater, it is likely to have mixed with any rainfall recharge water that is travelling towards groundwater beneath the towns due to lateral dispersion. Some lateral dispersion is expected to occur due to tortuosity and as the wastewater application rate through the boulder holes (0.13 m/day for a 4 m² boulder hole) is likely to be greater than the vertical hydraulic conductivity of parts of the underlying strata. When the wastewater encounters any layers with a

Modelling the Impacts of Darfield and Kirwee Wastewater Discharges on Groundwater Quality

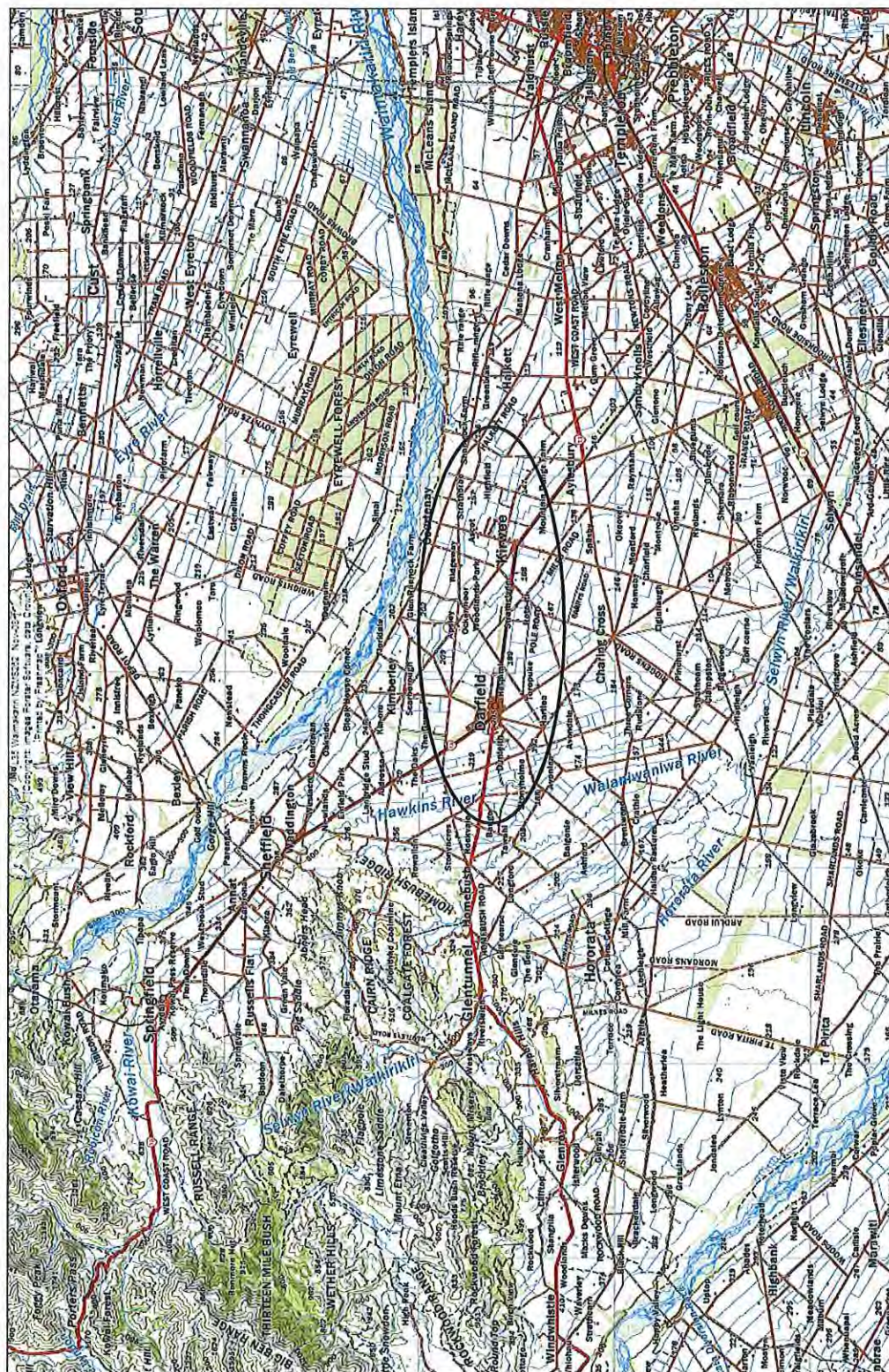
hydraulic conductivity of less than 0.13 m/day it will pond on these layers and spread laterally.

It was also assumed that all the wastewater enters the groundwater directly below each township. Based on this assumption, the modelling showed that the concentration in the drainage water at the point it enters groundwater beneath Darfield will range from approximately 5 to 60 mg/L over the different months of the year, depending on the contribution of rainfall recharge. A total of 26 kg of N/ha/year could enter groundwater under the Darfield township as a result of the wastewater discharges (6500 kg of nitrogen over the 248.4 ha area). Note that the total mass of nitrogen reaching groundwater is independent of the wastewater volume and rainfall recharge and can be simply calculated by the assumed nitrogen generation rate of 12 g/p/day and the 2006 population of 1482 people.

For Kirwee, the modelling showed that the concentration in the drainage water at the point it enters groundwater will range from approximately 6 to 60 mg/L over the different months of the year, depending on the contribution of rainfall recharge. A total of 31 kg of N/ha/year could enter groundwater under the Kirwee township as a result of the wastewater discharges (3940 kg of nitrogen over the 129 ha area).

The mass flux (kg/yr) is the relevant value for the contaminant transport model described in Section 6.0. The purpose of the soil moisture modelling was to gain an understanding of the likely range in nitrogen concentrations in the drainage water reaching the water table. The calculated rainfall recharge and wastewater recharge is also used in the mass-mixing model (Section 6.5). Table 8 summarises the inputs and outputs of the soil moisture modelling.

Table 8: Parameter values used for Darfield and Kirwee wastewater		
Parameter	Darfield Township	Kirwee Township
Expected wastewater generation rate	200 L/pp/day	200 L/pp/day
Expected household occupancy rate	2.6 people per house	2.6 people per house
Expected nitrogen generation rate per person	12 g/person/day	12 g/person/day
Expected number of disposal systems	2.3 per hectare	2.7 per hectare
Total expected wastewater flow rate	440 m ³ / hectare/year	510 m ³ / hectare/year
Total expected rainfall recharge	1350 m ³ / hectare/year	1350 m ³ / hectare/year
Nitrogen concentration in rainfall recharge	Set to 0	Set to 0
Nitrogen generation rate	12 g/pp/day	12 g/pp/day
Percentage nitrogen removal in treatment and disposal system	0 %	0 %
Mass of nitrogen expected to enter groundwater	26 kg/ha/year	31 kg/ha/year
Concentration in drainage water	5 - 60 mg/L	6 - 60 mg/L



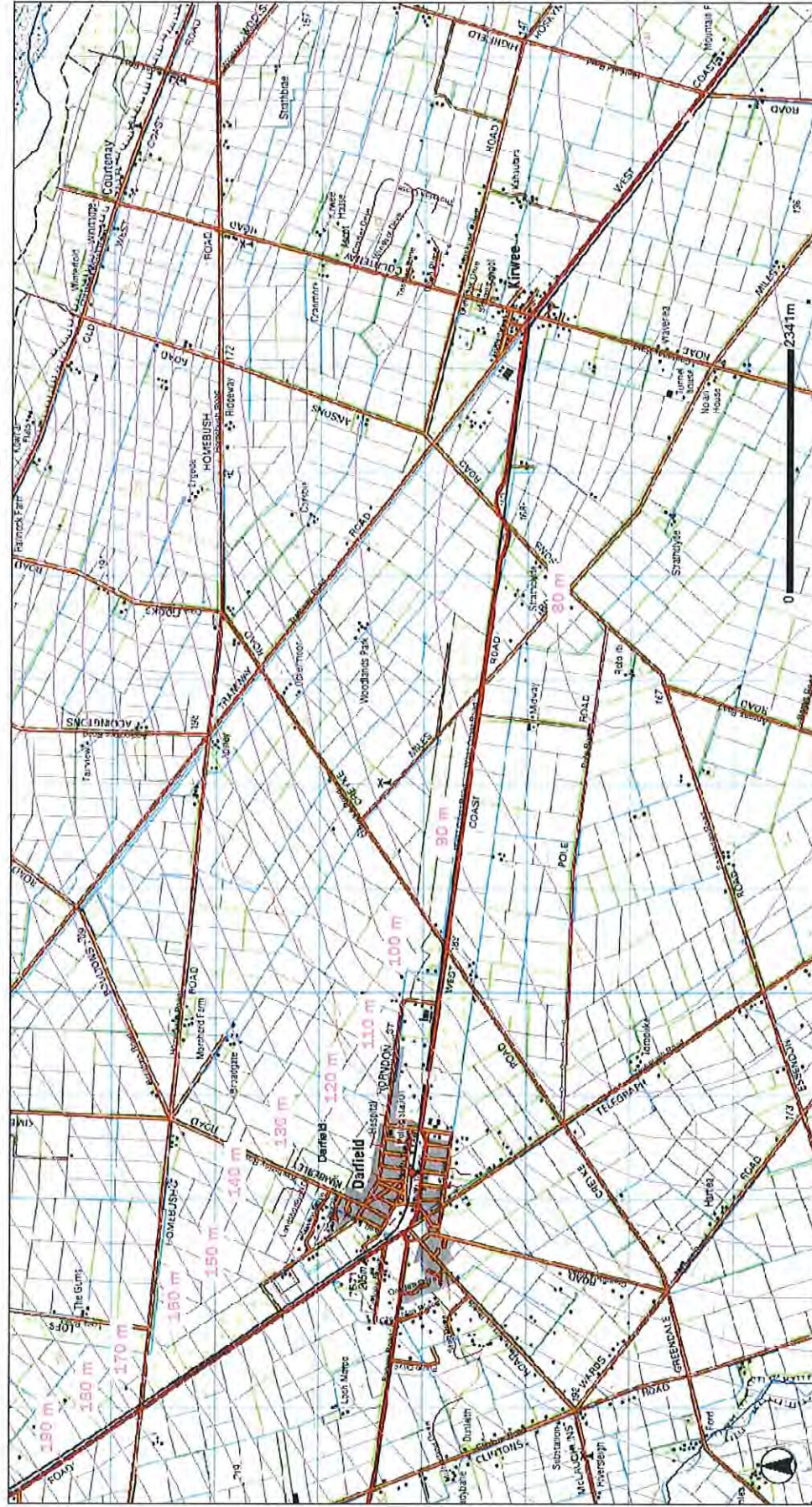


Figure 2: Piezometric contours



Figure 3: Darfield area included in 2006 census (top image) and satellite image taken on 3 August 2010 (lower image) showing residential areas within and outside census area

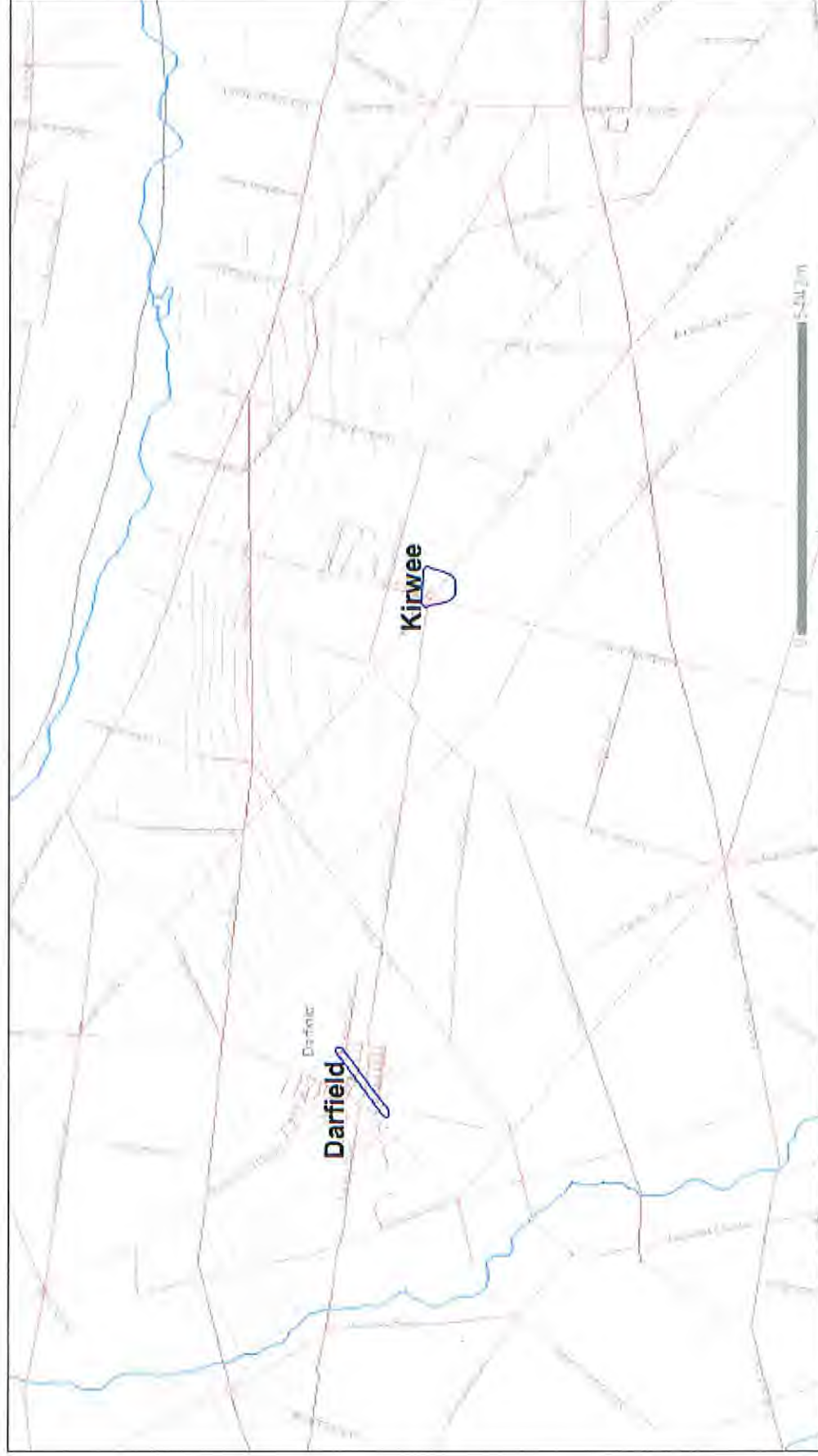


Figure 4: Predicted extent of 1.5 mg/L change for base-case scenario (blue line)

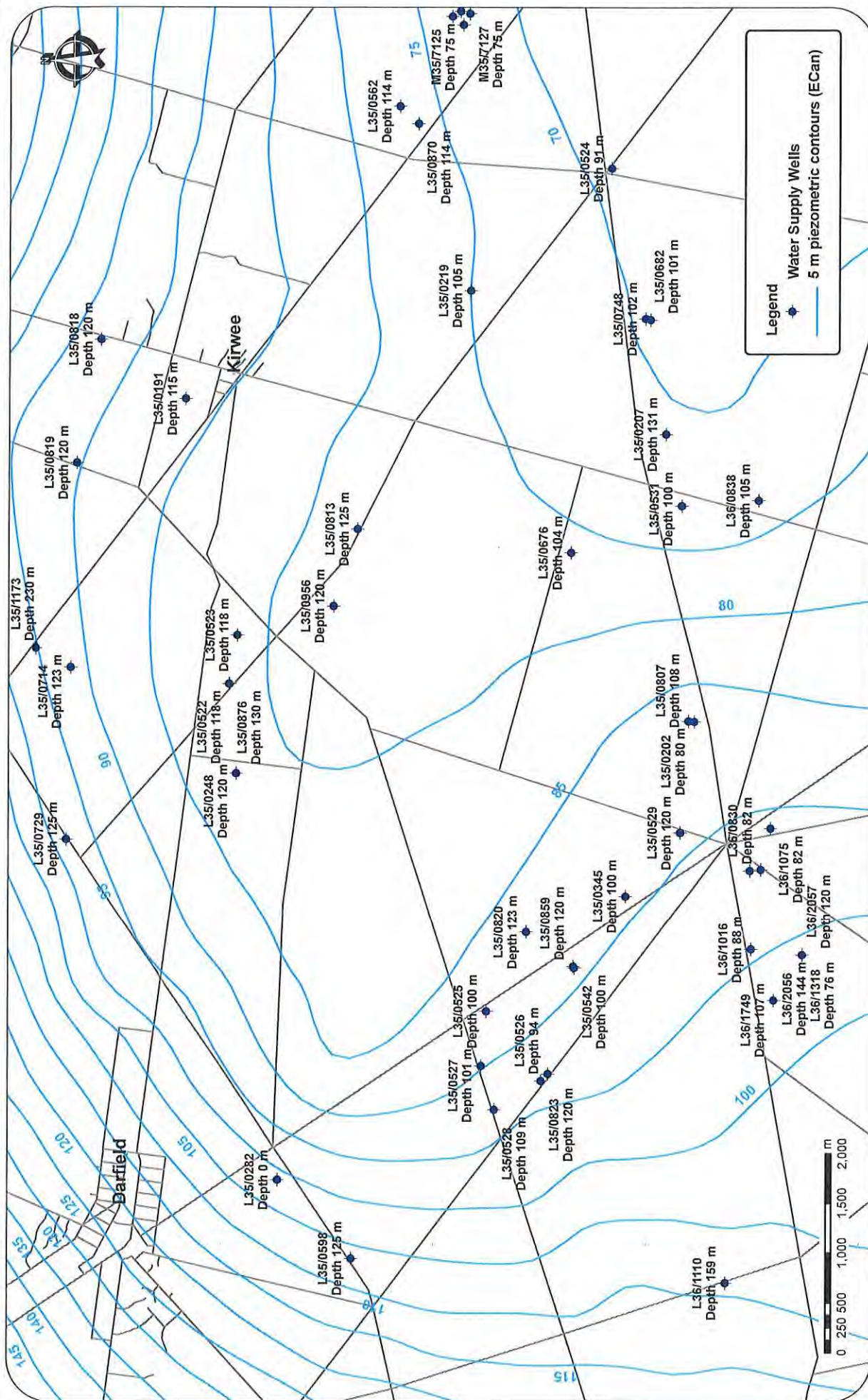


Figure 5 : Water supply wells