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Irrigation and Drainage Modelling of the Upper Waitaki Basin

Prepared for GHD Limited

Report No C08054/1

August 2008

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Quality Control			
Client:	GHD Limited		
Report reference:	Title: Irrigation and Drainage Modelling of the Upper Waitaki Basin	No: C08054/1	
Prepared by:	Dr. Peter Brown		
Reviewed by:	Ian McIndoe	Approved for issue by:	Ian McIndoe
Date issued:	August 2008	Project No:	C08054

Document History			
Version: 1	Status: Draft, for review by client	Author: P. Brown	Reviewer: I. McIndoe
Date: 18/7/08	Doc ID: 08-07-18 ,DrainageModelling_ UpperWaitakiBasin_draft_v1.doc	Typist:	Approver: I. McIndoe
Version: 1.1	Status: Draft, for review by client	Author: P. Brown	Reviewer: I. McIndoe
Date: 06/08/08	Doc ID: 08-07-18 ,DrainageModelling_ UpperWaitakiBasin_Final_v2.doc	Typist:	Approver: I. McIndoe

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1 INTRODUCTION

1.1 Background

Aqualinc Research Ltd (Aqualinc) has been engaged to carry out irrigation and drainage modelling for the Mackenzie Basin. This project forms part of a comprehensive water quality study commissioned by Mackenzie Water Research Ltd and carried out by GHD Limited to determine the potential effects of proposed water takes for irrigation in the Upper Waitaki Basin. A consent hearing is proposed for 2009.

An aerial overview of the Upper Waitaki catchment, and of the basin, is given in Appendix A.

1.2 Objectives of Study

The purpose of the project was to use soil water balance modelling to take into account spatial variations in climate, soils and irrigation practices to determine daily drainage and irrigation demand time-series for relevant climate, soil, and irrigation status combinations. The daily time-series data was processed and used by other project contributors for analysis of nutrient leaching and for groundwater balances.

The spatial extent of each combination is provided in GIS format.

2 MODEL INPUTS

The following data sources and inputs were used for the water balance modelling.

2.1 Rainfall

2.1.1 Rainfall regions

Based on climate station data, mean annual rainfall (MAR) across the Mackenzie Basin ranges from 400 - 900mm. Irrigation and drainage modelling requires discrete rainfall regions, and on that basis, four different rainfall regions or classes were defined. The four different rainfall classes were MAR = 500, 600, 700 and 800 mm: Class MAR 500 mm corresponded to MAR = 400-550 mm; Class MAR 600 mm corresponded to MAR = 550-650 mm; Class MAR 700 mm corresponded to MAR = 650-750 mm; and Class MAR 800 mm corresponded to MAR = 750-850 mm.

MAR isohyets derived from interpolated daily rainfall by Tait et al. (2006) were used to spatially define rainfall regions. Isohyets were compared with actual MAR for available climate station data and in general the two showed good agreement.

MAR isohyets, rainfall regions, and MAR for individual climate stations are presented in Appendix B.

2.1.2 Rainfall daily time-series

Two sources of daily rainfall time-series inputs were used in modelling, to test the sensitivity of model outputs to the spatial and temporal stochastic characteristics of rainfall in the Mackenzie Basin.

The first source of time-series data was interpolated daily rainfall (using thin plate smoothing spline interpolation and using a climatological rainfall surface) by Tait et al. (2006). Irrigation and drainage modelling required a representative daily time-series for each of the rainfall regions.

Since the data of Tait et al. was available for a 0.05 degree latitude and longitude grid, a single grid point was chosen for each rainfall region; at a location as close as possible to the assumed MAR for that region (i.e. four points were chosen, close to the 500 mm, 600 mm, 700 mm, and 800 mm MAR isohyets).

Due to the 0.05 degree resolution of the time-series grid, it was generally not possible to select grid points that were exactly located on a particular isohyet. Therefore, each time-series was proportionally scaled, such that the resulting MAR of a particular time-series was exactly equal to the desired MAR (e.g. 500 mm, 600 mm, 700 mm, or 800 mm).

A time-series from a fifth grid point was also used in modelling, close to the Tara Hills rainfall station. Grid point locations which were used are shown in Appendix B.

The second source of time-series data was the historical rainfall record from Tara Hills, Omarama (agent 5211/5212), proportionally scaled, such that the resulting MAR of a particular time-series was exactly equal to 500 mm, 600 mm, 700 mm, or 800 mm. Historical data from 1 June 1972 to 31 May 2006 was used.

Approximately 3% gaps were filled randomly with a stochastic model, which assumes the probability of a wet day varies throughout the year; while the depth of rainfall on a wet day has a Gamma distribution and this distribution is constant throughout the year. The error in mean annual irrigation demand, using this gap filling methodology, is expected to be less than $3\% \times$ the percentage of gaps (Brown 2007): $3\% \times 2\% = 0.06\%$. The Tara Hills station was used since no other rainfall stations in the basin had records for the majority of the period from 1972 to 2007. The MAR at Tara Hills was 516 mm.

Both sources of rainfall time-series inputs were used in irrigation and drainage modelling, for each soil, irrigation type and where appropriate, dryland combinations. Model outputs, using the fifth grid point using interpolated time-series and the Tara Hills historical time-series, were also compared.

From this modelling, difference in calculated mean annual irrigation demand was less than 1% for all rainfall class, soil class, and irrigation type or dryland combinations, indicating that: (a) spatial variations in rainfall characteristics other than MAR are not significant and MAR alone is sufficient for defining rainfall regions in the basin; and (b) temporal stochastic properties are adequately modelled by Tait et al. (2006). This result suggested the use of Tait et al. (2006) interpolated daily time-series, scaled to a given MAR, is justified for the basin. Results presented in Section 3.2 use Tait et al.'s interpolated data, scaled to a given MAR.

2.2 Reference Evapotranspiration

Historical daily reference evapotranspiration (ET_o) time-series from Tara Hills; Omarama (Agent 5211/5212) was used in modelling. No other ET_o records of any significant duration are available in the Mackenzie Basin. Historical data from 1 June 1972 to 31 May 2006 was used. Data gaps (approximately 10% of the record) were filled with long term monthly averages. Errors in mean annual irrigation demand, using this gap filling methodology, are expected to be less than $2\% \times$ the percentage of gaps = $2\% \times 10\% = 0.2\%$ (Brown 2007). Mean annual ET_o calculated by the Penman method was 892 mm.

Tait and Woods (2007) have produced interpolated daily ET_o time-series for New Zealand, for a 0.05 degree latitude and longitude grid. These time-series predict that mean annual ET_o in the Upper Waitaki Basin ranges from 1-18% less than the historical mean at Tara Hills. The interpolation of Tait and Woods (2007) is based on climate data throughout NZ, but due to the lack of any nearby ET_o records other than Tara Hills, the reliability of these estimates for the basin are uncertain. Therefore in the absence of further information, it has been assumed that the historical ET_o record from Tara Hills is representative for the basin.

2.3 Soils

Soils information was principally derived from the Upper Waitaki basin soil survey by Webb (1992). Average plant available water for pasture at field capacity (PAW) values for the soils identified in this survey have subsequently been estimated by Webb. In order to reduce the number of model input combinations, soils were aggregated by PAW into four regions or classes. The four soil classes were PAW = 30, 60, 90 and 130 mm: Class PAW 30 mm corresponded to average PAW = 15-45 mm; Class PAW 60 mm corresponded to average PAW = 46-75 mm; Class PAW 90 mm corresponded to average PAW = 76-105 mm; and Class PAW 130 mm corresponded to average PAW > 105 mm.

The Upper Waitaki basin soil survey and subsequent estimates by Webb were compared with the New Zealand Fundamental Soils Layer (NZFSL). The NZFSL has a lower resolution than the Waitaki Basin survey, and generally predicted higher PAW values. Where possible, the survey and estimates of Webb were used in preference to NZFSL PAW estimates, since Webb's estimates were considered more reliable. Around the perimeter of the basin, Webb's estimates were not available for some areas, and NZFSL PAW estimates were used. PAW estimates from both Webb's estimates and the NZFSL, aggregated into the four PAW classes, are shown in Appendix C.

2.4 Crop Type

The majority of land in the Upper Waitaki Basin is either pasture or alpine tussocks, with some wilding pines (Appendix D). Farming activities are principally low density pastoral grazing. The crop coefficient¹ for moderately grazed pastures is generally between 0.9-1.0 (Allen et al. 1998). In contrast, alpine tussocks may have a crop coefficient of as low as 0.4-0.5 (Buytaert et al. 2006). A lower crop coefficient results

¹ Kc from Allen et al. (1998). Potential ET = Kc × Reference ET.

in reduced ET and increased drainage. However the low ET for tussocks will be offset by higher interception losses and a deeper rooting system than grazed pasture – both factors which reduce drainage. In the absence of further site specific information of the drainage characteristics of tussocks relative to pasture, it was assumed that drainage beneath these two land covers were similar. Consequently a crop coefficient time-series typical of pasture, and PAW estimates assumed a rooting depth typical of pasture, were used in modelling. The crop coefficient time-series for pasture, as a function of the time of year, was derived from Dunsandel lysimeter data by Bright (2007).

2.5 Irrigation Practices

2.5.1 Current irrigated areas

Current irrigated areas have been estimated from satellite imagery taken in January 2007, from consented irrigation takes, and from local knowledge (Appendix 4). A total of 7,600 ha was identified, 4,800 ha of surface irrigation and 2,800 ha of spray irrigation (primarily centre pivots).

For comparison, McIndoe (2004) estimated existing consented irrigation as 10,600 ha (4,600 ha surface irrigation, 5,500 ha spray irrigation, and 500 ha irrigation type unspecified). Potts (2005) estimated 5,400 ha of actual irrigation based on LANDSAT satellite imagery taken in 2002, which excluded the potential 4,000 ha associated with the Benmore Irrigation scheme. Recent satellite imagery suggests about 2,000 ha of the Benmore Irrigation scheme has now been developed. A figure of 7,500 of current actual irrigation therefore is comparable with both McIndoe's and Pott's estimate, since about 2,000 ha of the Benmore scheme is currently undeveloped and McIndoe's estimate was of the consented area rather than actual irrigation².

2.5.2 Proposed irrigated areas

Proposed areas of new irrigation were estimated from resource consent applications supplied to Environment Canterbury. Most water permit applications propose to use spray irrigation. A few applications systems did not specify the irrigation type, however given the 80% irrigation efficiency requirements of the Waitaki Plan, it is reasonable to assume all new irrigation will use spray systems. Irrigation areas are given in Table 1, and shown graphically in Appendix F. Applications for consent renewals have been excluded from Table 1 and Appendix F. It is recommended these proposed irrigated areas be checked with the various consultants to ensure there are not consents which have been missed, and any changes to consent applications are updated.

² Pott's estimate excluded the 2,000 ha of the Benmore Irrigation scheme which is now developed. $5,500 + 2,000 = 7,500$ ha. McIndoe's estimate included 2,000 ha of the Benmore Irrigation scheme, which is not yet developed. $10,600 - 2,000 = 8,600$ ha. Therefore a figure of 7,800 ha is within 15% of these two estimates.

Table 1: Proposed new irrigation estimated from estimated from resource consent applications supplied to Environment Canterbury

CRC Number	Applicant/Farm	Consultant	Proposed new irrigation (ha)
CRC071649	Bellfield Land Co Ltd	I.R. Solutions	52
CRC011987	Bellfield Land Co Ltd	I.R. Solutions	208
CRC063106	Classic Properties Ltd (MaryburnStn)	Irricon	416
CRC070406	Classic Properties Ltd (MaryburnStn)	Irricon	485
CRC071362	Glentanner Stn Ltd	I.R. Solutions	200
CRC040994	Gloag, M. & A. (Buscott Stn)	Irricon	140
CRC072363	Graham F. (Te Akatarawa Stn)	I.R. Solutions	25
CRC042661	Grays Hills Stn Ltd	GHD	384 ⁽¹⁾
CRC042561	Haldon Stn Ltd	ECS	190
CRC072233	High Country Rosehip Ltd	I.R. Solutions	500
CRC072118 CRC021749	High Country Rosehip Ltd	I.R. Solutions	1225
CRC041542 CRC041543	Hope, A.N. (The Grampions)	Peter Clarke	385
CRC041331	Killermont Stn Ltd	Aqualinc	216
CRC041777 CRC041798 CRC040180	Killermont Stn Ltd	Aqualinc	396
CRC071786	Lilybank Stn	I.R. Solutions	172
CRC031175	Lone Star Farm Ltd/Star Holdings Ltd	Aqualinc	450
CRC011940	McAughtrie, D. W.	GHD	85
CRC042011 CRC042015 CRC042017	Ohau Co. Trust (Ribbonwood Stn)	Brooks & Assoc.	300
CRC042018	Ohau Co. Trust (Ribbonwood Stn)	Brooks & Assoc.	100
CRC042020	Ohau Co. Trust (Ribbonwood Stn)	Brooks & Assoc.	350
CRC042022 CRC042025	Ohau Co. Trust (Ribbonwood Stn)	Brooks & Assoc.	250
CRC-061154 CRC 061155 CRC 040835	Williamson Holdings Ltd and Five Rivers Ltd (Ohau Downs and Glen Eyrie Downs)	GHD & Aqualinc	4000
CRC041033	Otematata Stn Ltd	GHD	162
CRC062842	Simons Hill Stn Ltd	Aqualinc	2400
CRC062867	Simons Pass Stn Ltd	Aqualinc	2400
CRC062941	Twin Peaks Stn Ltd	I.R. Solutions	180
CRC063564	Twin Peaks Stn Ltd	I.R. Solutions	72
CRC030944	Waitangi Stn Ltd	I.R. Solutions	128
CRC041788	Williamson Holdings Ltd (Killermont Stn)	Aqualinc	1100
		Total	16971⁽²⁾
(1) Excludes 28 ha of existing irrigation associated with the renewal of consent WTK836261B			
(2) Excludes CRC020355 (GHD/37ha), CRC012047 (IR solutions/120ha new irrigation), and CRC041032 (GHD/62ha) since an irrigated command area was not included in the consent application. Also excludes CRC042713 (16ha) due to difficulties in obtaining a copy of the consent application.			

2.6 Irrigation Modelling Parameters

Two types of irrigation systems were modelled, border-dyke and centre pivot. The majority of existing irrigation in the basin is either border-dyke or centre pivots.

Assumed operating and performance parameters for these two systems varied depending on the soil PAW and are summarised in Table 1.

Table 2: Assumed irrigation parameters as a function of soil depth and system type

PAW (mm)	Application depth (mm)	Return interval (day)	TSML ⁽¹⁾ (% of PAW)	UCC ⁽²⁾
<i>Centre pivot</i>				
30	10	2	50%	0.80
60	20	4	55-60% ⁽³⁾	0.75
90	20	4	60%	0.75
130	20	4	60%	0.75
<i>Borderdyke</i>				
30	75	14	50%	0.85
60	75	14	50%	0.85
90	90	14	50%	0.85
130	120	18	55%	0.85
(1) Trigger soil moisture level (2) Christiansen's coefficient of uniformity (3) 55% for MAR=500mm, 60% for MAR>500mm				

Lower application efficiency was used for higher application depths because of the low infiltration capacity of some soils in the basin. An evapotranspiration reduction factor³ (r) of 15 was used in Heiler's (1981) water stress reduction equation. The irrigation season extended from 1 September to 30 April.

3 SOIL WATER BALANCE MODELLING

3.1 Model description

Irrigation demand and drainage volumes were calculated from Aqualinc's irrigation demand and scheduling daily water balance model, IrriCalc. The model is similar to Allen et al.'s (1998) single crop coefficient method (with a single soil layer) with the exception that Heiler's (1981) rather than Allen et al.'s water stress reduction equation is used, and Bright's (1986) application efficiency model⁴ is included.

This model does not determine surface runoff and lateral water movement and therefore is not appropriate for slopes greater than about 15 degrees. The model also ignores macro-pore flow.

³ The evapotranspiration reduction factor 'r' is the single parameter used by Heiler's (1981) to define the relationship between soil moisture (on a given day) and the water stress reduction factor (k_s).

⁴ Bright's application model accounts for the effect of spatial variations across a paddock in the amount of water which infiltrates following an irrigation event.

3.2 Results

Drainage and irrigation demand were calculated for 48 combinations of rainfall, ET, and irrigation system type (including no irrigation), on a daily time step. The period of simulation is 1 June 1972 to 31 May 2006.

Results are summarised below into yearly totals in Tables 2 – 4. Daily irrigation and drainage time-series for the period of simulation, for each of the 48 input combinations, are available in electronic format. The spatial extent of each of the 48 input combinations is available in electronic GIS format.

Table 3: Mean annual dryland drainage (mm/yr)

PAW (mm)	Mean annual rainfall (mm)			
	500	600	700	800
30	153	208	285	364
60	100	150	220	296
90	70	116	183	259
130	41	81	144	219

Table 4: Mean annual drainage under irrigation (mm/yr)

PAW (mm)	Mean annual rainfall (mm)			
	500	600	700	800
<i>Centre pivot</i>				
30	225	293	373	455
60	188	273	353	433
90	152	210	282	364
130	115	172	242	320
<i>Borderdyke</i>				
30	1017	1058	1141	1206
60	644	689	758	822
90	578	613	673	744
130	582	609	662	714

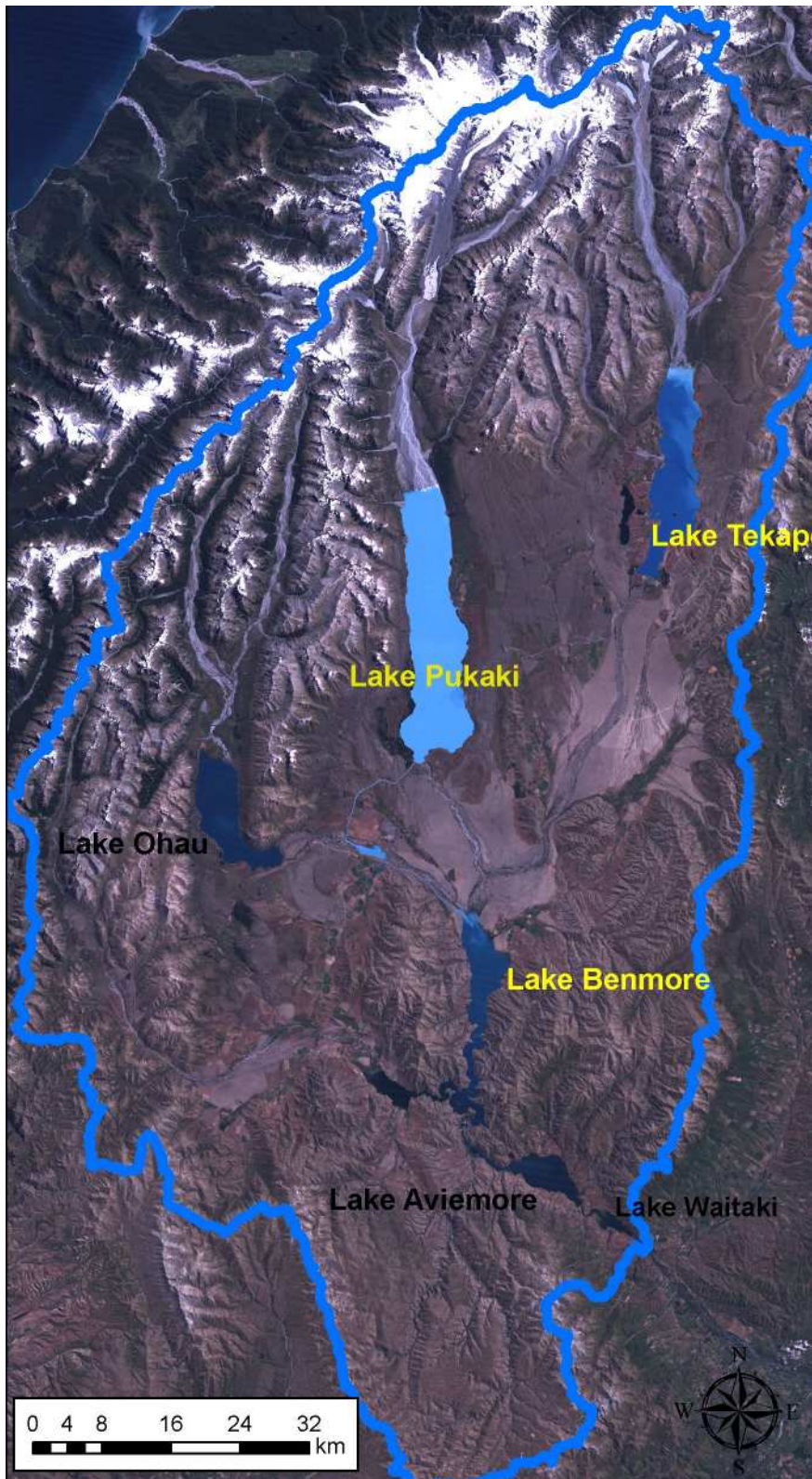
Table 5: Mean annual irrigation demand (mm/yr)

PAW (mm)	Mean annual rainfall (mm)			
	500	600	700	800
<i>Centre pivot</i>				
30	597	563	543	526
60	569	552	531	511
90	533	489	459	442
130	498	451	421	398
<i>Borderdyke</i>				
30	1181	1138	1127	1101
60	988	934	904	870
90	957	890	849	820
130	963	888	840	792

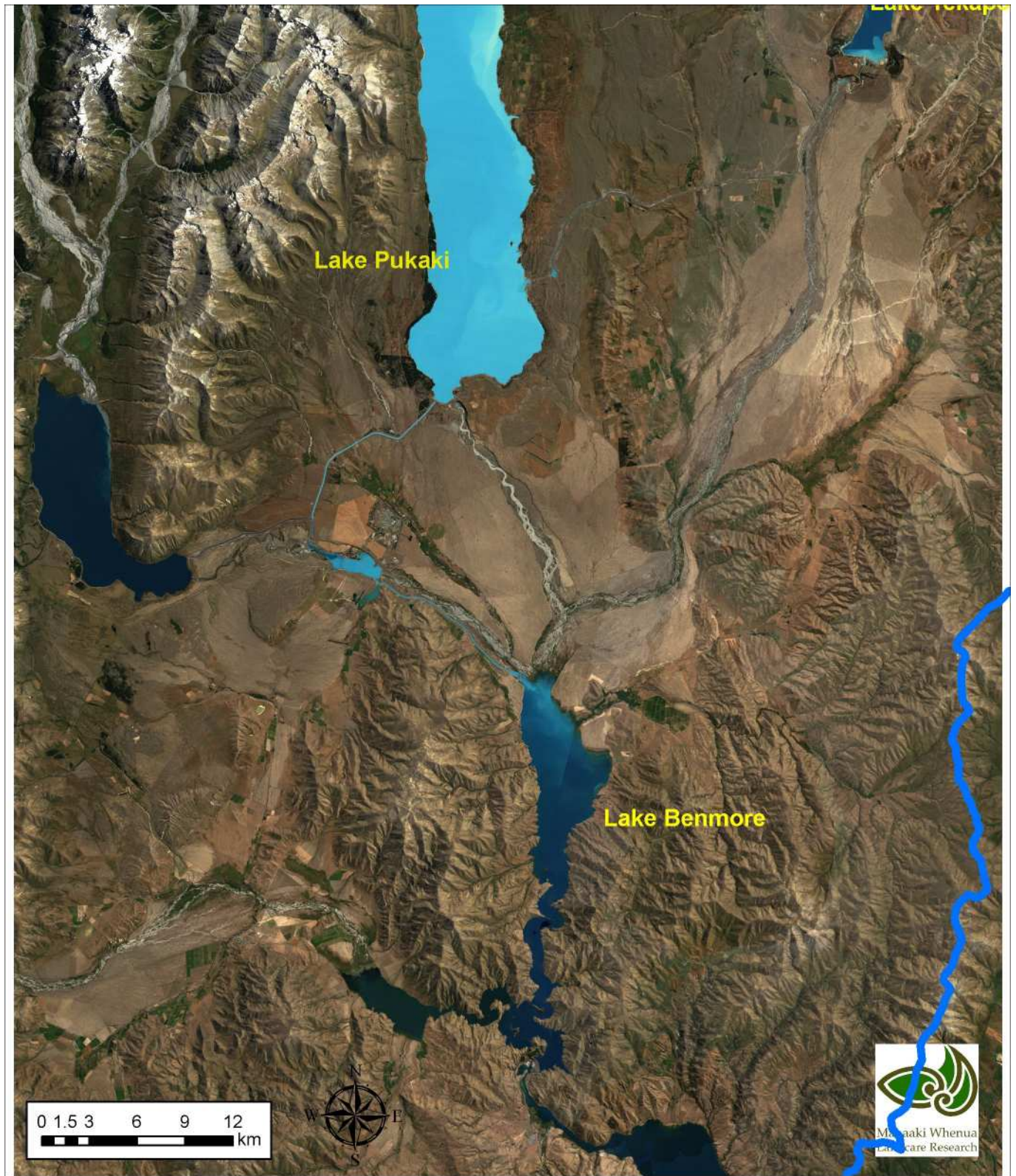
4 REFERENCES

- Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). "Crop evapotranspiration: Guidelines for computing crop water requirements." FAO Irrig. and Drain. Paper No. 56. Rome.
- Bright, J. C. (1986) "Optimal control of irrigation systems: An analysis of water allocation rules". PhD thesis. Univ. of Canterbury (Lincoln College), Christchurch, NZ.
- Bright, J. C. (2007) "Brief of evidence of John Charles Bright in the matter of the RMA 1991 and hearing of submission in regard to Canterbury Regional Council's PNRRP Hearing Stage 14 dealing with Variation 1 and 2 PNRRP Chapter 5 Reasonable and efficient use of water and Schedules WQN8 and WQN9". Presented 2 November 2007.
- Brown, P. D. (2007). "Optimal irrigation scheduling" PhD thesis. Univ. of Canterbury, Christchurch, NZ.
- Buytaert, W., Iñiguez, V., Celleri, R., De Bièvre, B., Wyseure, G. and Deckers, J. (2006). "Analysis of the water balance of small Paramo catchments in south Ecuador" in "Environmental role of wetlands in headwaters". Springer, Netherlands.
- Heiler, T. D. 1981. "Simulation-based design of water harvesting schemes for irrigation". PhD thesis. Univ. of Canterbury (Lincoln College), Christchurch, NZ
- McIndoe, I. (2004) "Mackenzie Basin irrigation takes – consent review". Prepared for Mackenzie Farmers Group, September 2004.
- Potts, R. J. (2005) "Brief of evidence of Robert John Potts in the matter of the Resource Management (Waitaki Catchment) Amendment Act 2004 and in the matter of a Submission on the Waitaki Catchment Water Allocation Regional Plan to Waitaki Catchment Water Allocation Board".
- Tait, A., Henderson, R.D., Turner, R. and Zheng, X. (2006). "Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface". *International Journal of Climatology* 26(14): 2097-2115.
- Tait, A. and Woods, R.A. (2007). "Spatial interpolation of daily potential evapotranspiration for New Zealand using a spline model". *Journal of Hydrometeorology*.
- Webb, T. H. (1992). "Soils of the Upper Waitaki Basin, South Island, New Zealand" DSIR Land Resources Scientific Report No. 3.

Appendix A: Aerial Photographs

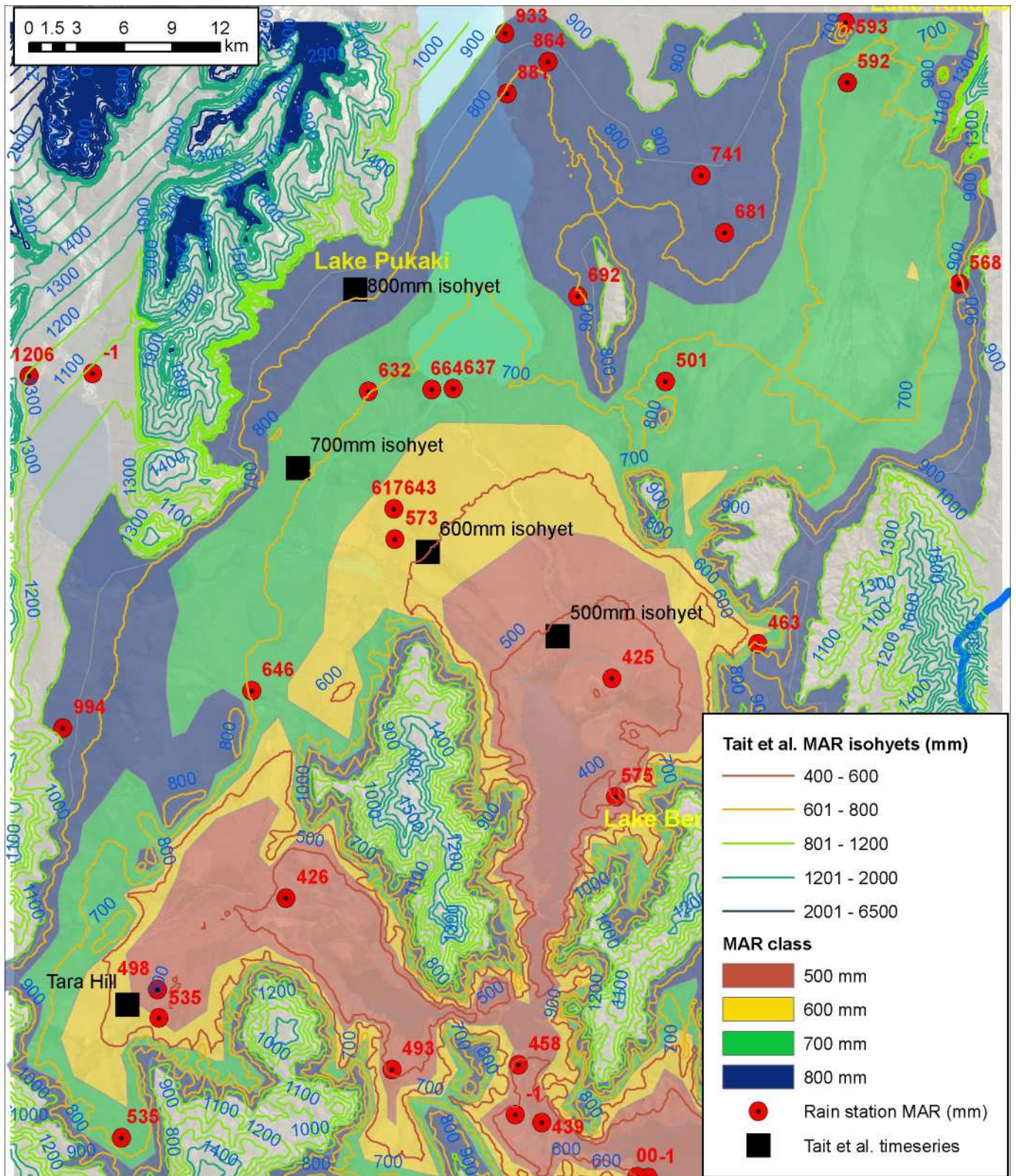


Waitaki catchment, up-gradient of the Waitaki Dam



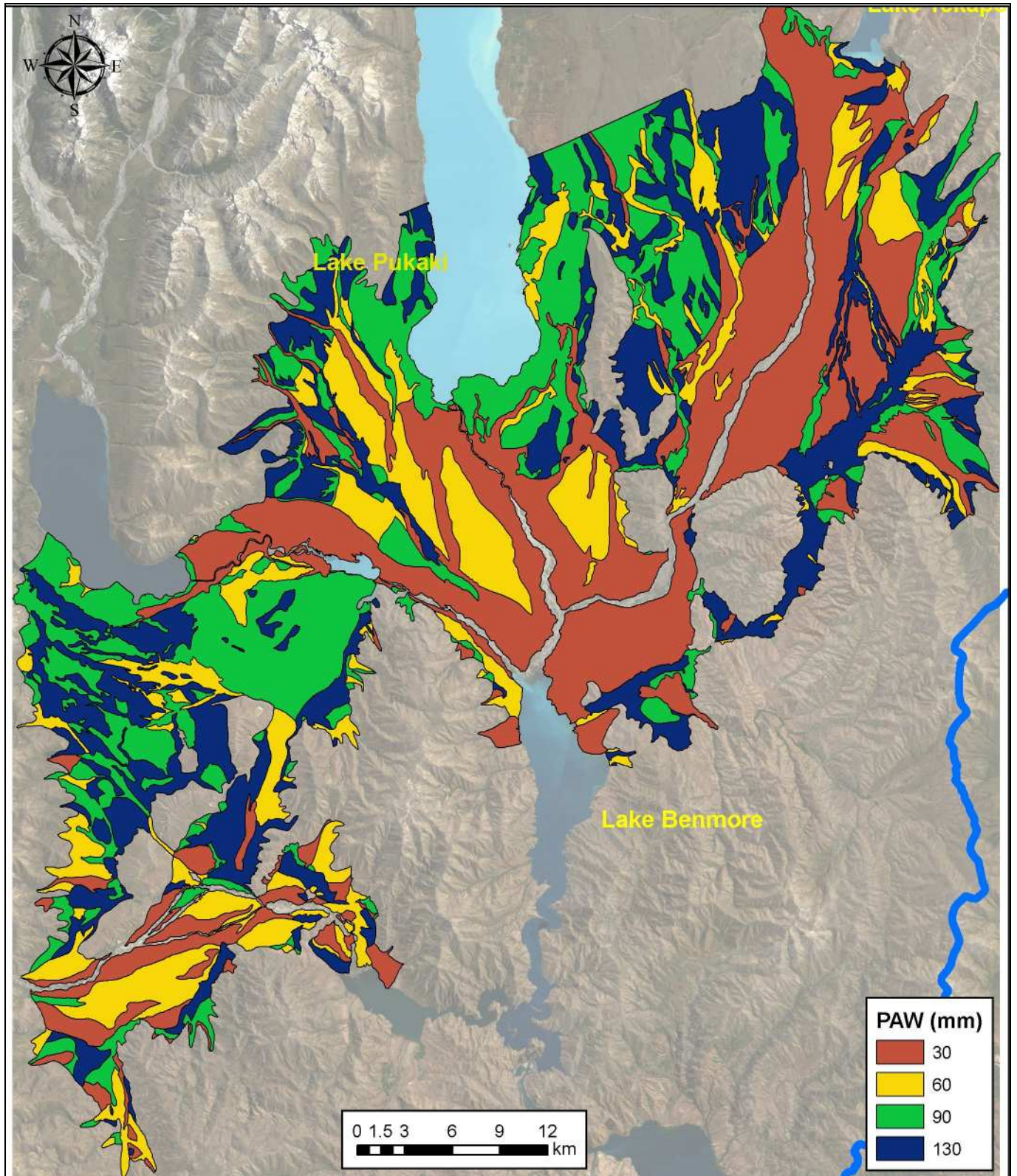
Upper Waitaki Basin

Appendix B: Rainfall

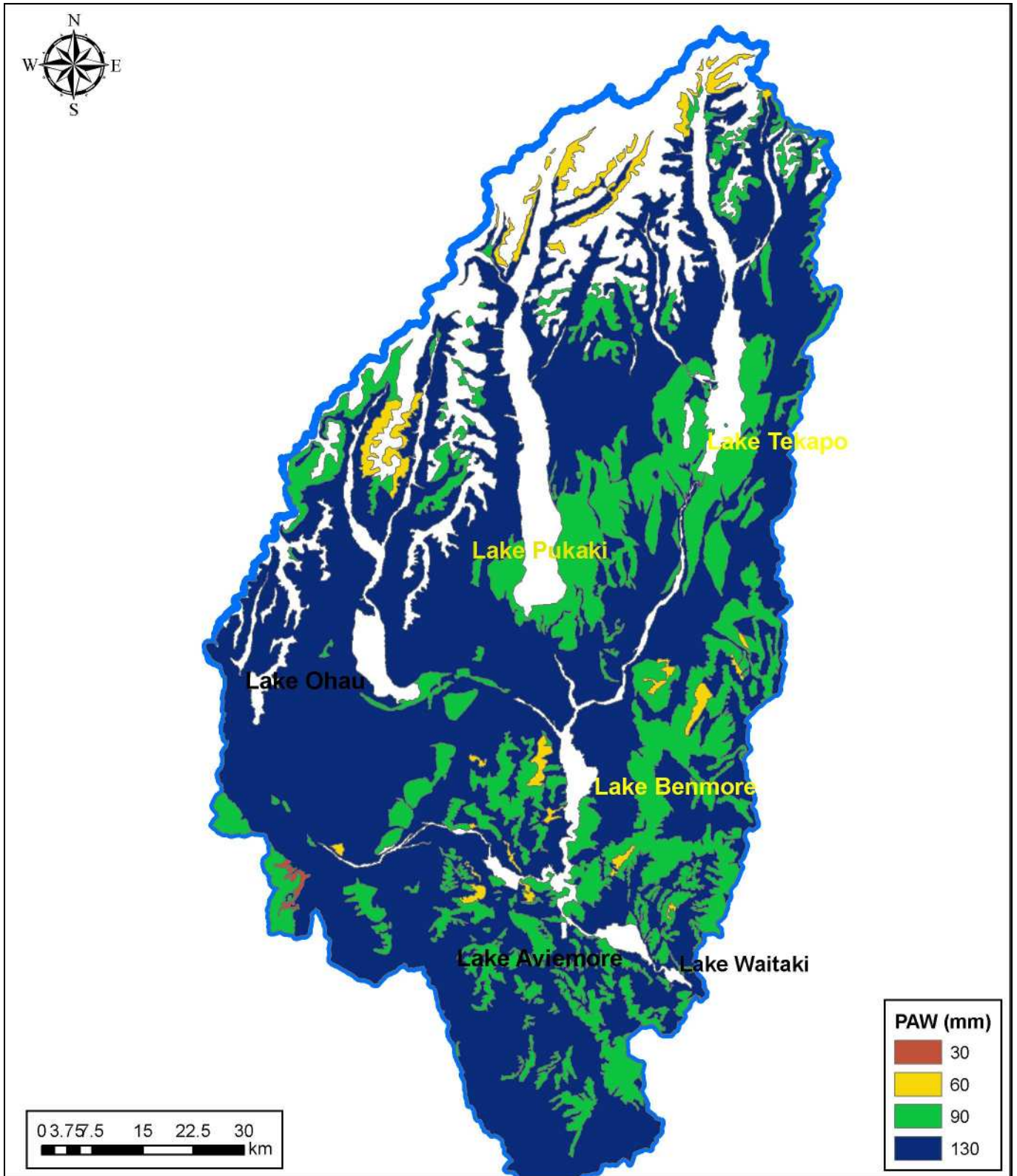


Notes: MAR = Mean annual rainfall. Some rainfall stations have short records, and consequently the standard error of MAR estimates can be in excess of 90 mm (the standard error is the standard deviation of the difference between the sample and population mean). MAR classes are the rainfall regions. Tait et al. (2006) interpolated daily rainfall time-series for the grid-points as shown above were inputs for irrigation and drainage modelling.

Appendix C: Soils

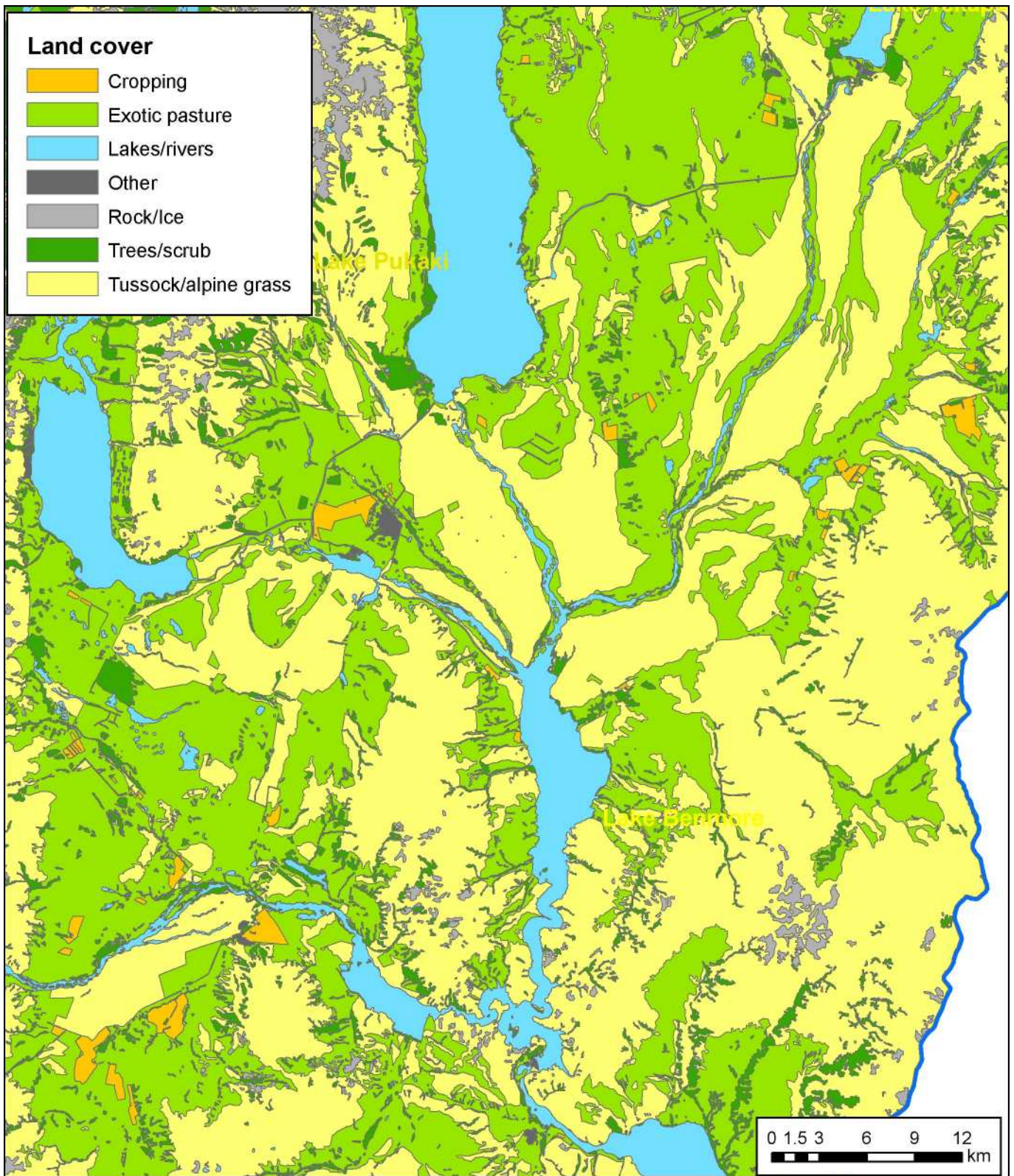


Plant available water for pasture at field capacity (PAW) as estimated by Webb



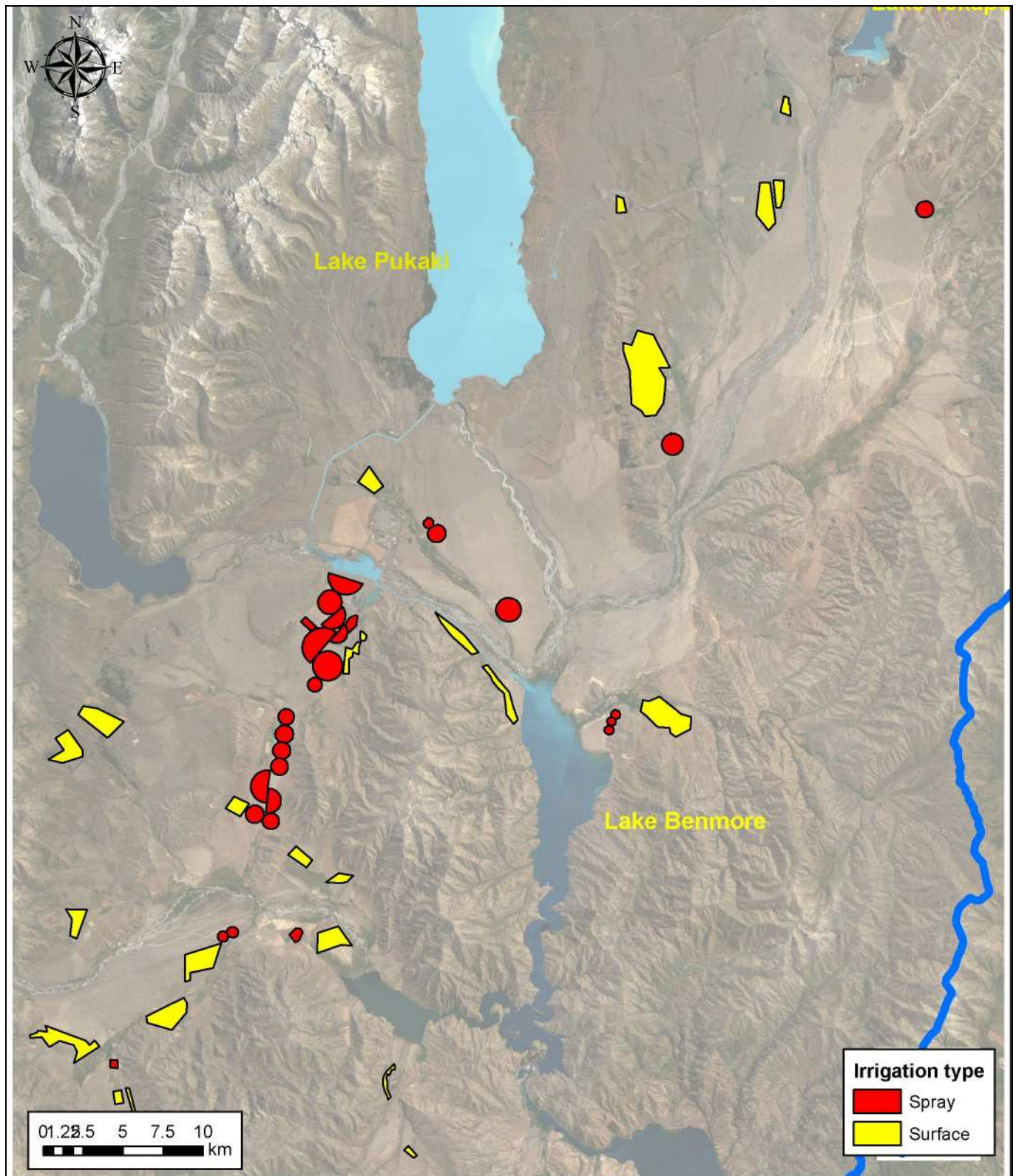
Plant available water for pasture at field capacity (PAW) from the NZ Fundamental Soils Layer

Appendix D: Land Cover



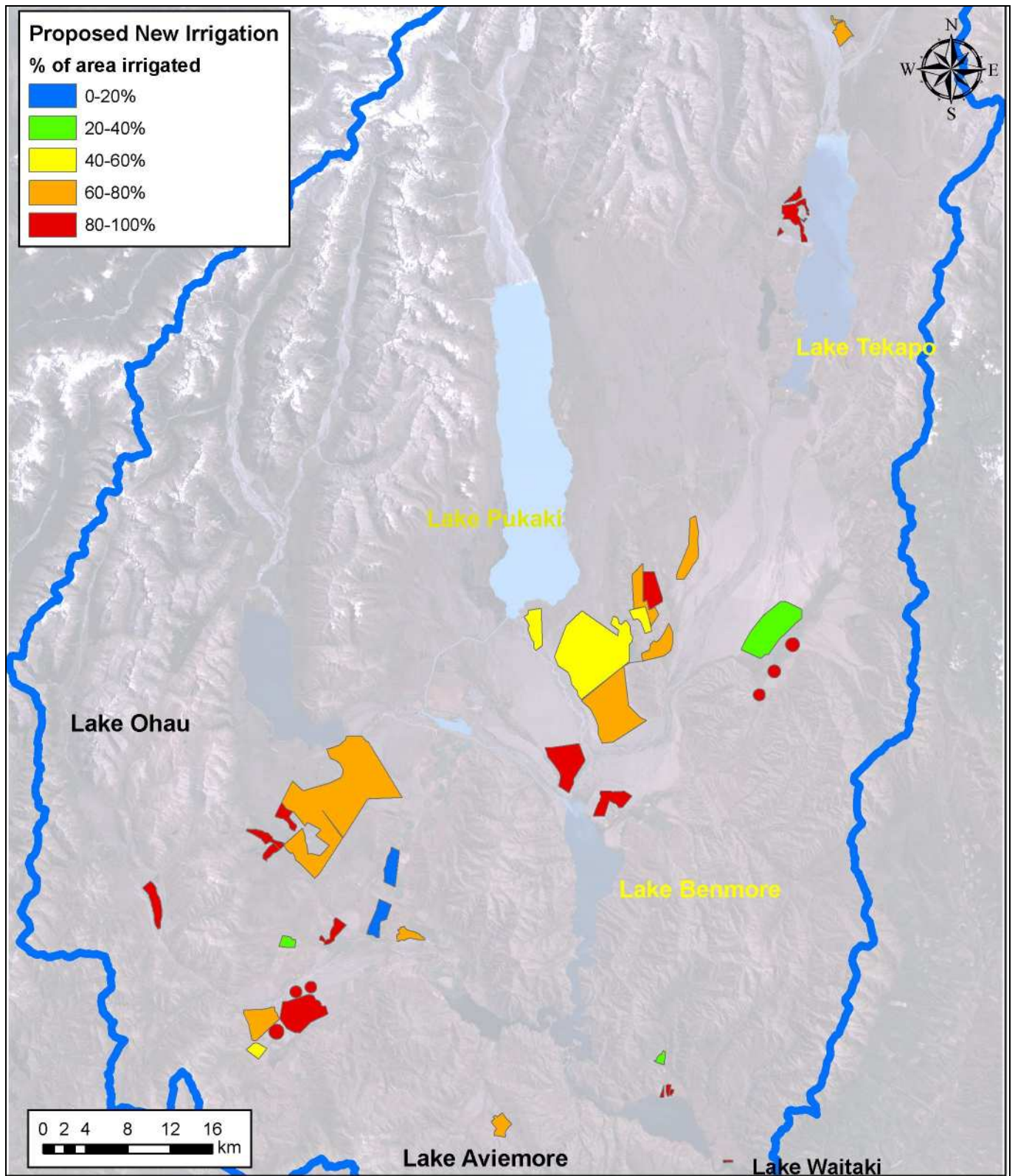
Land cover for 2001/2002 from Land Cover Database v2 (TerraLink)

Appendix E: Existing Irrigation



Approximate location of existing irrigation as of January 2007, identified from satellite imagery, consent information, and local knowledge.

Appendix F: Proposed Irrigation



Approximate location of proposed new irrigation as of March 2008, derived from information provided to Environment Canterbury.