Review of water allocation limits for the South Canterbury downlands

Report No. U07/09

Mike Thorley
Marc Ettema

April 2007

Environment Canterbury
Your regional council

Environment Canterbury
Your regional council

Report U07/09

58 Kilmore Street
PO Box 345
Christchurch
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru
Phone (03) 688 9069
Fax (03) 688 9067

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

Executive Summary

This report redefines the Groundwater Allocation Zone boundaries based on geology and major surface water catchments across the South Canterbury downlands area. The area covers the coastal downs south from Timaru to the Waitaki River Catchment boundary and inland to the Hunter Hills. This review has led to adjustments in the areas of land-surface recharge capture. Additionally, three new zones have replaced the Waihao-Wainono groundwater allocation zone (GWAZ).

Loess deposits across the South Canterbury area exhibit poor drainage characteristics. Therefore the model that calculates the land-surface recharge uses a factor that limits the sub soil drainage for the areas covered by loess. Excess soil moisture is assumed to represent runoff. The extent of the loess cover is greatest in the north of the South Canterbury downlands area and decreases towards the Waitaki River to the south. Therefore, the decrease in calculated land-surface recharge compared to previous calculations will be greatest in the northern groundwater allocation zones. The remaining areas mapped as Late Quaternary, Timaru Basalt, or Kowai Formation have had all the calculated land-surface recharge routed to the underlying aquifer.

The volume of water currently allocated in each GWAZ will fall within the new allocation limits. The exception is the proposed Hook GWAZ, where the allocation exceeds the revised allocation limit.

In the South Canterbury downlands area, the groundwater and surface water resources are closely linked. Therefore the surface water allocation needs to be considered at the same time as the groundwater allocation. In the absence of a steady Alpine river recharge into the zones, as in mid Canterbury, a certain amount of groundwater needs to be reserved for the surface water flows from the land-surface recharge estimate, prior to setting the groundwater allocation limit. In this report the equivalent of the 7 day mean annual low flow (7DMALF) yearly volume is reserved from the land surface recharge if the river flows at the coastal side. Although there is no guarantee that that the river will maintain its 7DMALF it is a recognition that the surface water relies on the groundwater recharge, and that not all groundwater can be allocated when surface water abstractions and in-stream values depend on this groundwater contribution to the streams.

When we apply the rules of the proposed NRRP to the rivers in South Canterbury we find that many surface water allocations are at a level that only a very low reliability of supply can be expected for the existing users.

Table of Contents

List of Figures

List of Tables

1 Introduction

Revised estimates of land-surface recharge and intermittent stream recharge to the groundwater system found across the downlands area between Timaru and the Waitaki River are required. Aitchison-Earl et al. (2006) highlighted many water allocation issues in this area through the resource summary. This work addresses four main issues, summarised by the following guiding questions:

1. How could we account for the poor drainage properties of loess strata and what are the implications for estimates of mean annual land-surface recharge?
2. Are the current groundwater allocation zone boundaries appropriate to the physical dynamics of the surface and groundwater systems?
3. Based on the flow dynamics of the surface waterways, which waterways should be classified as intermittent, what are the contributions to and from surface waterways, and what is the status of surface water allocation?
4. What are the revised interim groundwater allocation limits, and status, for the Pareora, Otaio, Makikihi, and Waihao-Wainono groundwater allocation zones?

The information in this report, together with other information, is used to formulate interim water allocation limits in the proposed NRRP, for the South Canterbury downlands area. This report represents advice to Environment Canterbury based on the best available information at the time of publication.

2 Hydrogeology

2.1 Overview

The important geological factor for this work is the coverage of loess deposits, their hydraulic properties, how these deposits affect land-surface recharge relative to recent Quaternary deposits, and how recharge may be reaching the Timaru Basalt deposits and Cannington Gravel deposits that underlie the mantle of loess. The basic premise is that the loess deposits have poor drainage properties, and that a higher proportion of rainfall becomes surface runoff across those areas with loess cover. The surface runoff from these loess dominated areas is likely to consist of short-duration flows in ephemeral streams which then flow into the higher order streams and rivers, groundwater, and/or directly to the coast. In some areas, the surface waterways have eroded through the loess cover, exposing the underlying deposits of Timaru Basalt and/or Cannington Gravel. In these areas, leakage from surface waterways to the groundwater system is expected to be relatively higher, and may form an important recharge source for the deeper parts of the groundwater system. However, there are limited surface water gauging data, and therefore it is not yet possible to give quantitative estimates of contributions from these possible recharge sources.

The geological map is shown in Figure 1, which is an electronic version (shapefiles) of the 1:250,000 scale QMAP series (GNS, 2006). Aitchison-Earl et al. (2006) provides an overview of the physiographical and geological setting of the South Canterbury downlands area.

Groundwater recharge entering pre-Quaternary consolidated rock formations has not been assessed as part of this study. Groundwater abstractions seeking supplies from tertiary rock aquifers should be dealt with on a case by case basis. Generally the older, consolidated rocks have been treated as impermeable no-flow boundaries for the purposes of this work.

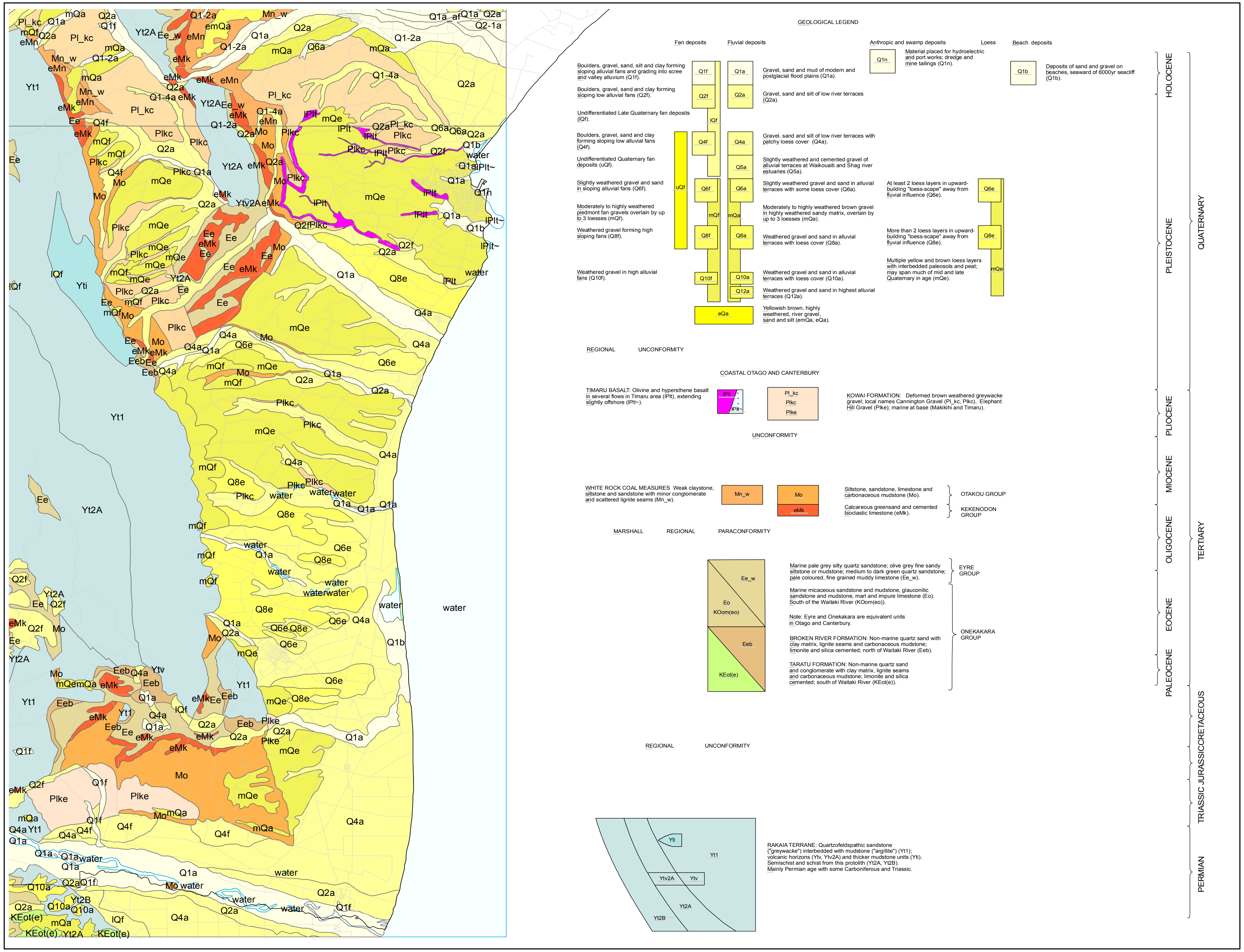


Figure 1: Geology of South Canterbury (GNS, 2006).

2.2 Literature review

A brief literature review was conducted to examine the known hydraulic properties of the loess deposits across the South Canterbury downlands area. Loess of Pleistocene age is widely distributed over the eastern hills, terraces and downlands of the South Island and has been mapped and described by many authors, notably Hardcastle (1908), Raeside (1964), Ives (1972), Bell (1978), Berger et al. (2001) and Schmidt et al. (2005). The major loess deposits of South Canterbury are generally considered to be associated with periods of glacial advance, although there is some uncertainty about the paleo-climatic conditions at the time of deposition. They consist of reasonably uniform composition comprising quartzo-feldspathic silt derived from local metamorphic rocks. Up to six stratigraphic units have been identified (Raeside, 1964), which have been mostly linked to other records of paleo-climatic changes in New Zealand and globally (Berger et al., 2001). Many authors indicate that 3 m thickness of loess cover is common across the South Canterbury area, although it may present up to 30 m total thickness near the coast. Hardcastle (1908) describes wetting and drying processes in the loess and indicates that some drainage does occur, although predominantly through fractures and fissures. Raeside (1964) states that when the material is wetting it lets some water through its vertical fractures, but as it wets, these fractures close, and the bulk material becomes less permeable. There does not appear to be permeability data for the loess deposits in South Canterbury, although some testing was carried out with samples collected from the Port Hills, described by Dodd et al. (1978), who indicated that permeability is in the order of 1×10^{-9} m/s as a bulk mass, but as high as 1×10^{-7} m/s (equivalent to 0.36 mm/hour) in the fractured zones. Generally, all authors describe the loess soils as poorly drained.

2.3 Infiltration testing

Due to the absence of hydraulic properties data for loess strata in South Canterbury, ECan carried out some infiltration tests during January 2007, with some assistance from Pattle Delamore Partners Ltd (PDP). The selected test site is located immediately north of Pareora township. The site was kindly made available by PPCS Ltd, for whom previous investigations of the loess soils have been carried out by PDP in this area.

Test pits were excavated at five locations with three of these selected for infiltration tests, as shown in Figure 2 (overleaf). The test pits encountered loess strata that contained slight residual soil development apparent to about 1 m below ground surface. This included heavy mottling, slight fracturing and infilling, and plant roots, which then graded into the denser, massive silt material beneath this. The top soils are approximately 300 mm deep and appeared to be well developed. The deepest of the test pits (J39/0684) was excavated to 4 m depth within one of the low-lying swamp depressions, to determine if deeper drainage from these relatively wet areas was apparent. Test pit J39/0684 revealed much heavier mottling and mineral staining to a greater depth than the other test pits, although the lighter coloured and less stained material was observed at the base of the excavation. The occurrence of such staining seems to confirm that drainage does occur, albeit at extremely low rates, through the relatively un-weathered loess material.

Extensive or continuous fragipan[1] deposits were not encountered in any of these test pits. However, fragipan deposits are expected to occur at the base of the stratigraphic unit, rather than below the subsequent, near-surface soil development (Raeside, 1964). The presence of fragipan material is expected to significantly decrease deep drainage from the loess strata. Observations of drainage and subsurface occurrence of fragipan materials in South Canterbury are limited to anecdotal. Therefore, any possible further reductions in drainage

---

[1] Fragipan deposits are horizons or layers that are distinctively compact, cemented, or rich in clay. They are commonly sufficiently dense and low in permeability to interfere with moisture and root penetration (Taylor et al., 1962).

through the loess deposits caused by fragipan material have not been factored into the land-surface recharge calculations.

The results and analyses of the infiltration testing are described in a letter report prepared by PDP, which is appended in Appendix A. PDP have recommended that ECan limits any drainage calculated by the soil-water balance model at 3 mm/day, which is higher than that reported by Dodd et al. (1978) for Port Hills loess. The left-over, or excess drainage, is assumed to then occur as runoff. The results of the soil-water balance modelling incorporating this are discussed in section 3 of this report.

Figure 2: Map showing locations of test pits and those test pits within which infiltration tests were conducted. The sub-circular features shown in the aerial photograph are topographically isolated depressions that have swamps developed within these areas. These depressions do not have natural channel outlets although culverts now drain these areas.

3 Land-surface recharge

3.1 Overview

3.2 Soil-water balance model zonation

A hydro-spatial approach using ESRI ArcMap 9.2 has been used to spatially delineate and link different components of the land-surface recharge calculation. This is similar to the approach taken by Aqualinc (2005) for the Waipara Groundwater Allocation Zone, and differs somewhat from the grid based approach used by Scott (2004). The approach taken enabled a differentiation of areas based on geological deposits.

Data describing broad recharge areas (groundwater allocation zones), categories of geology, soil moisture capacity (PAW), irrigated area, and climate information were collated and combined to produce unique hydro-spatial parcels describing the hydrological input parameters required to compute land-surface recharge. Land-surface recharge calculations were then computed for each unique hydrological parcel using a slightly modified version of the FORTRAN soil moisture budget model (DRAIN.FOR) written and described by Scott (2004).

3.2.1 Land-surface recharge extents & new groundwater allocation zonation

Groundwater recharge areas mapped on the basis of geological information (GNS, 2006) and surface water catchments for the South Canterbury downlands area were required to accurately distinguish and group the hydro-spatial parcels. The recharge areas differ somewhat from the existing groundwater allocation zones. The justifications for the adjustments of groundwater allocation zone boundaries are:

- Current groundwater allocation zone boundaries follow roads and land parcels which leads to spatial inconsistencies between the physical system and the management policies that are applied to them;
- Current allocation zone boundaries cut across surface water catchments in some areas. It is preferable to include whole surface water catchments when net contributions or deductions are applied to the underlying groundwater system;
- Current zone boundaries do not conform to geological boundaries. In some areas, the existing zone boundaries do not incorporate unconsolidated deposits that are physically and hydraulically part of the downlands groundwater system and therefore the groundwater allocation zone. The new extents now include these areas. Other areas that can be considered hydraulically isolated from the main downlands aquifer system are currently included within the existing allocation zone extents. The new extents exclude such areas, which generally have very few groundwater takes in any case, and can be dealt with on an individual basis if they are outside of an allocation zone;
- A groundwater allocation zone is required immediately north of the Waitaki Plan extents and those NRRP groundwater allocation zones that lie within the Waitaki Plan extents, are not currently required.

The new recharge zones are recommended as the groundwater allocation zone boundaries by Environment Canterbury staff. The approach used in delineating the new boundaries is consistent with that used by Weeber (2006) for the Waipara GWAZ.

A map showing the new recharge areas, the existing allocation zone extents, and the geology demonstrates the justification for revising the spatial extents of the groundwater allocation zones (Figure 3). The following figure shows more clearly the proposed changes (Figure 4).

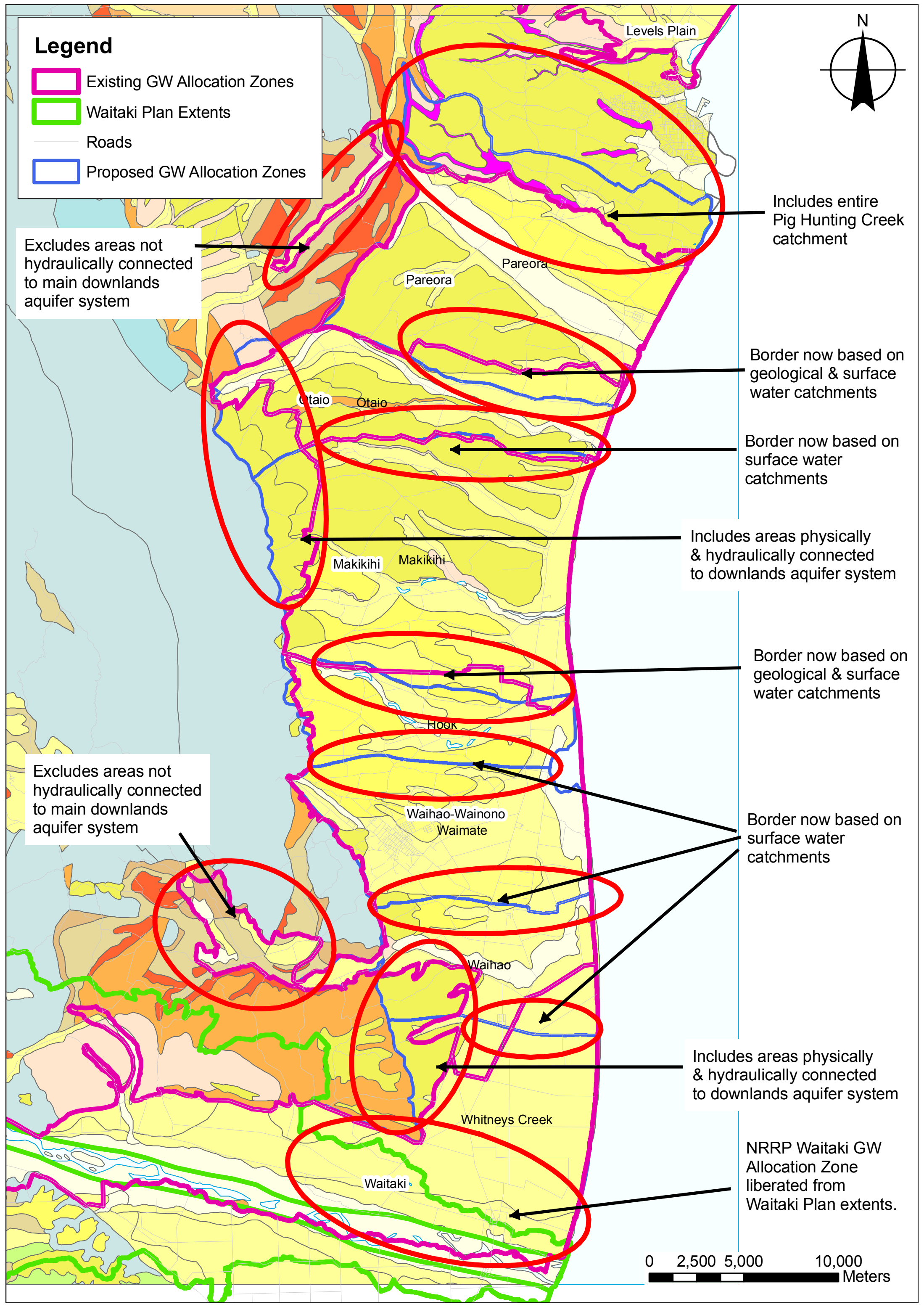


Figure 3: Proposed changes and justification for redefining the groundwater allocation zones in South Canterbury.

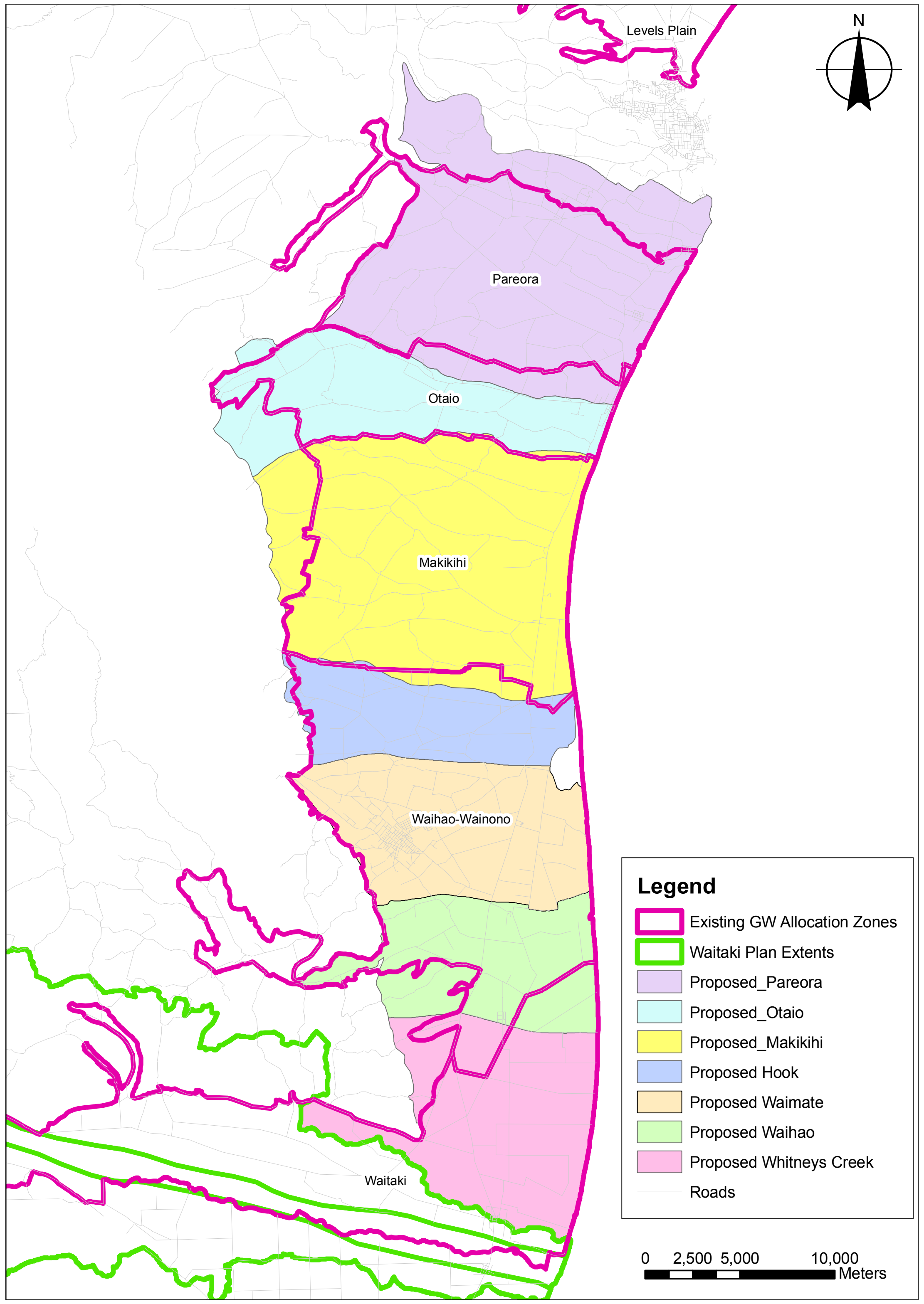


Figure 4: Proposed changes to the groundwater allocation zones in South Canterbury.

The change in area of each groundwater allocation zone is summarised in the following table (Table 3.1).

Table 3.1: Summary of changes proposed for the groundwater allocation zones south of Timaru.

Existing GW Allocation Zone	Existing Zone Area (ha)	Proposed GW Allocation Zone	Proposed Zone Area (ha)	Change in Area (%)
Pareora	14160.33	Pareora	19,628.67	+39%
Otaio	9023.08	Otaio	8,779.80	-3%
Makikihi	17527.79	Makikihi	20,003.48	+14%
Waihoa-Wainono	24655.76	Hook	6,071.52	-5%
		Waimate	9,642.38	
		Waihao	7,756.63	
Waitaki	36064.02	Whitneys Creek	10,467.22	-71%

The Pareora Groundwater Allocation Zone (GWAZ) has been altered to include the entire adjacent catchment of Pig Hunting Creek. The current zone boundary includes some of this catchment; entire catchments should be included when considering surface water gains and losses to and from groundwater.

Other changes to the Pareora zone include the exclusion of unconsolidated sediments surrounding the South Branch of the Pareora River from the GWAZ extents as this area is considered to contain only a thin veneer of water bearing strata bounded by consolidated rocks. Therefore, this area cannot be considered any more hydraulically connected to the wider downlands aquifer system than the areas upstream of the Pareora River Gorge, which are connected by surface waterways. It would be inappropriate to calculate land-surface recharge in these areas and include it as a contribution to the main downlands system.

The margin of the Pareora GWAZ and the Otaio GWAZ has also been realigned to follow the geological change from loess strata to Late Quaternary sediments and the catchment boundary of the lower Otaio River and Pareora River catchments.

The inland boundary of the Otaio GWAZ and the Makikihi GWAZ now incorporates areas mapped as unconsolidated sediments that are considered to be physically and hydraulically part of the wider downlands aquifer system. The boundary now traces the contact between consolidated metamorphic rocks and younger unconsolidated fan deposits.

The existing Waihao-Wainono GWAZ has been subdivided into three new GWAZ. The proposed zones now encompass the Hook River, the Waimate Stream, and the Waihao River systems, and are named as such. These changes are required to take account of the differences in net contributions from the surface water systems across the area. If the status quo remained, it would offset any net contribution from the Waimate Stream against any net gain from groundwater to the Hook River. To avoid surface water contributions been shifted across catchments, and any allocation inequities that may follow, it seems appropriate to designate a GWAZ to each major catchment within the existing Waihao-Wainono GWAZ.

Part of the inland area of the Waihao-Wainono GWAZ (in the vicinity of Waihao Forks) has been excluded as this area is not considered to be hydraulically connected to the main downlands aquifer system. The unconsolidated deposits in the area will only be connected by surface waterways and the Tertiary rock aquifers are not believed to be hydraulically connected to any other aquifer system. Therefore it would be inappropriate to calculate land-surface recharge in these areas and include it as a contribution to the main downlands system. Very few groundwater takes exist in this area and these can be managed on a case-by-case basis.

The proposed border between the Makikihi GWAZ and the proposed Hook GWAZ has been realigned to take account of a geological change from Late Quaternary sediments to loess-dominated deposits in the upper catchment area and the surface water catchment boundary across the lower catchment area.

The proposed Whitneys Creek GWAZ incorporates the area immediately north of the Waitaki Plan boundary and runs north to incorporate the bulk of the Morven-Glenavy Irrigation Scheme area. The boundary between the new Whitneys Creek GWAZ and the Waihao GWAZ traces the southern-most catchment boundary of the Waihao River and its tributaries.

3.2.2 Hydrogeological data

Using the 1:250,000 QMAP shape file data supplied by Geological and Nuclear Sciences (GNS) (2006), hydrogeological categories of mapped lithologies have been derived. Three categories have been used to summarise the mapped geological units as follows (see geological legend in Figure 1 for explanations of the unit codes):

1. Late Quaternary (Recent) Units:
   - Q1-2a, Q1-4a, Q1a, Q1a_af, Q1b, Q1f, Q1n, Q2-1a, Q2a, Q2f, Q4a, Q4f;
2. Loess Units:
   - Q6a, Q6e, Q8e, mQa, mQe, mQf;
3. Kowai Formation:
   - Plkc, Plke;
4. Timaru Basalt Formation:
   - lPlt.

The relative spatial coverage is summarised in Table 3.2. The spatial extents of the hydrogeological categories are displayed in Figure 5.

Table 3.2: Summary of the relative spatial coverage of hydrogeological units within the proposed groundwater allocation zones, in the South Canterbury downlands area.

Hydrogeological Unit	Pareora	Otaio	Makikihi	Hook	Waimate	Waihao	Whitneys Creek
Quaternary (ha)	5,863	3,607	5,851	2,605	5,611	5,618	9,385
Loess (ha)	12,896	4,585	13,768	3,424	4,038	2,061	1,082
Kowai (ha)	220	208	291	0	0	77	0
Basalt (ha)	589	0	0	0	0	0	0
Total (ha)	**19,569**	**8,400**	**19,909**	**6,029**	**9,648**	**7,757**	**10,467**
Quaternary (%)	30%	43%	29%	43%	58%	72%	90%
Loess (%)	66%	55%	69%	57%	42%	27%	10%
Kowai (%)	1%	2%	1%	0%	0%	1%	0%
Basalt (%)	3%	0%	0%	0%	0%	0%	0%
Total (%)	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: There are slight differences between some of the proposed GWAZ areas and the total areas of geology because surface water areas and some Tertiary formations have not been included.

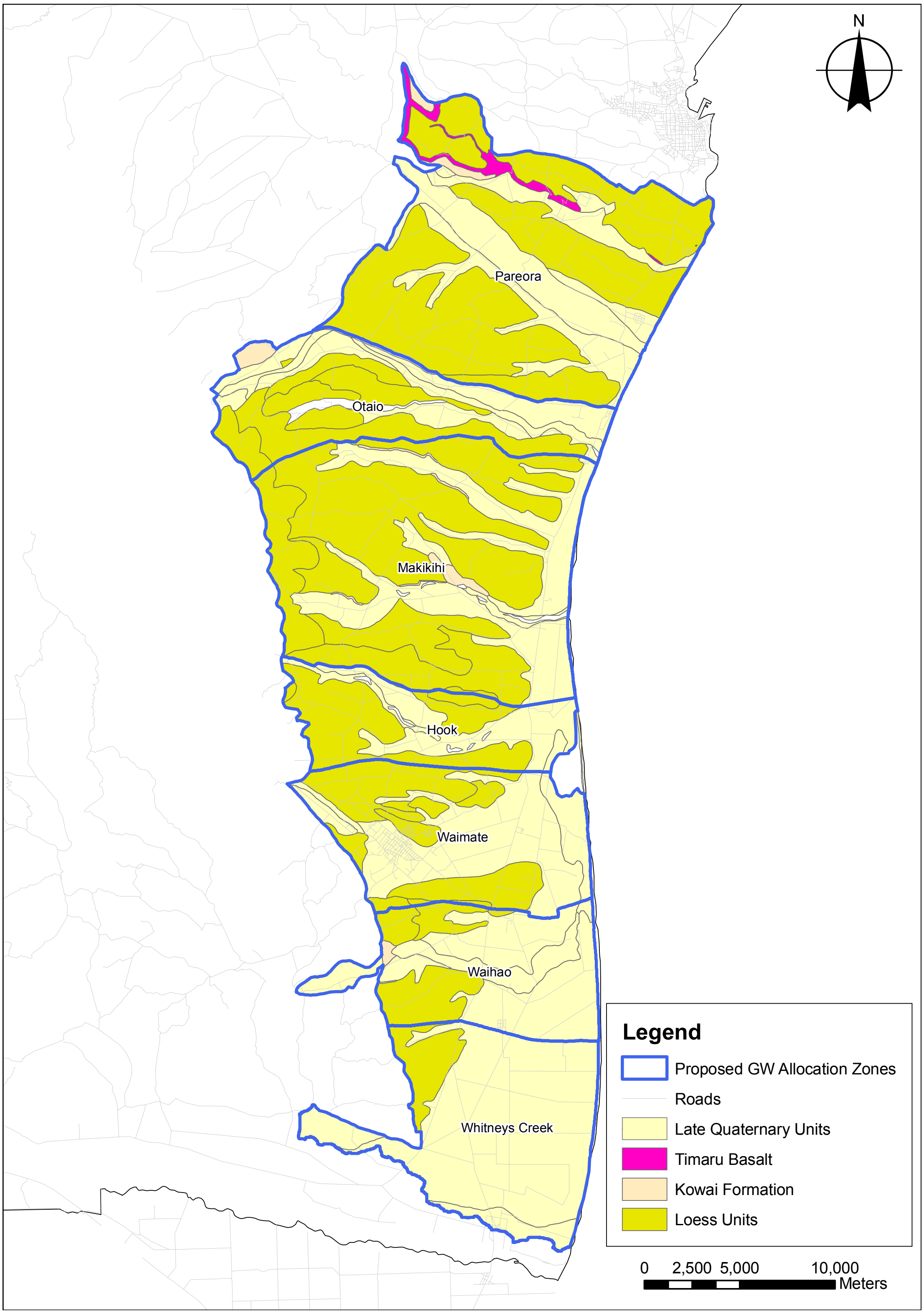


Figure 5: Map showing geological deposits across the South Canterbury downlands area. The geological deposits have been grouped into four categories based on their likely hydraulic properties and formation position.

3.2.3 Soils data

The soils data set used is the same as that used in Scott (2004). The soils data set has a complete coverage across the groundwater recharge areas. This file can be found in Q:\GISDATA\NAT_RES\LAND\MISC\CombinedSoils.shp, and is displayed in Figure 6 below.

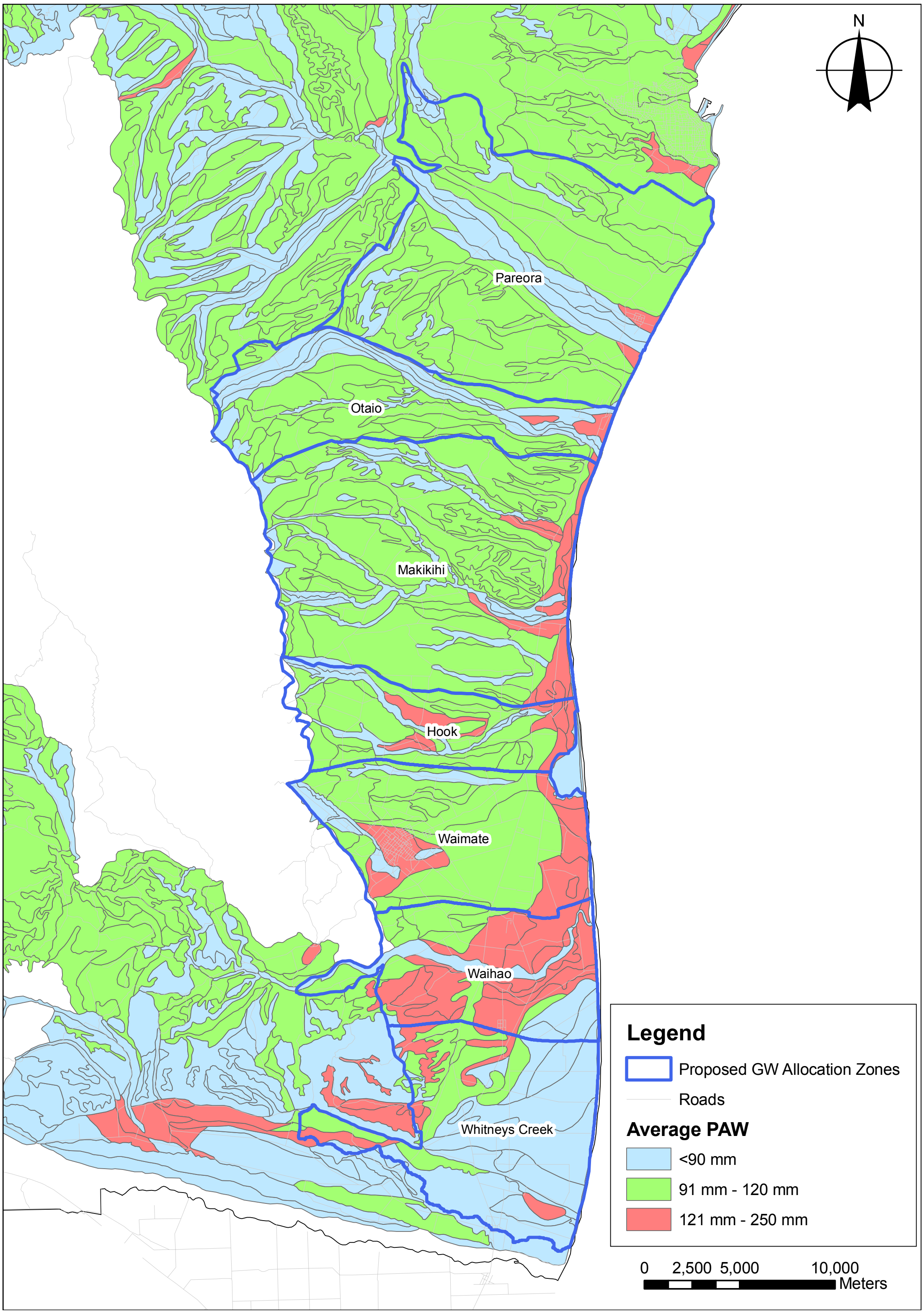


Figure 6: Soils mapped by average profile available water capacity (PAW).

Irrigation Extent

The spatial distribution of consented irrigated areas was mapped from the consents database using the land-parcel description for both groundwater and surface water takes (including surface water irrigation schemes) across the South Canterbury downlands area. The consented irrigated areas were cross-referenced with information held in AgriBase™ (AgriQuality Ltd, 2006), which in most cases, were consistent. It was assumed that the entire land-parcel is irrigated as detailed information about actual irrigated areas and scheduling is not available. In some cases, this may over-state the actual or consented irrigated area. However, in most cases the irrigated area described on the consents database was consistent with the land-parcel area.

Approximately 40% of the total area covered by the proposed groundwater allocation zones is mapped as irrigated by either surface water or groundwater. Of the total irrigated area, approximately 63% is sourced from surface water and 37% from groundwater. There was the occasional land parcel that sourced water from both surface and groundwater; however these were too few to warrant a third category for the purposes of this work. The mapped areas are shown in Figure 7 (overleaf).

Generic irrigation rules were applied during computation using the same methodology as Scott (2004).

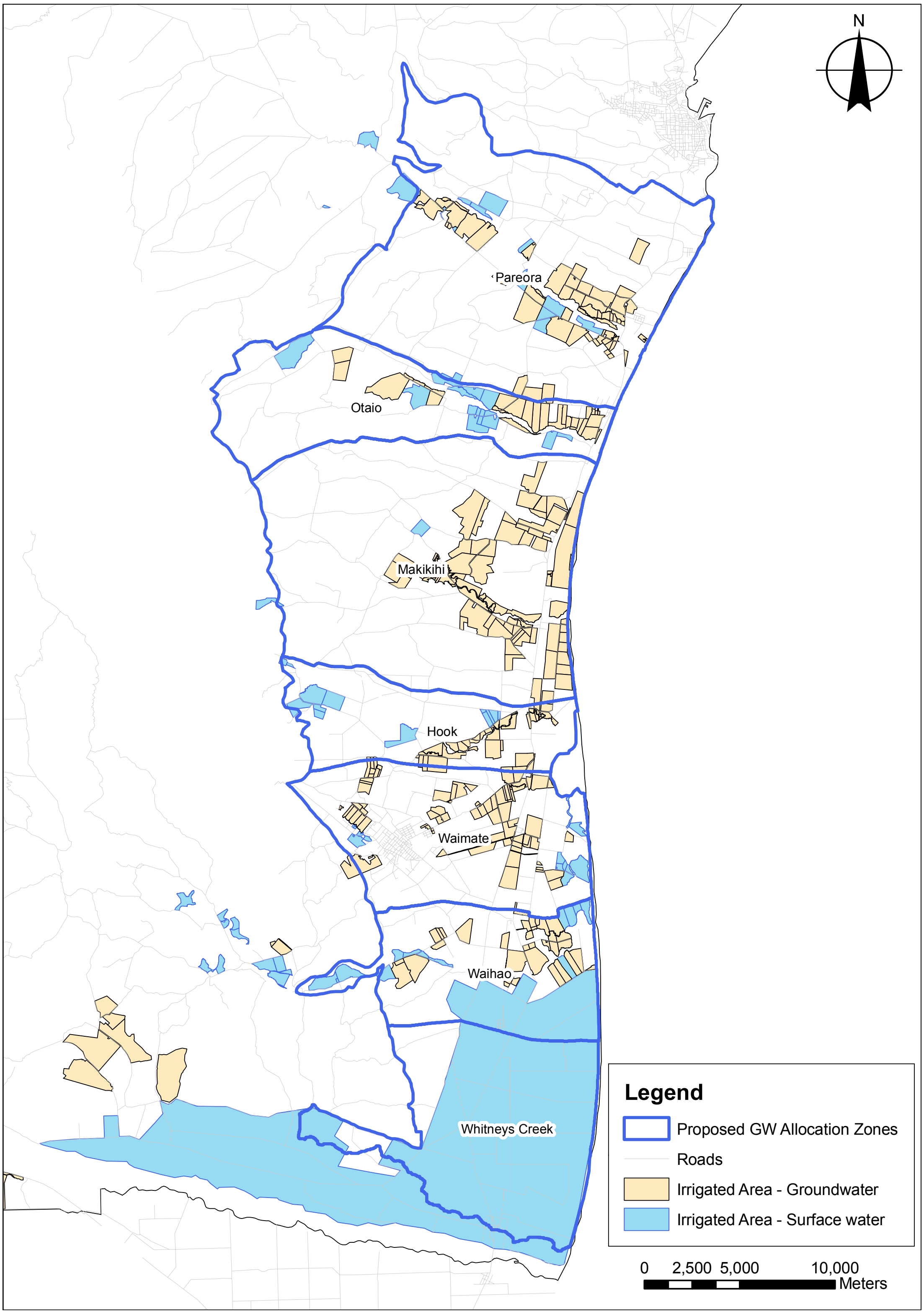


Figure 7: Map showing land-parcels that have resource consent to take and use water for irrigation (and their sources) across the South Canterbury downlands area.

3.2.4 Slope

Categories of slope were mapped from 15 m resolution DEM data sourced from LINZ. This was broken into three categories which are shown in Figure 8. The areas that had slope gradients greater than 15% appear to be consistent with those areas where runoff is expected to predominate. These areas included incised valleys and loess terrace margins across which land-surface recharge is thought to be limited by slope. Therefore these areas were excluded from those assessed for land-surface recharge. It is assumed that runoff will predominate over these areas and any contribution to the groundwater system will be accounted for by the intermittent stream recharge assessments. The total area excluded because of slope comprised about 8% of the total area assessed for land-surface recharge. A summary is provided in Table 3.3 below.

Land-surface recharge will be entering the groundwater system from these areas either as runoff and/or through-flow. It was beyond the scope of this work to estimate this component of recharge; however if technically robust estimates are determined, this could be added to the total land-surface recharge of any GWAZ discussed herein.

Table 3.3: Summary of relative spatial coverage of hydrological parcels and slope<15%.

Hydrogeological Unit	**Pareora**	**Otaio**	**Makikihi**	**Hook**	**Waimate**	**Waihao**	**Whitneys Creek**
Quaternary (ha)	5,736	3,547	5,463	2,525	5,453	5,482	9,269
Loess (ha)	11,947	3,934	11,914	3,190	3,868	1,842	653
Kowai (ha)	54	134	196	-	-	37	-
Basalt (ha)	303	-	-	-	-	-	-
Slope >15% (ha)	1,529	785	2,337	314	327	396	545
Total (ha)	**19,569**	**8,400**	**19,909**	**6,029**	**9,648**	**7,757**	**10,467**
Quaternary (%)	29%	42%	27%	42%	57%	71%	89%
Loess (%)	61%	47%	60%	53%	40%	24%	6%
Kowai (%)	0%	2%	1%	-	-	-	-
Basalt (%)	2%	-	-	-	-	-	-
Slope >15% (%)	8%	9%	12%	5%	3%	5%	5%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

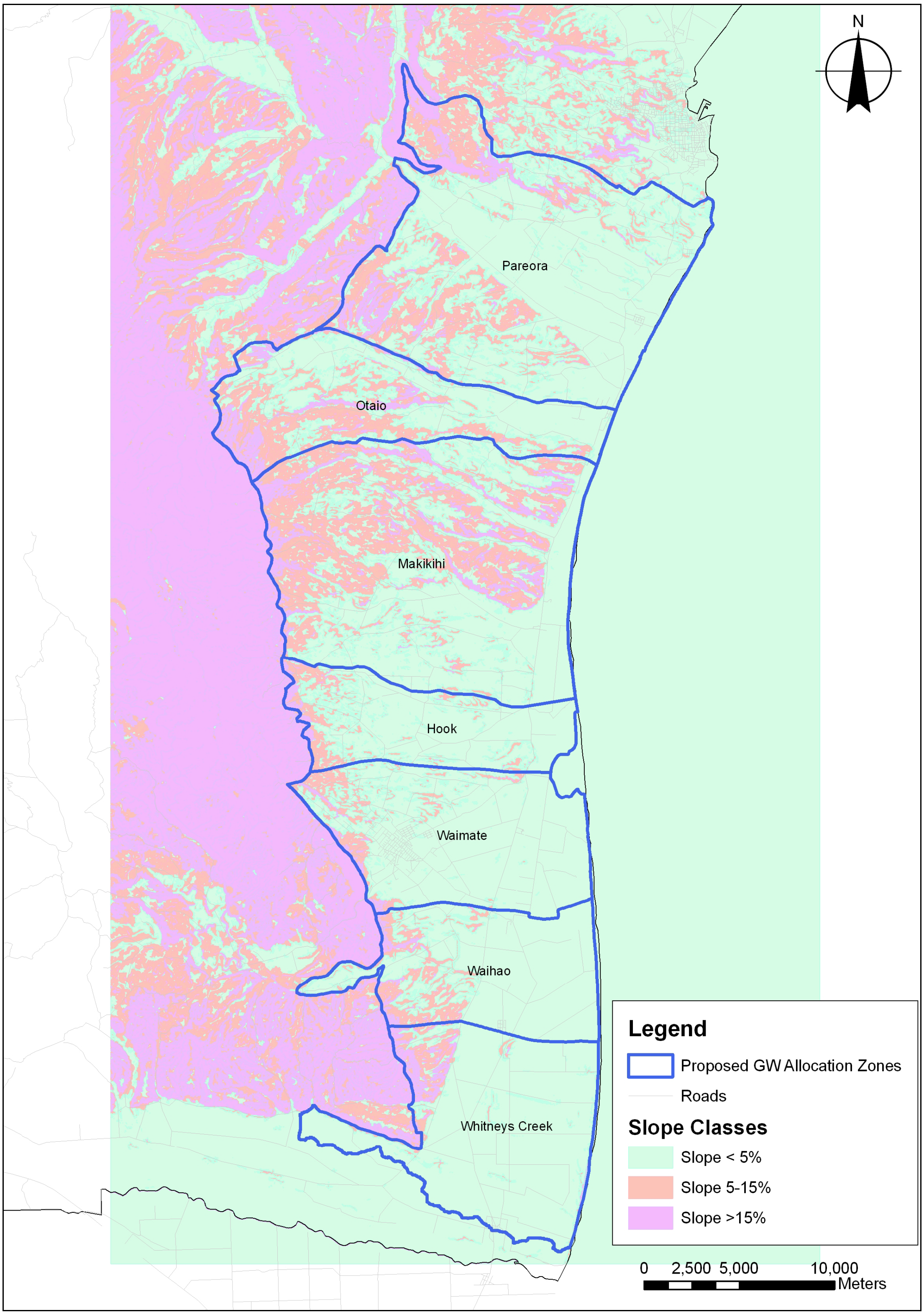


Figure 8: Map showing categories of slope across the South Canterbury downlands area. This map gives an indication of where surface runoff is likely to dominate relative to land-surface recharge.

3.2.5 Climate data

The climate dataset used for this review is an updated version of the dataset used by Scott (2004). The updated rainfall and PET data now traverse a period between 2/1/1972 and 31/12/2006, totalling 12783 days or time steps. The interpolation method used by NIWA to produce the rainfall and PET distribution has also changed.

There were three main changes to the methodology (Andrew Tait, NIWA scientist, 2007 pers.com):

"*1. The interpolation for each day now uses every available rainfall measurement from all of the rain gauges and climate stations with data archived in the national climate database. Previously, a subset of 500 stations was chosen (using the ANUsplin "selnot" routine).*

2. Ten high elevation "dummy" sites have been added, where the daily precipitation is estimated using a scaling method based on the ratio of the long-term mean annual rainfall between the high elevation sites and key long-term lower elevation stations (e.g. Franz Joseph and Milford Sound). This helps to force the rainfall interpolation in the mountains.

3. A post-interpolation adjustment is made to each daily rainfall grid. The adjustment is a multiplication factor derived from the ratio of the long-term mean annual rainfall grid derived from the unadjusted daily rainfall grids to the long-term mean annual rainfall grid derived from an interpolation of long-term mean annual rainfall values calculated at over 1000 rain gauges and climate stations. This adjustment ensures that long-term rainfall-runoff calculations based on the daily rainfall grids are in balance (Andrew Tait, NIWA Scientist, 2007 pers.com)."

The latest NIWA data have been compared with the previous version by calculating the total of the daily rainfall values at each of the grid points for the period 2 January 1972 to 28 June 2006. The resulting ratio of the revised total versus the previous total ranged from 76% to 170% with an average of 111% (i.e. the revised rainfall is on average about 10% greater than the earlier values). In the South Canterbury area, the revised figures are more than 5% higher over a substantial proportion of the area (David Scott, Groundwater Scientist, Environment Canterbury, 2007 pers.com).

The coverage of climate data and the change in total annual rainfall from the previous dataset and that currently supplied is shown in the following figure (Figure 9).

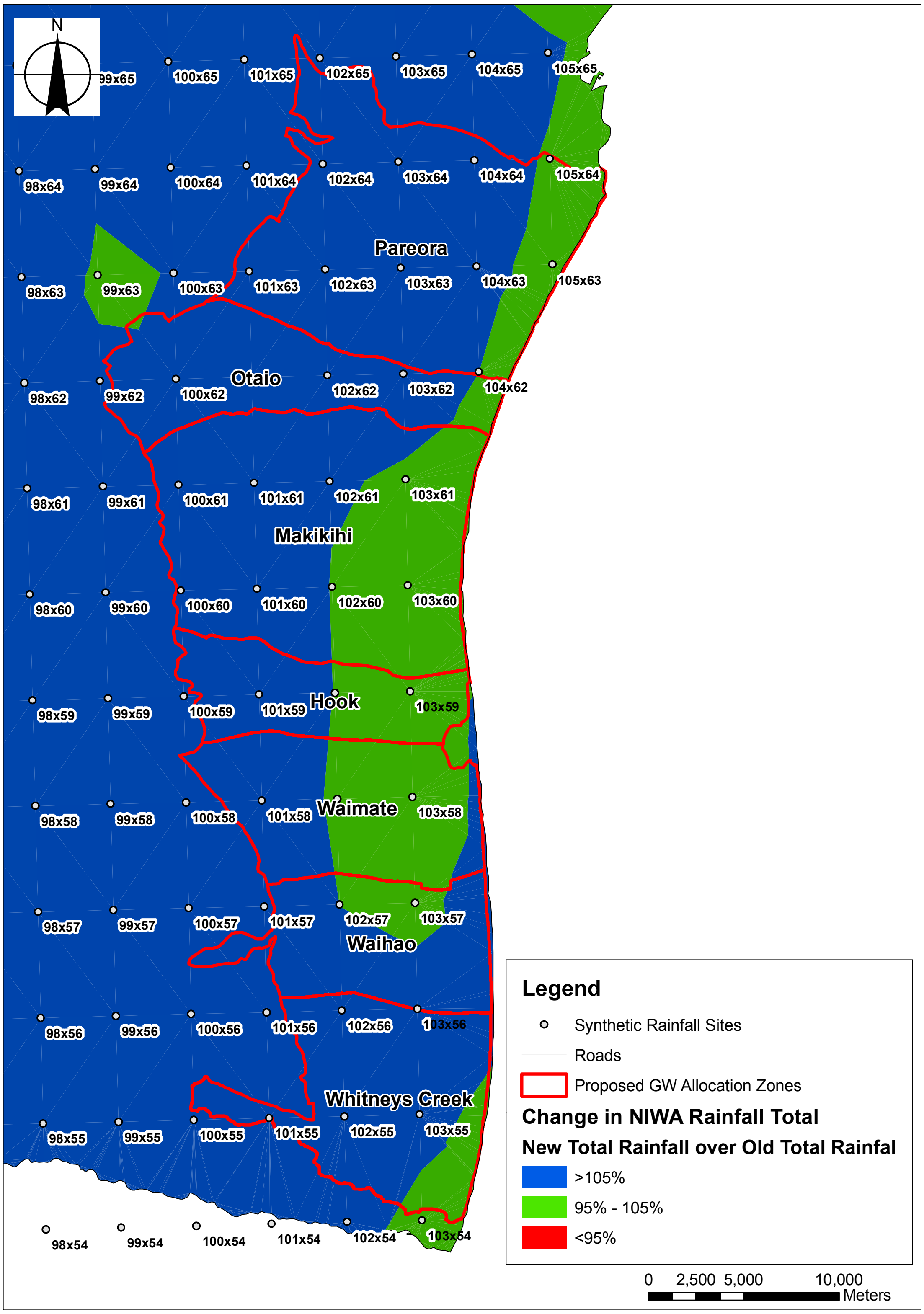


Figure 9: Map showing change in total rainfall owing to an update of the NIWA dataset. The 0.05˚ latitude/longitude synthetic climate sites for which NIWA has provided interpolated rainfall and PET information are also shown.

3.2.6 Hydrological parcels

The mapped coverage of soils was clipped to the mapped extents of each of the hydrogeological units described above (section 3.2.2), and therefore sub-divided to the scale of the polygons mapped by the “combined_soils.shp” shapefile. These polygons were then merged with the irrigated area polygons by a “union” command in ArcMap. This ultimately indicated whether those hydrological parcels should be tallied as an irrigated block or not, and indicated the average PAW value for each hydrological parcel. The hydrological parcels were then “clipped” using ArcMap according to the boundary of each proposed GWAZ.

A total of 5,097 hydrological parcels were generated for the proposed groundwater allocation zones south of Timaru. The resulting hydrological parcel discretization is shown in Figure 10, and the relative coverages are summarised in Table 3.3 shown previously.

The area and centroid for each polygon were then calculated using the field calculator in ArcMap. The centroid coordinates were used to select the nearest NIWA synthetic climate site within the FORTRAN program. The FORTRAN program is presented in Appendix B of this report.

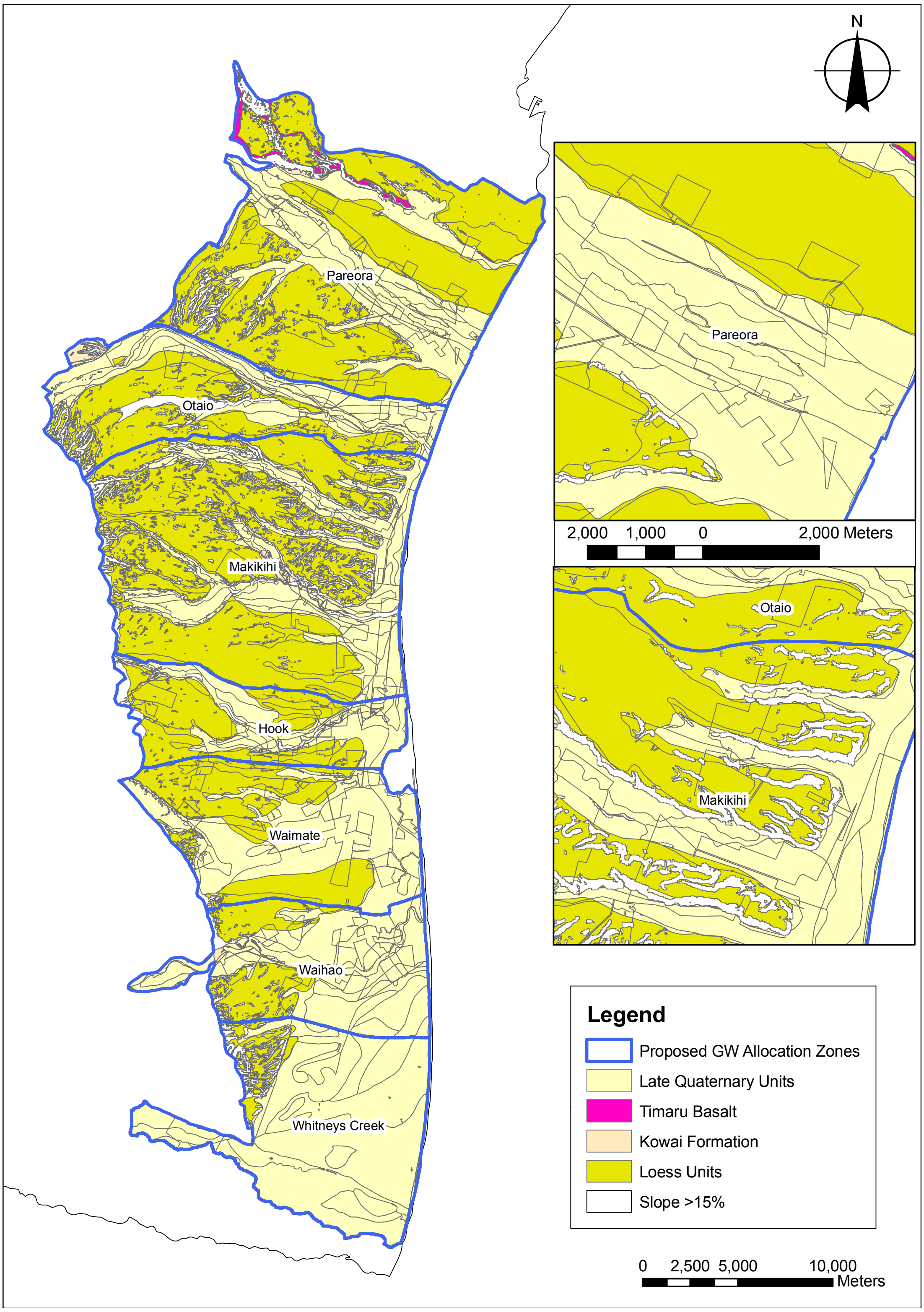


Figure 10: Map showing coverage of unique hydrological parcels used to compute land-surface recharge across the South Canterbury downlands area.

3.3 Land-surface recharge results

The soil-water balance modelling used to calculate soil moisture deficits, irrigation demands and land-surface recharge is the same as described in Scott (2004). The modifications of Scott's (2004) FORTRAN code are shown in Appendix B. The code used to calculate drainage for the Loess Formations is shown in Appendix B, highlighted in **bold** text (DRAIN5_LOESS.FOR). The code can be used to calculate drainage for the Late Quaternary, Basalt and Kowai Formations by using a very large throttling factor to calculate un-impeded drainage. The results of the land-surface recharge calculations are summarised in Table 3.4 (overleaf).

The results of the modelling show that calculated drainage from loess soils is significantly reduced compared with the other hydrogeologic units. This has also had the effect of reducing zone-wide mean annual dry-land drainage when compared to mean annual rainfall. The "excess drainage" was the left-over from applying the 3 mm/day limiting soakage factor to daily drainage totals calculated over areas underlain by loess. The "excess drainage" that is generated is assumed to be run-off, which can be accounted for in the groundwater allocation budget by any surface water loss or gain to or from groundwater.

Drainage through the loess is expected to be relatively uniform compared with runoff over these areas. The calculated land-surface recharge over the loess areas varied by less than 1%, when compared with mean annual rainfall across the groundwater allocation zones. In contrast, the calculated excess drainage varied by nearly 5%, when compared with mean annual rainfall across the groundwater allocation zones. It is plausible that runoff will vary more across catchments than land-surface recharge will.

Total mean annual dry-land drainage is reduced more significantly in those zones with high loess coverage. The total dry-land drainage was calculated as low as 12.4% of mean annual rainfall for the Makikihi GWAZ. This is contrasted by the Whitneys Creek GWAZ that has the lowest coverage of loess and a mean annual dry-land recharge at 26.3% of mean annual rainfall.

Table 3.4: Summary of calculated mean annual land-surface recharge.

Late Quaternary, Timaru Basalt, Kowai Formation	**Pareora**	**Otaio**	**Makikihi**	**Hook**	**Waimate**	**Waihao**	**Whitneys Creek**
Area (ha)	6,093	3,681	5,659	2,525	5,453	5,519	9,269
Mean annual rainfall (mm)	638	656	637	633	616	616	603
Dryland drainage (m^3/yr x 10^6)	**10.91**	**7.73**	**9.47**	**4.20**	**8.14**	**8.61**	**15.51**
Equivalent depth increment (mm)	179	210	167	166	149	156	167
Dryland drainage as % of mean annual rainfall	28.0%	32.0%	26.3%	26.3%	24.2%	25.3%	27.7%
Loess							
Area (ha)	11,947	3,934	11,914	3,190	3,868	1,842	653
Mean annual rainfall (mm)	642	690	662	679	649	623	622
Dryland drainage - Loess (m^3/yr x 10^6)	**4.22**	**1.65**	**4.73**	**1.38**	**1.55**	**0.68**	**0.24**
Equivalent depth increment (mm)	35	42	40	43	40	37	37
Dryland drainage as % of mean annual rainfall	5.5%	6.1%	6.0%	6.4%	6.2%	5.9%	5.9%
Dryland drainage excess (m3/yr x 106)	14.96	6.14	17.36	4.97	5.32	2.14	0.74
Dryland excess drainage as % of mean annual rainfall	19.5%	22.6%	22.0%	22.9%	21.2%	18.6%	18.3%
Dryland Drainage - Total							
Area (ha)	18,040	7,615	17,573	5,715	9,321	7,361	9,922
Mean annual rainfall (mm)	641	674	654	659	630	618	604
Total dryland drainage (m^3/yr x 10^6)	**15.13**	**9.38**	**14.20**	**5.58**	**9.69**	**9.28**	**15.75**
Equivalent depth increment (mm)	84	123	81	98	104	126	159
Total dryland drainage as % of mean annual rainfall	13.1%	18.3%	12.4%	14.8%	16.5%	20.4%	26.3%
Irrigation - Late Quaternary, Timaru Basalt, Kowai Formation							
Irrigated area (ha)	1,743	1,183	1,864	476	1,201	3,324	8,744
Recharge increment (m^3/yr x 10^6)	**3.13**	**2.13**	**3.38**	**0.85**	**2.21**	**6.05**	**15.10**
Equivalent depth increment (mm)	180	181	181	178	184	182	173
Irrigation - Loess							
Irrigated area (ha)	762	491	1,278	569	642	228	61
Recharge increment (m^3/yr x 10^6)	**0.50**	**0.30**	**0.81**	**0.35**	**0.41**	**0.12**	**0.04**
Equivalent depth increment (mm)	65	62	63	62	64	53	62
Excess increment - Loess (m3/yr x 106) **Irrigation - Total**	0.99	0.62	1.58	0.69	0.79	0.29	0.08
Irrigated area (ha)	2,505	1,673	3,143	1,045	1,843	3,552	8,805
Recharge increment (m^3/yr x 10^6)	**3.63**	**2.44**	**4.19**	**1.20**	**2.62**	**6.17**	**15.13**
Equivalent depth increment (mm)	145	146	133	115	142	174	172
Total Land-surface Recharge							
Mean annual land-surface recharge (m^3/yr x 10^6)	**18.76**	**11.82**	**18.39**	**6.79**	**12.31**	**15.45**	**30.88**

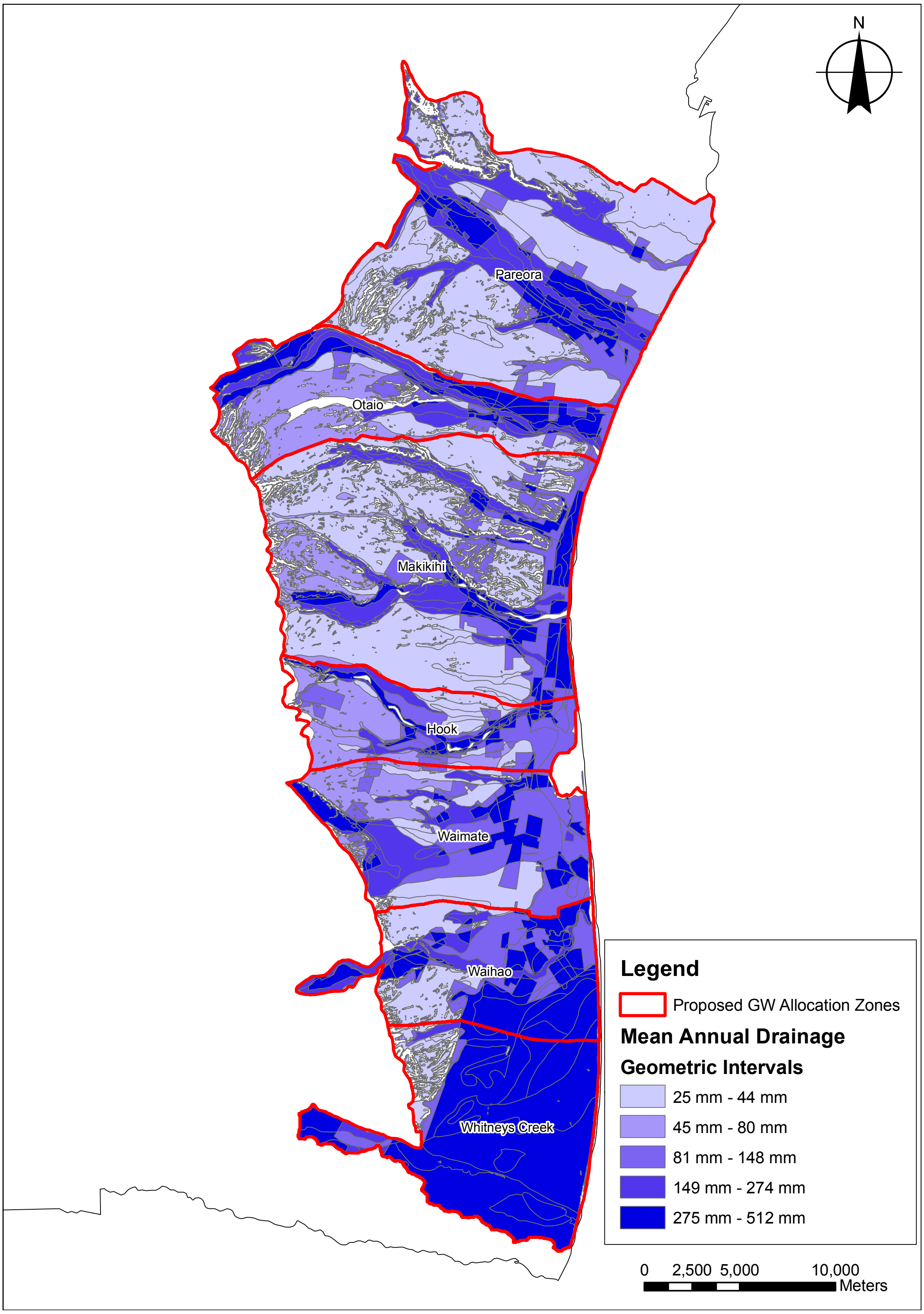


Figure 11: Map showing calculated mean annual land-surface recharge. The lowest class of recharge shown is dominated by loess soils. The highest recharge class shown is dominated by irrigated areas.

4 Intermittent stream recharge

4.1 Overview

The proposed NRRP states in WQN4 a) (ii) that "*the interim allocation block is 50% of the annual average land-surface recharge including the recharge component contributed by intermittent streams.*"[2]

For the Rakaia-Selwyn GWAZ this contribution of intermittent streams was calculated as the **difference** between inflow and outflow of the Selwyn River including some streams depending on the Selwyn losses upstream. Initial 'contribution' estimates in ECan (2006) used the total inflow at the top end without taking into account the gains from groundwater occurring at many coastal ends of foothill rivers. There was no recognition that the lowland streams, including the Selwyn River, largely depend on this recharge to maintain their flows.

For continuous flowing alpine rivers the contribution of leakage to the aquifers is not added to the groundwater allocation block as this provides the stable basis for the groundwater levels and the spring-fed streams. This buffer of alpine recharge is not present in the zones south of Timaru.

4.2 Pareora

The Pareora is neither a spring-fed stream nor an alpine river but it does flow continuously for most years with some exceptions. Like many other foothill rivers, the Pareora looses water upon entering the coastal plains. The proposed change to the Pareora groundwater allocation zone boundary makes the Pareora Huts flow recorder the main point of entry of surface water flow. Aitchison-Earl et al. (2006) Figure 4.3 showed that between the recorder at the Huts and the Railway Bridge, the most coastal site, the mean flow only reduces slightly from 4001 to 3745 L/s under natural conditions (Figure 12 overleaf). Initially the river looses even more water, but further down the plains it gains a similar amount from groundwater to end up with nearly the same amount as it started with at the Huts. The difference is within the error of margin of the naturalised, calculated flows at the SH1bridge. Current abstractions from surface water and hydraulically connected groundwater already reduce the flow in the Pareora River to the point that it becomes intermittent. The groundwater resource in the Pareora zone is closely linked with surface water and vice versa especially in the area with Quaternary gravels beside the river. Allocating groundwater with a contribution from surface water losses would ignore the fact that most groundwater is directly derived from surface water and that the Pareora will reduce its flow at the lower end by a similar amount. It is clear that a surface water allocation should be set first with a minimum flow condition for all surface water and directly connected groundwater takes. All directly or indirectly hydraulically connected groundwater takes will affect the overall flow regime. The tolerable reduction in mean flow etc should also be known before a total groundwater allocation block can be set as a proportion of land-surface recharge. In the interim, however, we have to set allocation blocks that allow the use of the resource with a precautionary approach to the environment and reliability of supply for existing users. It might be difficult to achieve given the high amount of allocation of surface water and connected groundwater takes. Aitchison -Earl et al. (2006) gives the allocation from surface water and hydraulically connected groundwater, expressed as flows, for June 2005. The figures for the Pareora main branch alone are 520 L/s for surface water and a calculation of 421 L/s for part of the connected groundwater abstraction, a total of 940 L/s (Table 7.7 in Aitchison-Earl et al., 2006). This compares to a 7DMALF of 648 L/s at the Huts and 125 L/s at Brasells Bridge (Table 4.4 in Aitchison-Earl et al., 2006). Some additional surface and

---

[2] As part of Variation 4 it is proposed to remove this detail from NRRP and replace it with the actual allocation blocks for each of the groundwater zones. The approach outlined will still be applied to derive these allocation blocks

groundwater takes exist outside the main branch as well bringing the total to 1,027 L/s. Clearly the takes can dry up the Pareora River below the Huts recorder, which indicates a very poor reliability of supply for the more downstream users.

If we consider the Pareora as a continuous flowing river then calculating a surface water contribution to groundwater is not required under the proposed NRRP.

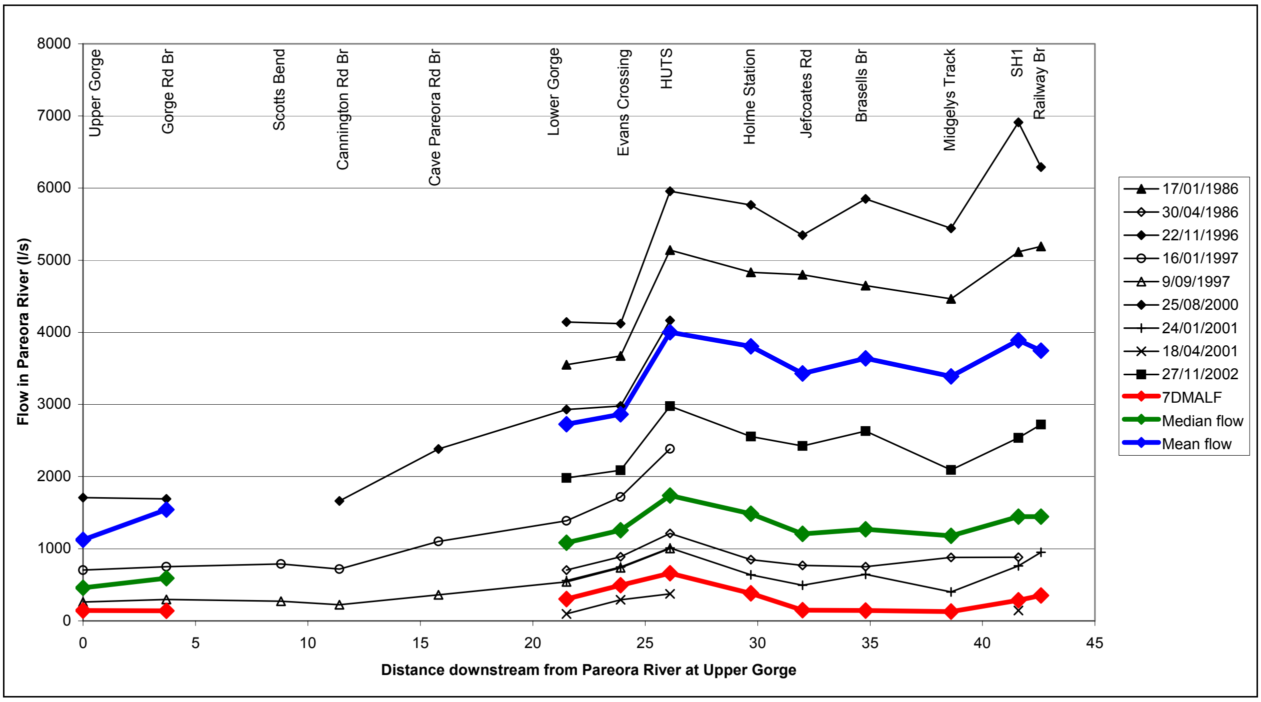


Figure 12: from Aitchison-Earl et al., (2006).

4.3 Otaio River

The Otaio River gains more water than it loses between the Gorge recorder where the river enters the groundwater zone, and the coastal State Highway 1 (SH1) site. The river flow is in part reliant on groundwater in the groundwater zone. Again we need to know the tolerable reduction in mean flows, and set minimum flow conditions, if we want to protect in-stream values of the river. Groundwater takes directly and indirectly connected will eventually affect the flows in the Otaio River just as for the Pareora River. Compared to the Rakaia Selwyn GWAZ, there is no buffer of alpine river recharge contributing to base flows, with an additional large groundwater reservoir buffering yearly climatic fluctuations. If we want to allocate groundwater in the Otaio GWAZ in the interim, we need to reserve some of land-surface recharge for the dependent river flow. The proposal is to reserve a volume of the rainfall recharge in the Otaio GWAZ which is equivalent to the 7DMALF (62 L/s). From a hydrological perspective there is no guarantee that this 7DMALF will be secured with this reservation; it simply recognises that the Otaio River is more sensitive to the land-based recharge than the streams in the Mid Canterbury Plains area.

The surface water allocation for the Otaio River summarised in Aitchison-Earl et al. (2006) shows that 423 L/s is allocated to surface water takes and 27 L/s to hydraulically connected groundwater takes; a total of 450 L/s compared to a 7DMALF of 124 L/s. This is a similar situation to the Pareora River; no apparent reliability of supply and an induced dry river. If more surface water or connected groundwater consents are granted, then this is likely to reduce reliability of supply and increase dry reaches in the river (spatially and temporally) even further.

4.4 Makikihi

Much fewer data are available for this river than for the Pareora or Otaio Rivers. The SH1 site is usually dry. There is no upstream site to measure all the inflows from the foothills before surface water has a chance discharge to groundwater. Because of the lack of data there is also a lack of understanding of the resource here. The mean flow calculation of 389 L/s for the Makikihi River at Teschemaker Valley Road site given in Atchison-Earl et al. (2006) should be considered very preliminary because there are only a few simultaneous gaugings with the recorder at the Waihao River McCulloughs Bridge site (adjusted R^2 of 0.93). The second tributary site at the Teschemakers Creek has a weaker regression with McCulloughs Bridge (R^2 0.79) and adds 172 L/s to the mean flow in the Makikihi. If we adopt a mean flow of 389L/s + 172L/s and assume that most of this water is lost to groundwater without re-emergence closer to the coast, then this means that about 86.4*365*561 L/s =17.7 million m^3/year can be added to the groundwater allocation.

Generally, the surface water allocation in the Makikihi is 65 L/s with only an additional 1 L/s for the connected groundwater takes.

The Kohika Stream catchment falls within the Makikihi groundwater allocation zone. Ideally this area should also be separated for shallow groundwater allocation purposes. It flows within its own catchment without direct surface water connection to the Makikihi River catchment. The 10 gaugings on this stream indicate flows ranging from dry to 25L/s including 4 occasions with an estimated flow of 1 L/s. Many other (very) small streams between Timaru and the Waitaki flow directly into the sea. Shallow groundwater takes in these small catchments should be assessed on their own land-based recharge area. If it is a shallow take it doesn't have to be allocated against the allocation block of the larger zone. If it is a deep groundwater take it will have to be because of the possible connection with the wider groundwater zone. The available shallow groundwater resource is very small anyway because these small streams are often dry.

4.5 Waihao-Wainono

The Wainono-Waihao area contains a number of small streams flowing separately into the Wainono Lagoon. Again we should use these smaller catchments for the groundwater allocation regime. The newly proposed groundwater allocation zones outlined previously in this report are used to determine intermittent stream contributions if any.

4.6 Hook

The Hook River gains water all the way downstream to about 522 L/s mean flow at the Hook River Beach Road recorder, just before its entry to the Wainono Lagoon (based on regression with the Otaio). Two gauged tributaries at the top end of the Hook ('upstream intake' and Gunns Bush tributary) have a mean flow of 216 L/s combined. There are a few more ungauged smaller tributaries in the upper catchment, which contribute about 80 L/s based on the mean flow yield map produced for Aitchison Earl et al. (2006). This report also describes in detail the methodology for the derivation of these flows. When we compare the amount of flow coming into the groundwater zone at the top, and how much is lost at the bottom, then we see that about 200 L/s must be entering the river in between. This 200 L/s equates to 86.4*365*200L/s=6.3 million m^3/year, which is about equal to the land-surface recharge calculation for this zone (6.79). Two independently derived numbers for the same flow gives confidence in both calculations. It also shows that the surface water flow at the Hook River recorder site will be affected by groundwater takes in the catchment to a large degree. Allocating 50% of the land-based recharge will almost certainly reduce the flow at the recorder site by up to 100 L/s, depending on the actual amount of groundwater taken.

If the same reasoning as for the Otaio River is applied; the land based recharge should be reduced by the yearly volume of the 7DMALF (57 L/s) before the groundwater allocation block is set.

4.7 Waimate

The Wainono Lagoon inflows: Very little water is found in the other streams flowing into the Wainono Lagoon or Dead Arm; therefore allocation should be based on land based recharge alone.

Waimate Creek has an estimated mean flow of 128 L/s (at the Gorge above the plains) and is dry for most of the time in its middle reaches across the plains.
We can therefore add 86.4*365*128 L/s=4.039 million m^3/year to the groundwater allocation block if nothing returns further downstream. It is recommended to that the groundwater allocation area of Waimate Creek is combined with the Wainono Lagoon inflow area because of their close proximity.

4.8 Waihao

Buchanans Creek has a mean flow at Fletchers Rd of 355 L/s (the most downstream site). Flows in the area seem to be more related to groundwater levels than to flow at other flow sites. A contribution to groundwater from Waihao River losses is likely.

Sir Charles Creek has a mean flow of 244 L/s, estimated from gaugings, which is groundwater related and mostly sourced from losses from the Waihao River.

The Waihao River at the lower reaches receives about 1m^3/s of by-wash in the irrigation season from the Morven-Glenavy Irrigation scheme. When the flows are normalised and naturalised the Waihao River looses 569 L/s between McCulloughs Bridge recorder and Bradshaws Bridge, which are approximately at the upper and lower end of the GWAZ. This loss appears to be consistent and independent of the flow in the river. Some of this is known to be lost through groundwater to Buchanans Creek and Sir Charles Creek catchments, which is a good reason to combine these catchments within a Waihao GWAZ. The outflows in Buchanans and Sir Charles Creek amount on average to 355 + 244 L/s = 599 L/s which is 30 L/s higher then the mean loss of the Waihao, indicating no surface water contribution to the groundwater zone. The Waihao River is a continuously flowing surface waterway despite the ‘dry’ 7DMALF at Waihao River Bradshaws Bridge, as the tributaries contribute most of the 7DMALF.

4.9 Whitneys Creek

When we split off the 3 catchments as described above (Hook, Waimate, and Waihao) from the previous Waihao-Wainono groundwater zone, the area coinciding with the Morven-Glenavy irrigation scheme is left over. For groundwater allocation purposes it is called the Whitneys Creek area. There is no need to contemplate any surface water contribution from natural flows here as the area receives large amounts of Waitaki River water for irrigation under this scheme. The land-based recharge alone in this area should give a relatively large groundwater allocation block allowing the remaining area ample water.

4.10 Discussion

Although the report is about the groundwater allocation limits, it is hard to avoid consideration of the surface water allocation as the two resources are very closely linked in the Pareora – Waihao area. Setting a limit on the groundwater resource independently from the surface water allocation will interfere with the setting of appropriate limits for surface water and vice versa. There are no minimum flows or allocation limits set yet under Schedule WQN1 of the proposed NRRP within any of the discussed groundwater allocation zones; therefore Schedule WQN2 should be applied. The schedule specifies a methodology for setting interim surface water allocation limits. This methodology is consistent with that outlined in Brown and McIndoe (2004).

Table 4.1 lists the 7DMALF, the minimum flow and allocation rates for A and B Blocks for some of the catchments in South Canterbury if Schedule WQN2 were to be applied.

Table 4.1 Surface water allocation according to Schedule WQN2

Site	7DMalf (L/s)	Min Flow (L/s)	Alloc rate 85% (L/s)	A Block (L/s)	**A Block (% of Allocated)**	B Block (L/s)	Current Surface Allocated (Mar 07) (L/s)	Including connected GW takes (Mar 07) (L/s)
Pareora at Huts	659	400	728	328	**281%**	892	**461**[1]	**923**[1]
Pareora Railway	353	-	432	79	**-**	472	-	-
Otaio at SH1	62	-	82	20	**1,845%**	92	**342**	**369**
Hook at Lower Beach Rd	57	-	68	11	**818%**	74	**52**	**90**
Makikihi	0	-	-	-	**-**	-	**81**[2]	**83**[2]
Waihao upstream Bradshaws	0	-	19[3]	19[3]	**1,195%**	-	**150 (379)**[4]	**227 (503)**[4]

Notes: [1] *Includes allocation for Pareora River, Springbrook Creek, Southburn Creek, South Branch Pareora River, White Rock River, Cannington Creek.*

[2] *Includes allocation for Makikihi River and Teschemakers Creek.*

[3] *Based on naturalised flows of the Waihao River only, therefore not applicable to other tributaries.*

[4] *Includes allocation for Waihao River, Willowbridge Creek, Buchanans Creek, South Branch Waihao River, North Branch Waihao River, and Waihaorunga Stream.*

From this table it is clear that with the current rate of surface water allocation the reliability of supply for the abstractors must be very low. And that is without the connected groundwater takes portion. It seems therefore that any further applications for allocation from surface water or shallow connected groundwater would further reduce the reliability of supply for existing users.

Intermittent streams

The NRRP definition of an intermittent stream is not clear for the purposes of groundwater allocation in South Canterbury. At present any foothill stream that has experienced dry periods has been improperly assumed to be intermittent when considering if net contributions should be included in estimates of land-surface recharge. Aitchison-Earl & Scott (2006) in a memorandum to the Environment Canterbury staff Water Allocation Group (WAG) described the intermittent status of surface waterways using *average* flow criteria, as did Gabites (Suzanne Gabites, ECan surface water scientist, 2007 pers.com) when indexing types of surface waterways for the planning section. Using this approach, the Pareora River and many other foothill rivers in Canterbury would loose their intermittent status when applying the interim groundwater allocation framework of proposed NRRP, and would not have net contributions added to estimates of land-surface recharge.

Alpine river recharge

A further point to note is the absence of alpine river recharge in the aquifer system in South Canterbury. Under the current interim allocation approach, the alpine river recharge is excluded from the estimate of land-surface recharge because it is reserved for aquifer base-flow and partly for surface water discharges from the groundwater system (in-conjunction with the reservation of 50% land-surface recharge). In areas where alpine river recharge is absent, the discharges from groundwater to surface water are mostly reliant on rainfall recharge (land-surface recharge). To account for this in South Canterbury, the estimates of land-surface recharge in the Otaio and Hook GWAZs have had a residual flow deducted equal to 7DMALF. It is intended that this will provide some protection for the contribution from groundwater required to maintain minimum flows in these surface waterways. In the Pareora and Waihao GWAZs, the inflows and outflows are almost balanced and it is considered that a residual flow deduction from the land-surface recharge is not required. The Makikihi River and the Waimate Creek are on average dry across their lower reaches and therefore do not require an additional allowance from groundwater.

Groundwater takes in the smaller independent catchments between the main rivers as discussed above might have to be assessed on their own merits. Shallow groundwater takes do not necessarily have to count against the block in the large zone, but the deeper groundwater takes always should be.

Table 4.2: Summary of intermittent stream gains and losses to and from groundwater.

Groundwater Zone	Stream	Inflow	Outflow	Net contribution from surface water to groundwater
Pareora	Pareora River	**4001 L/s** (mean flow at Huts)	**3745** L/s (mean flow at Railway Bridge)	**0 L/s** [1]
Otaio	Otaio River	**741 L/s** (mean flow at Otaio Gorge	**892 L/s** (mean flow at SH1)	**- 62 L/s** [2, 5]
Makikihi	Teschemakers Creek	**172 L/s** (mean flow u/s of confluence	**Dry** at SH1	**561 L/s**
	Makikihi River	**389 L/s** (mean flow u/s of confluence		
Waihao-Wainono	Hook River	**216 L/s** (mean flow u/s intake + Gunn's Bush)	**522 L/s** (mean flow @ Hook Beach Road)	**- 57 L/s** [3, 5]
	Waimate Creek	**128 L/s** (mean flow u/s of Kelceys Bush intake)	**Dry** at SH1 (some ponding of water in lower reaches towards Wainono Lagoon)	**128 L/s**
	Waihao River	**3775 L/s** (Mean flow at McCulloughs)	**3206 L/s** (mean flow u/s Bradshaws Bridge)	**0 L/s** [4]
			355 L/s (mean flow of Buchanans Creek @ Fletchers)	
			244 L/s (mean of gaugings, Sir Charles Creek @ Haymans)	

[1] Permanently flowing Foothill River due to continuous flow at mean flows, no contribution added to groundwater.

[2] Flow is higher at SH1 than the gorge at mean flow, as more run-off is contributed to the catchment downstream of the gorge. At median flow and MALF, the inflow is slightly less then the outflow.

[3] The net gain matches the catchment yield maps (Aitchison-Earl et al. 2006).

[4] Summed outflow from Waihao @ Bradshaws and spring-fed creeks Buchanans and Sir Charles exceed losses in the Waihao at mean flow. Inputs and outputs are close to balancing at median and surface water is lost to groundwater at MALF. The inclusion of Sir Charles Creek could be debated, as it is probably fed by a mixture of Waihao River losses and some general groundwater therefore probably no net contribution.

[5] MALF is reserved from land-surface recharge to maintain residual flow to surface waterways.

5 Revision of groundwater allocation limits

The proposed Natural Resources Regional Plan sets out the basis for establishing an interim groundwater allocation regime under Policy WQN14 and Schedule WQN4. Two levels of interim groundwater allocation strategies are outlined under this policy. Environment Canterbury has already moved on from the 1st Order approach in the South Canterbury downlands area. Environment Canterbury therefore considers it appropriate to revise the previous 2nd Order allocation limits using the same threshold of 50% of land-surface recharge.

The South Canterbury downlands area is not considered to have sufficient hydrologic data or understanding to move to the equivalent of 3rd order management outlined under Policy WQN14 (7).

Several options for approaching groundwater allocation in the South Canterbury downlands area have been worked through by groundwater and surface water investigations personnel, and Planning Section staff, with an agreed approach reached by those staff involved (Thorley, 2007). The manner in which groundwater and surface water interacts in each catchment is slightly different. Applying broad brush allocation strategies to all catchment-specific settings is problematic for determining interim groundwater allocation limits. The general mechanisms for integrated allocation between surface and groundwater do exist in NRRP; however how these are implemented may require some discretion to suit local conditions.

The first of the changes in approach since the previous work of Aitchison-Earl et al. (2006) is the updated estimate of land-surface recharge which takes into account the reduced recharge through the loess strata. The second change is to classify the Pareora River as a permanent foothill river, so that any estimated contribution is not included in the estimate of land-surface recharge. The third is to deduct a residual flow equal to 7DMALF from the estimate of land-surface recharge in the Otaio and Hook GWAZs. This provides some protection of the contribution groundwater makes to surface water flows and also accounts for the absence of alpine river recharge in these catchments. The fourth change applies Policy WQN14(6)(d) by reducing the EAV of shallow hydraulically connected groundwater abstractions in the Pareora GWAZ by the ratio of stream depletion to pumping rate. This means that allocation management for the shallow takes in the Pareora valley will rely more on the surface water allocation, which seems appropriate given the aquifer dynamics there.

The revised interim groundwater allocation limits are shown in Table 5.1 (overleaf). Comparing these with the current estimates of effective allocation shows that the Hook GWAZ could be more than fully allocated. The current effective allocation in other zones appears to be within the revised allocation limits. The EAV in the Pareora GWAZ has been reviewed due to the nature of the shallow hydraulically connected groundwater takes in this zone (see overleaf).

Table 5.1: Summary of recharge estimates for Groundwater Allocation Zones south of Timaru and corresponding allocation blocks (millions of cubic metres per year).

Recharge Zone	**Land surface recharge**	Surface water component	Groundwater allocation limit	Effective allocation volume (EAV)[1]	Effective allocation volume (EAV) (%)	Total if granted in process	In process (%)
Pareora	18.76	0	9.38	6.94	**74.0%**	1.05	**85.2%**
Otaio	11.82	-1.96[3]	4.93	2.56	**52.0%**	0.19	**55.7%**
Makikihi	18.39	17.70	18.05	9.97	**55.3%**	5.17	**83.9%**
Hook	6.79	-1.80[3]	2.49	3.09	**124.1%**	0.81	**156.3%**
Waimate	12.31	4.04	8.18	6.40	**78.3%**	-	**78.3%**
Waihao	15.46	0	7.73	3.39	**43.9%**	0.16	**46.0%**
Whitneys Creek	30.88	0	15.44	0.096	**0.6%**	-	**0.6%**

Notes [1] The effective allocation will be subject to verification when adopted into the consents database.
[2] Estimated when applying discount to EAV using methods outlined in NRRP Policy WQN8 and Policy WQN14.
[3] To account for the absence of alpine river recharge, 7 day MALF has been reserved to protect residual flow in the surface waterway.

The EAV for the Pareora GWAZ has taken account of the shallow, hydraulically connected groundwater abstractions, as these takes do fit the criteria of Policy WQN14(6)(d). Because the Pareora River is continuous the effect of taking near the river is to draw more water into the groundwater system. Using the Jenkins solution, estimates of the equivalent proportion of surface water and groundwater taken by these users has been determined. Based on that, the annual volume allocated from groundwater reduces from 15.55 m^3x10^6 to 6.94 m^3x10^6. The equivalent amount to be included into a surface water allocation block is estimated at 511 L/s. This is indicative of the high proportion of water allocation held by hydraulically connected groundwater abstractions rather than deeper abstractions.

The implication of the above changes is that water allocation for the shallow groundwater abstractions in the Pareora valley will be administered predominantly as surface water takes. Such a management approach seems more appropriate for the physical dynamics of the Pareora valley than the current management approach. Aitchison-Earl et al. (2006) showed that the shallow groundwater levels in the Pareora valley are primarily controlled by flows in the Pareora River compared with rainfall recharge patterns. Therefore the appropriate allocation mechanism should be based on the river in this case.

The Pareora GWAZ has the highest proportion of hydraulically connected takes of the groundwater allocation zones in the South Canterbury area. The current level of surface water allocation for these shallow hydraulically connected takes is approximately 461 L/s, which is based on 30 day stream depletion assessments. If all takes in the Pareora GWAZ were assessed under NRRP policy, the surface water allocation to hydraulically connected takes could increase to 511 L/s from 462 L/s as shown in Table 4.1.

It is not anticipated that other groundwater allocation zones in the South Canterbury area require alterations to the EAV like the Pareora GWAZ, although that position could be reviewed in the future.

6 Conclusions

Groundwater allocation zone boundaries have been delineated based on geology and major surface water catchments across the South Canterbury downlands area. This has led to adjustments in the areas of capture. Additionally, three new zones have replaced the Waihao-Wainono GWAZ.

Calculations of land-surface recharge have had a limiting soakage factor applied for those areas covered by loess deposits. The drainage rate from areas covered by loess has been limited to 3 mm/day. This has led to significant differences in calculated land-surface recharge across areas mapped as loess, and those mapped as Late Quaternary, Timaru Basalt, and Kowai Formation. The extent of loess cover is greatest toward the north of the South Canterbury downlands area, decreasing towards the Waitaki River. Therefore, the decrease in calculated land-surface recharge will be greatest in the north of the area.

The revised groundwater allocation blocks have used a slightly modified version of the 2nd Order methodology outlined in Schedule WQN4 of the proposed NRRP. The main modification is the reservation of land-surface recharge to protect contributions from the groundwater system to some of the surface waterways.

Comparing the estimates of effective allocation volumes shows that the Hook GWAZ could be more than fully-allocated. The current effective allocation in other zones appears to be within the revised allocation limits. The EAV in the Pareora GWAZ has been reviewed due to the nature of the shallow hydraulically connected groundwater takes in this zone (see overleaf).

6.1 Recommendations for further work

Further field testing and verification of the relationship between rainfall, runoff and drainage on the loess downlands is required. This work should aim to verify the findings of the infiltration testing carried out near Pareora and the “excess drainage” calculated over these areas. A catchment runoff investigation should be able to answer some of the questions we have about land-based recharge and runoff relationships over the loess downlands.

A potential source of groundwater recharge that is not really understood is the more distal and preferential leakage from surface waterways that could be entering deposits that lie beneath the loess mantle. A brief visual survey was undertaken of some localities where Timaru Basalts and Cannington Gravels outcrop around surface waterways. Generally, in areas where these deposits outcrop at ground surface, the topographic relief is relatively steep; therefore, rainfall runoff is expected to predominate rather than drainage. However, where these deposits form the base of a valley or depression, and are connected to the wider groundwater system, recharge from surface waterways is likely to be comparatively high. Surface water gauging could indicate whether higher losses are in fact occurring over such localities, and piezometric surveys of groundwater levels and surface water stage heights could indicate localised changes in hydraulic gradients that would be expected across such preferential recharge areas. This work would further refine the net contribution to the groundwater system from runoff and surface waterways. Furthermore, a number of surface water catchments have insufficient gauging data to assess possible additions or subtractions to or from the groundwater resource.

A map showing those areas where distal surface water recharge is possibly occurring and un-gauged surface water catchments are shown in Figure 13 (overleaf).

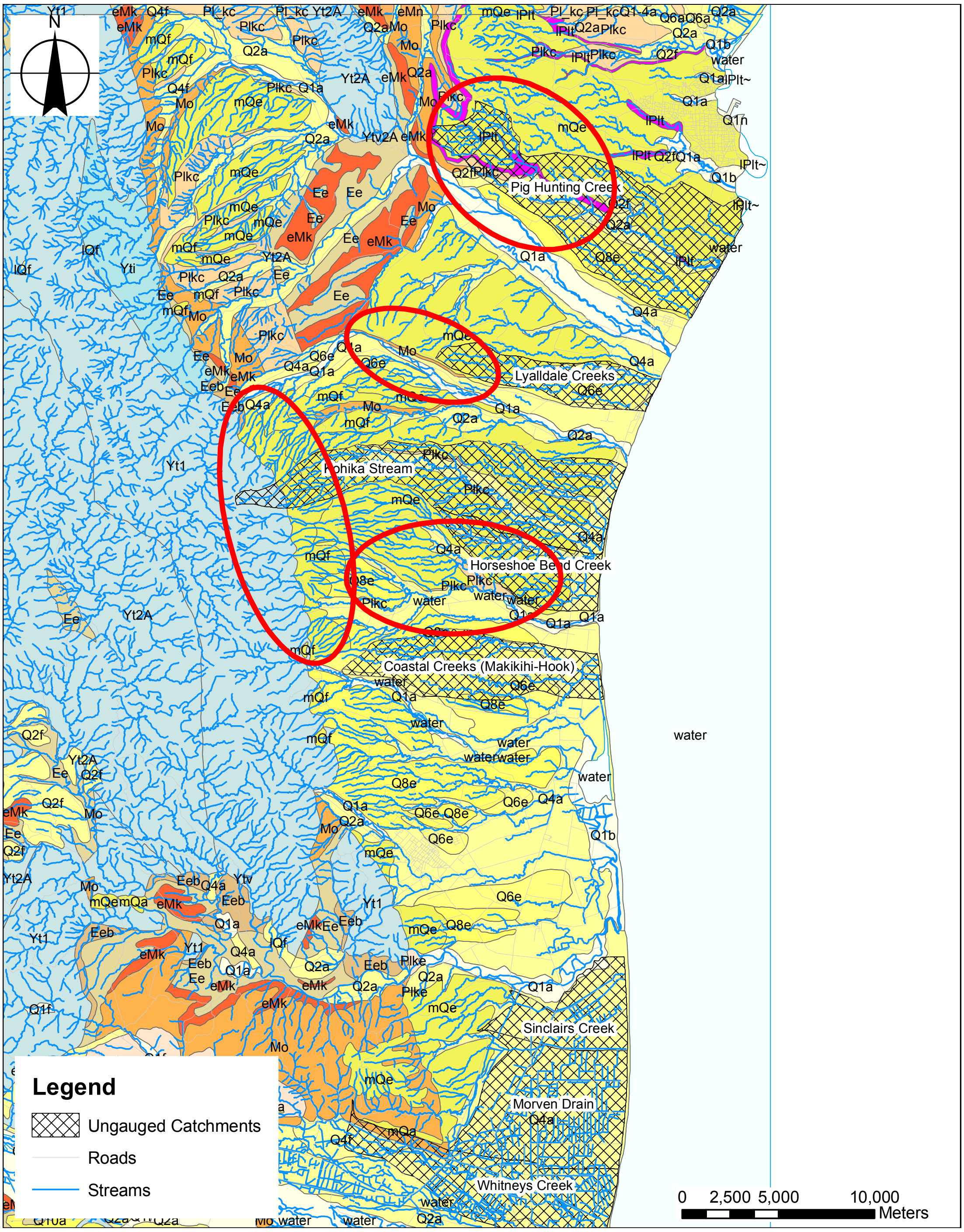


Figure 13: Map showing areas where surface waterways intersect outcrops of strata that underlie loess deposits. Also shown are the catchments that have insufficient data to assess potential net contributions from surface waterways. The red ovals indicate those areas where surface waterways are likely to be in direct contact with strata that underlie loess deposits. Further investigation of surface water losses in these areas is recommended.

7 Acknowledgements

This project was initiated following discussions within the Environment Canterbury staff Water Allocation Group (WAG) about groundwater allocation recommendations made in Aitchison-Earl et al. (2006). It was lead by Mike Thorley, Groundwater Hydrologist, Environment Canterbury with input from Marc Ettema, Surface Water Hydrologist, Environment Canterbury.

The infiltration testing was carried out by Environment Canterbury staff with the assistance of Pattle Delamore Partners Ltd and PPCS Ltd, the later of which we are very grateful. These staff included Mike Thorley and Matt Dodson, Assistant Hydrological Officer, Environment Canterbury.

We would like to thank Jane Forsyth and Belinda Smith Lyttle of Geological and Nuclear Science (GNS) for providing geological map data and many useful comments about the geology in the South Canterbury downlands area.

Many thanks go to David Scott, Groundwater Hydrologist, Environment Canterbury, for supplying the soil-water balance model code and support in making it go!

Many thanks go to all the members of WAG at Environment Canterbury who constructively debated the water allocation issues surrounding this project. Agreement was reached within this group on the approach this project has taken to interim water allocation limits for the South Canterbury downlands area.

Thanks also go to the external peer reviewers, Tom Heller of BECA Ltd, and Ian Fraser of URS Ltd, for their constructive comments on the report.

8 References

Aitchison-Earl, p., Scott, D., Saunders, R., 2002. Groundwater allocation limits – Guidelines for the Canterbury Region. Unpublished Technical Report U04/02. Environment Canterbury.

Aitchison-Earl, P., Ettema, M., Horrell, G., McKerchar, A., Smith, E., 2006. Pareora-Waihao River: Water Resource Summary. Unpublished Technical Report R06/20. Environment Canterbury. ISBN 1-86937-602-1.

Aitchison-Earl., 2006. Proposed changes to Pareora, Otaio, Makikihi, and Waihao-Wainono Groundwater Allocation zone Limits. Internal ECan memorandum to the Water Allocation Group (WAG). 15 June 2006.

Aitchison-Earl, P., Scott, D., 2006. Memorandum to WAG regarding Policy WQN14 (6) (d).

AgriQuality Ltd, 2006. AgriBase™ 2006. AgriQuality Ltd, Palmerston North, NZ

Aqualinc, 2005. Groundwater Allocation for the Waipara Groundwater Zone. Unpublished Technical report U05/87. Prepared for Environment Canterbury.

Bell, D. H., (1978). The Engineering Geology of Banks Peninsular loess deposits. Paper presented at a seminar on “Slope Stability and Urban Development” held at the University of Canterbury. Geology Department, University of Canterbury.

Berger, G. W., Pillans, B. J., Tonkin, P. J., 2001. Luminescence chronology of loess-paleosol sequences from Canterbury, South island, New Zealand. New Zealand Journal of Geology and Geophysics, v 44: pp 501-516.

Brown, P., McIndoe, I., 2004. Reliability of Supply for Irrigation in Canterbury. Lincoln Environmental. Report No. 4465/2. Prepared for Environment Canterbury.

Dodd, T. A. H., Northey, R. D., 1978. Paper presented at a seminar on “Slope Stability and Urban Development” held at the University of Canterbury.

ECan, 2006. Summary of estimated recharge from the Selwyn River and tributaries to the Rakaia-Selwyn Groundwater Allocation Zone. Internal memorandum from Surface Water and Groundwater Sections to the Water Allocation Group (WAG). Ref: C06C/9695. Environment Canterbury.

Geological and Nuclear Sciences (GNS), 2006. Forsyth, P. J. (compiler), 2001. Geology of the Waitaki area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 19. 1 sheet and 64p. Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited. ISBN 0-478-09739-5. Cox, S.C. and Barrell, D.J.A. (compilers) 2007 (in preparation). Geology of the Aoraki area. Institute of Geological and Nuclear Sciences 1:250 000 geological map 15. 1 sheet + ??p. Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited. ISBN 0-478-09521-X. Provided as electronic shapefiles by GNS to ECan in 2006.

Hardcastle, J., 1908. Notes on the Geology of South Canterbury. Reprinted from the Timaru Herald, 1908.

Ives, D., 1972. Nature and distribution of loess in Canterbury, New Zealand. New Zealand Journal of Geology and Geophysics, v 16 (3):pp 587-610. Soil Bureau, DSIR, Christchurch.

Raeside, J. D., 1964. Loess Deposits of the South Island, New Zealand, and soils formed on them. New Zealand Journal of Geology and Geophysics, v 7:pp 811-838. Soil Bureau Publication 310.New Zealand Soil Bureau, Dunedin.

Schmidt, J., Almond, P. C., Basher, L., Carrick, S., Hewitt, A. E., Lynn, I .H., Webb, T. H., 2005. Modelling loess landscapes for the South Island, New Zealand, based on expert knowledge. New Zealand Journal of Geology and Geophysics, v 48:pp 117-133.

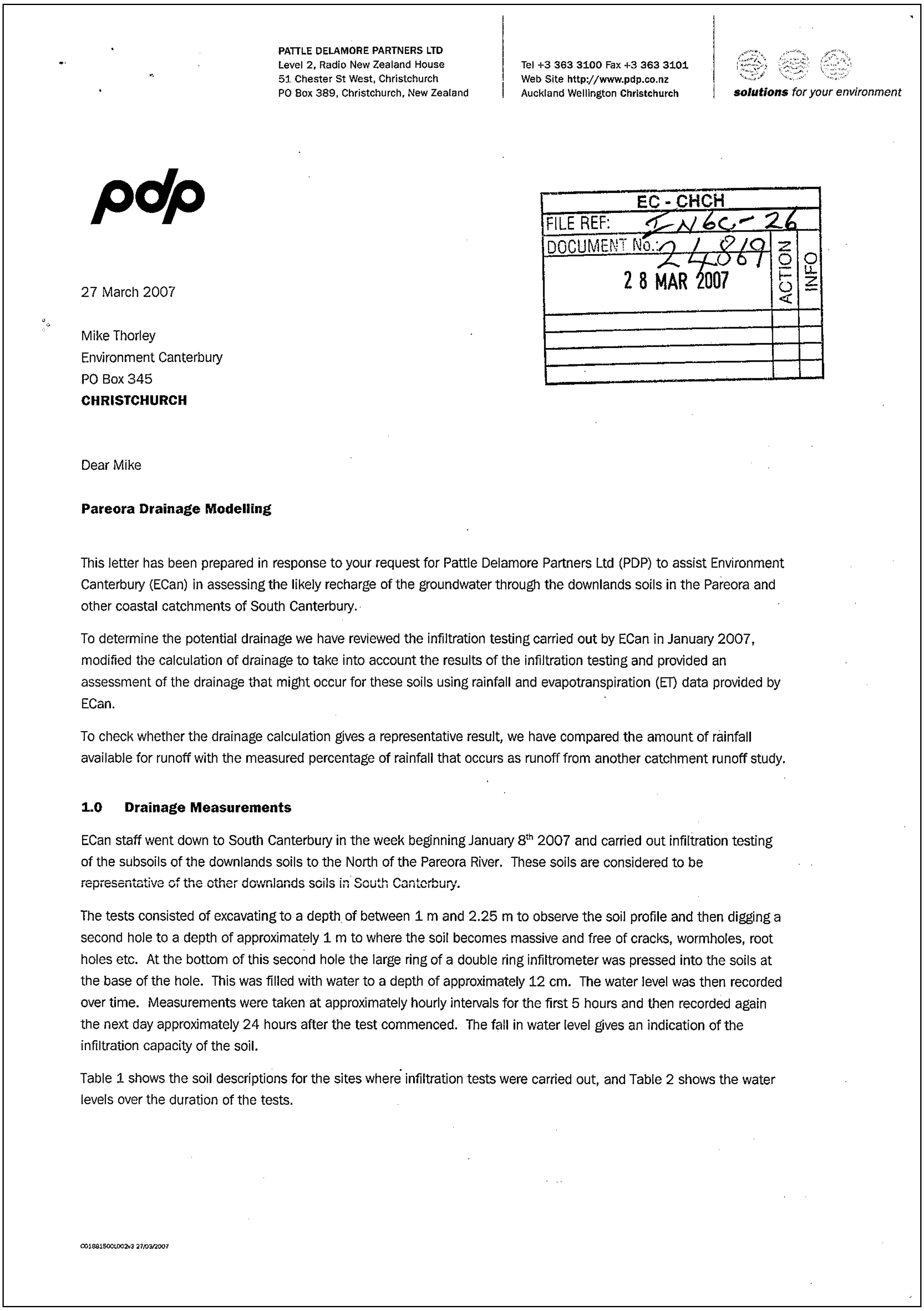
Scott, D., 2004. Groundwater Allocation Limits: land-based recharge estimates. Unpublished Technical Report U04/97. Environment Canterbury.

Taylor, N. H., Pohlen, I. J., 1962. Soil Survey Method. N.Z. Soil Bureau Bull. 25. DSIR.

Thorley, M., 2007. South Canterbury Groundwater Allocation Limits. Internal staff memorandum to the Water Allocation Group (WAG), 19 March 2007. Environment Canterbury.

Weeber, J., 2006. Waipara Groundwater Zone Boundary. Environment Canterbury File Note IN6C/00039-05, 8 September 2006.

Appendix A – PDP report



PATTLE DELAMORE PARTNERS LTD
Level 2, Radio New Zealand House
51 Chester St West, Christchurch
PO Box 389, Christchurch, New Zealand

Tel +3 363 3100 Fax +3 363 3101
Web Site http://www.pdp.co.nz
Auckland Wellington Christchurch

solutions *for your environment*

pdp

EC - CHCH
FILE REF: I-N6C-26
DOCUMENT No.: 24869
28 MAR 2007
ACTION
INFO

27 March 2007

Mike Thorley
Environment Canterbury
PO Box 345
CHRISTCHURCH

Dear Mike

Pareora Drainage Modelling

This letter has been prepared in response to your request for Pattle Delamore Partners Ltd (PDP) to assist Environment Canterbury (ECan) in assessing the likely recharge of the groundwater through the downlands soils in the Pareora and other coastal catchments of South Canterbury.

To determine the potential drainage we have reviewed the infiltration testing carried out by ECan in January 2007, modified the calculation of drainage to take into account the results of the infiltration testing and provided an assessment of the drainage that might occur for these soils using rainfall and evapotranspiration (ET) data provided by ECan.

To check whether the drainage calculation gives a representative result, we have compared the amount of rainfall available for runoff with the measured percentage of rainfall that occurs as runoff from another catchment runoff study.

1.0 Drainage Measurements

ECan staff went down to South Canterbury in the week beginning January 8th 2007 and carried out infiltration testing of the subsoils of the downlands soils to the North of the Pareora River. These soils are considered to be representative of the other downlands soils in South Canterbury.

The tests consisted of excavating to a depth of between 1 m and 2.25 m to observe the soil profile and then digging a second hole to a depth of approximately 1 m to where the soil becomes massive and free of cracks, wormholes, root holes etc. At the bottom of this second hole the large ring of a double ring infiltrometer was pressed into the soils at the base of the hole. This was filled with water to a depth of approximately 12 cm. The water level was then recorded over time. Measurements were taken at approximately hourly intervals for the first 5 hours and then recorded again the next day approximately 24 hours after the test commenced. The fall in water level gives an indication of the infiltration capacity of the soil.

Table 1 shows the soil descriptions for the sites where infiltration tests were carried out, and Table 2 shows the water levels over the duration of the tests.

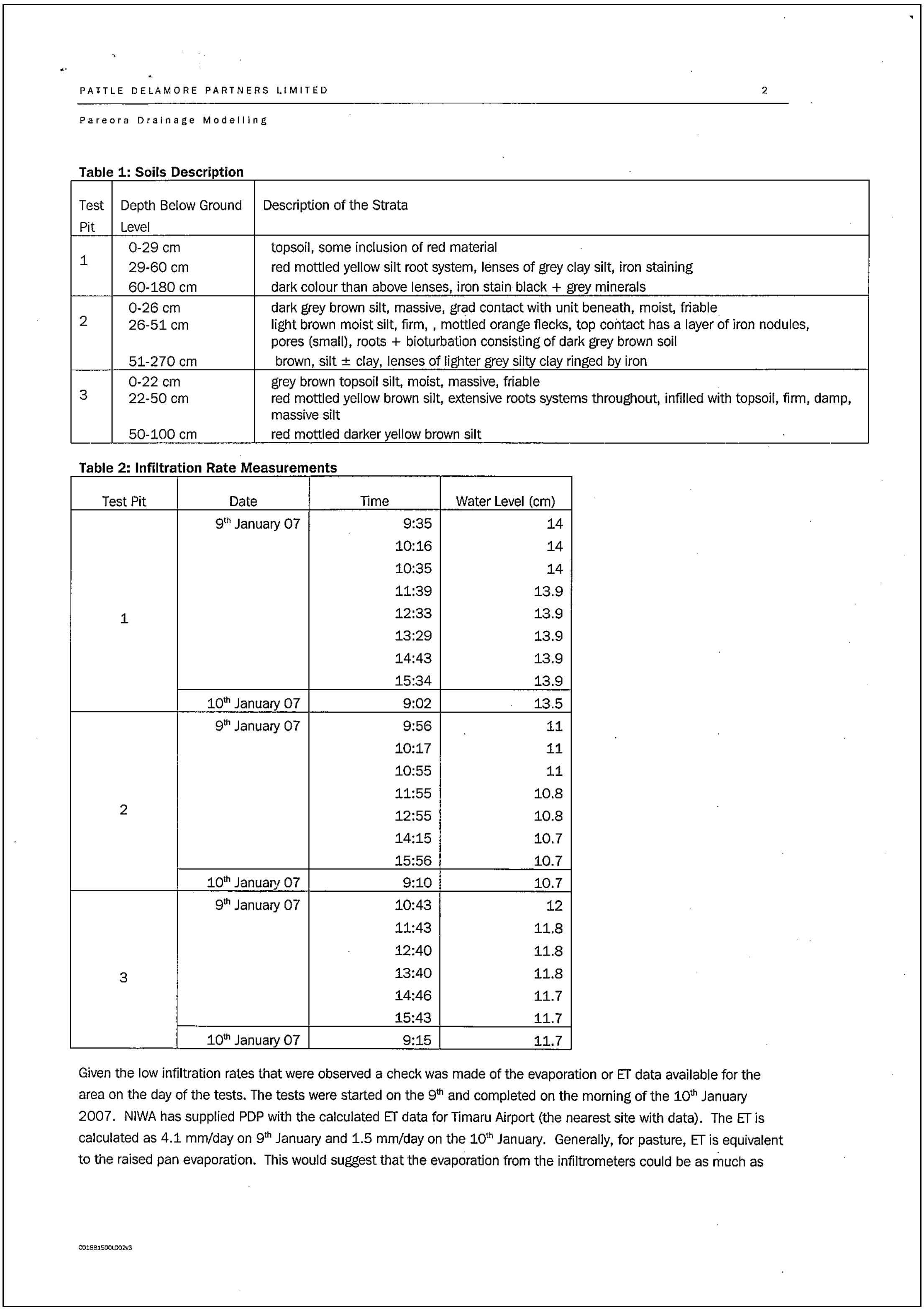


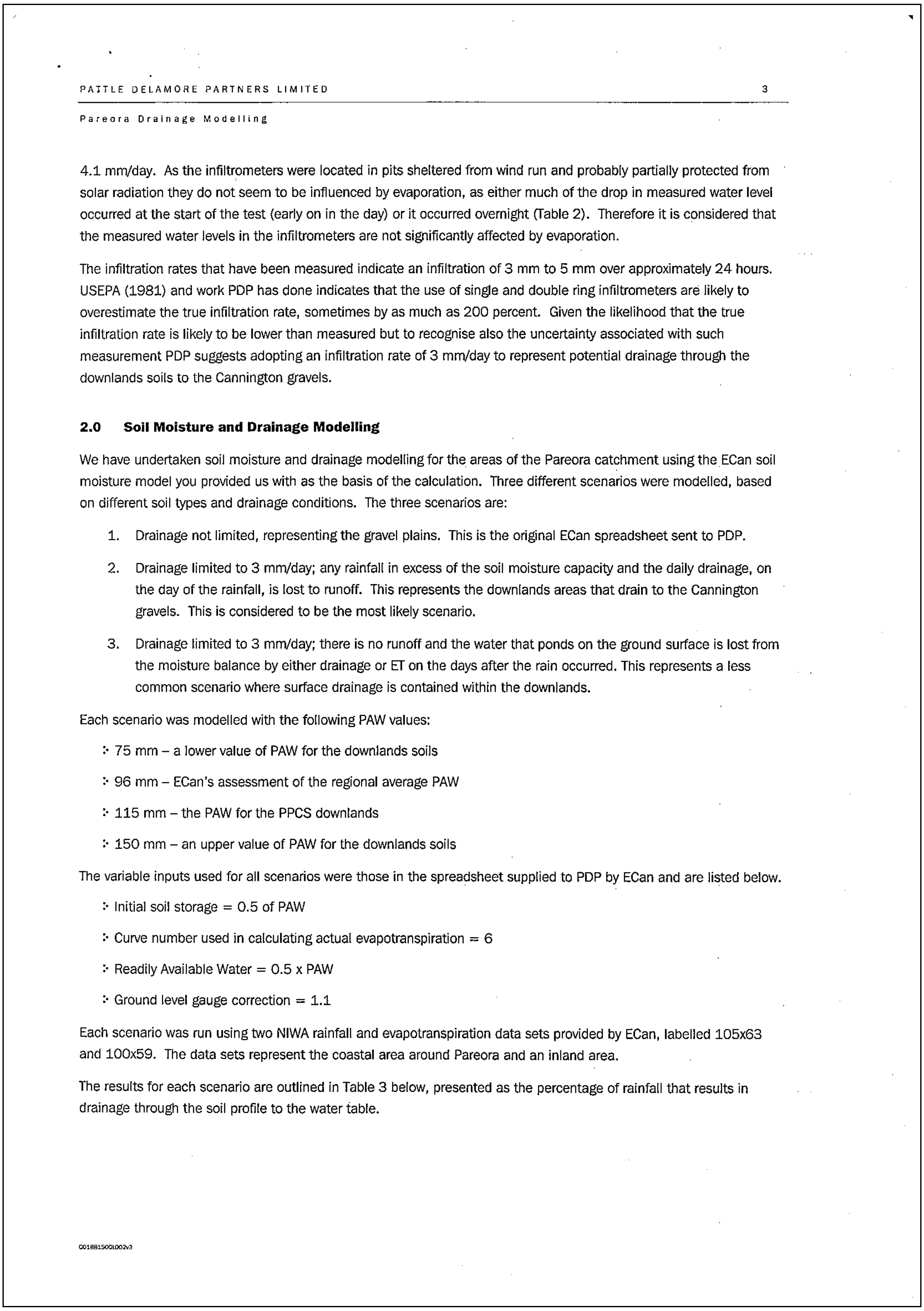
Table 1: Soils Description

Test Pit	Depth Below Ground Level	Description of the Strata
1	0-29 cm	topsoil, some inclusion of red material
	29-60 cm	red mottled yellow silt root system, lenses of grey clay silt, iron staining
	60-180 cm	dark colour than above lenses, iron stain black + grey minerals
2	0-26 cm	dark grey brown silt, massive, grad contact with unit beneath, moist, friable
	26-51 cm	light brown moist silt, firm, , mottled orange flecks, top contact has a layer of iron nodules, pores (small), roots + bioturbation consisting of dark grey brown soil
	51-270 cm	brown, silt ± clay, lenses of lighter grey silty clay ringed by iron
3	0-22 cm	grey brown topsoil silt, moist, massive, friable
	22-50 cm	red mottled yellow brown silt, extensive roots systems throughout, infilled with topsoil, firm, damp, massive silt
	50-100 cm	red mottled darker yellow brown silt

Table 2: Infiltration Rate Measurements

Test Pit	Date	Time	Water Level (cm)
1	9th January 07	9:35	14
		10:16	14
		10:35	14
		11:39	13.9
		12:33	13.9
		13:29	13.9
		14:43	13.9
		15:34	13.9
	10th January 07	9:02	13.5
2	9th January 07	9:56	11
		10:17	11
		10:55	11
		11:55	10.8
		12:55	10.8
		14:15	10.7
		15:56	10.7
	10th January 07	9:10	10.7
3	9th January 07	10:43	12
		11:43	11.8
		12:40	11.8
		13:40	11.8
		14:46	11.7
		15:43	11.7
	10th January 07	9:15	11.7

Given the low infiltration rates that were observed a check was made of the evaporation or ET data available for the area on the day of the tests. The tests were started on the 9th and completed on the morning of the 10th January 2007. NIWA has supplied PDP with the calculated ET data for Timaru Airport (the nearest site with data). The ET is calculated as 4.1 mm/day on 9th January and 1.5 mm/day on the 10th January. Generally, for pasture, ET is equivalent to the raised pan evaporation. This would suggest that the evaporation from the infiltrometers could be as much as



4.1 mm/day. As the infiltrometers were located in pits sheltered from wind run and probably partially protected from solar radiation they do not seem to be influenced by evaporation, as either much of the drop in measured water level occurred at the start of the test (early on in the day) or it occurred overnight (Table 2). Therefore it is considered that the measured water levels in the infiltrometers are not significantly affected by evaporation.

The infiltration rates that have been measured indicate an infiltration of 3 mm to 5 mm over approximately 24 hours. USEPA (1981) and work PDP has done indicates that the use of single and double ring infiltrometers are likely to overestimate the true infiltration rate, sometimes by as much as 200 percent. Given the likelihood that the true infiltration rate is likely to be lower than measured but to recognise also the uncertainty associated with such measurement PDP suggests adopting an infiltration rate of 3 mm/day to represent potential drainage through the downlands soils to the Cannington gravels.

2.0 Soil Moisture and Drainage Modelling

We have undertaken soil moisture and drainage modelling for the areas of the Pareora catchment using the ECan soil moisture model you provided us with as the basis of the calculation. Three different scenarios were modelled, based on different soil types and drainage conditions. The three scenarios are:

1. Drainage not limited, representing the gravel plains. This is the original ECan spreadsheet sent to PDP.
2. Drainage limited to 3 mm/day; any rainfall in excess of the soil moisture capacity and the daily drainage, on the day of the rainfall, is lost to runoff. This represents the downlands areas that drain to the Cannington gravels. This is considered to be the most likely scenario.
3. Drainage limited to 3 mm/day; there is no runoff and the water that ponds on the ground surface is lost from the moisture balance by either drainage or ET on the days after the rain occurred. This represents a less common scenario where surface drainage is contained within the downlands.

Each scenario was modelled with the following PAW values:

- 75 mm – a lower value of PAW for the downlands soils
- 96 mm – ECan's assessment of the regional average PAW
- 115 mm – the PAW for the PPCS downlands
- 150 mm – an upper value of PAW for the downlands soils

The variable inputs used for all scenarios were those in the spreadsheet supplied to PDP by ECan and are listed below.

- Initial soil storage = 0.5 of PAW
- Curve number used in calculating actual evapotranspiration = 6
- Readily Available Water = 0.5 x PAW
- Ground level gauge correction = 1.1

Each scenario was run using two NIWA rainfall and evapotranspiration data sets provided by ECan, labelled 105x63 and 100x59. The data sets represent the coastal area around Pareora and an inland area.

The results for each scenario are outlined in Table 3 below, presented as the percentage of rainfall that results in drainage through the soil profile to the water table.

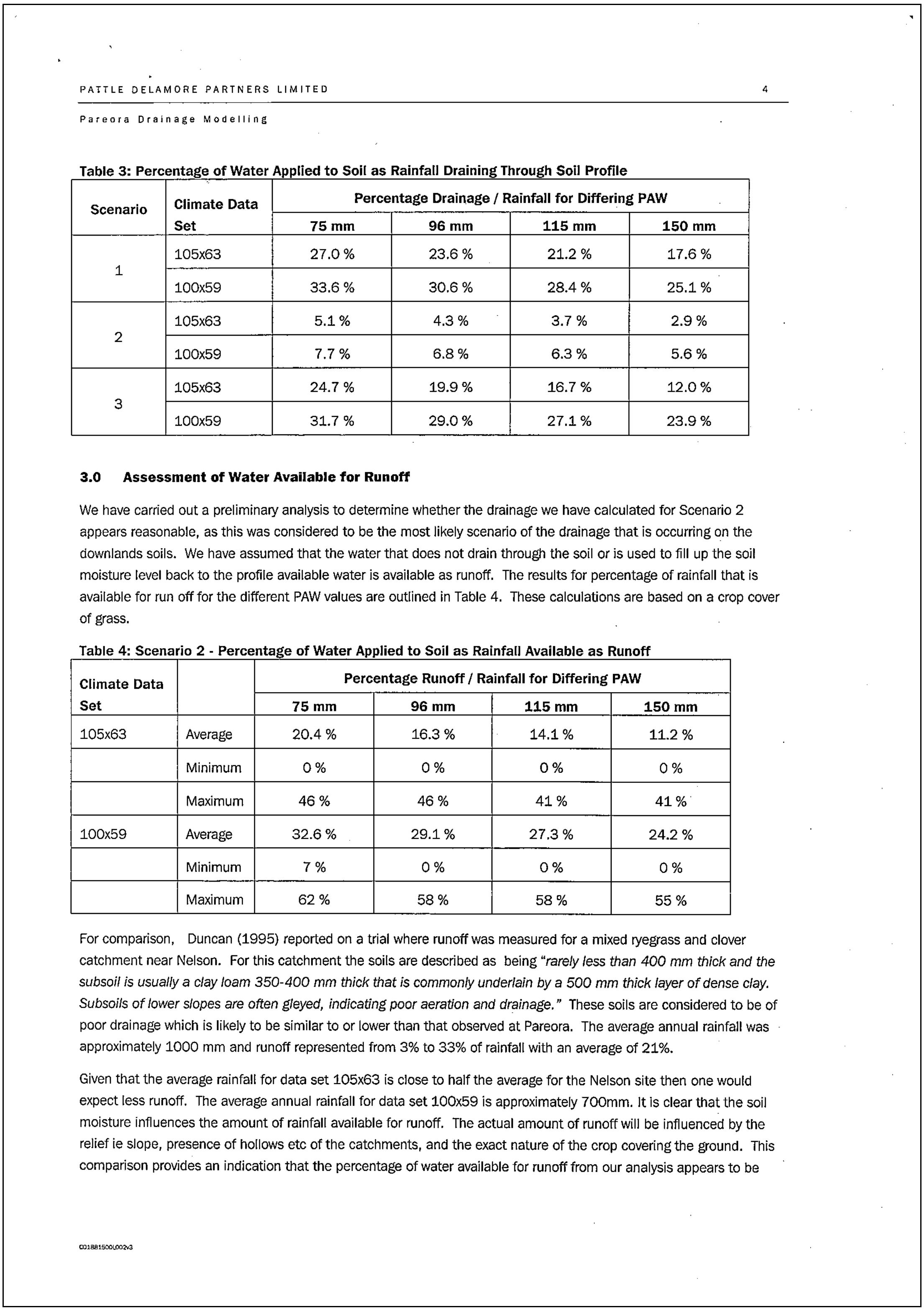


Table 3: Percentage of Water Applied to Soil as Rainfall Draining Through Soil Profile

Scenario	Climate Data Set	Percentage Drainage / Rainfall for Differing PAW			
		75 mm	96 mm	115 mm	150 mm
1	105x63	27.0 %	23.6 %	21.2 %	17.6 %
	100x59	33.6 %	30.6 %	28.4 %	25.1 %
2	105x63	5.1 %	4.3 %	3.7 %	2.9 %
	100x59	7.7 %	6.8 %	6.3 %	5.6 %
3	105x63	24.7 %	19.9 %	16.7 %	12.0 %
	100x59	31.7 %	29.0 %	27.1 %	23.9 %

3.0 Assessment of Water Available for Runoff

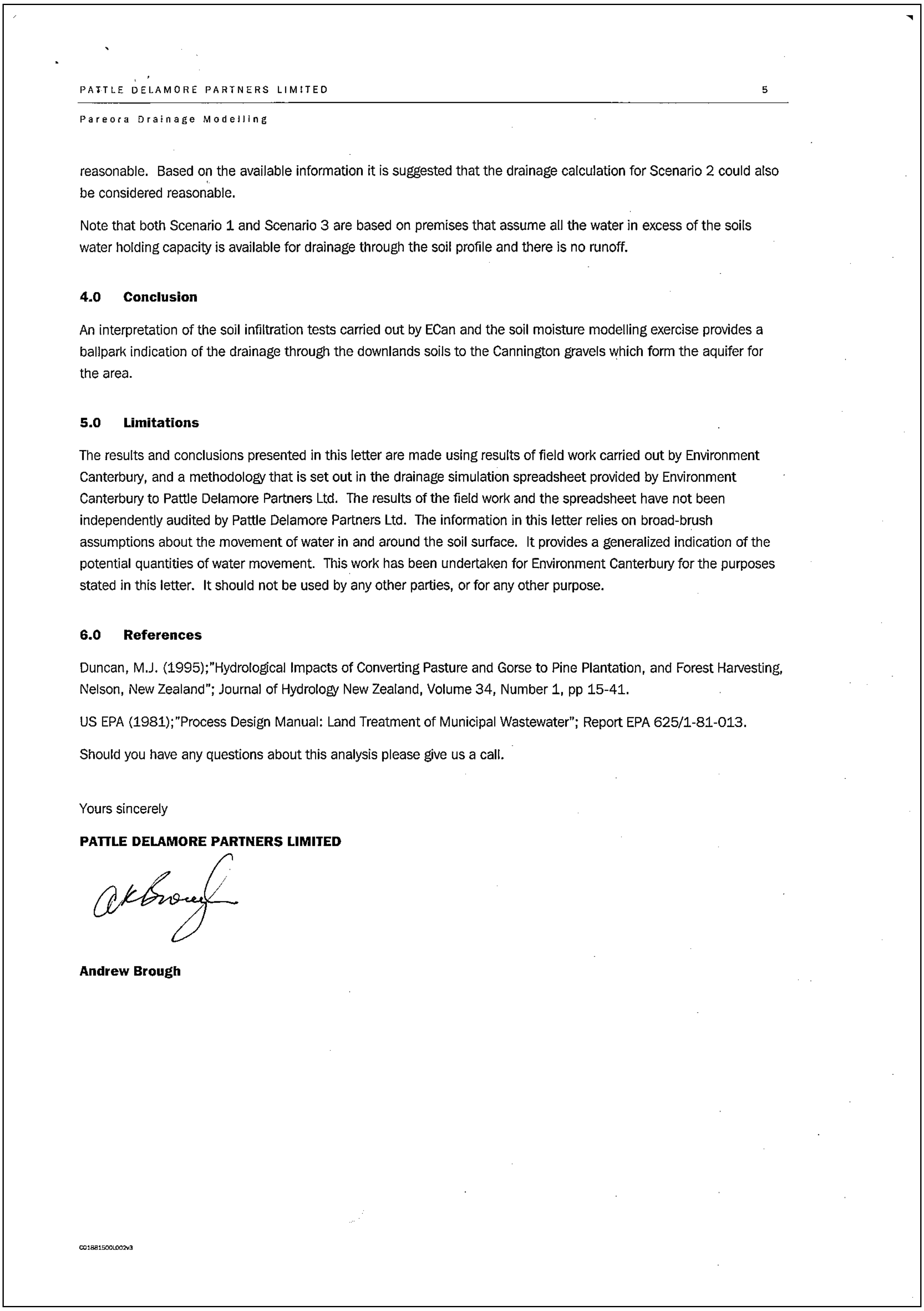
We have carried out a preliminary analysis to determine whether the drainage we have calculated for Scenario 2 appears reasonable, as this was considered to be the most likely scenario of the drainage that is occurring on the downlands soils. We have assumed that the water that does not drain through the soil or is used to fill up the soil moisture level back to the profile available water is available as runoff. The results for percentage of rainfall that is available for run off for the different PAW values are outlined in Table 4. These calculations are based on a crop cover of grass.

Table 4: Scenario 2 - Percentage of Water Applied to Soil as Rainfall Available as Runoff

Climate Data Set		Percentage Runoff / Rainfall for Differing PAW			
		75 mm	96 mm	115 mm	150 mm
105x63	Average	20.4 %	16.3 %	14.1 %	11.2 %
	Minimum	0 %	0 %	0 %	0 %
	Maximum	46 %	46 %	41 %	41 %
100x59	Average	32.6 %	29.1 %	27.3 %	24.2 %
	Minimum	7 %	0 %	0 %	0 %
	Maximum	62 %	58 %	58 %	55 %

For comparison, Duncan (1995) reported on a trial where runoff was measured for a mixed ryegrass and clover catchment near Nelson. For this catchment the soils are described as being *"rarely less than 400 mm thick and the subsoil is usually a clay loam 350-400 mm thick that is commonly underlain by a 500 mm thick layer of dense clay. Subsoils of lower slopes are often gleyed, indicating poor aeration and drainage."* These soils are considered to be of poor drainage which is likely to be similar to or lower than that observed at Pareora. The average annual rainfall was approximately 1000 mm and runoff represented from 3% to 33% of rainfall with an average of 21%.

Given that the average rainfall for data set 105x63 is close to half the average for the Nelson site then one would expect less runoff. The average annual rainfall for data set 100x59 is approximately 700mm. It is clear that the soil moisture influences the amount of rainfall available for runoff. The actual amount of runoff will be influenced by the relief ie slope, presence of hollows etc of the catchments, and the exact nature of the crop covering the ground. This comparison provides an indication that the percentage of water available for runoff from our analysis appears to be



reasonable. Based on the available information it is suggested that the drainage calculation for Scenario 2 could also be considered reasonable.

Note that both Scenario 1 and Scenario 3 are based on premises that assume all the water in excess of the soils water holding capacity is available for drainage through the soil profile and there is no runoff.

4.0 Conclusion

An interpretation of the soil infiltration tests carried out by ECan and the soil moisture modelling exercise provides a ballpark indication of the drainage through the downlands soils to the Cannington gravels which form the aquifer for the area.

5.0 Limitations

The results and conclusions presented in this letter are made using results of field work carried out by Environment Canterbury, and a methodology that is set out in the drainage simulation spreadsheet provided by Environment Canterbury to Pattle Delamore Partners Ltd. The results of the field work and the spreadsheet have not been independently audited by Pattle Delamore Partners Ltd. The information in this letter relies on broad-brush assumptions about the movement of water in and around the soil surface. It provides a generalized indication of the potential quantities of water movement. This work has been undertaken for Environment Canterbury for the purposes stated in this letter. It should not be used by any other parties, or for any other purpose.

6.0 References

Duncan, M.J. (1995);"Hydrological Impacts of Converting Pasture and Gorse to Pine Plantation, and Forest Harvesting, Nelson, New Zealand"; Journal of Hydrology New Zealand, Volume 34, Number 1, pp 15-41.

US EPA (1981);"Process Design Manual: Land Treatment of Municipal Wastewater"; Report EPA 625/1-81-013.

Should you have any questions about this analysis please give us a call.

Yours sincerely

PATTLE DELAMORE PARTNERS LIMITED

Andrew Brough

Appendix B –Soil moisture budget model (DRAIN5_Loess.FOR)

```
integer*4    x, y, x0, y0, cellid, days, dayno, day0, date
      character*80 line
      character*11 climate
      logical*1    irrig

      open(14,'drain_out5.txt')
      write(14,*) 'cellid, x0, y0, paw, j0, k0, rtot, etot, 
drain_rain,
     *drain_irrig, excess_rain, excess_irr'

      open(10,'table5.prn')
      read(10,*) line
      days = 12783                        ! number of days in 
climate records 1972-2006
      day0 = 26300                        ! 2/1/1972

c........read grid cell details (file 10)
      kount = 0
    1 read(10,*,end=98) cellid, paw0, x0, y0
      paw = 0.67*paw0                     ! limit paw to 2/3rds 
PAWavg value
      if(paw .eq. 0.0) then
         j0          = 0
         k0          = 0
         rtot        = 0.0
         etot        = 0.0
         drain_rain  = 0.0
         drain_irrig = 0.0
         excess_rain = 0.0
         excess_irr  = 0.0
         write(14,2) cellid, x0, y0, paw0, j0, k0, rtot, etot,
     *               drain_rain, drain_irrig, excess_rain, 
excess_irr
    2    format(3(i,','),f10.4,',',2(i,','),5(g10.4,','),g10.4)

         go to 1
      endif
      kount = kount + 1
      write(*,*) kount

c........identify closest sythetic climate station (file 11)
      open(11,'coords.prn')
      read(11,*) line
      distance = 1e12
   10 read(11,*,end=20) x, y, j, k
      r = (real(x - x0)/1000.0)**2 + (real(y - y0)/1000.0)**2
      if(r .lt. distance) then
         distance = r
         j0       = j
         k0       = k
      endif
      go to 10
   20 close(11)

c........open climate station record (file 12)
      if(j0 .ge. 100 .and. k0 .ge. 100) then
         write(climate,30) j0, k0
   30    format(i3,'x',i3,'.dat')
      else if (j0 .ge. 100 .and. k0 .lt. 100) then
         write(climate,32) j0, k0
```

```
   32    format(i3,'x',i2,'.dat')
      else if (j0 .lt. 100 .and. k0 .lt. 100) then
         write(climate,33) j0, k0
   33    format(i2,'x',i2,'.dat')
      else if (j0 .lt. 100 .and. k0 .ge. 100) then
         write(climate,34) j0, k0
   34    format(i2,'x',i3,'.dat')
      else
         write(*,*) "woops", j0, k0
      endif

      open(12,climate,err=91)
      w_rain      = paw
      drain_rain  = 0.0
      w_irrig     = paw
      drain_irrig = 0.0
      rtot        = 0.0
      etot        = 0.0
      excess_rain = 0.0
      excess_irr  = 0.0
      dayno       = day0
   31 read(12,*,end=40) date, rain, pet
      rain = 1.1*rain                            ! apply ground-level
gauge correction
      if(pet .lt. 0.0) pet = 0.0                 ! correct negative
pet estimates
      rtot = rtot + rain
      etot = etot + pet
      day  = mod(dayno - day0,365.25)
      if(day .le. 120.0 .or. day .ge. 274.0) then      ! irrigation
season october thru april
         irrig = .true.
      else
         irrig = .false.
      endif

c........dryland
      appl1 = 0.0                          ! zero application depth
for dryland option
      call budget(paw,rain,pet,w_rain,appl1,drainage1,excess1)
      drain_rain = drain_rain + drainage1
      excess_rain = excess_rain + excess1

c........generic irrigation
      appl2 = 0.0
      if(irrig) then
         if(w_irrig .lt. 0.5*paw) then
            appl2 = (paw - w_irrig)/0.8                ! appl to
restore to field capacity with 80% efficiency
         endif
      endif
      call budget(paw,rain,pet,w_irrig,appl2,drainage2,excess2)
      drain_irrig = drain_irrig + drainage2
      excess_irr  = excess_irr + excess2

c........other irrigation rules to be incorporated

      dayno = dayno + 1
      go to 31

   40 close(12)
      factor      = 365.25/real(days)
      rtot        = factor*rtot
      etot        = factor*etot
      drain_rain  = factor*drain_rain
      drain_irrig = factor*drain_irrig
      excess_rain = factor*excess_rain
      excess_irr  = factor*excess_irr
      write(14,2) cellid, x0, y0, paw0, j0, k0, rtot, etot,
     *            drain_rain, drain_irrig,
```

```
     *            excess_rain, excess_irr
      write(*,*) cellid, rtot, etot,
     *               drain_rain, drain_irrig,
     *               excess_rain, excess_irr
      go to 1

   91 write(*,*) 'error opening ', climate
      go to 99
   98 write(*,*) 'finished reading grid cell details'
   99 stop
      end

      subroutine budget(paw,rain,pet,w,appl,drainage,excess)
      a        = 6.0                      ! constant in aet/pet vs
w/paw relationship
      smfac    = (1.0 - exp(-a*w/paw))/
     *           (1.0 - 2.0*exp(-a) + exp(-a*w/paw))
      aet      = smfac*pet
      w        = w + rain + appl - aet
      drainage = 0.0
      excess   = 0.0

      if(w .gt. paw) then
         drainage = w - paw
         w        = paw
      elseif(w .lt. 0.0) then
         w        = 0.0
      endif
      if(drainage .gt. 3.0) then
         excess   = drainage - 3.0
         drainage = 3.0
      endif

      return
      end
```