8. APPENDICES

Appendix A: Revision of estimated nitrate impacts

Present day impacts

According to the 2013 census statistics results, the current resident population in Darfield is 1935, and this population lives within a unit area of 337 ha. This represents an increase from 1671 people living within an area of 247 ha, evaluated in 2006. A simple visual inspection of the current distribution of septic tanks with active discharge consents in Darfield and a survey of recent satellite imagery on Google maps, suggest that that the area to which the 2013 census population statistics applies might be larger than that recorded by Statistics New Zealand, and could be closer to 464 ha (Figure A1). The population density in Darfield is thus estimated to be within the realm of 4.2–5.7 people/ha. In this study, the higher value reported by Statistics New Zealand is assumed to be the more reliable estimate.

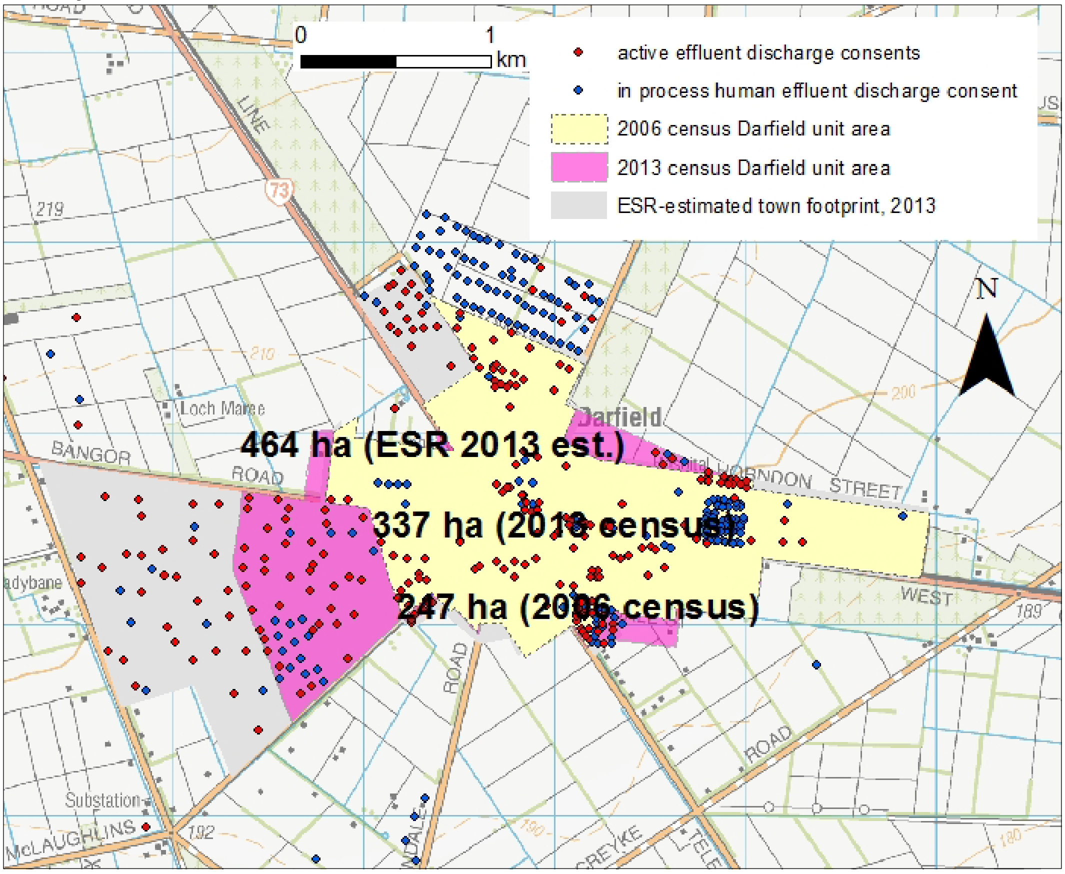


Figure A1. Darfield town unit area as reported in the 2006 and 2013 censuses, and in ESR's independent estimate based on 2013 satellite imagery.
Active resource consents to discharge human effluent are shown together with consents listed on ECan's database as 'inactive', which includes consents being processed.

Population statistics are not reported by Statistics New Zealand for Kirwee town per se, but are reported for a broader rural unit area covering 46,739 ha. Hence, the resident population of the town has to be estimated. SDC is currently refining their estimate of the town's size based on the Living Zone area, rates and building consents data, and the best estimate of Kirwee's township size is currently 1081 people living within an area of 290 ha (Cameron Wood, Strategic Policy Planner, SDC, personal communication, December 2013). ESR attempted an independent estimate based on a count of the 247 properties that feature on the 2013 Google maps satellite imagery within an area of 218 ha (See Figure A2), multiplied by the 2006 NZ census household occupancy rate of 2.8 people/residence. Based on these figures, the population density in Kirwee is estimated to be in the range of 3.2–3.7 people/ha, which is notably less dense than Darfield's population density.

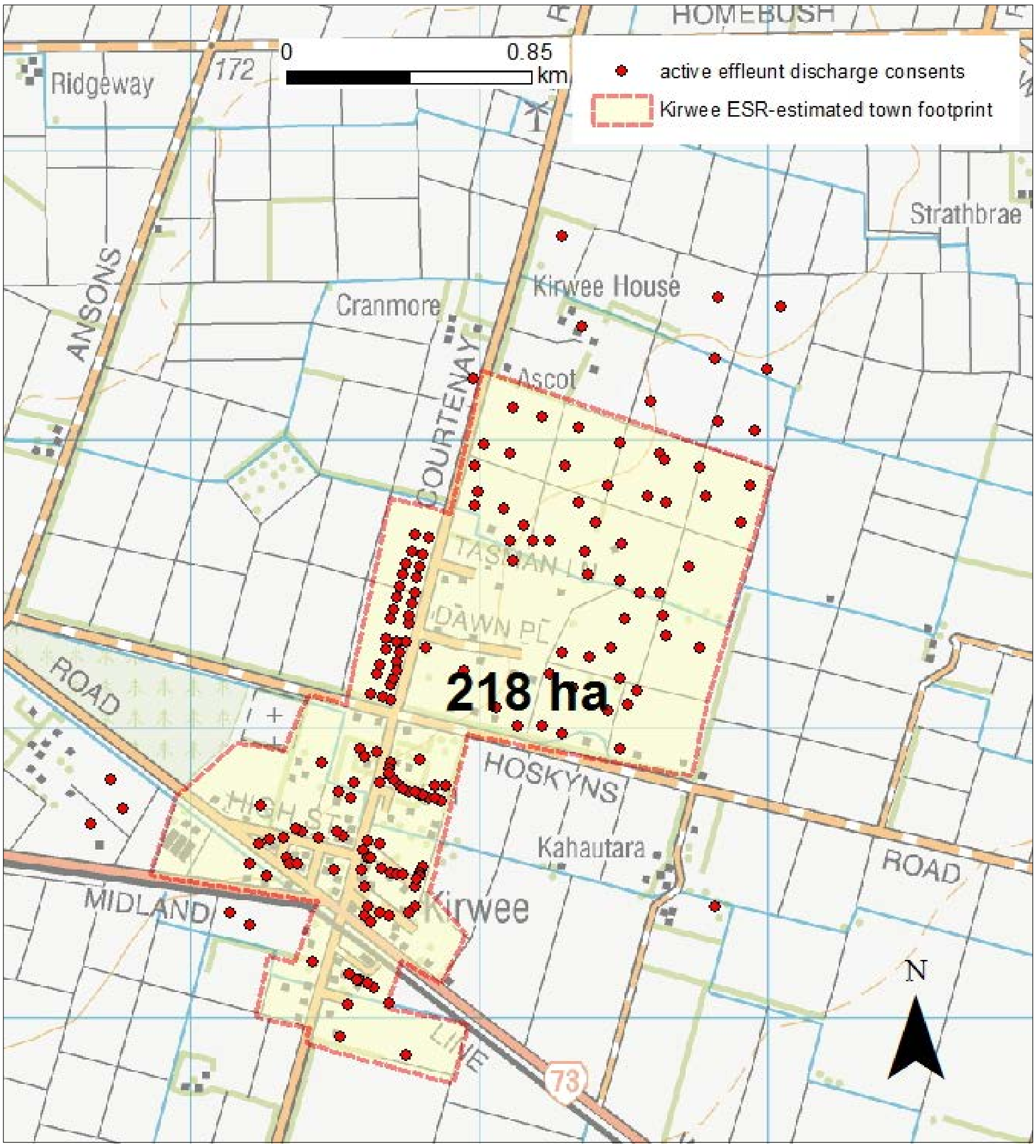


Figure A2: The Kirwee town area that was assumed for this work, bounding the cluster of resource management consents to discharge human effluent (data from ECan's CONSENTS database).

Interestingly, in their previous impact assessment work PDP (2011) had to make similar estimates about the size of the resident population in Kirwee town. They counted 350 dwellings in a supposed area of just 129 ha and, hence, assumed a population density of 7 people/ha. This is almost twice the population density estimated by SDC and ESR. Furthermore, it is inconsistent with SDC's town plans that provide for higher density living in Darfield than in Kirwee. It is suspected that

PDP's (2011) population density estimate was grossly overestimated, hence their predictions about nitrogen impacts associated with Kirwee town were also overestimated. PDP's (2011) results are provided in this work for the purposes of comparison.

Considering the townships as isolated entities, a measure of their nitrate environmental footprint can be determined from a simple mass balance equation, which assumes all contamination released from the town is perfectly mixed and diluted with drainage water from the same finite area (Hantzsche and Finnemore 1992). Dividing the sum of nitrogen sourced from human effluent discharges and that leaches from the land contained within the town boundary by the sum of (artificial and natural) drainage water within the same boundary estimates the average nitrate concentration for the town, C_i:

$$C_i = \frac{(P_i \times N_{eff}) + N_{land}}{V_{eff} + (LSR \times A_i)} \qquad \text{(A1)}$$

where P_i is the population of the town *i*, N_{eff} is the rate of nitrogen waste production per person and discharged via a septic system; N_{land} is the nitrogen mass leached from land in the town, V_{eff} is the volume of wastewater a person generates each day, LSR is the land surface recharge rate and A_i is the area of the town footprint.

Such 'lumped' models are simplistic, because they do not mimic the spatial distribution of the contamination or route it takes in the subsurface system. At the regional scale such complete mixing assumptions are valid. Furthermore, based on the results of water-tracing experiments ESR conducted in a 10-m deep vadose zone in the Canterbury alluvial aquifer (Burbery et al 2012), one can infer that point-source pollution, including effluent from a septic tank, will undergo significant lateral spreading as it infiltrates over a vertical depth of over 65 m to reach the water table, as is the situation at Darfield and Kirwee. This lateral spreading associated with vertical transport under gravitational flow tends towards a complete mixing model assumption that underpins the use of Equation A1. The same methods were applied by PDP (2011) in their earlier assessment of the nitrate impacts from septic tanks systems at Darfield and Kirwee, but PDP (2011) did not factor in the background nitrate loading from the land that provides the diluent (background nitrate concentrations were, however, accounted for in a separate mass-mixing model assessment).

Table A1 lists the predictions of the spatially- and temporally-averaged nitrate contamination that can be perceived to be associated with the cluster of septic waste systems currently at Darfield, whereby impacts from septic tank wastes are diluted by local land surface recharge (LSR) sourced within the constraints of the town footprint. The 'low' estimate provides a lower bound, whereas the 'high' estimate implies a probable worst-case scenario. The 'more probable' value (shaded grey) can be considered as the best educated guess, and is based on the range of mass loading rates and recharge estimates published in the literature. PDP's (2011) assessment is provided for comparison, although it is important to realise the nitrate concentration value estimated by PDP (2011) assumes effluent dilution with LSR water free of any residual nitrate, which in reality is not possible. Table A2 shows the results for Kirwee.

Table A1: Estimate of the general nitrate footprint Darfield town imposes on the groundwater system underlying the town as a consequence of wastewater discharges diluted with local soil drainage.

Variable	Units	Low	High	More probable	PDP (2011)
Darfield population[$]	people	1935	1935	1935	1482
Darfield area	ha	464	337	337	248.4
Darfield population density	people/ha	4.2	5.7	5.7	6.0[*]
N production: effluent	g N /person/d	6	17	13	12
	tonnes N/yr (town)	4.2	12.0	9.2	6.5
	kg N/ha/yr	9.1	35.6	27.2	26.2
Wastewater production	L/person/day	200	200	200	200
	m^3/person/yr	73	73	73	73
	milllion m^3/yr (town)	0.14	0.14	0.14	0.11
N concentration: effluent	mg NO_3-N/L	30	85	65	60
N mass leached from land[%]	kg N/ha /yr	8.8	16	8.8	0
	tonnes N/yr (town)	4.08	5.39	2.97	0.00
LSR	mm/yr	227	129	140	135
	million m^3/yr (town)	1.05	0.43	0.47	0.34
N concentration: LSR	mg NO_3-N/L	3.88	12.40	6.29	0.00
N concentration under town	mg NO_3-N/L	7.0	30.2	19.8	14.7

N, nitrogen; LSR, land surface recharge

[$] Population from the 2013 national census or 2006 census in the case of the PDP (2011) data.

* PDP (2011)-determined population density from: 2.3 septic systems/ha x 2.6 people/system/town area, not census population statistic.

[%] Dryland sheep farming land use assumed representative of nitrogen leaching rates for gardens and so on within Darfield town ('low' and 'more probable' estimates); lifestyle block land use assumed representative of nitrogen leaching rates for 'high' assessment. All soil leaching rates taken from Lilburne et al (2010).

Note: The nitrate-leaching tables generated by Lilburne et al (2010), which have become the standard reference dataset for land-use impact assessments in Canterbury, were used in the current evaluations. For the 'low' and 'more probable' estimates, all land within the townships (eg, gardens, verges) were assigned nitrogen-leaching rates that are comparable to dryland sheep farming and not lifestyle blocks, which Lilburne et al (2010) predicted to have a larger nitrogen impact than low-intensity land used for sheep grazing. Nitrogen loads from lifestyle blocks were used in the 'high' assessment.

Rainwater run-off from impermeable roads and roof tops in the towns constitutes an effective nitrate-free diluent that it is often discharged direct to ground via boulder pits. The net effect of this stormwater component, for every 5 percent land coverage of this type, is estimated to equate to a 16 percent reduction in the total nitrate concentration sourced from Darfield and 24 percent reduction in nitrate sourced from Kirwee.

Table A2: Estimate of the general nitrate footprint Kirwee town imposes on the groundwater system underlying the town as a consequence of wastewater discharges diluted with local soil drainage.

<table>
<tr><th>Variable</th><th>Units</th><th>Low</th><th>High</th><th>More probable</th><th>PDP (2011)</th></tr>
<tr><td>Kirwee population</td><td>people</td><td>692</td><td>1081</td><td>1081</td><td>906*</td></tr>
<tr><td>Kirwee area</td><td>ha</td><td>218</td><td>290</td><td>290</td><td>129</td></tr>
<tr><td>Kirwee population density</td><td>people/ha</td><td>3.2</td><td>3.7</td><td>3.7</td><td>7.0</td></tr>
<tr><td rowspan="3">N production from effluent</td><td>g N /person/d</td><td>6</td><td>17</td><td>13</td><td>12</td></tr>
<tr><td>tonnes N/yr (town)</td><td>1.5</td><td>6.7</td><td>5.1</td><td>4.0</td></tr>
<tr><td>kg N/ha/yr</td><td>6.9</td><td>23.1</td><td>17.7</td><td>30.7</td></tr>
<tr><td rowspan="3">Wastewater production</td><td>L/person/day</td><td>200</td><td>200</td><td>200</td><td>200</td></tr>
<tr><td>m^3/person/yr</td><td>73</td><td>73</td><td>73</td><td>73</td></tr>
<tr><td>million m^3/yr (town)</td><td>0.05</td><td>0.08</td><td>0.08</td><td>0.07</td></tr>
<tr><td>N concentration: effluent</td><td>mg NO_3-N/L</td><td>30</td><td>85</td><td>65</td><td>60</td></tr>
<tr><td rowspan="2">N mass leached from land$</td><td>kg N/ha /yr</td><td>8.8</td><td>16</td><td>8.8</td><td>0</td></tr>
<tr><td>tonnes N/yr (town)</td><td>1.92</td><td>4.64</td><td>2.55</td><td>0.00</td></tr>
<tr><td rowspan="2">LSR</td><td>mm/yr</td><td>227</td><td>129</td><td>140</td><td>135</td></tr>
<tr><td>million m^3/yr (town)</td><td>0.49</td><td>0.37</td><td>0.41</td><td>0.17</td></tr>
<tr><td>N concentration: LSR</td><td>mg NO_3-N/L</td><td>3.88</td><td>12.40</td><td>6.29</td><td>0.00</td></tr>
<tr><td>N concentration under town</td><td>mg NO_3-N/L</td><td>6.3</td><td>25.0</td><td>15.8</td><td>16.5</td></tr>
</table>

N, nitrogen; LSR, land surface recharge

* PDP (2011) population calculated from density statistics reported by PDP (2011), ie, 2.7 septic systems/ha x 2.6 people/system x town area.

$ Dryland sheep farming land use assumed representative of nitrogen leaching rates for gardens and so on within Kirwee town ('low' and 'more probable' estimates); lifestyle block land use assumed representative of nitrogen leaching rates for 'high' assessment. All soil-leaching rates are from Lilburne et al (2010).

The concentration of nitrate in undiluted septic effluent is predicted to be within the range of 30–85 mg NO_3-N /L, most likely closer to 65 mg NO_3-N/L, and groundwater impacts could be of this magnitude on a local scale at the water table, in the absence of any dilution effects. The nitrogen mass load from the septic tanks in operation at Darfield is predicted to be in the range of 9.1–35.6 kg N/ha/yr, probably closer 27.2 kg N/ha/yr. Nitrogen loads attributed to effluent generated in Kirwee are predicted to be in the range of 6.9–23.1 kg N/ha/yr, more likely 17.7 kg N/ha/yr, because of the lower population density. PDP (2011) previously estimated a substantially higher nutrient load coming from Kirwee that was equivalent to 30.7 kg N/ha/yr, but as discussed previously, it is strongly suspected that an erroneous judgement was made about the population density.

When nutrient loads from the septic tanks are compounded with the unmanageable loads sourced from soils associated with general rural residential land use, the actual estimates of nitrogen loads coming from the two towns are more likely to amount to

36.0 kg N/ha/yr and 26.5 kg N/ha/yr from Darfield and Kirwee, respectively. If one were able to assume LSR (the diluent) were free of nitrate then the net areal averaged groundwater nitrate impacts from effluent disposal would lie in the range of 7.0–30.2 mg NO_3-N/L for Darfield and 6.3–25.0 mg NO_3-N/L for Kirwee.

Population density threshold for sustainable on-site waste-water disposal practice

In an effort to answer the question: ‘at what point do on-site wastewater treatment systems become unsustainable?’, equation A1 can be applied to determine a population density threshold, assuming of course that nitrogen is the contaminant of critical concern. If the drinking-water MAV for nitrate is set as a desirable outcome for groundwater quality and the protection of public health then, based on the same range of assumptions about nitrogen loads in effluent and dilution potential in the Darfield-Kirwee setting as above, the critical capacity of septic tank systems can be determined. Figure A3 plots groundwater nitrate impacts against population density, with the boundary between the light (‘high’) and dark (‘low’) shaded regions marking the ‘most probable’ outcome.

Considering the cumulative nitrate impact of nitrogen leached from the land and septic tank effluent, it is predicted that a ‘sustainable’ human population density in Darfield-Kirwee might be just 1.8 people/ha. Based on the 2006 census, the Kirwee housing occupancy density of 2.8 people/dwelling equates to an average housing allotment minimum size threshold of 1.56 ha. Figure A3 also highlights that within the bounds of uncertainty that currently apply to current knowledge about nitrate-leaching rates in the Canterbury environment, one should not reject the possibility that the nitrate drinking-water MAV will ultimately be exceeded in groundwater as a consequence of standard land use on lifestyle sections, even in the absence of any nitrogen load from human effluent.

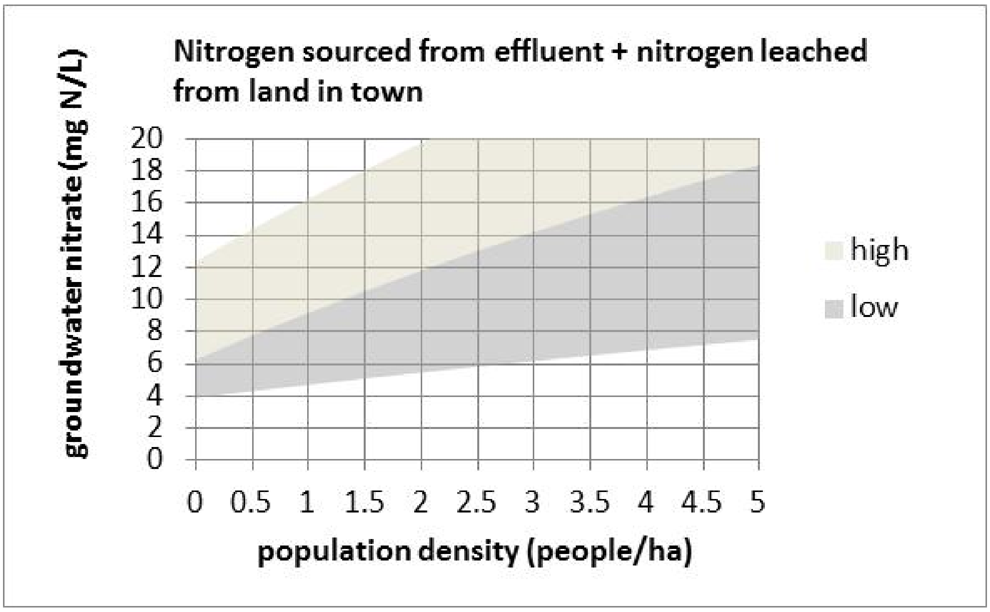


Figure A3: Population density plot against predicted groundwater nitrate impacts at the water table for the Darfield-Kirwee setting.

Note that the drinking-water maximum acceptable value corresponds to 11.3 mg NO_3-N /L. The most probable estimate lies between the high and the low estimates.

If one were to ignore the unmanageable background nitrate load associated with rural residential land use and consider the septic tank effluent in isolation, then a population density of 4.0 people/ha, or an average 0.69-ha allotment size would be suitable, but it should be recognised that the town will have an effective nitrate footprint larger than its territorial border at this density (Figure A4). According to Lilburne et al (2010), the only land uses that dilute groundwater nitrate impacts from septic tank effluent to meet the drinking-water quality standards are forestry (0.01–4.42 mg NO_3-N/L), fruit growing (5.7–8.2 mg NO_3-N/L), viticulture (5.3 mg NO_3-N/L), sheep (6.3 mg NO_3-N/L), deer (7.5 mg NO_3-N/L) and low-intensity dairying at 3 cows/ha (9.4 mg NO_3-N/L), where the bracketed numbers represent the hypothesised nitrate impact of the land uses. The benefit of nitrate-free alpine river inputs for maintaining groundwater nitrate levels below the MAV is obvious, but as suggested, river dilution is likely to only really be effective in the Selwyn-Waimakariri aquifer system down-gradient of Darfield and Kirwee.

For reference, the smallest allotment sizes prescribed in SDC's residential plans are for Living Zone 1 land and these are 650 m^2 for Darfield and 800 m^2 for Kirwee. Living Zone 2 land parcels are required to be no smaller than 5000 m^2 in Darfield and 1 ha in Kirwee. Assuming an average residential occupancy rate of 2.8 people/house and if all of Darfield was to be developed as Living Zone 1 land, then at the worst the population density might reach 43 people/ha. This is 10-times the sustainable population density required to comply with the drinking-water nitrate MAV in groundwater that was predicted in this work.

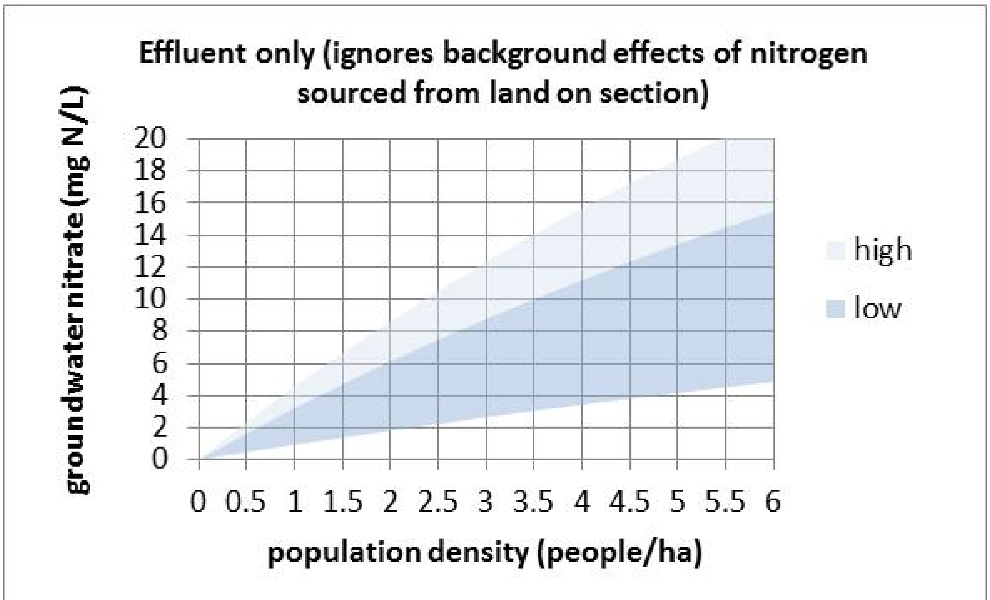


Figure A4: Population density plot against predicted groundwater nitrate impacts at the water table for the Darfield-Kirwee setting, ignoring unmanageable nitrogen loads from rural land uses.

Note that the drinking-water maximum acceptable value corresponds to 11.3 mg NO_3-N /L.

Appendix B: Selected borelogs from the Darfield area

Advanced datasets are accessible online, please replace XXXX for a four-digit well number suffix in following link:
http://ecan.govt.nz/services/online-services/tools-calculators/pages/well-detail.aspx?WellNo=L35%2fXXXX

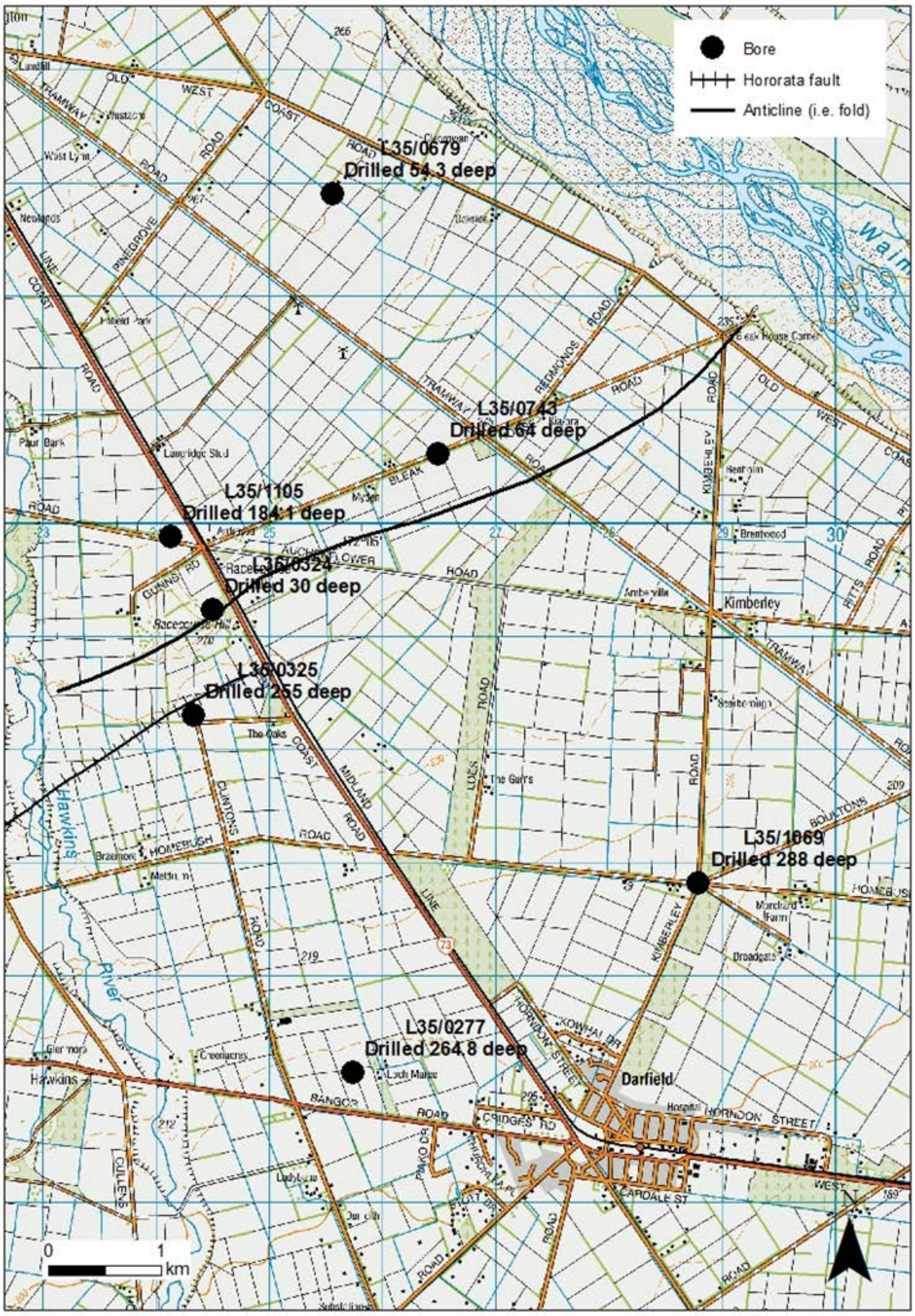
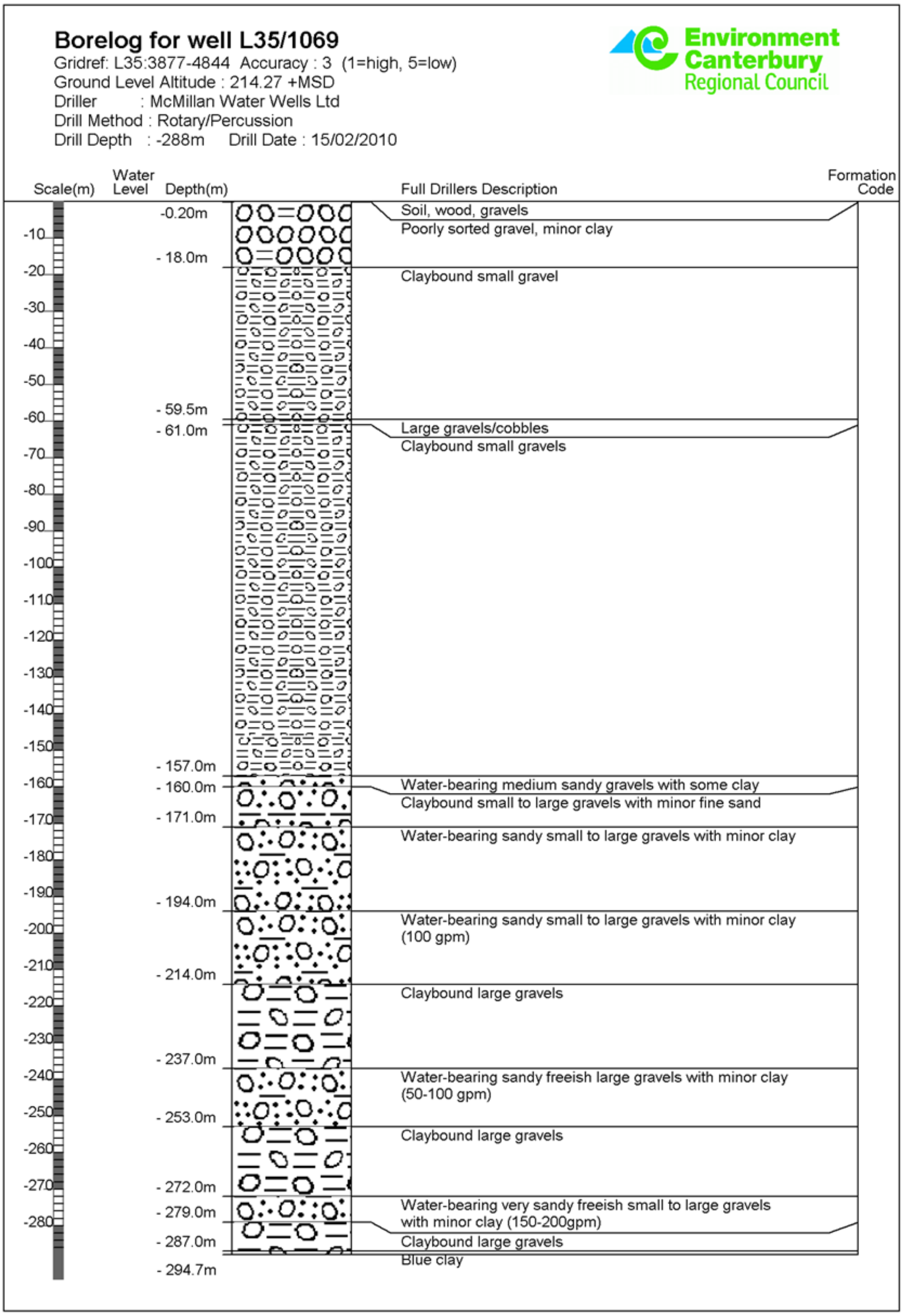


Figure B1: Location map for select bores for which borelog data are provided.


Borelog for well L35/1069
Gridref: L35:3877-4844 Accuracy : 3 (1=high, 5=low)
Ground Level Altitude : 214.27 +MSD
Driller : McMillan Water Wells Ltd
Drill Method : Rotary/Percussion
Drill Depth : -288m Drill Date : 15/02/2010
Environment Canterbury Regional Council
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.20m
Soil, wood, gravels
Poorly sorted gravel, minor clay
- 18.0m
Claybound small gravel
- 59.5m
- 61.0m
Large gravels/cobbles
Claybound small gravels
- 157.0m
- 160.0m
Water-bearing medium sandy gravels with some clay
Claybound small to large gravels with minor fine sand
- 171.0m
Water-bearing sandy small to large gravels with minor clay
- 194.0m
Water-bearing sandy small to large gravels with minor clay (100 gpm)
- 214.0m
Claybound large gravels
- 237.0m
Water-bearing sandy freeish large gravels with minor clay (50-100 gpm)
- 253.0m
Claybound large gravels
- 272.0m
- 279.0m
Water-bearing very sandy freeish small to large gravels with minor clay (150-200gpm)
- 287.0m
Claybound large gravels
- 294.7m
Blue clay
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
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-190
-200
-210
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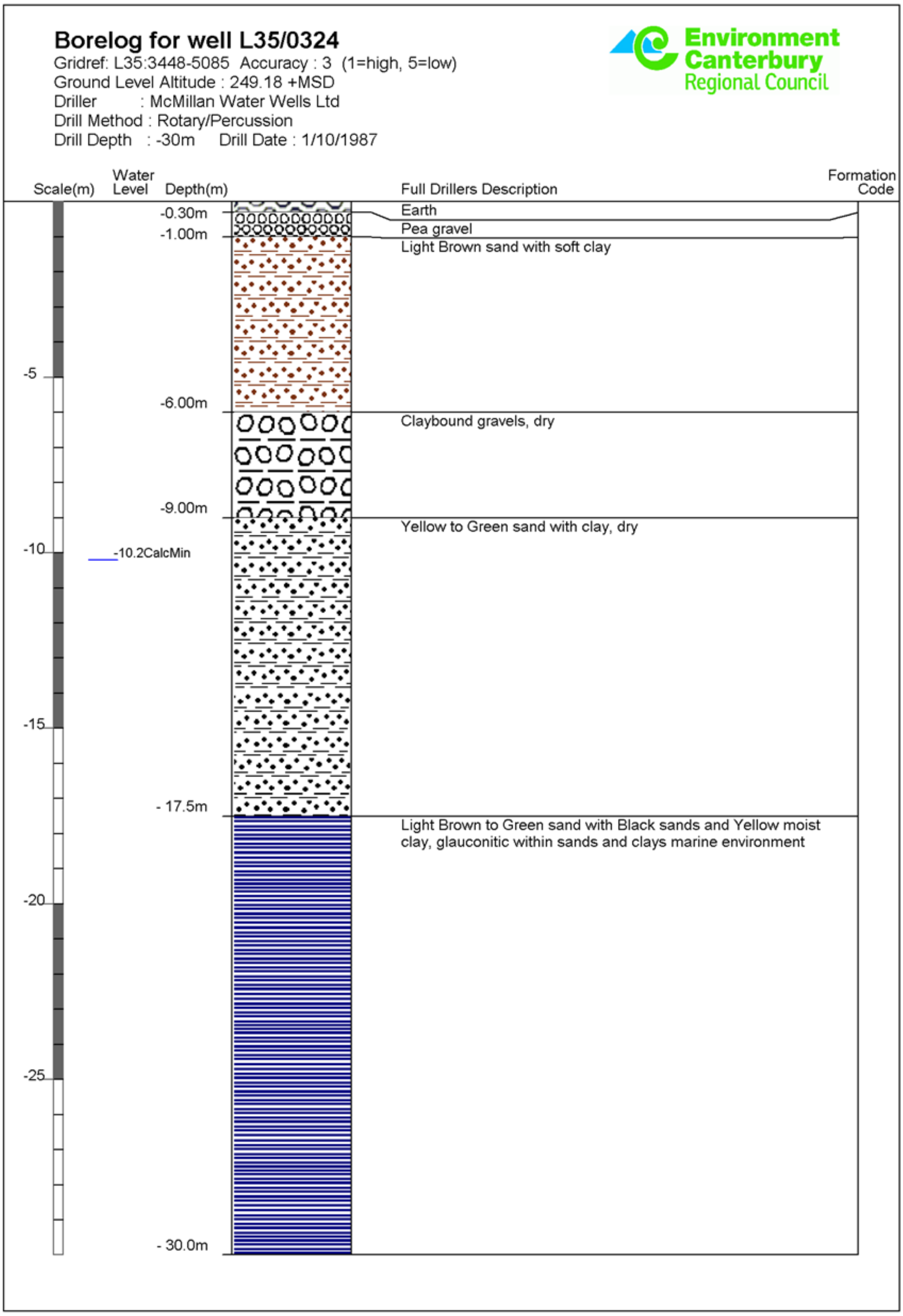
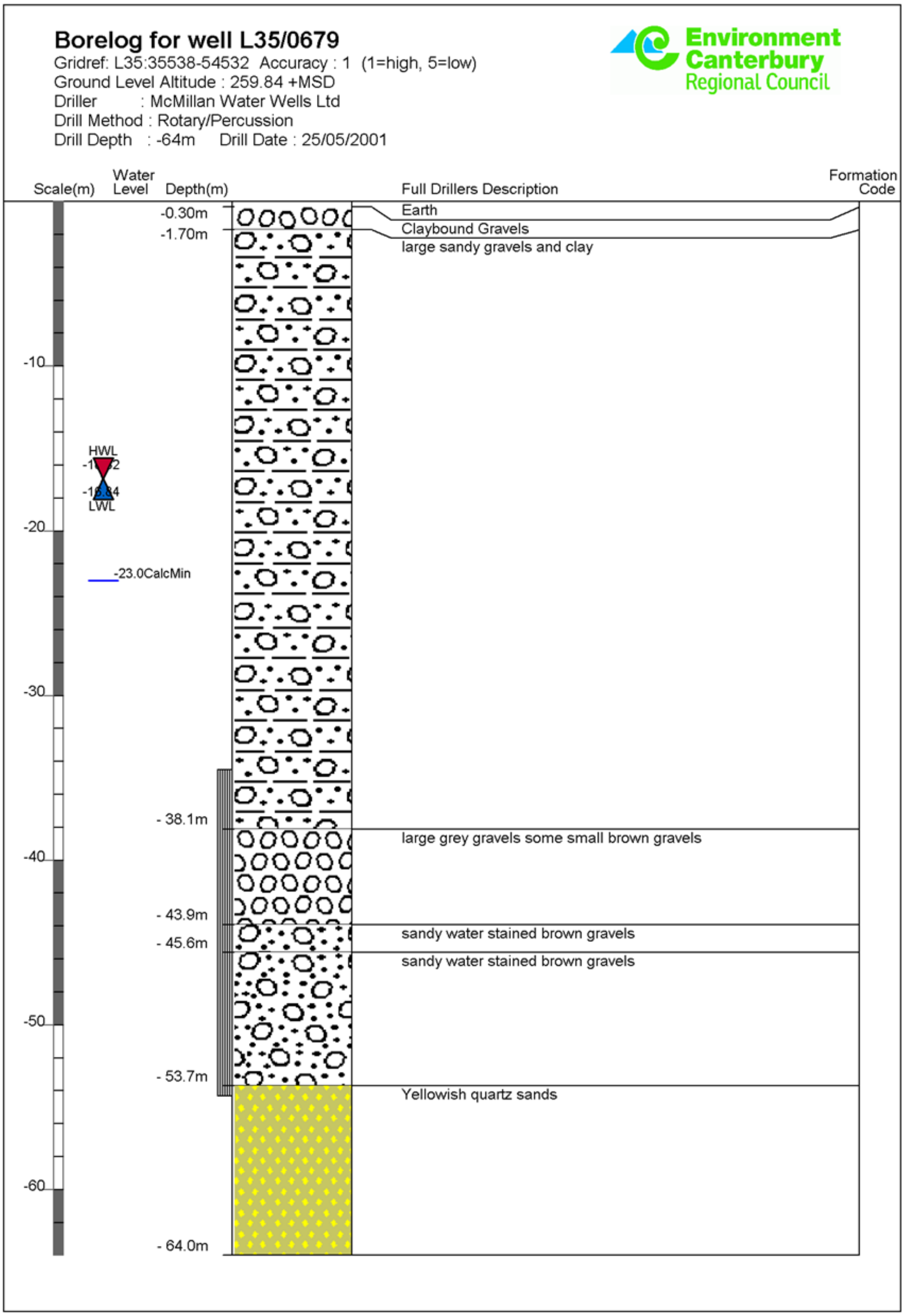
-230
-240
-250
-260
-270
-280


Borelog for well L35/0324
Gridref: L35:3448-5085 Accuracy : 3 (1=high, 5=low)
Ground Level Altitude : 249.18 +MSD
Driller : McMillan Water Wells Ltd
Drill Method : Rotary/Percussion
Drill Depth : -30m Drill Date : 1/10/1987
Environment Canterbury Regional Council
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.30m
Earth
-1.00m
Pea gravel
Light Brown sand with soft clay
-5
-6.00m
Claybound gravels, dry
-9.00m
Yellow to Green sand with clay, dry
-10
-10.2CalcMin
-15
- 17.5m
Light Brown to Green sand with Black sands and Yellow moist clay, glauconitic within sands and clays marine environment
-20
-25
- 30.0m

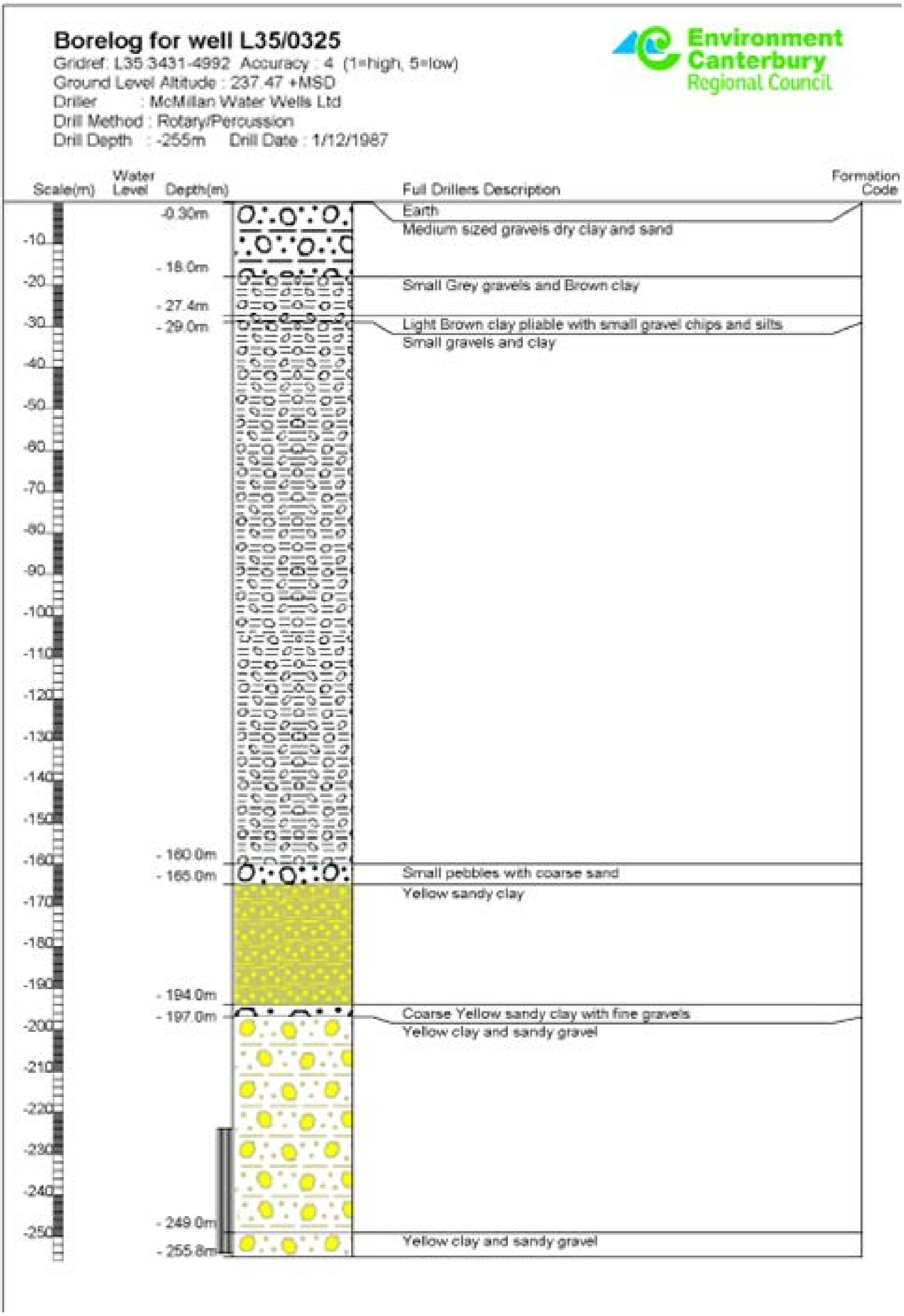


Borelog for well L35/0679
Gridref: L35:35538-54532 Accuracy : 1 (1=high, 5=low)
Ground Level Altitude : 259.84 +MSD
Driller : McMillan Water Wells Ltd
Drill Method : Rotary/Percussion
Drill Depth : -64m Drill Date : 25/05/2001
Environment Canterbury Regional Council
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-10
-20
-30
-40
-50
-60
HWL
LWL
-23.0CalcMin
-0.30m
-1.70m
- 38.1m
- 43.9m
- 45.6m
- 53.7m
- 64.0m
Earth
Claybound Gravels
large sandy gravels and clay
large grey gravels some small brown gravels
sandy water stained brown gravels
sandy water stained brown gravels
Yellowish quartz sands

Borelog for well L35/1105

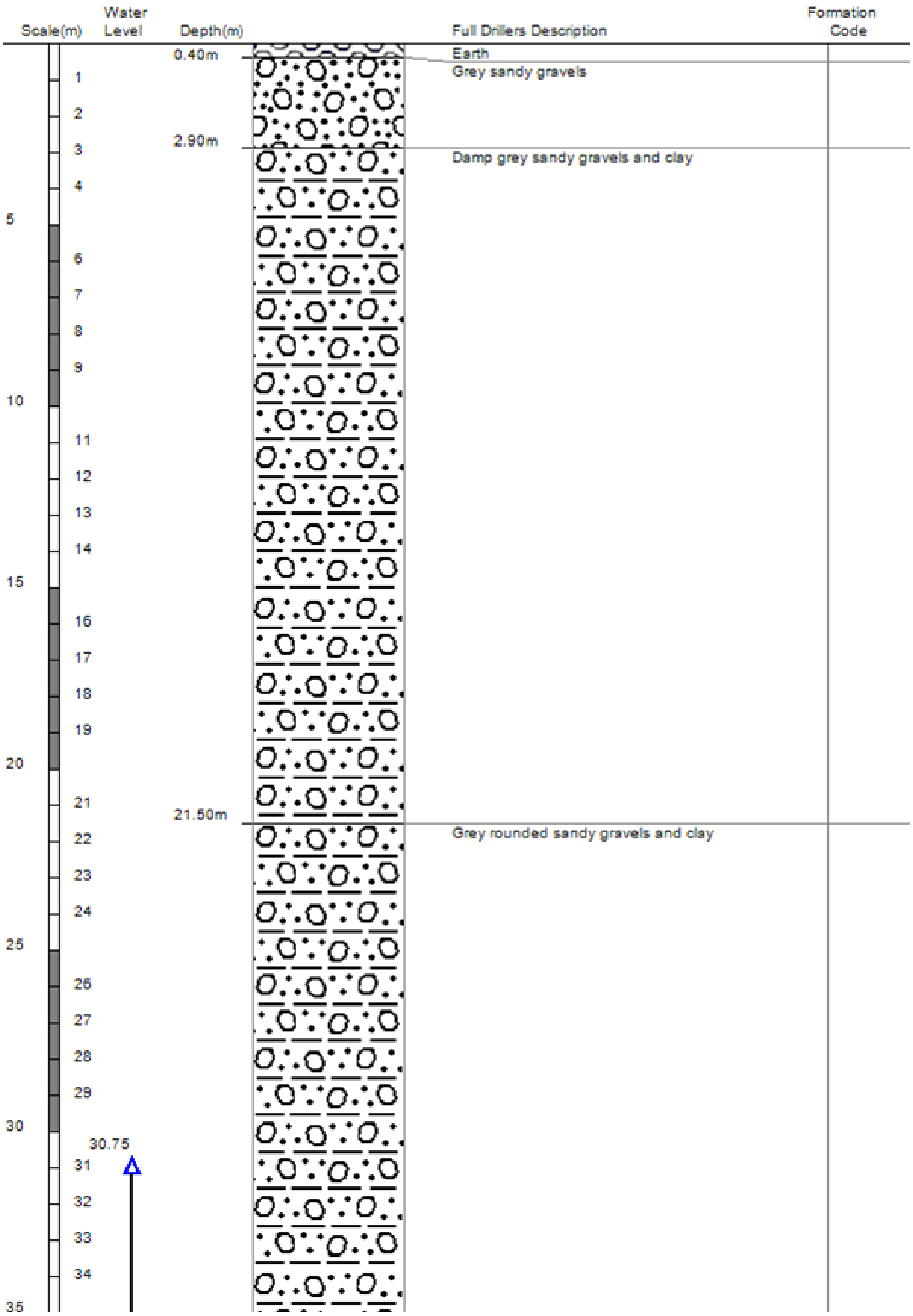
Gridref: L35:34111-51506 Accuracy : 2 (1=high, 5=low)
Driller : McMillan Water Wells Ltd
Drill Method : Rotary/Percussion
Drill Depth : -184m Drill Date : 23/04/2011

Depth(m)	Full Drillers Description	Formation Code
-0.30m	soil	
- 43.0m	claybound coarse gravel	
- 71.0m	clay, sand with traces of gravel	
- 80.5m	white silty sand	
- 83.0m	sitly sand with pockets of sandstone	
- 99.0m	silty sand, brown\white	
- 130.5m	silty sand, greyish with clear and light coloured coarser grains of sand	
- 145.0m	silty sand and clay with fragments of sandstone/limestone and iron ore	
- 153.0m	silty sand and clay	
- 159.0m	silty sand and clay with fragments of sandstone/limestone and iron ore	
- 174.0m	silty sand with larger fragments of snadstone and ore	
- 175.0m	silty sandy traces of white hard clay	
- 179.0m	silty sand white layers of clay, very hard	
- 182.0m	silty sandy black layer with rusty hard layer above and below black	
- 189.9m		


Borelog for well L35/0325
Gridref: L35:3431-4992 Accuracy : 4 (1=high, 5=low)
Ground Level Altitude : 237.47 +MSD
Driller : McMillan Water Wells Ltd
Drill Method : Rotary/Percussion
Drill Depth : -255m Drill Date : 1/12/1987
Environment Canterbury Regional Council
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
-200
-210
-220
-230
-240
-250
-0.30m
Earth
Medium sized gravels dry clay and sand
- 18.0m
Small Grey gravels and Brown clay
- 27.4m
- 29.0m
Light Brown clay pliable with small gravel chips and silts
Small gravels and clay
- 160.0m
Small pebbles with coarse sand
- 165.0m
Yellow sandy clay
- 194.0m
Coarse Yellow sandy clay with fine gravels
- 197.0m
Yellow clay and sandy gravel
- 249.0m
Yellow clay and sandy gravel
- 255.8m

Borelog for well L35/0743 page 1 of 9

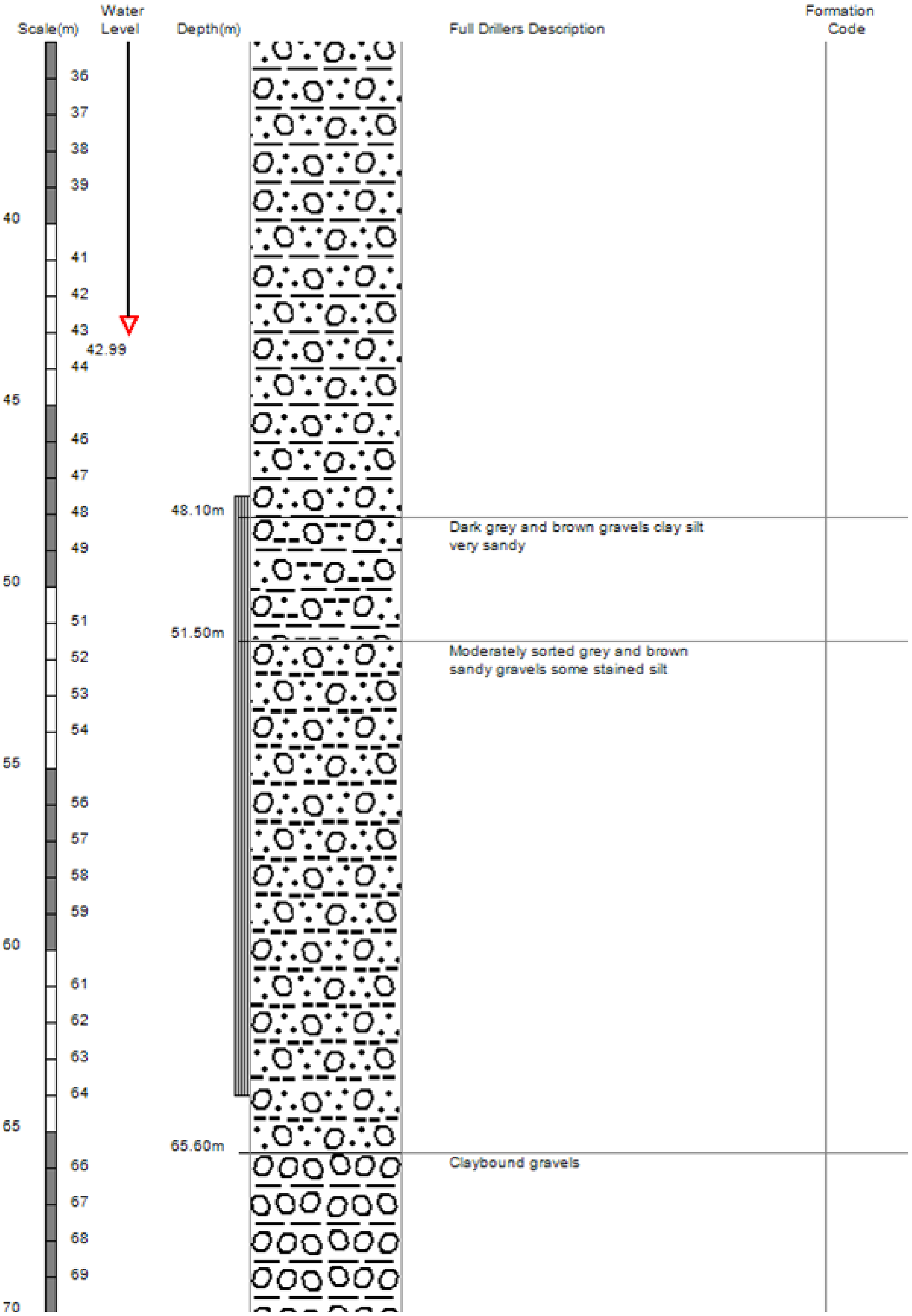
Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002



Borelog for well L35/0743 page 2 of 9

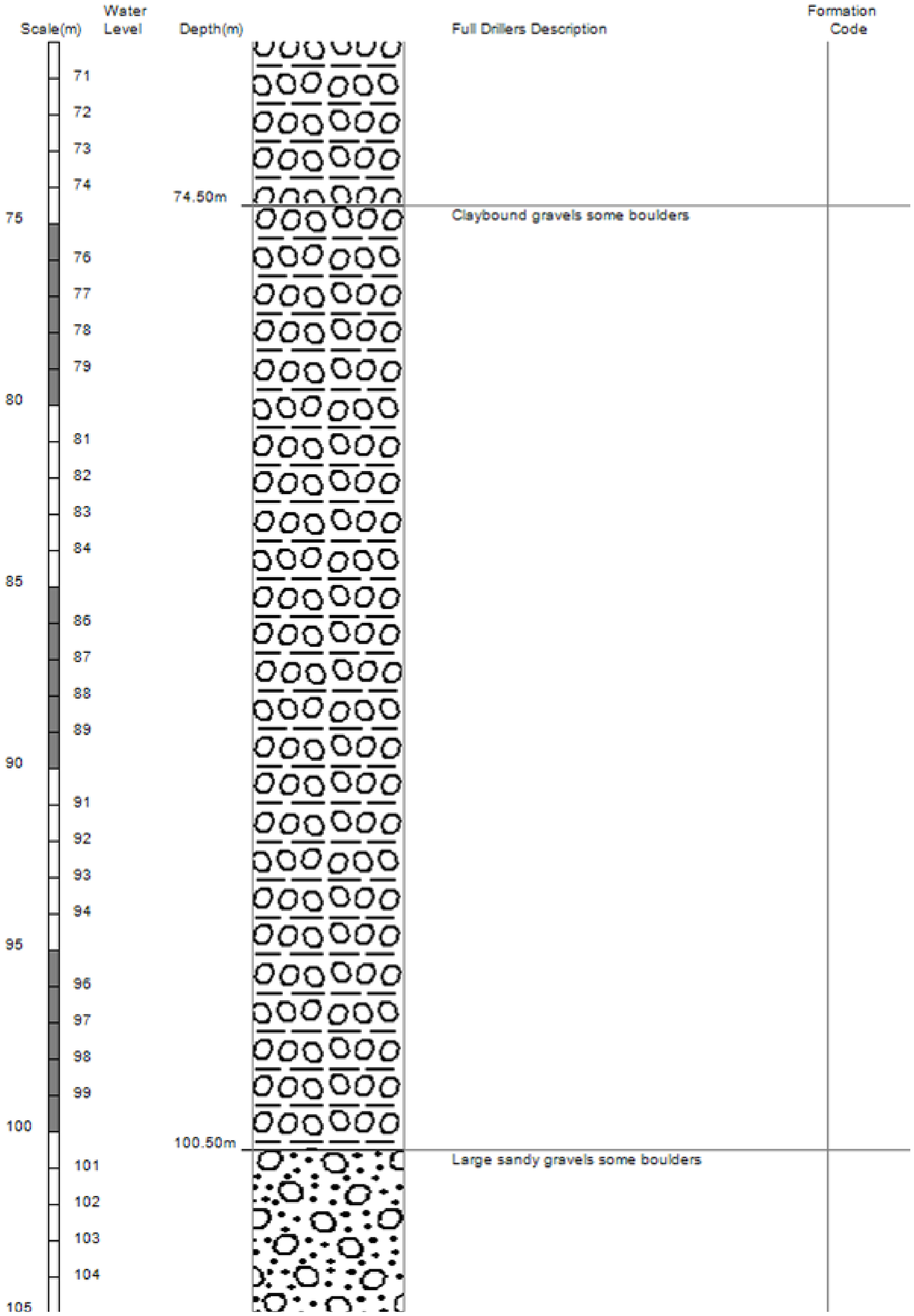
Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha



Borelog for well L35/0743 page 3 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002



Borelog for well L35/0743 page 4 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002

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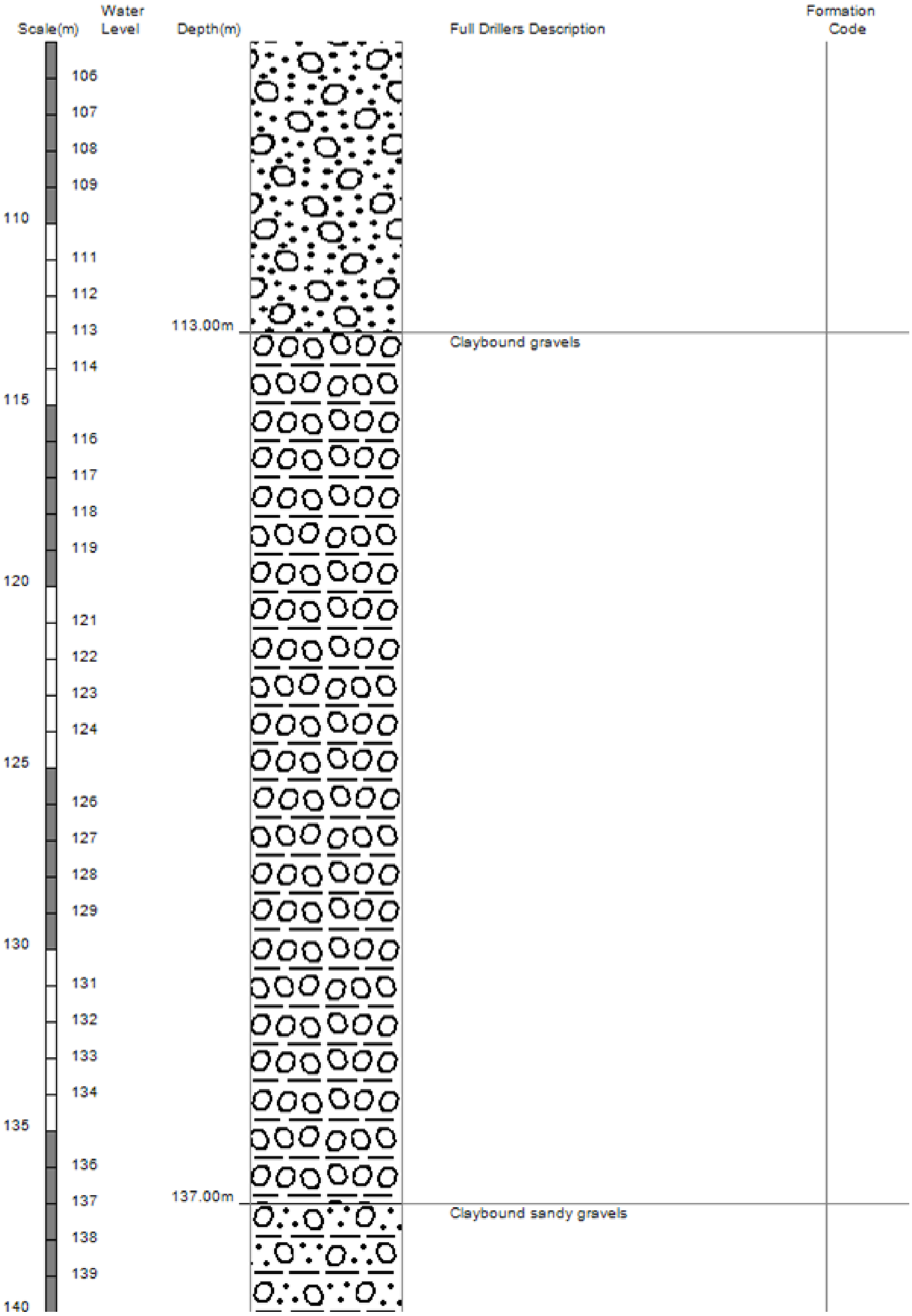
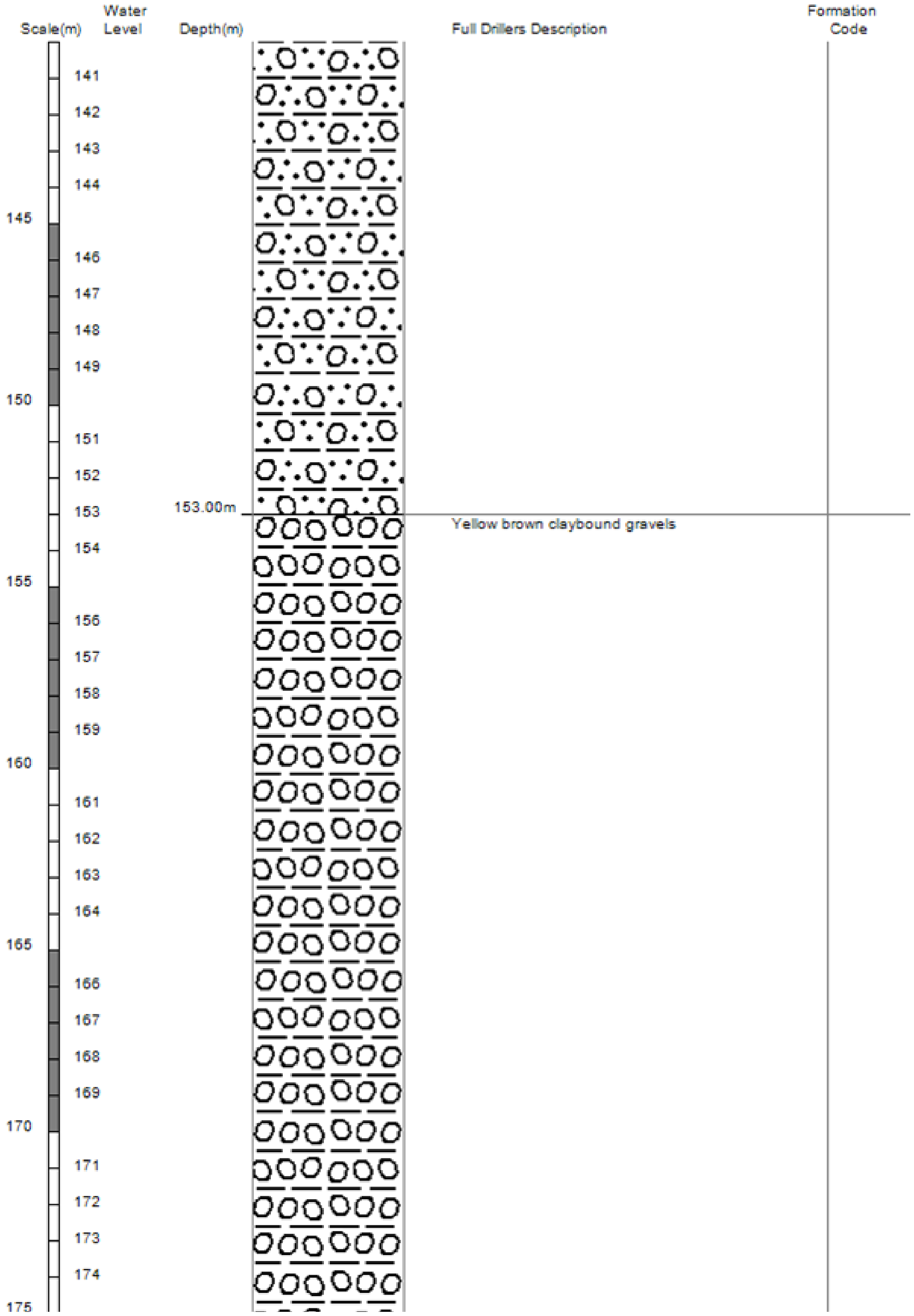


Borelog for well L35/0743 page 5 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002



Borelog for well L35/0743 page 6 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002

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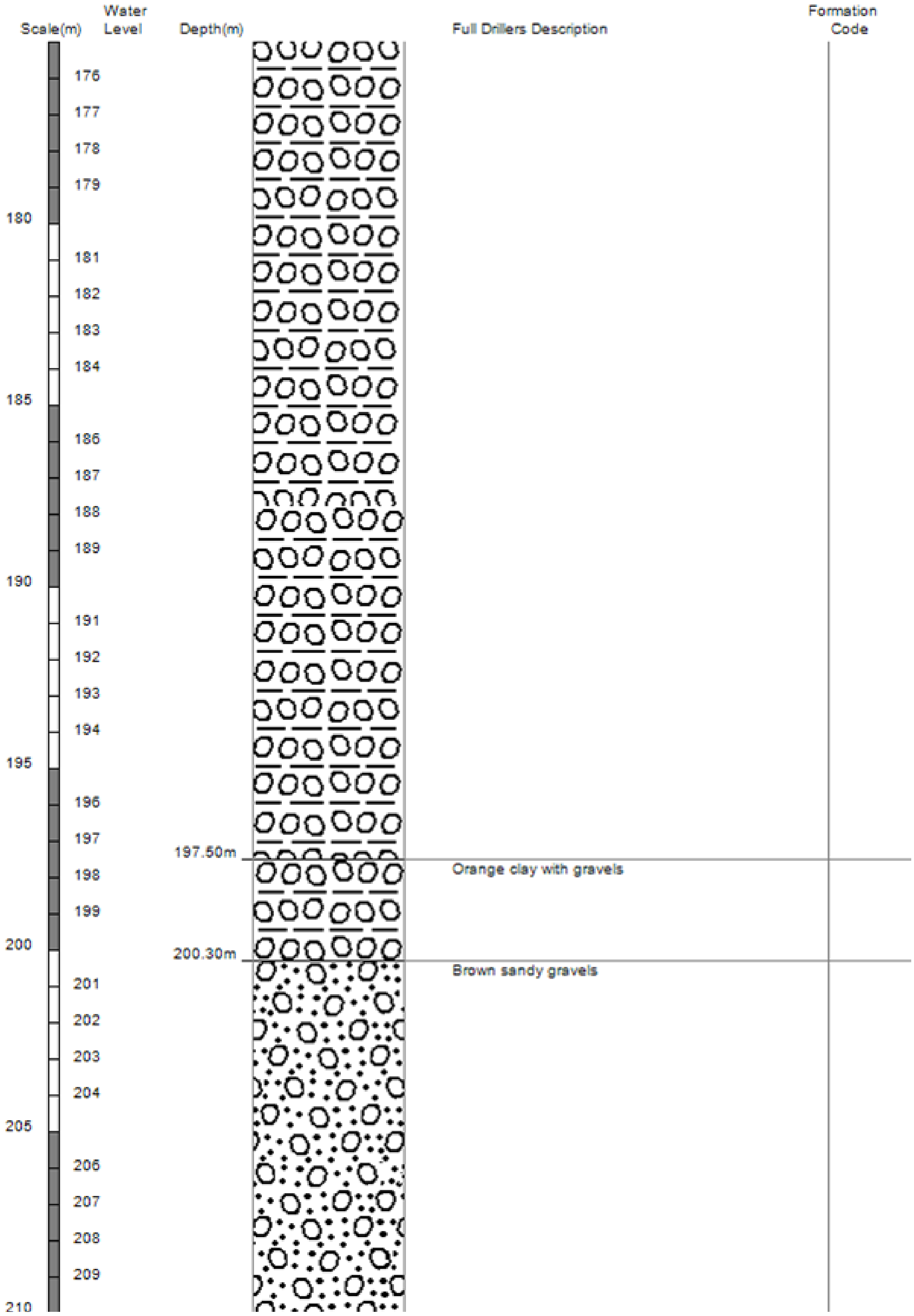
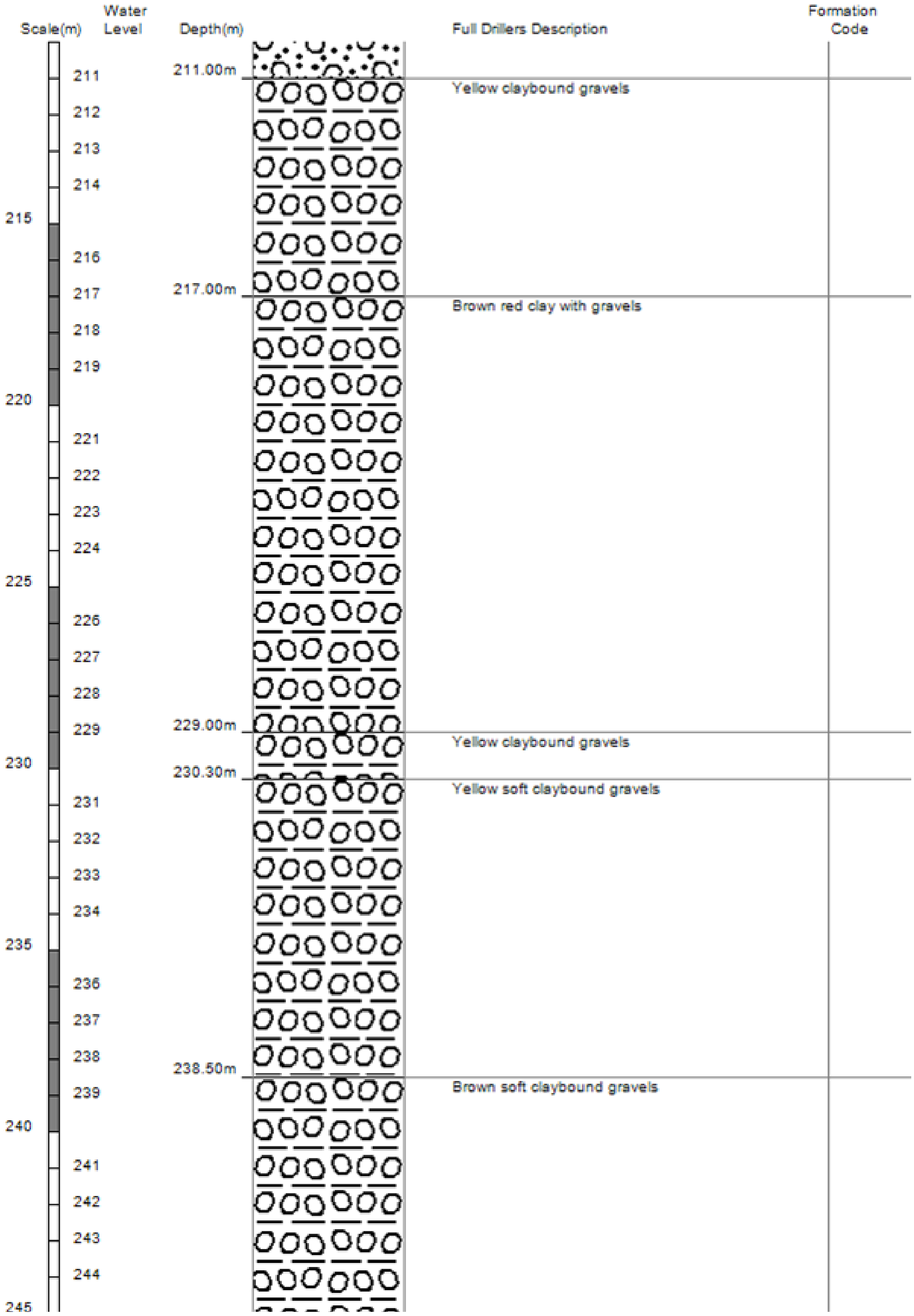


Borelog for well L35/0743 page 7 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002



Borelog for well L35/0743 page 8 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
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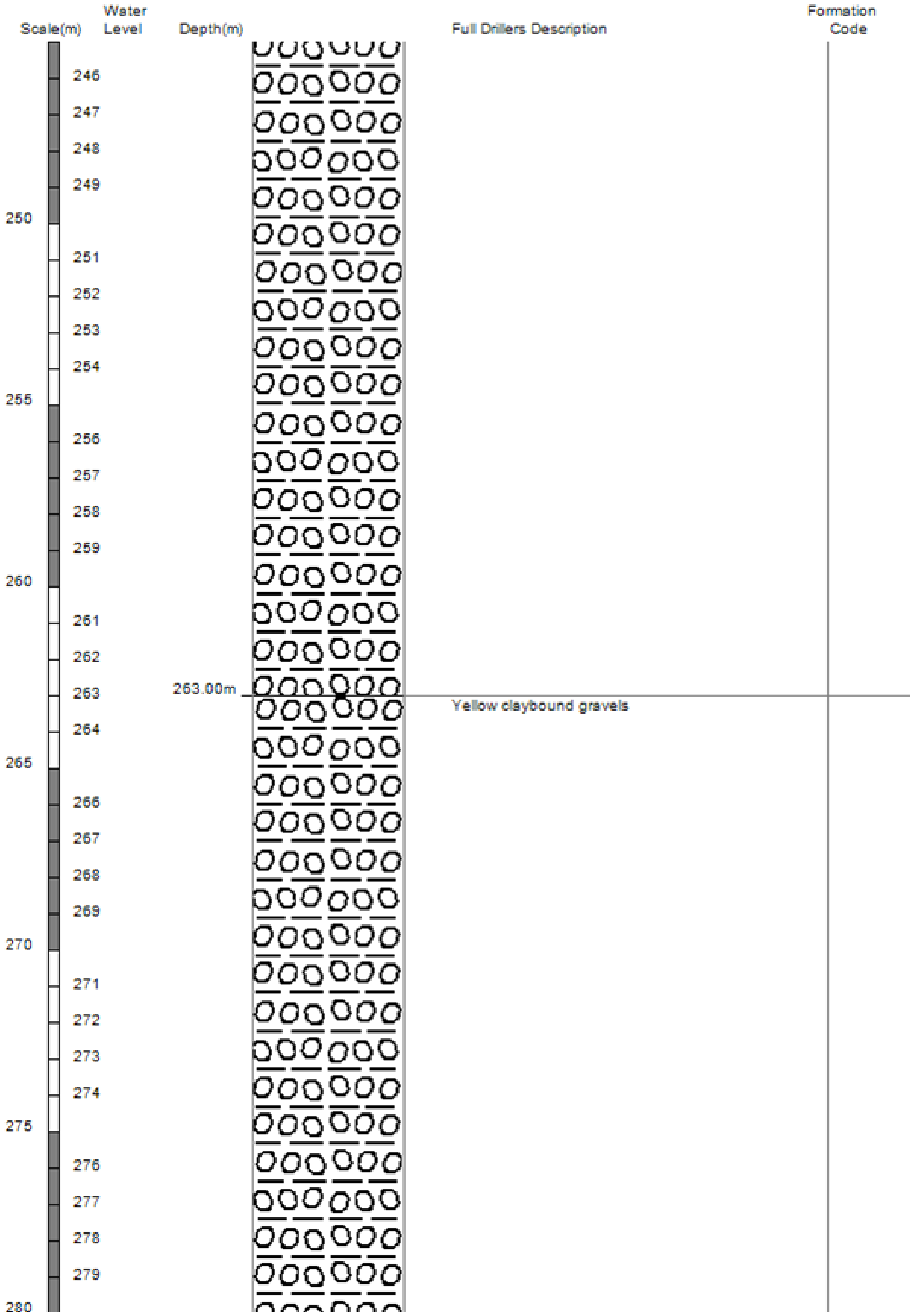
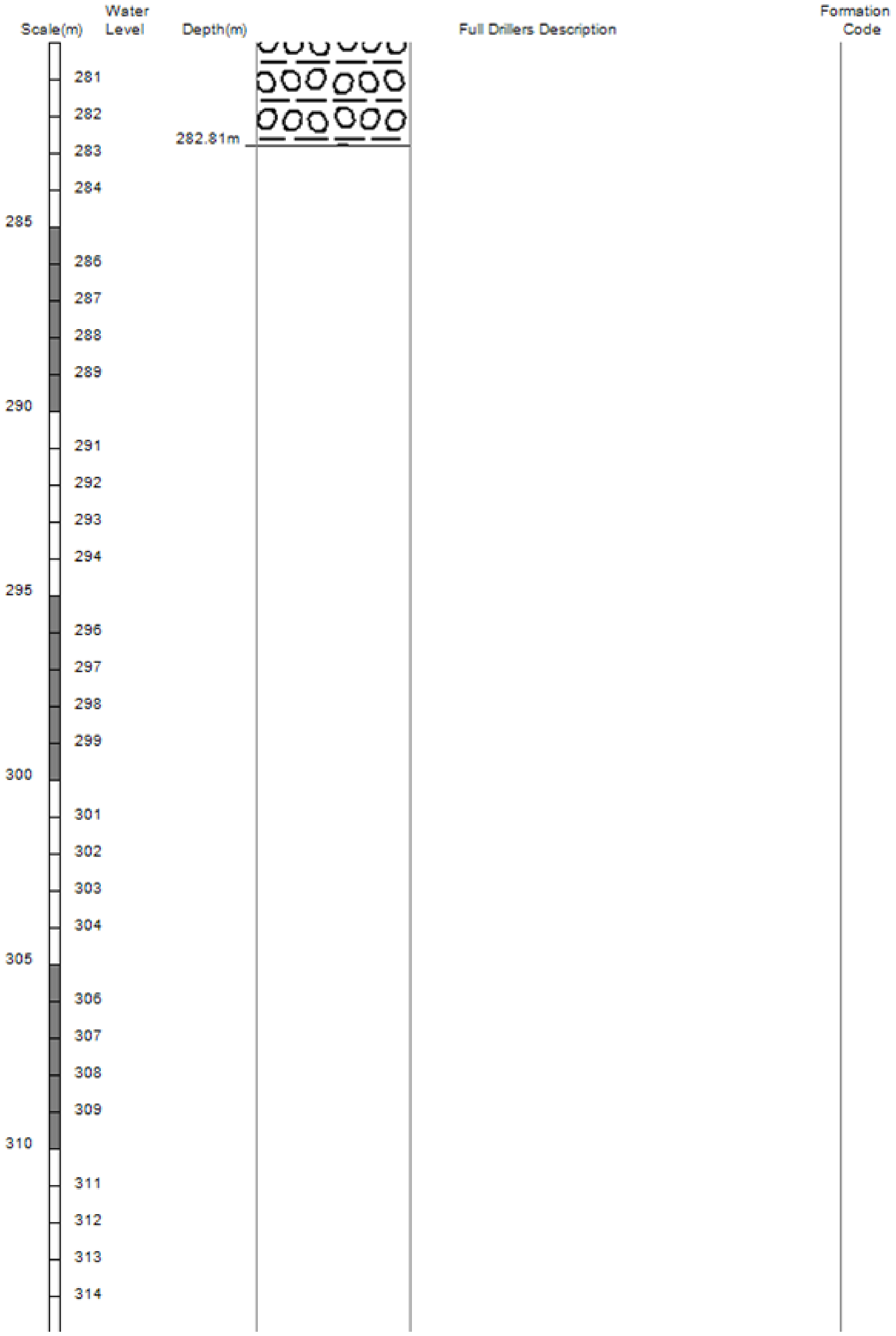


Borelog for well L35/0743 page 9 of 9

Map Reference (NZMG): 2436470 mN, 5752232 mE
QAR Accuracy: 2
Ground Level Altitude: 246.8 +MSD
Driller: McMillan Water Wells Ltd
Drill Method: Rotary/Percussion
Well Depth: 282.809997558594m Drill Date: 12/12/2002

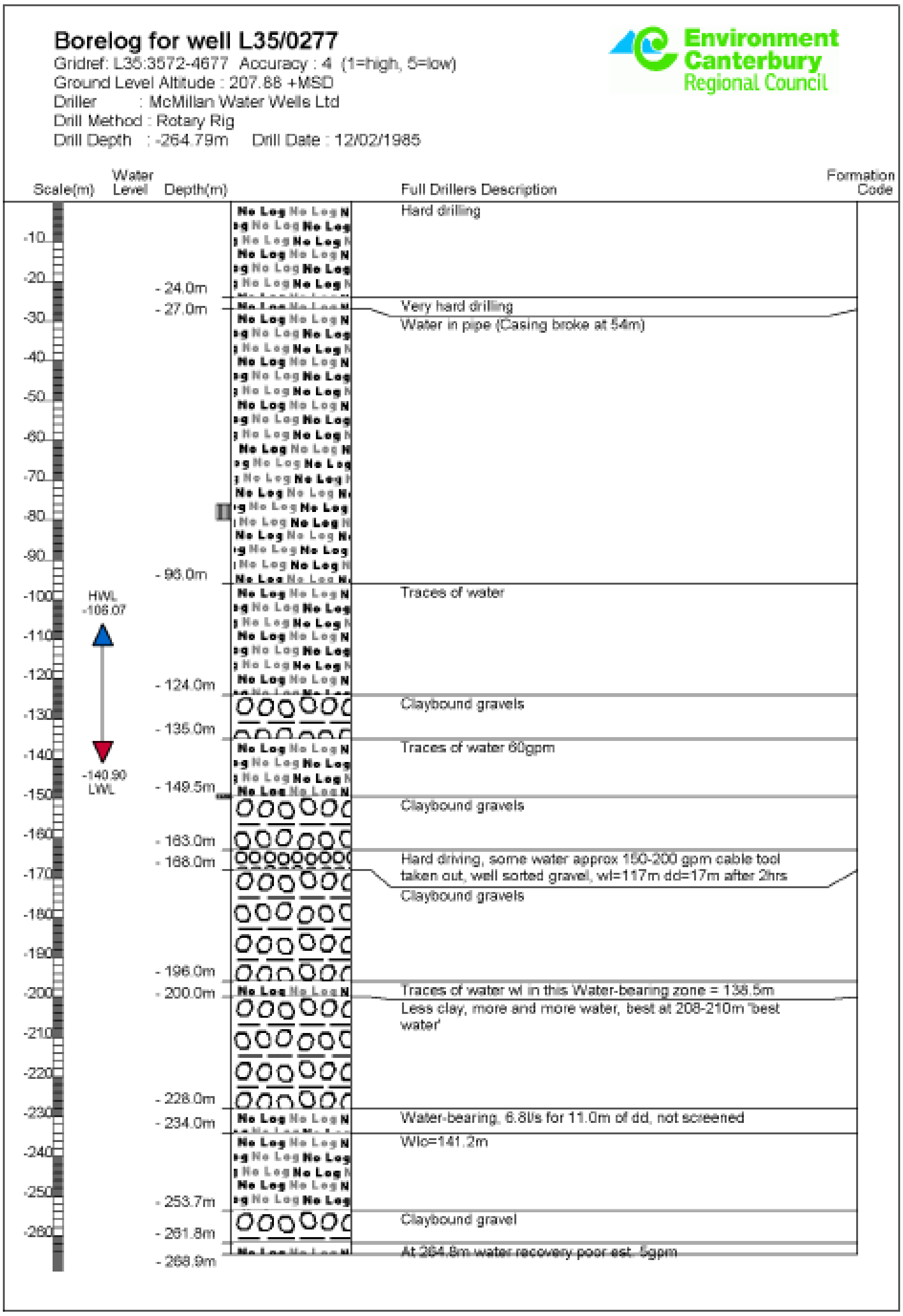


Bore or Well No: L35/0277	Environment Canterbury — Your regional council
Well Name:	
Owner: LOGAN, R	

Street of Well:	HOMEBUSH-DARFIELD RD	**File No:**	CO6C/06950
Locality:	DARFIELD	**Allocation Zone:**	Selwyn-Waimakariri
NZGM Grid Reference:	L35:3572-4677 QAR 4		
NZGM X-Y:	2435720 - 5746770		
Location Description:		**Uses:**	
ECan Monitoring:			
Well Status:	Capped (semi- permanent)		

Drill Date:	12 Feb 1985	**Water Level Count:**	6
Well Depth:	264.80m -GL	**Strata Layers:**	15
Initial Water Depth:	-113.50m -MP	**Aquifer Tests:**	1
Diameter:	300mm	**Isotope Data:**	0
		Yield/Drawdown Tests:	2
Measuring Point Alt:	208.18m MSD QAR 4	**Highest GW Level:**	106.37m below MP
GL Around Well:	-0.30m -MP	**Lowest GW Level:**	141.20m below MP
MP Description:	ToC	**First Reading:**	15 Aug 1984
		Last Reading:	01 Sep 1998
Driller:	McMillan Drilling Group	**Calc. Min. GWL:**	
Drilling Method:	Rotary Rig	**Last Updated:**	08 Feb 2002
Casing Material:		**Last Field Check:**	01 Sep 1998
Pump Type:	Unknown		
Yield:	20 l/s	**Screens:**	
Drawdown:	22 m	**Screen Type:**	Slotted Casing
Specific Capacity:	1.65 l/s/m	**Top GL:**	76.00m
		Bottom GL:	80.00m
Aquifer Type:	Unknown	**Screen Type:**	Slotted Casing
Aquifer Name:		**Top GL:**	149.00m
		Bottom GL:	150.00m

Date	**Comments**
	BASIC DRILLERS LOG
01 Sep 1998	Well originally owned by R M Stewart.
21 Nov 2000	Jan 1995, downhole camera (D Clemence) revealed g/w @ 76m entering well through slots. Chemical analysis Nitrate nitrogen 2.8, Chloride 9. 1995 test pumped by Clemence. Reinforcing rod, concrete, sheep carcass and steel plough sheers removed from well. Large split and belling of casing
21 Nov 2000	Drilling history. May 84-Aug 84, 168m deep, screen 159-168. Schramm rotary/percussion rig, McMillans Feb 1985, 235m deep, no screen. WB 196-210m. Arch-May 1985, Cable ttool, 264.8m, no screen. May-July 1985, Caswing slotted 149.5-150, test pumped at 9.1 l/sec, 14m dd 18/7/1985. 200mm casing cut off from 152m down.
10 May 2011	First WL reading set as ISWL


Borelog for well L35/0277
Gridref: L35:3572-4677 Accuracy : 4 (1=high, 5=low)
Ground Level Altitude : 207.88 +MSD
Driller : McMillan Water Wells Ltd
Drill Method : Rotary Rig
Drill Depth : -264.79m Drill Date : 12/02/1985
Environment Canterbury Regional Council
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
HWL -108.07
-140.90 LWL
- 24.0m
Hard drilling
- 27.0m
Very hard drilling
Water in pipe (Casing broke at 54m)
- 98.0m
Traces of water
- 124.0m
Claybound gravels
- 135.0m
Traces of water 60gpm
- 149.5m
Claybound gravels
- 163.0m
Hard driving, some water approx 150-200 gpm cable tool taken out, well sorted gravel, wl=117m dd=17m after 2hrs
- 168.0m
Claybound gravels
- 196.0m
Traces of water wl in this Water-bearing zone = 138.5m
- 200.0m
Less clay, more and more water, best at 208-210m 'best water'
- 228.0m
Water-bearing, 6.8l/s for 11.0m of dd, not screened
- 234.0m
Wlo=141.2m
- 253.7m
Claybound gravel
- 261.8m
At 264.8m water recovery poor est. 5gpm
- 268.9m

Appendix C: Dorn et al (2010)

Extracts from Dorn et al (2010) showing the interpretation of seismic reflections recorded along transect S2. Dorn et al (2010) suggest that the lack of reflections east of FA6, 16 km along the seismic line (coincident with Bleakhouse Road), likely indicates strong fault-related disruption of expected Late Cretaceous-Tertiary geological units and Quaternary gravels.

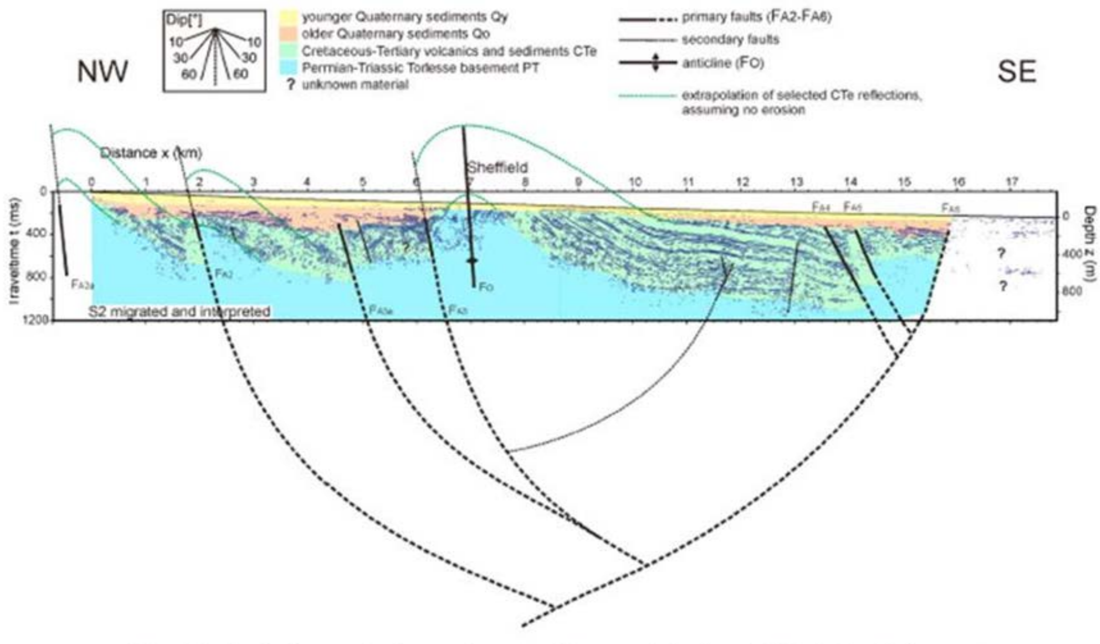


Figure 10. Sketch of interpreted geology superimposed on fully processed seismic section S2 (as in Figure 8) plus speculative extrapolation of some structural features.

Appendix D: Finnemore (2004)

Extracts from Finnemore (2004) showing the results of a seismic survey (Racecourse Hill-2 seismic line) conducted along Bleakhouse Road that runs between Racecourse Hill and the Waimakariri River.

Figure 9.1: Map showing the location of roads where differential G.P.S. measurements were taken near Racecourse Hill.

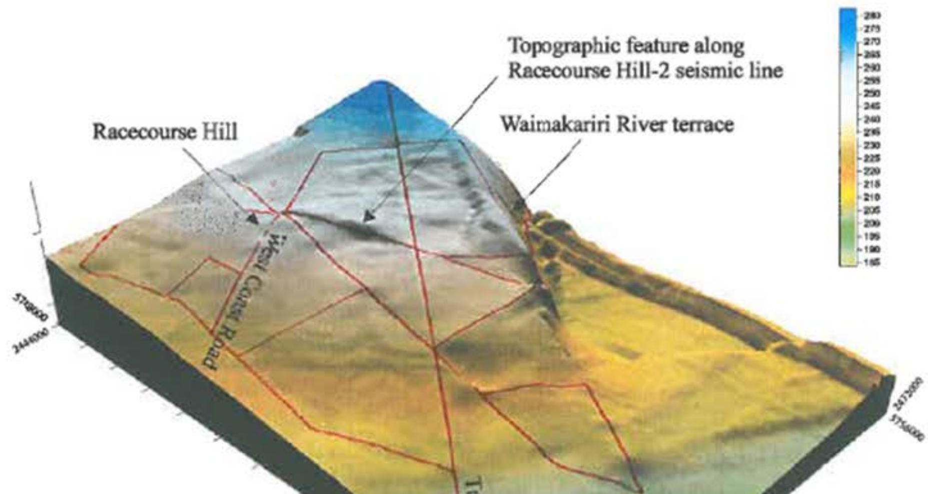


Figure 9.2: Topographic expression around Racecourse Hill. The topography is determined using P-code differential G.P.S. with an accuracy of +/- 1. A 70 x 70 m grid spacing using Kring gridding algorithms was used to produce the topographic model. Red lines show G.P.S. track. 143

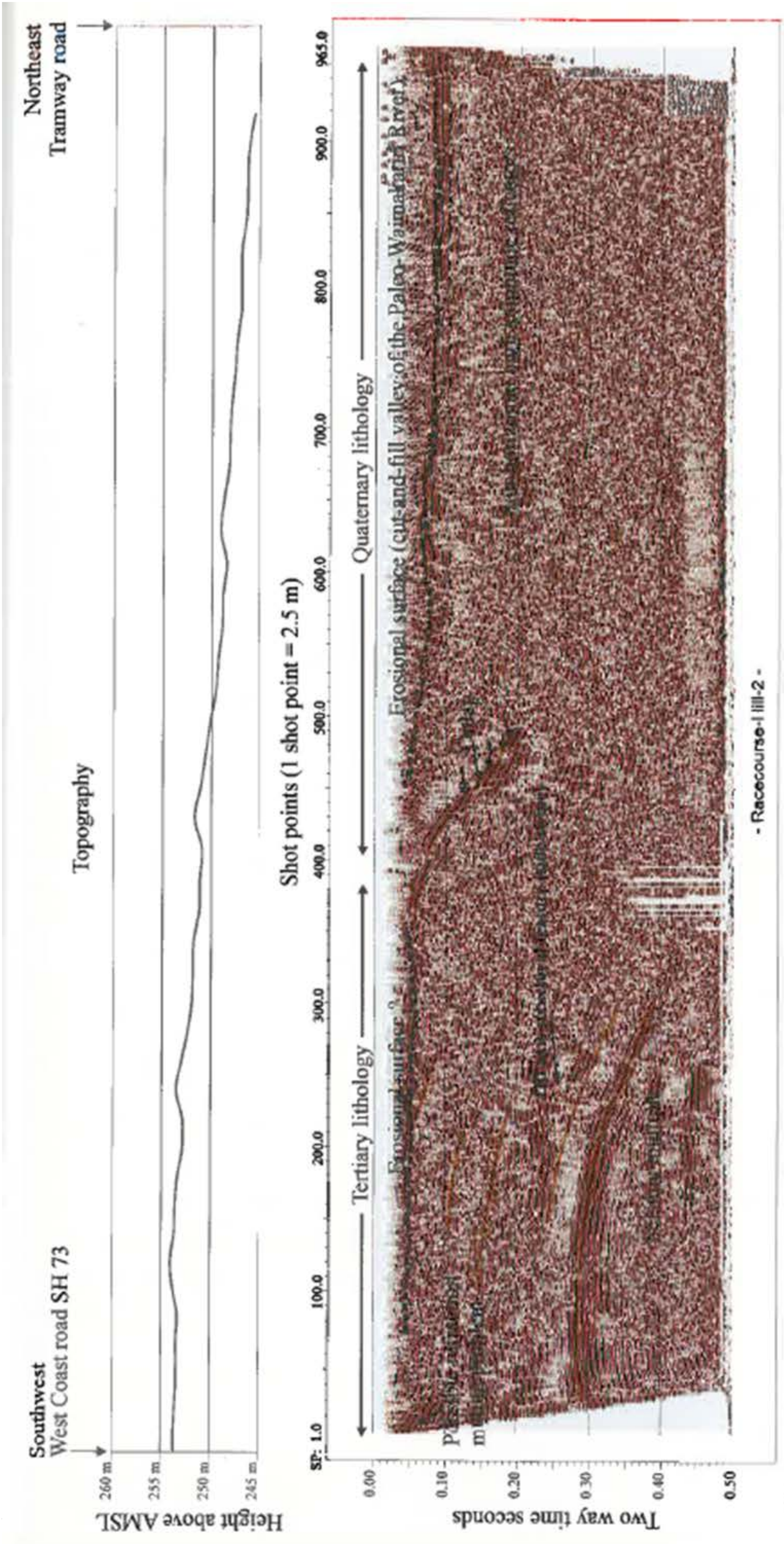


Figure 10.2: Final seismic section Racecourse Hill-2. Intepretation of the seismic section is shown on the overlay. Vertical exaggeration 1.5:1.

Appendix E: Interpretation of the available piezometric data

1. Estimation of the local hydraulic gradient

Methods

Piezometric data from wells along transect A-A' (see Figure 3) have been divided into three separate datasets in an effort to filter the vertical flow gradient from the horizontal flow gradient.

i) Shallow unconfined groundwater in possible Waimakariri paleochannel inferred by Finnemore (2004) (see Appendix D), labelled here as 'perched'.

ii) Assumed water table under Darfield town, labelled here as 'phreatic'.

iii) Piezometric levels associated with deep wells mostly screening >200 m below ground level (bgl).

The hydraulic gradient for each depth group was subsequently estimated from linear regression (Figure E1).

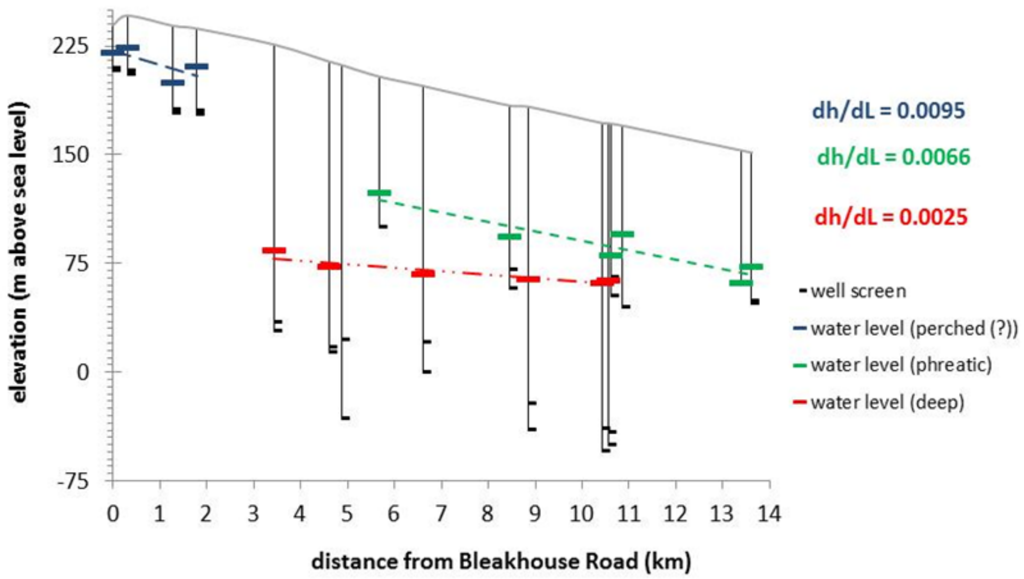


Figure E1: Piezometric gradient estimates based on water levels recorded in a set of wells under the Darfield area (see Figure 3 in the main text for the location plan).

Limitations

- The horizontal distance is that measured from origin of transect A-A', that is, well BW22/0021 on Bleakhouse Road, not necessarily the true horizontal distance along the assumed flow vector.
- Groundwater levels are the highest levels recorded.
- Most data were sourced from ECan's public WELLS database queried on 21 October 2013 and do not reflect measurements on any common date. Water levels for the 'perched' set of wells were provided by Fonterra, the shallowest levels for which were recorded in July and August 2013.

2. Prediction of groundwater flow direction

Note that all vectors shown in this analysis are estimates, marked by a visual inspection of the data, and not using any rigorous mathematical techniques.

- The red arrows in Figure E2 plot the general direction a contaminant plume emanating from Darfield or Kirwee would be presumed to take if inferred from ECan's regional piezometric contour dataset (the red contours). The length of the arrows roughly reflects the relative velocity assuming that the gradient is proportional to groundwater velocity.
- The black arrows mark the general topographic gradient, that is, the surface of the abandoned Waimakariri River fan and, hence, the assumed orientation of the main axis for the hydraulic conductivity tensor of an alluvial gravel aquifer.
- The green arrows denote an informed best guess of the true migration direction a contaminant plume emanating from Darfield or Kirwee would probably take.
- In effect, the red and black arrows mark the degree of uncertainty in the piezometric contour data available for analysis at present.

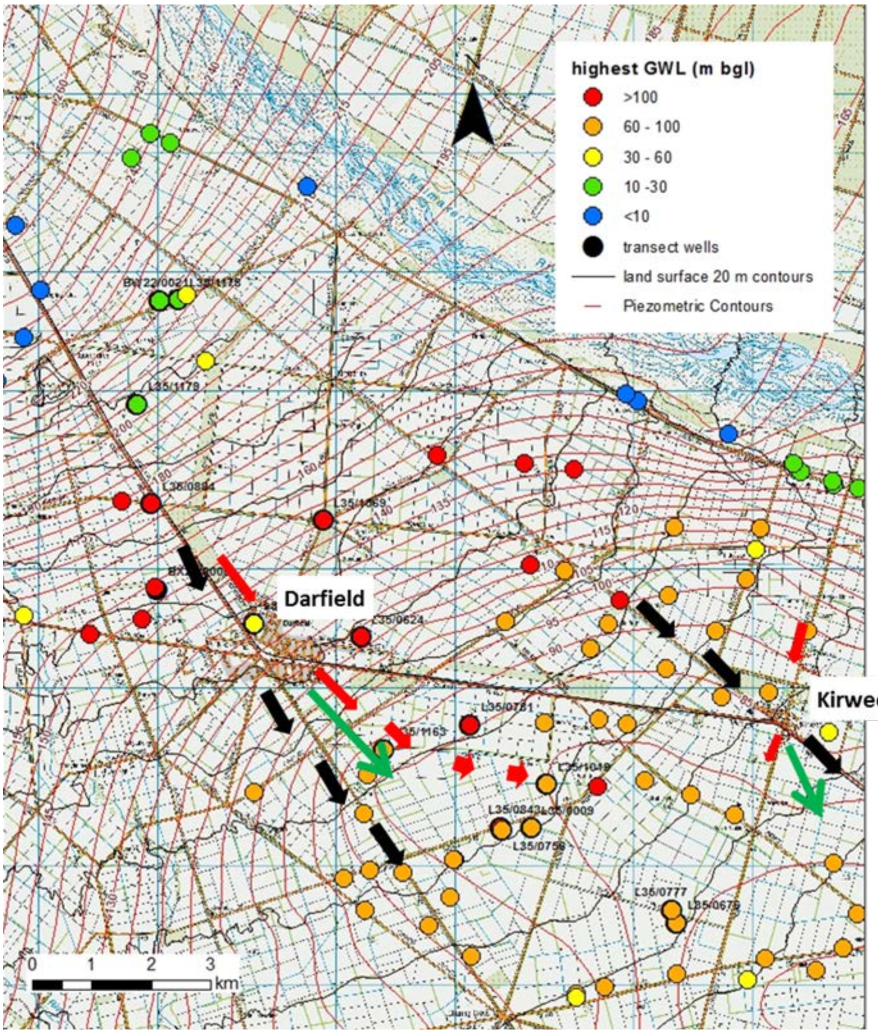


Figure E2: Predicted direction of contaminant transport from Darfield and Kirwee

Appendix F: Depths at which wells screen

A query of ECan's WELLS database in October 2013 records 23 bores drilled within an arbitrary 3-km radius of Darfield and four that are proposed for drilling. Of the existing bores, 16 are reported as either abandoned or unused. Information about the depths from which water is drawn is available for 13 wells, the distribution of which is shown in Figure F1. The wells screening at approximately 77 m bgl in Figure F1 relate to L35/0277 and L35/0340 and are reportedly 'not used' and 'capped/semi-permanent', respectively.

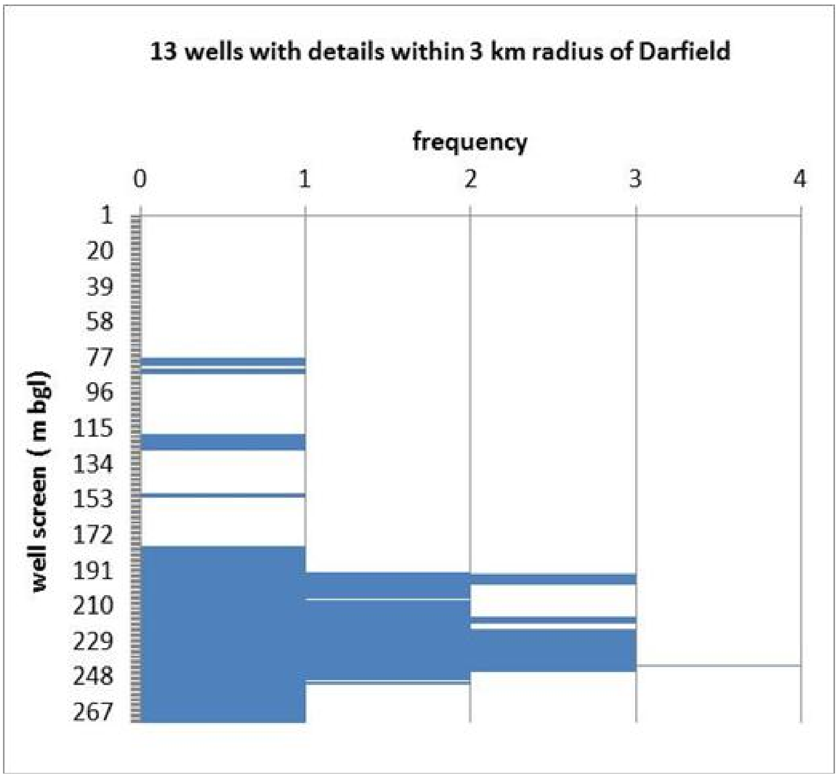


Figure F1: Frequency distribution plot for the depths at which wells screen the aquifer within a 3-km search radius of Darfield.
The data were exported from ECan's WELLS database during July 2013.

Thirty-three bores have been reportedly drilled within a 3-km radius of Kirwee and two more are proposed. Information about the depths at which wells are screened is available for 32 of the bores, with four of the bores reported as either abandoned or not used. The depth distribution of screened well intervals is shown in Figure F2.

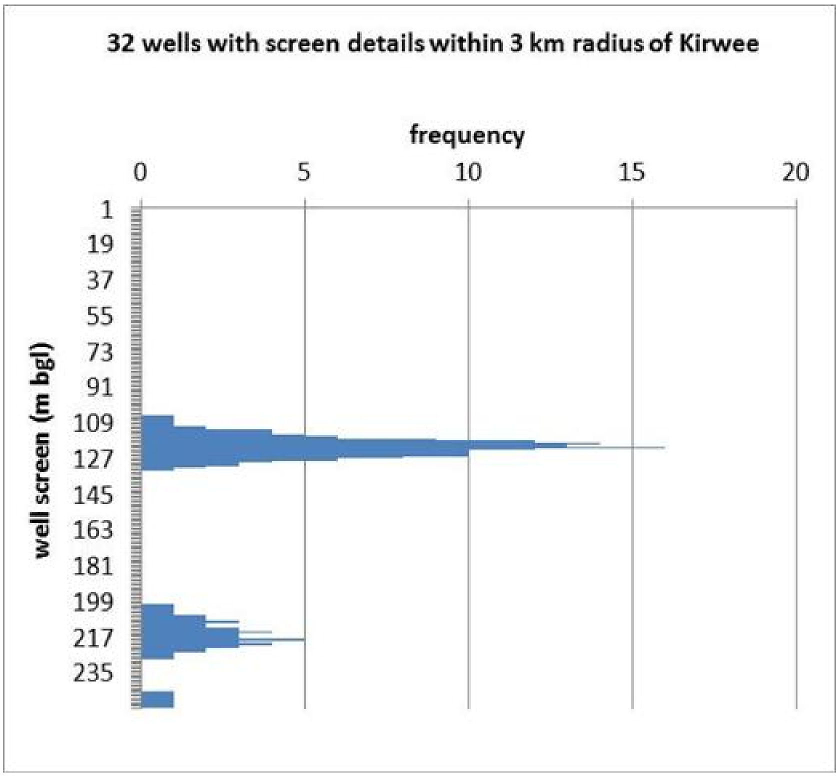


Figure F2: Frequency distribution plot for the depths at which wells screen the aquifer within a 3-km search radius of Kirwee.
The data were exported from ECan's WELLS database during July 2013.

Appendix G: Assessment of groundwater stresses in the Darfield-Kirwee area

A simple water balance has been calculated for a nominal 14,210 ha area that is marked in Figure G1, and largely covers the Darfield-Kirwee area, to gauge the relative hydraulic stresses induced by water abstraction on the groundwater system. The projected extension of the Hororata geological fault (assumed in this case to underlie Bleakhouse Road) defines the top boundary of the sub-regional aquifer studied here.

It is assumed that the groundwater system has effectively no connection with the Hawkins or Waimakariri Rivers, hence, the groundwater resource is completely dependent on LSR. This is a gross simplification yet conservative assumption, the potential errors in which are examined below.

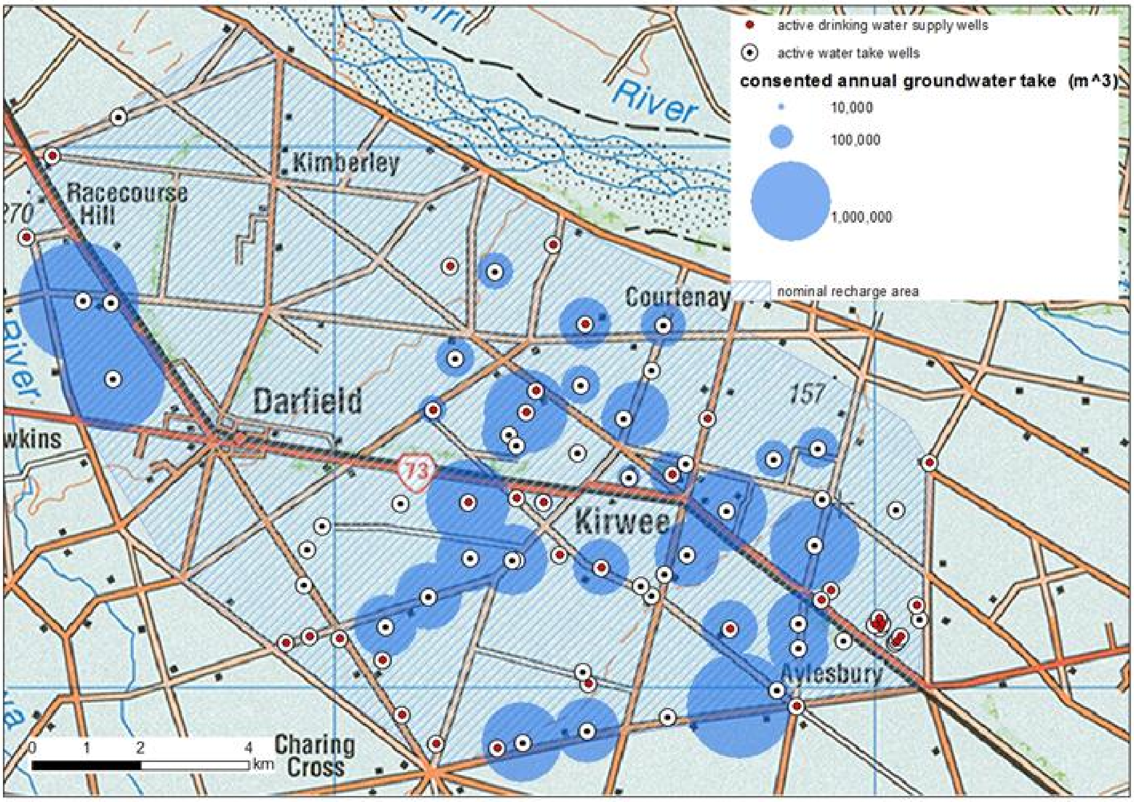


Figure G1: Location of active water take consents in the Darfield-Kirwee area. Wells recorded as potable water supply wells, for which no formal groundwater take consent is required if the daily take is <10,000 L, are marked in red. Other wells marked on the map are active and used for irrigation, industrial or stockwater uses.

The water balance has been computed assuming the aquifer can be treated as a simple closed system (ie, a bucket) for the sub-region of interest, marked by blue hatching in Figure G1. ECan provided information on all of the active groundwater take consents in the marked area (42 in total see Table G1; see Figure G1 for locations). The 'full effective annual' volume of groundwater consented for abstraction is 24,320,251 m^3/yr. Dividing this by the sub-regional area of 14,210 ha equates to an effective depth of abstraction of 171 mm/yr.

Table G1: Active groundwater take consents in the Darfield-Kirwee sub-region marked in Figure G1.

Data were provided by ECan's CONSENTS database queried on 17 October 2013.

Consent no.	Full effective annual volume (m^3)	Water use
CRC000502	237,610	Irrigation
CRC001888	540,660	Irrigation
CRC001889.2	729,960	Irrigation
CRC002098	290,850	Irrigation
CRC002099.2	1,195,950	Irrigation
CRC010861.3	715,340	Irrigation
CRC010890	313,800	Public Water Supply (Municipal/Community)
CRC010945.2	494,570	Irrigation
CRC010982.2	271,911	Irrigation
CRC011081.2	472,640	Irrigation
CRC020319.3	852,350	Irrigation
CRC022119.3	67,667	Irrigation
CRC030266	628,350	Irrigation
CRC030440	267,840	Irrigation
CRC030991	1,219,080	Irrigation
CRC031193.1	789,912	Irrigation
CRC031798.1	812,287	Irrigation
CRC032114	147,260	Irrigation
CRC040323	102,780	Irrigation
CRC041959.3	1,133,324	Irrigation
CRC042659.1	363,750	Irrigation
CRC042689.2	1,903,900	Irrigation
CRC042752.1	563,573	Irrigation
CRC042753	726,165	Irrigation
CRC042798	1,392,000	Irrigation
CRC060458.3	2,599,000	Irrigation
CRC101670	1,171,497	Irrigation
CRC135842	67,720	Irrigation
CRC136768	46,090	Irrigation
CRC951149.6	33,860	Irrigation
CRC951150.2	33,860	Irrigation
CRC951714.3	46,090	Irrigation
CRC951722.2	46,090	Irrigation
CRC981464.6	46,360	Irrigation
CRC982160	671,910	Irrigation
CRC982178.1	46,090	Irrigation
CRC991897	228,345	Irrigation
CRC992125	668,450	Irrigation
CRC992490.2	34,460	Irrigation
CRC061232	294,540	Irrigation
CRC093539.1	1,679,000	Public Water Supply (Municipal/Community)
CRC992345	373,360	Irrigation
TOTAL (m^3)	**24,320,251**	

The average annual rainfall for the Darfield-Kirwee area based on 30-years' historic virtual rainfall records sourced from the national climate database (CLIFLO) is 758 mm/yr. Assuming 30 percent of the annual rainfall actively recharges the groundwater system (ie, 70% is lost by evapotranspiration, which has been the general assumption of most LSR estimates for the region [David Scott, Hydrogeologist, ECan, personal communication, December 2013]), then it is estimated that the groundwater resource under Darfield and Kirwee is the recipient of 227 mm/yr of rainfall recharge. Note that in the nitrogen-leaching rate 'look-up tables' in Lilburne et al (2010), soil drainage estimates for the light soils in the Darfield-Kirwee area under dryland conditions are reportedly just 140 mm/year. This disparity in LSR estimates has recently been recognised by ECan and serves to highlight the uncertainty in the general knowledge about the Canterbury hydrological system (Lisa Scott, Groundwater Quality Scientist, ECan, personal communication, November 2013).

Depending upon which LSR estimate is believed, the consented groundwater abstraction in the area equates to between 75 percent (171/227) and >100 percent (171/140) of the net aquifer recharge, should the system be dominated by LSR. All but two of the groundwater take consents are for irrigation water, for which it is generally acknowledged that the actual water usage is less than the consented water usage (Glubb and Durney 2014). Metering of actual water use would reduce this uncertainty. The effects of return irrigation water have not been factored in and could be significant.

Comment on uncertainty of the water balance

The relative scale of the consented groundwater takes evaluated previously represents a conservative estimation based on our conceptualised model of the Darfield-Kirwee groundwater system that assumes no river recharge inputs to the system from either the Hawkins or Waimakariri Rivers.

At the other end of the scale, one could argue that some undetectable volume of water from both the Waimakariri River and the Hawkins River leaks into the aquifer underlying the central Canterbury Plains along the river reaches bordering the Darfield-Kirwee area and that this provides continuous recharge to the system. The calculations that follow involve a raft of arbitrary assumptions regarding river leakage rates. The aim is to provide some understanding of the scale of uncertainty in the water balance computed for Darfield and Kirwee.

Although no significant flow losses are reported for the Waimakariri River between the Waimakariri Gorge and Courtenay (White et al 2011), it remains that some leakage may occur from the river bed undetected, and within the range of flow gauging errors. Considering the seven-day mean annual low flow for the Waimakariri River is around 44 m^3/s, a river low-flow gauging error of 5 percent equates to about 2200 L/s. If one assumes this potential measurement error equates to immeasurable flow losses from the river between the gorge and SH1 flow recorder sites and the losses are distributed evenly along this 49 km reach, then the 8 km of the Darfield-Kirwee aquifer that borders the Waimakariri River (see Figure G1) might be the recipient of 8/49 x 2200 = 359 L/s (or 180 L/s if one were to assume these speculative losses are split 50:50 to each side of the river).

The mean flow statistic for the Hawkins River is 742 L/s at Auchenflower Road (ie, upstream of Racecourse Hill). As mentioned in the main report, essentially all flow from the Hawkins River infiltrates to groundwater. Assuming half of this leakage to the central Canterbury Plains were to occur upstream of Darfield, then one could roughly estimate that the Hawkins and Waimakariri Rivers collectively provide a continuous input of 551 L/s of water to the Darfield-Kirwee area. If distributed evenly over the nominal 14,210 ha area marked in Figure G1, then the river inputs equate to 122 mm/yr. This recharge value is almost half that estimated for LSR (227 mm/yr). For this scenario, the consented groundwater abstractions in the Darfield-Kirwee area equate to 49 percent (171 mm/349 mm) of the annual water budget, which is a relatively significant portion of the water balance.

The water balance calculations in this Appendix are fraught with gross uncertainty, because the true hydraulic influence of the rivers on the aquifer at Darfield-Kirwee remains to be properly characterised. As stated in the main report, the general impression from the regional water quality data is that the aquifer at Darfield-Kirwee is largely insensitive to any river recharge inputs, thus from a water quality management perspective the uncertainties in the water balance are not of major importance. A precautionary approach to water quality management in the region would assume no river recharge inputs.

Appendix H: Existing wells in the Darfield-Kirwee area

Figure H1 shows the distribution of bores/wells in the Darfield-Kirwee area according to ECan's WELLS database (queried on October 2013). Status codes are as follows: AE = active; NO = not operational; PL = planned/proposed; PW = water permit proposed. Reported usage is also indicated.

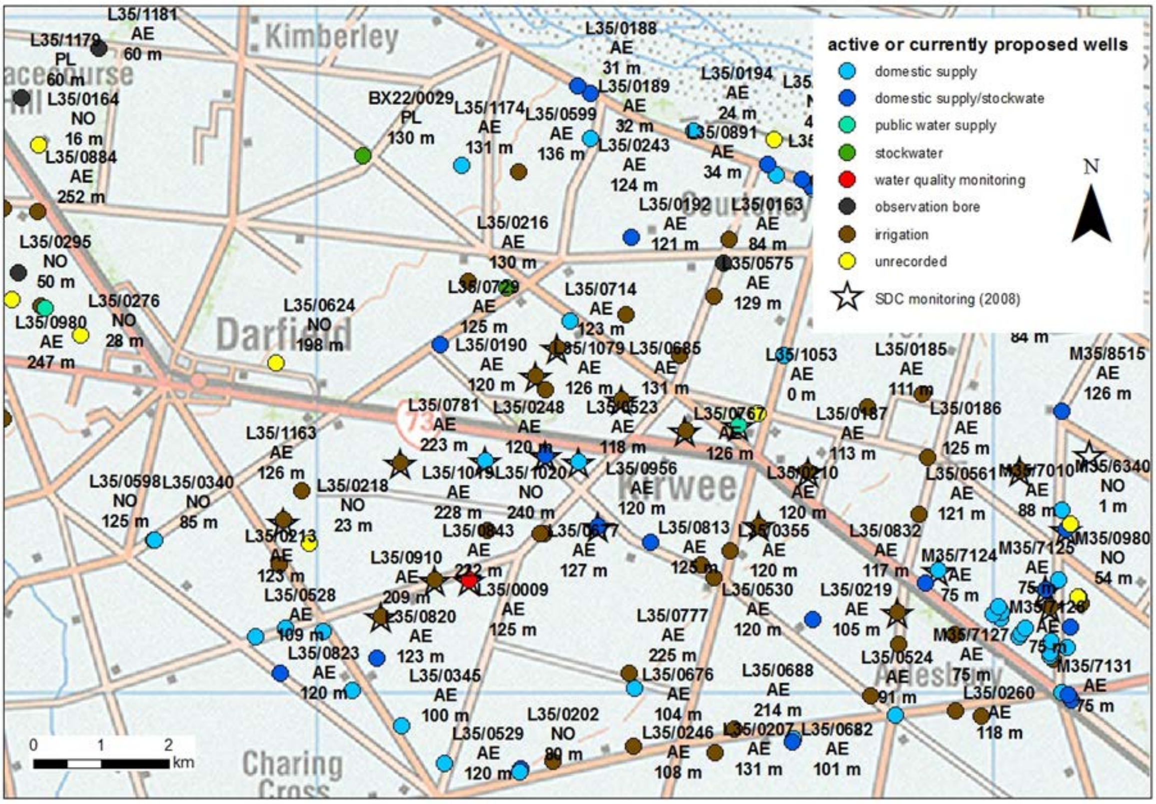


Figure H1: Wells in the Darfield-Kirwee area. Stars indicate wells used in SDC's 2008 survey.

Tables H1 and H2 contain lists of the wells surveyed by SDC over the years. The well construction details are provided, as is a well ranking, which is the perceived use of the well for any future water quality monitoring of potential impacts from septic tanks. The score system is as follows: 1 = useful, retain the well; 2 = some use, retain; 3 = not informative, abandon.

The colour formatting applied to the different physical parameters is green = good; red = bad.

Table H1: Details of SDC survey wells in Darfield.

Well No	Depth	Documented use	Top of well screen (m bgl)	Bottom of well screen (m bgl)	Screened length (m)	Water level above screen height (m)	Distance from Darfield (km)	For	Against	Rank
L35/0213	122.8	irrigation	113	122.8	9.8	21.44	3.05	Down-gradient of Darfield;		1
L35/0009	125	water quality	no information				4.82	Down-gradient of Darfield;	No screen info	2
L35/0528	109	irrigation/ domestic supply	106	109	3	28	1.58	Down-gradient of Darfield;		2
L35/0876	130	irrigation/ domestic supply	no information				6.63	Impacted by animal waste	No screen info	2
L35/0781	223	irrigation	205	223	18	86.15	4.84		Deep	3
L35/0843	221.84	irrigation/ dairy	212.84	221.84	9	104.14	4.35	Down-gradient	Deep; distant	3
L35/0884	251.6	irrigation	191.25	197.24	39.01	48.65	7.24		Up-stream of Darfield;deep; long stream	3
L35/0910	209	irrigation	185	209	24	79	3.43	Down-gradient of Darfield	Deep	3
L35/0980	246.8	irrigation	191.5	203.5	44.5	40.65	5.89		Up-gradient of Darfield;deep; long screen	3

Table H2: Details of SDC survey wells in Kirwee.

Well No	Depth	Documented use	Top of well screen (m bgl)	Bottom of well screen (m bgl)	Screened length (m)	Water level above screen height (m)	Distance from Kirwee (km)	For	Against	Rank
L35/0523	118.2	irrigation/ public water supply	115.2	118.2	3	42.9	1.65	Background well	Cross-gradient	1
L35/0187	113.1	irrigation	109.4	113.1	3.7	54.73	1.91	Down-gradient of Kirwee	Cross-gradient	1
L35/0191	115.2	public water supply	112.2	115.2	3	47.53	0.79	Central to Kirwee		1
L35/0210	120.1	irrigation	118	120.1	2.1		1.78	Down-gradient of Kirwee		1
L35/0562	114	domestic supply	111	114	3		4.27		Distant	2
L35/0568	113.45	irrigation	106.5	113.45	6.95		4.13		Distant	2
L35/0685	131	irrigation/ dairy	118.38	131.1	12.72	32.08	1.05		Up-gradient	2
L35/0767	125.5	irrigation	119.5	125.5	6	36.5	0.00	Historic E.coli impact	Up-gradient	2
L35/0870	114	domestic/ stockwater	111	114	3	35.9	4.21	Down-gradient of Kirwee; potable supply	Distant	2
L35/0248	120	irrigation/ domestic supply	117	120	3	39.54	3.00		Cross-gradient	3
L35/0729	125	irrigation/ domestic supply	117	123	6	20.68	3.85		Cross-gradient	3
L35/0956	120	domestic/ stockwater	117	120	3	34.5	1.92		Up-gradient	3
L35/0190	120.1	irrigation/dairy	117.1	120.1	3	43.58	2.35	Up-gradient of Kirwee		3
L35/0714	123.3	irrigation/ domestic supply	116.3	123.3	7	22.2	2.27		Up-gradient	3
L35/1173	250.83	domestic/ public water supply	242.6	250.6	8	131.89	2.36		cross-gradient; Distant; deep	3
M35/7555	107	irrigation	102	107	5	56	5.99		Distant	3
M35/0921	65.5	irrigation/ domestic supply	60.4	65.5	5.1	35.53	5.98		cross-gradient; Distant	3
M35/7010	88	irrigation/ domestic supply	82	88	6	82	5.81		cross-gradient; Distant	3
M35/9293	72	domestic/ stockwater	66	72	6	10.2	5.83		Distant	3
M35/9628	120.25	irrigation	114.25	120.25	6	55.7	4.97		Cross-gradient; Distant	3
L35/0194	23.7	domestic supply	no information				4.42		Waimakariri River	3