BEFORE CANTERBURY REGIONAL COUNCIL
AT CHRISTCHURCH

In the matter of	the Resource Management Act 1991
And	
In the matter of	Proposed Variation 2 to the Proposed Canterbury Land and Water Plan
And	
In the matter of	a submission by Te Rūnanga o Ngāi Tahu

STATEMENT OF EVIDENCE OF M J THORLEY ON BEHALF OF TE RŪNANGA O NGĀI TAHU

Dated 15 MAY 2015

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INTRODUCTION

1. My full name is Michael James Thorley.

Qualifications and Experience

2. I am a senior Hydrogeologist employed by the multidisciplinary consulting firm Beca Limited. I have been with Beca since 2012 and have 11 years' experience in the field of hydrogeology.

3. I am a graduate of the University of Auckland with a Bachelor of Science degree majoring in Geology awarded in 2002, a Post-graduate Diploma in Environmental Science awarded in 2003, and a Master of Science degree in Geology awarded in 2004.

4. My work at Beca has involved the guidance of groundwater aspects of a range of projects including assessment of the interaction and effects of infrastructure projects on groundwater, groundwater resource planning, water supply from groundwater and land drainage.

5. Previously, I have worked at Fortescue Metals Group Pty (FMG) and URS Pty in Australia as a Senior Hydrogeologist and at Pattle Delamore Partners Limited based in Christchurch. I also worked at Canterbury Regional Council (''the Council") as a Groundwater Hydrologist from 2006 to 2011, during which time I provided technical evaluations of the groundwater resource for allocation to irrigation and other users. I conducted regional science investigations into groundwater and surface water interaction, land-surface recharge and determining groundwater allocation limits in many parts of the Canterbury Region.

6. In the course of my work, I have completed technical assessments for infrastructure projects, conducted many pumping tests and pumping test reviews, soil-water balance modelling, conceptualisation of aquifer systems and complex numerical groundwater flow and transport modelling. Most of this work has been completed in Canterbury, although I have worked in many parts of New Zealand and Western Australia.

Code of Conduct for Expert Witnesses

7. I confirm that I have read and am familiar with the Code of Conduct for expert witnesses contained in the Environment Court consolidated Practice Note 2014. I agree to comply with the Codes. Other than where I state that I am

relying on the evidence of another person, my evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

8. I am authorised to give evidence on behalf of Te Rūnanga O Ngāi Tahu and Te Runanga o Arowhenua.

Ambit of Evidence

9. I have been asked by Te Rūnanga O Ngāi Tahu to give evidence on the following matters:

   (a) Review the State of the Groundwater Resource in the Hinds/Hekeao Plains

   (b) Review the Hinds/Hekeao Plains water balance and Managed Aquifer Recharge (MAR)

   (c) Review the water allocation approach adopted by Environment Canterbury in Variation 2 and discuss possible alternative methods

10. In reviewing these matters, I have considered the following documents:

   (a) Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51

   (b) Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64

   (c) Thorley, MJ, Bidwell, VJ, and DM Scott, 2010. Land surface recharge and groundwater dynamics – Rakaia-Ashburton Plains; Environment Canterbury technical report U09/55, 61 p

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

   (e) Smith, M., 2008. In the matter of 78 Applications to take water in the Ashburton River and Valetta Groundwater allocation Zones. S42a Officers report, dated 21 July 2008

   (f) Golder, 2014. Managed Aquifer Recharge (MAR) as a tool for managing water quality and quantity issues

(g) McCallum-Clark, M., Maw, P., Woudberg, L., Field, D., Guthrie, G., Vattala, D. and B. Bower, 2015. Variation 2 to the Land and Water Regional Plan. Section 42a Report. Environment Canterbury Report R15/48

(h) Thorley, M. and M Ettema, 2007. Review of water allocation limits for the South Canterbury downlands. Environment Canterbury Technical Report U07/09

(i) Bidwell, V. J., Lilburne, L., Thorley, M. J., Scott, D. M., 2009: Nitrate discharge to groundwater from agricultural land use: an initial assessment for the Canterbury Plains. Report prepared by Lincoln Ventures Limited, Landcare Research, and Environment Canterbury

(j) Painter, D., 2009. A Comparative Review of Two Methods for Estimating Seasonal Irrigation Demand. Report Number CP5R-09

(k) Thorley, M. and D Scott, 2010. A Methodology to model groundwater flow in sub-areas of the Canterbury Plains. Environment Canterbury Technical Report R10/43

(l) Callander, P. and L Torgerson, 2011. Preliminary Strategic Assessment of Water Infrastructure Option 4: Managed Aquifer Recharge. Report prepared by Pattle Delamore Partners Ltd for Canterbury Water Management Strategy.

CHARACTERISATION OF EXISTING ENVIRONMENT

Hydrogeology

11. The Hinds/Hekeao Plains geology consists of coalescing alluvial fan deposits that are characteristically heterogeneous and anisotropic[1]. This means that the underlying geological materials are highly variable and can be more permeable in one direction, particularly in channel deposits which tend to follow former stream/river flow directions. I agree with the general description given in the Hinds/Hekeao Plains water resource report[2]. The summary of aquifer properties in the Hinds/Hekeao Plains integrated model report[3] describes the occurrence of highly transmissive buried alluvial

[1] Anisotropy is the property of being directionally dependent, as opposed to isotropy, which implies identical properties in all directions
[2] Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51.
[3] Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64.

channel deposits with high anisotropy. Vertical leakage results from pumping tests also reflect a relatively high hydraulic connection between deep and shallow saturated strata.

12. Environment Canterbury has summarised the groundwater level trends[4] (map shown below) and identified several wells in which groundwater levels are trending downwards or are relatively stable over the long term. I have checked these records and can confirm that the wells identified as having declining water levels are still declining, and that several (K37/0581, K36/0282 and K38/0384) of the "stable" wells have shown declines over this most recent (2014/2015) irrigation season. K38/1571 and K38/0093 appear to show a small and gradual declining trend. K37/1748 and K37/2416 appear to show rises in groundwater levels during summer months, likely a result of localised border-dyke irrigation activities.

[4] Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51.

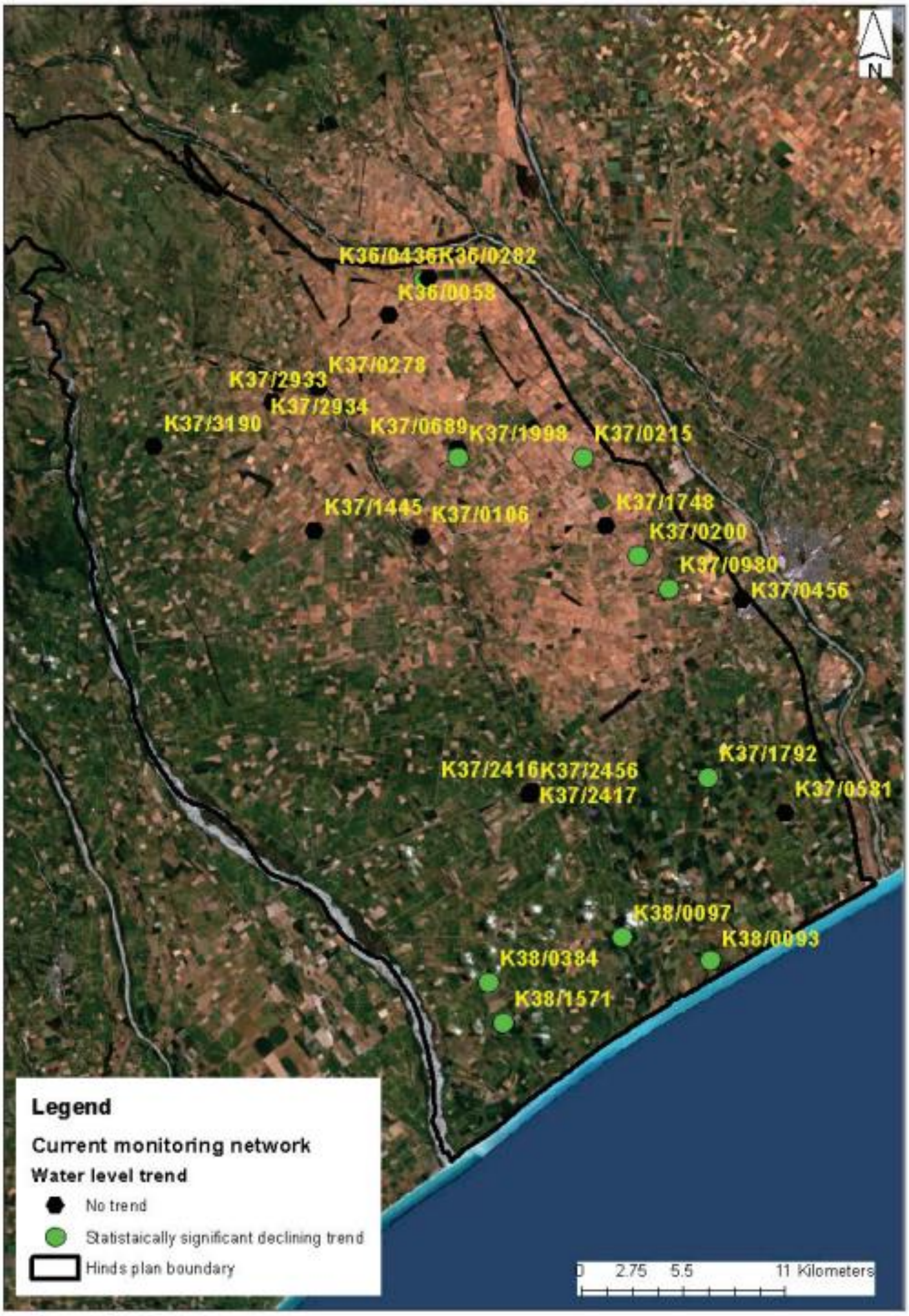

Figure 7.8: Current monitoring network trends

Water Balance

13. Theis (1940)[5] outlined the following fundamental groundwater principle:

> *"…Under natural conditions, therefore, previous to development by wells, aquifers are in a state of approximate dynamic equilibrium.*

[5] Theis, C. V., 1940. THE SOURCE OF WATER DERIVED FROM WELLS ESSENTIAL FACTORS CONTROLLING THE RESPONSE OF AN AQUIFER TO DEVELOPMENT. Civil Engineering magazine (p. 277-280), American Society of Civil Engineers, May 1940.

Discharge by wells is thus a new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by loss of storage in the aquifer, or by a combination of these."

14. Therefore, any take from a groundwater system will alter the equilibrium of that system, resulting in diminished natural discharges.

15. A significant recharge source to the Hinds/Hekeao Plains area has been the Valetta and Mayfield-Hinds Irrigation Schemes which are supplied water primarily via the Rangitata Diversion Race (RDR). The groundwater system has historically been artificially and inadvertently "topped up" by border-dyke irrigation and by losses of water via conveyance including race leakage and by-wash. The water race system operated by Ashburton District Council also contributed significant recharge to the aquifer system, primarily via leakage from races. The figure 3-10 (below) showing the ADC race system is shown to have been a network of races spaced at approximately 0.5 km to 2 km[6].

[6] Figure 3-10 *in* Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64.

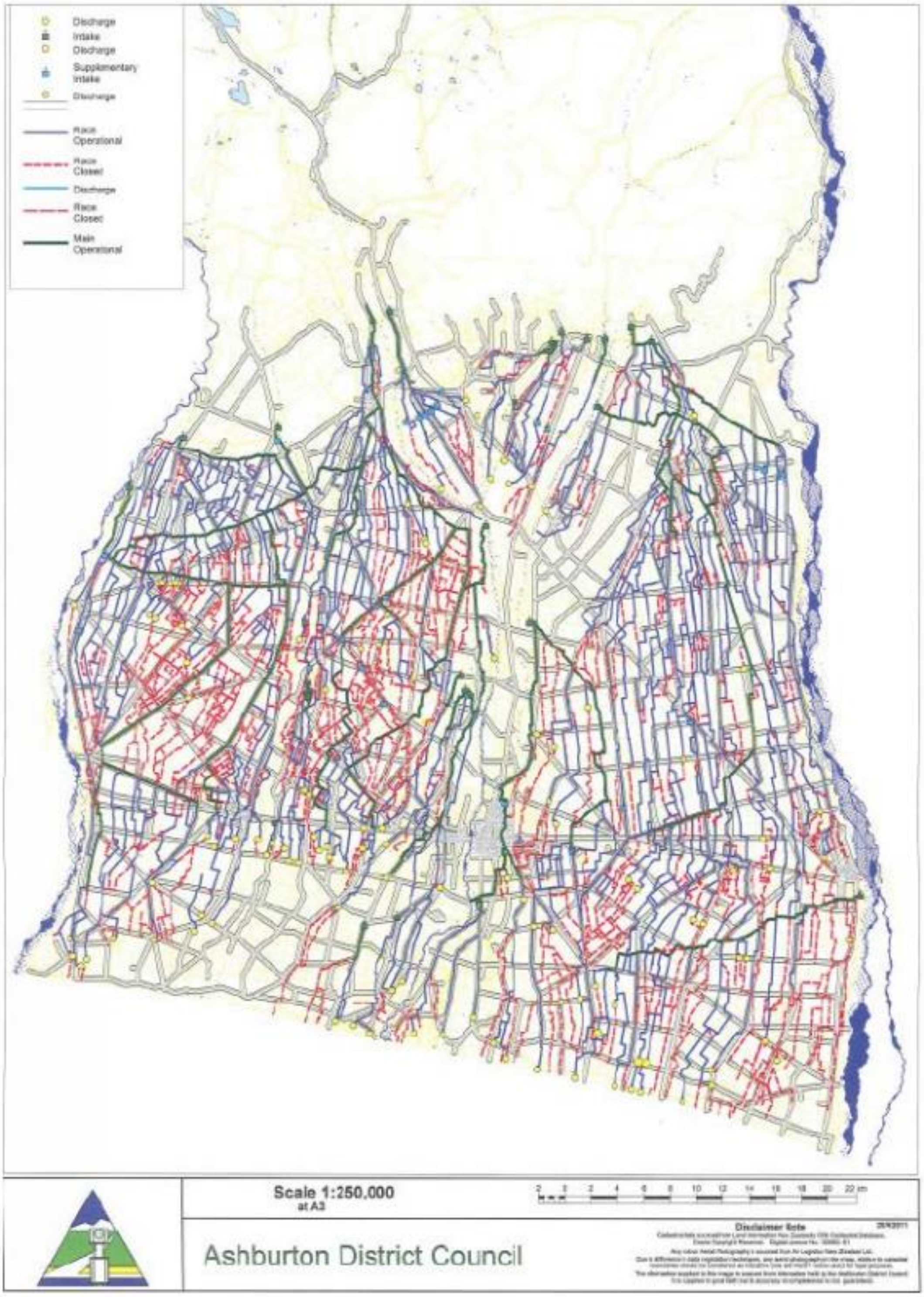

Figure 3-10: Ashburton District Council stockwater network (Opus, 2012)

16. The move to more efficient irrigation and conveyance methods has seen recharge to the aquifer system reduce and a corresponding decline in groundwater levels and spring-fed stream flow is occurring. This has coincided with increased volumes of water abstracted from the groundwater resource which has likely reduced groundwater levels and spring-fed stream flows.

17. A summary of the water balance for the Valetta and Mayfield-Hinds groundwater allocation zones (GWAZ) is shown in Table 7.1 below[7]. The land surface recharge component is consistent with that presented by Scott (2004)[8]. However, it is not clear if and how much additional recharge from surface water irrigation schemes such as border-dyke is or is not accounted for in Table 7.1 below. If these data were included, it would enable a clearer understanding of what makes up the land-surface recharge input volume such as dry land and irrigated incidental recharge caused by surface water schemes or groundwater irrigation. I am also not sure that the input versus outputs presented in Table 7.1 is balanced as indicated given the large variances in the outputs as they are listed.

Table 7.1: Analytical groundwater budget

Average Inputs (m^3/s)		Average Outputs (m^3/s)	
Land surface recharge[4]	15.5	Coastal drains	3.0-7.0
River recharge:		Groundwater abstraction	3.0-7.5[5]
-Ashburton River/Hakatere	1	Discharge to the Rangitata River	0.3
-Hinds River/Hekeao	0.3	Offshore groundwater flow	9.2-9.7
-Rangitata River	0		
Water race losses	3.2		
Total inputs	20	Total outputs	20

18. Technical reports published by Environment Canterbury use a vast array of recharge estimates and there appears to be a lack of consistency when determining water balances. In particular, it is difficult to compare the water balance estimates[9] with the modelled estimates[10] because additional zones and areas are included in the modelling report. The main water balance tables presented in the modelling report are included below.

[7] Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51.
[8] Scott, D., 2004. Groundwater Allocation Limits: land-based recharge estimates. Environment Canterbury Technical Report U04/97
[9] Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51.
[10] Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64.

Table 10-6: Mayfield-Hinds to Ashburton River GAZ modelled water balance comparison with annual average

Average annual 1982-2012	Conceptual water balance	Baseline scenario (30 year average)
Inputs (m^3/s)		
Precipitation	N/A (included in LSR assessment)	40.11
Irrigation	N/A (included in LSR assessment)	13.26
LSR (precipitation + irrigation – evapotranspiration)	22.1	16.38
Gains from rivers (e.g. Hinds, Ashburton)	4-13.2[30]	12.99
Boundary inflows	Unknown	14.28[31]
Race losses	3.2	3.42
Total in	***30.4-39.5***	***47.07 (32.79 excluding boundary inflows)***
Outputs (m^3/s)		
Evapotranspiration	N/A	36.74
Pumping	0-7.5	6.87
Losses to rivers (Hinds, Northern and O'Shaunessy's, Ashburton)	4-15[32]	7.07
Coastal stream outflow		2.87
Boundary outflow	16.5-31.5	30.76[33]
Loss to external rivers	<1	0.17
Total outputs	***Assumed to balance with inputs***	***47.74***

Table 10-7: Seasonal water balance comparison

	RDM and analytical		Model	
Water balance for 2000-2001 irrigation season	Winter	Summer	Winter	Summer
Recharge from river leakage (m^3/s)	6.6	6.1	6.6	4.0
Recharge from distribution losses (m^3/s)	0.2	3.1	3.7	3.7
Land surface recharge (m^3/s)	30.7	17.9	34.8	14.0
Recharge from stockwater (m^3/s)	1.1	1.1	Included in distribution	Included in distribution
Pumping withdrawals (m^3/s)	0	18.5	0.4	10.9
Discharge to streams (m^3/s)	7	3	6.7	3.3
Discharge to ocean (m^3/s) (assuming total outputs assumed to balance inputs)	31.6	6.7	38.8	7.6

19. For example, if the Valetta and Mayfield-Hinds groundwater annual volume allocation is averaged over 150 days (which is the basis for determining the volumes required on a consent), this totals 18.5 m^3/s. This matches Table 10-7 in the RDM/analytical column; however the model includes allocation in the Ashburton River Zone too, but the value does not increase as would be expected. Therefore, I am unsure how accurate these figures are in Tables 7.1, 10-6 or 10-7.

20. The surface water allocation for the spring-fed streams in Valetta and Mayfield-Hinds Zones adds an additional 9 m^3/s[11] taking the total water allocation over the irrigation season to something in the order of 27.8 m^3/s (excluding Ashburton River Zone). The pumping withdrawal in the model in summer is well short of this (only 10.9 m^3/s), particularly given the model also includes withdrawals from the Ashburton River Zone (Table 10-7). A clearer explanation of the values and how they relate back to the figures that are used for allocation or actual usage is needed. In my opinion, a modelling scenario assuming full utilisation of the existing consents should be carried out to inform allocation policy and MAR requirements.

21. Furthermore, the model also includes a substantial (14 m^3/s) component of "cross-zone" flow from surrounding zones[12] (Table 10-6). The cross-zone flow introduces a major inconsistency in the water balance and it is unclear what bearing this has on the model, the applicability of its predictions and the resulting management approaches proposed by Variation 2.

22. Scott (2004) provided estimates of land surface recharge which excluded race losses and border-dyke irrigation. His estimates equate to ~15.5 m^3/s annual average recharge for the Mayfield-Hinds and Valetta GWAZ's. This is consistent with values presented in the Hinds/Hekeao water resource report[13]. However, it is not clear how the figures used in the modelling report[14] compare.

23. I have requested the peer review reports from Environment Canterbury but have not been provided with them. I also attempted to contact Environment Canterbury scientists to clarify these matters but have not been able to speak with them directly. Therefore, I am not confident of the robustness and reliability of aspects of the technical information prepared by Environment Canterbury.

24. New data could have resulted in Environment Canterbury updating the allocation limits for the Valetta and Mayfield-Hinds GWAZ since the Scott (2004) report was published. There is a significant amount of new information regarding rainfall, evapotranspiration, irrigated land and water use, which has not then been used to revise the groundwater allocation limit.

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[11] Table 9.3 *in* Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51

[12] Table 10-6 in Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64

[13] Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51.

[14] Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64

It would be a relatively straightforward process to update the Scott (2004) methodology to determine land surface recharge estimates and apply the 50 % threshold for groundwater allocation. This would have assisted in evaluating a combined groundwater allocation limit that included surface water takes from spring-fed streams.

25. The groundwater allocation zone boundaries could also be reviewed if the limits were updated. Changes such as moving the boundary of the Mayfield-Hinds and Valetta GWAZ's to run down the centre of the Hinds/Hekeao River and pushing the zone further inland would go some way to tidying the original zone boundaries. This would ensure all users in the catchment are included in allocation zones and subject to the management plans.

Replacing Surface Water & Shallow Groundwater Takes with Deeper Groundwater

26. My understanding is that one option for addressing effects of abstraction on low flows in spring-fed streams in Variation 2 is to allow the replacement of surface water takes and shallow groundwater takes with deeper groundwater takes.

27. Replacements of surface water and shallow groundwater takes from the lowland streams to groundwater and/or surface water schemes are likely to benefit the flows in the streams. However, the increased groundwater take resulting from replacement with deep groundwater is likely to have cumulative loss effects on the aquifer system and spring-fed streams. As noted in paragraph 12 there is relatively high connectivity indicated between deep and shallow saturated strata in this catchment.

28. Smith (2008)[15] shows an example in the Valetta GWAZ of how quickly vertical leakage from shallow saturated strata can occur using the two aquifer model of Hunt and Scott (2007)[16]. Figure 6 from Smith (2008) is shown below and demonstrates that within a few days all of the water sourced by the pumping well is coming from shallow saturated strata. Figure 5 shows the slow development of drawdown at the water table over the season (<0.2 m) as the overlying area of the aquifer system surrounding the pumping well is dewatered. This demonstrates that deeper takes are likely to have an

[15] Smith, M., 2008. In the matter of 78 Applications to take water in the Ashburton River and Valetta Groundwater allocation Zones. S42a Officers report, dated 21 July 2008.
[16] Hunt, B. and Scott, D. 2007: Flow to a well in a two-aquifer system. ASCE Journal of Hydrologic Engineering. Vol. 12 (2), 146-155.

effect on surface aquifers and hydraulically connected water bodies or spring-fed streams.

29. This effect is supported by the baseline scenario undertaken using the Hinds/Hekeao groundwater model which showed more consistent spring discharges in the lower plains area when pumping ceased[17].

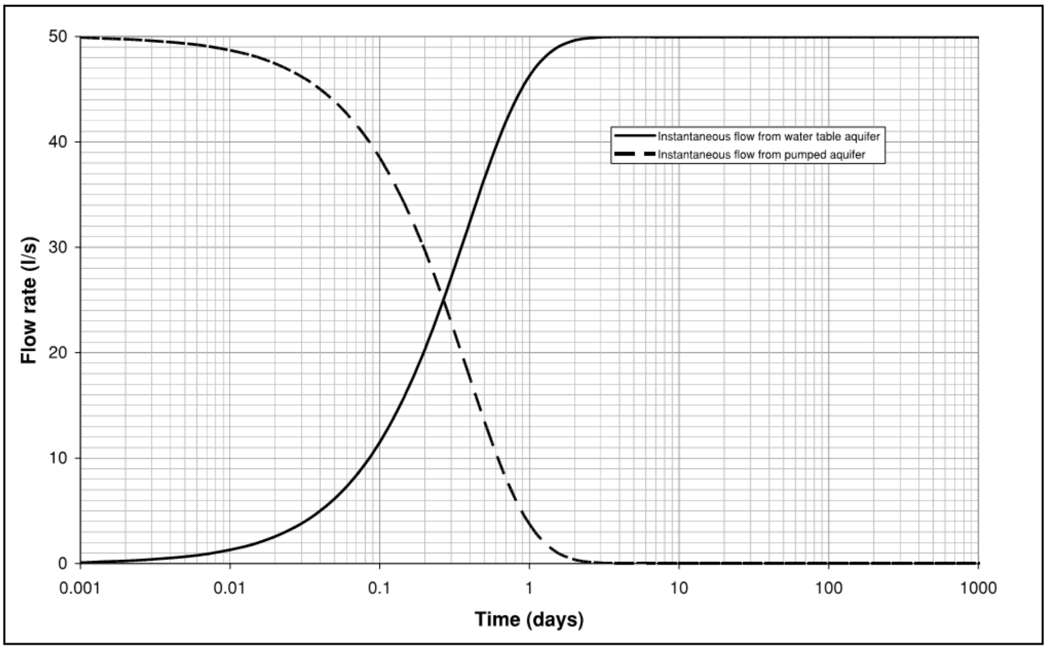

Figure 6: Flow rates from water table and pumped aquifer for a two-aquifer system with the aquifer parameters determined for K37/1907

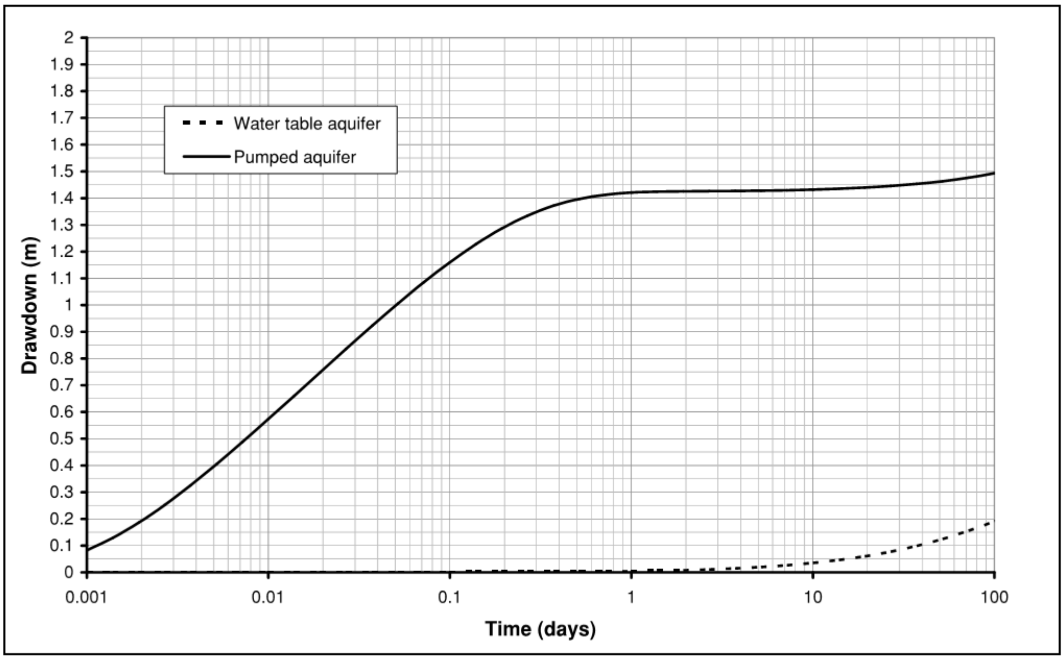

Figure 5: Calculated drawdowns in the pumped and overlying layer derived for the aquifer parameters determined for K37/1907

[17] Page 84 *in* Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64

30. Environment Canterbury has provided an estimate of the annual volumes that could be associated with replacements of surface water takes from spring-fed streams[18]. In the Valetta GWAZ, up to ~42 M m^3/year could potentially be replaced from surface water into groundwater. Given the current limit for the Valetta Groundwater Allocation Zone is 96.6 M m^3/year with a current effective allocation of 132.2 M m^3/year, if all of the surface water allocation from the spring fed streams was moved to groundwater, the Valetta GWAZ could potentially become 180 % allocated. It appears from the information provided by Environment Canterbury that many of these surface water takes already have groundwater takes associated with the properties; however it is not clear how much additional water may be required beyond existing groundwater entitlements.

31. The implications of this further over-allocation include: potentially reduced reliability for existing groundwater users through drawdown interference and cumulative lowering of groundwater levels; additional cumulative effects on spring-fed streams causing reduced flows; and potentially saline intrusion.

32. If replacement of surface water takes to groundwater goes ahead, the hydraulic resistance to flow between the stream and the pumping well is a key consideration. I consider that a minimum well depth (>50 m depth) and/or a cumulative seasonal leakage ratio of the average annual pumping rate (<10%) could be required to achieve the desired benefit to the stream sought by Variation 2. This could be similar to the aquifer testing and adaptive management assessment criteria set down for resource consents that have been granted beyond the groundwater allocation limit in recent years.

33. In Mayfield-Hinds, there appears to be more capacity to sustain replacements of surface water takes with groundwater takes. Based on the numbers provided by Environment Canterbury, there is up to ~28.8 M m^3/year associated with surface water takes from spring-fed streams in the Mayfield-Hinds GWAZ. The groundwater allocation limit is 148 M m^3/year and if all of the surface water takes were replaced, that would bring the total groundwater allocation to ~151 M m^3/year or 101 % allocated.

34. Therefore, additional measures to address over-allocation are particularly important in the Valetta GWAZ but also in the Mayfield-Hinds GWAZ. For

[18] Downloaded from http://www.ecan.govt.nz/our-responsibilities/regional-plans/regional-plans-under-development/lwrp/variation-2/Pages/supporting-docs.aspx

example, in the Valetta GWAZ, additional incentives and/or regulations may be required to promote the replacement of as many takes (groundwater and surface water) into the surface water irrigation schemes. The Valetta Irrigation Scheme has only a modest coverage compared to Mayfield-Hinds, and is one of the key factors in the lesser availability of groundwater and lower spring-fed stream flows.

35. Supplying more irrigation as part of the Mayfield-Hinds, Valetta and/or Barrhill-Chertsey Irrigation Scheme (BCI) would take demand off the groundwater resource, and potentially increase land-surface recharge back towards that which has occurred under border-dyke irrigation. A similar scenario has been demonstrated to be beneficial to the water balance in the Ashburton-Lyndhurst Zone by distributing the surface water to irrigation over a larger area of land[19].

Use of Managed Aquifer Recharge

36. My understanding is that Variation 2 proposes the use of MAR of up to 4 m^3/s of water as a means to address both low flows and nitrate concentrations in spring-fed streams. However, estimates ranging up to 7.5 m^3/s are also given by Environment Canterbury. The requirement for replacement water via MAR seems to be focussed around recent changes in the water balance such as irrigation scheme upgrades and stock water race closures.

37. Environment Canterbury seems to assume that if these components are replaced, that restoration of groundwater levels and spring-fed stream flows will occur. In practice, very specific targets (flow and/or groundwater levels) will be required and iterative processes of trial and error of adding recharge under different aquifer conditions will be needed.

38. The savings in water take due to the closure of ADC Stockwater race system is reported as 3.2 m^3/s across the Hinds/Hekeao Plains[20]. Most of his water would have otherwise leaked through the base and sides of the race and recharged groundwater. A split of this leakage between Valetta and Mayfield-Hinds groundwater allocation zones is given in Table14-1[21] (shown below) however little explanation is provided. The race leakage would have

[19] Thorley, MJ, Bidwell, VJ, and DM Scott, 2010. Land surface recharge and groundwater dynamics – Rakaia-Ashburton Plains; Environment Canterbury technical report U09/55, 61 p.
[20] Table 7.1 *in* Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51
[21] Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64.

changed over time depending on the programme of race closures and where flows were directed over the period of operation.

39. The reduction in recharge since the upgrade across the Valetta and Mayfield-Hinds irrigation schemes is also reported in the Hinds modelling report in Table 14-1, under “Changed Irrigation Practices (lost recharge)” totalling ~1.6 m^3/s. Again, there is very little explanation of these numbers provided and my understanding is that Mayfield-Hinds have not made the types of upgrades mentioned in the report. In Valetta, the “Changed Irrigation Practices (lost recharge)” range from 0.4 to 0.5 m^3/s, which seems low given conveyance losses of 20 %, could be possible (including race leakage, operational losses and by-wash)[22].

Table 14-1: Solutions Package iteration comparisons

Scenario	Valetta GAZ (m^3/s)	Mayfield-Hinds GAZ (m^3/s)
Solutions Package iteration 1 (5.4 MAR)		
Total MAR	2.5	2.9
Lost recharge from piping (stockwater and distribution losses)	-0.7	-2.4
Changed Irrigation Practices (lost recharge)	-0.5	-1.1
Net Increased Recharge (new water)	1.3	-0.6
Solutions Package iteration 2 (7.5 MAR)		
Total MAR	3.4	4.1
Lost recharge from piping (stockwater and distribution loses)	-0.7	-2.4
Changed Irrigation Practices (lost recharge)	-0.4	-1.2
Net Increased Recharge (new water)	2.3	0.5

40. Furthermore, the item in Table 14-1 titled “Net Increased Recharge (new water)” seems to be an estimate of additional incidental recharge due to adding 30,000 ha of new irrigation. The “New Water” accounts for between 1.9 m^3/s and 2.8 m^3/s which is approximately half of the MAR claimed by Environment Canterbury depending on the scenario. This water is not MAR. This water is the additional land-surface recharge or soil drainage that occurs due to rainfall intercepting irrigated soils. Such additional recharge is normally included in land-surface recharge estimates and will vary depending on soils, climate, irrigation area and practice.

41. I compared the “New Water” values with estimates of additional soil drainage previously calculated by Scott (2004)[23]. Scott (2004) modelled ~ 12942 ha of

[22] Thorley, M. and D Scott, 2010. A Methodology to model groundwater flow in sub-areas of the Canterbury Plains. Environment Canterbury Technical Report R10/43
[23] Table 3.3 *in* Scott, D., 2004. Groundwater Allocation Limits: land-based recharge estimates. Environment Canterbury Technical Report U04/97

surface irrigation in the Valetta groundwater zone which results in an average additional recharge of ~21 M m^3/year or 163 mm depth equivalent. If this is pro-rated to 30,000 ha, this results in an additional average annual recharge rate of 48.6 M m^3/year or ~1.54 m^3/s. Scott (2004) also reported additional incidental recharge over 30330 ha of the Mayfield-Hinds Scheme at 54.1 M m^3/year or ~1.7 m^3/s. This is somewhat similar in Scenario 1 but significantly less than assumed by Environment Canterbury in Scenario 2[24]. This incidental recharge will also be dependent on the new irrigation development occurring which is uncertain, and Scott (2004) may have already accounted for an increase in the Valetta Irrigation Scheme given its irrigation area was noted at ~6862 ha[25]. Furthermore, the drainage water from the "New Water" will also not be "clean" and may not reduce nitrates in groundwater as much as has been indicated by Environment Canterbury[26].

42. If the additional recharge from 30,000 ha is added to the Hinds/Hekeao Plains based on Table 14-1 values, the recharge would increase (due to rainfall intercepting irrigated soils) and the groundwater allocation zones could become under allocated (based on current limits and effective allocation). If the land-surface recharge increment due to surface water irrigation is used from Scott (2004) and the same assumptions are followed about the new development (Table 14-1[27] indicates <80 % of the New Water or ~24,000 ha of new irrigation occurs in Valetta) then the Valetta GWAZ would still remain over-allocated using the 50% threshold.

43. There is also mention of an additional 1 m^3/s of MAR required for addressing quality issues in the lower Hinds River[28] which does seem to be included in the figures in Table 14-1. Therefore total MAR requirements described by Environment Canterbury could increase up to 8.5 m^3/s.

44. The approach taken by Scott (2004) to calculating groundwater recharge and allocation in this catchment was 'conservative' in my view, in that he did not include "temporary" or "uncertain" parts of the water balance as being available for allocation. For instance, the race leakage from the ADC Stockwater system was not included in the recharge assessment nor was the

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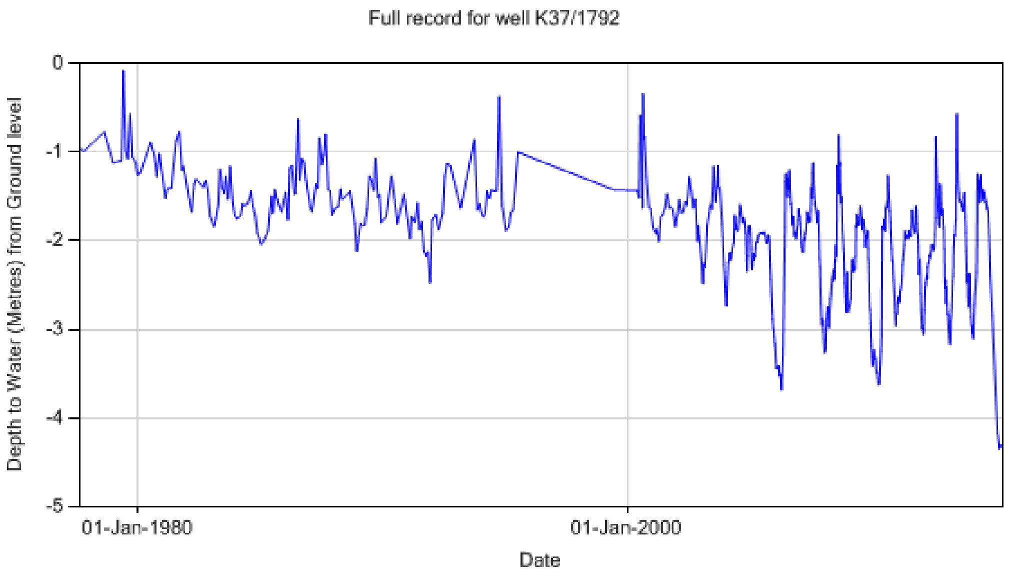
[24] Table 14-1 *in* Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64
[25] Table 3.1 *in* Scott, D., 2004. Groundwater Allocation Limits: land-based recharge estimates. Environment Canterbury Technical Report U04/97
[26] McCallum-Clark, M., Maw, P., Woudberg, L., Field, D., Guthrie, G., Vattala, D. and B. Bower, 2015. Variation 2 to the Land and Water Regional Plan. Section 42a Report. Environment Canterbury Report R15/48
[27] Table 14-1 *in* Durney, P., Ritson, J., Druzynski, A., Alkhaier, F., Tutulic, D. and M Sharma, 2014. Integrated Catchment Modelling of the Hinds Plains. Environment Canterbury Technical Report R14/64
[28] Page 284 *in* McCallum-Clark, M., Maw, P., Woudberg, L., Field, D., Guthrie, G., Vattala, D. and B. Bower, 2015. Variation 2 to the Land and Water Regional Plan. Section 42a Report. Environment Canterbury Report R15/48

recharge from border dyke irrigation or conveyance losses because of the likelihood of infrastructure upgrades or closures, or changes to allocation rules (such as a reduction in the Ashburton River SW allocation). In hindsight this "conservative" approach has proved correct.

45. MAR is largely untested in Canterbury and carries with it uncertainties. There is no clear source of the water required for MAR in this catchment, and the claimed benefits to spring fed streams and water quality are debatable, in my opinion.

46. For instance, Durney & Ritson (2014)[29] indicate that when groundwater levels in K37/1792 drop below -2.75 m (below ground surface), Blees and Flemington drains dry up. The hydrograph of K37/1792 indicates that it has fallen below -2.75 m almost every summer since 2003, with the groundwater level recently measured at -4.3 m in April 2015 (shown below). MAR would have needed to have increased groundwater levels in the area by 1.5 m during this most recent summer season just to get back to drain invert level. A level rise of ~2 m is probably more likely required to achieve flow into these drains. MAR is unlikely to be able to achieve that kind of areal increase in groundwater level during the summer. Direct or highly targeted stream augmentation may be a better option.



47. Another example of the relatively tenuous nature of MAR schemes includes altering the resource consent for the Waimakariri Irrigation Scheme to allow the 1.5 m^3/s of MAR to be used for irrigation following the initial MAR trial.

[29] Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51

The use of MAR in that area had very limited success (showed only localised and short-lived changes in groundwater levels near the Eyre River) and it is somewhat fortunate that the water balance did not include the MAR water in allocation decisions at the time, given it will now be largely used for irrigation.

48. One of my biggest concerns with the MAR analyses thus far is that the 'point source' approach for implementing MAR does not match the way in which it was represented in the groundwater model. The MAR water was applied uniformly across the model which is not what is likely to occur in practice. This would have the effect of indicating a much more positive outcome on groundwater levels, spring flow and water quality than if the MAR was distributed at discreet recharge sites.

49. Furthermore, the model set up does not allow for representation of the heterogeneity and anisotropy of the geological materials. This modelling is possible and previous groundwater modelling investigations by Environment Canterbury (Thorley & Scott, 2011[30]) did develop a numerical flow modelling approach that utilised pilot points. This model methodology was applied such that various water balances and hydraulic conductivity arrays could be calibrated relatively quickly. These models were also utilised to determine the dispersion and likely flow paths of diffuse nutrient leaching from land use in the Central Plains (Bidwell et. al., 2009[31]). The modelling approach selected is likely to have significant bearing on the results for evaluating water management options such as MAR, particularly when claiming benefits to groundwater quality.

50. It is not clear if augmentation by MAR is targeted only at stream restoration or at restoration of reliable abstraction for groundwater users, or both. It would seem that implementing MAR to benefit groundwater users' ability to take water is an inefficient way of delivering water for supply and that moving these users to surface water irrigation scheme supplies would be more effective and efficient.

51. Whilst I agree that MAR could assist in alleviating the water balance pressure, it would seem premature to base allocation decisions on it at this time. The basis for allowing replacements of the surface water takes into groundwater or even maintaining existing levels of allocation, particularly in

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[30] Thorley, M. and D Scott, 2010. A Methodology to model groundwater flow in sub-areas of the Canterbury Plains. Environment Canterbury Technical Report R10/43.

[31] Bidwell, V. J., Lilburne, L., Thorley, M. J., Scott, D. M., 2009: Nitrate discharge to groundwater from agricultural land use: an initial assessment for the Canterbury Plains. Report prepared by Lincoln Ventures Limited, Landcare Research, and Environment Canterbury.

the Valetta GWAZ, does seem to be on the premise that MAR will solve the water balance and water quality issues.

Alternative Water Allocation Approaches

52. The ideal situation from a water (quantity) balance view is to have users' primary water supply sourced from one of the SW Irrigation Schemes that is used in conjunction with groundwater, to meet the higher levels of demand reliability. I am aware that this is already occurring on some farms.

53. In the Valetta GWAZ, a much more rigorous review of paper allocation and actual use appears to be warranted, given the current over-allocation and potential for further takes due to replacements of stream depletion and surface water to be allowed by Variation 2. The allocation volumes could be reviewed to take account of actual use. Recent data indicate < 38 % (Mayfield-Hinds) and < 58 % (Valetta) actual usage and even less for surface water takes[32]. The main changes that could be applied in the determination of annual volumes is to increase the application efficiency and/or lower the demand reliability that is met by irrigation in the soil-water balance model, from say 9 in 10 years to 7 or 8.

54. Painter (2009) provides a summary of the issues and different models available to determine annual irrigation requirements[33]. If the demand reliability is lowered, and depending on the irrigation method, up to ~ 20 % reduction in annual irrigation requirements can be achieved by lowering the demand reliability to the average[34]. However, one of the biggest factors in reducing seasonal demand is using more precise irrigation methods such as Centre Pivot or Lateral Move irrigators. The way in which irrigation water is applied in the soil-water balance models could also be adjusted to minimise annual water demand. Corresponding reductions in recharge from more efficient irrigation is likely, although reductions in net groundwater use is likely to occur the more efficient the irrigation practice is.

55. Another option to protecting a portion of the groundwater balance for spring-fed streams is to deduct the minimum flows required for all of the spring-fed streams from the water balance and allocate say 50 % of the remaining recharge. This approach was taken in the determination of limits for the Otaio

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[32] Table 9.3 *in* Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51
[33] Painter, D., 2009. A Comparative Review of Two Methods for Estimating Seasonal Irrigation Demand. Report Number CP5R-09. http://ecan.govt.nz/publications/General/EstimatingSeasonalIrrigationDemand.pdf
[34] Compared results in Tables 5.1, 5.2 and 5.3 *in* Painter, D., 2009. A Comparative Review of Two Methods for Estimating Seasonal Irrigation Demand. Report Number CP5R-09.

and Hook GWAZ's in South Canterbury allocation zones where there was a net gain to surface water bodies from groundwater, and 7 day MALF was reserved in the water balance[35]. This was further justified because these zones lacked alpine river recharge which helps to maintain base flow in the groundwater system and spring-fed streams. The 7 day MALF flows[36] for the Hinds/Hekeao Plains total ~2 m^3/s or ~63 M m^3/year, although not all of the surface water bodies are included in Environment Canterbury's flow analyses due to insufficient data. This would take the combined Valetta and Mayfield-Hinds GWAZ limits to ~213 M m^3/year from 244 M m^3/year and increase allocation to 120 % up from 104 % allocated.

56. The COMAR flows were derived to maintain 300 mm water column in the surface water ways[37] and totals ~3.5 m^3/s or ~113 M m^3/year. This volume of water could similarly be deducted from the land-surface recharge volume in order to better protect cultural flow values.

57. Creating separate allocation blocks depending on whether the resource consents are subject to adaptive management conditions and/or used in conjunction with surface water irrigation scheme supplies, could assist in dealing with the apparent "paper" over-allocation. This concept could be extended to surface water replacements into groundwater, whereby the past water usage or supply reliability is accounted for in the determination of an annual volume and is put to one side in the allocation tally.

58. This approach would mean that allocation management could be better tailored to a certain groups of users. The four main groups of users as I understand it include: primary groundwater takes, dual supplies, adaptive management takes and surface water/shallow groundwater replacements. Variation 2 could set some specific guidance around the expected demand and/or supply reliability and irrigation efficiency that is to be met, which could be different for different groups of users.

59. The requirement for non-renewal of certain permits could be part of the approach to moving takes away from more sensitive parts of the catchment. This would amount to a "sinking lid" approach to reducing over-allocation. Particularly in Valetta, shallow groundwater takes, surface water takes from spring-fed streams and potentially deep groundwater takes in the upper parts

[35] Thorley, M. and M Ettema, 2007. Review of water allocation limits for the South Canterbury downlands. Environment Canterbury Technical Report U07/09.
[36] Table 9.4 *in* Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51
[37] Table 10.12 *in* Durney, P. and J. Ritson, 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Environment Canterbury Technical Report R14/51

of the catchment could be subject to a sinking lid approach, although the availability of alternative sources should be considered.

Conclusions

60. The groundwater resource in the Hinds/Hekeao Plains appears to be in a general state of decline, likely due to a combination of reduced land-surface recharge, closure of water races and increased groundwater development.

61. The water resource reductions and over-allocation of groundwater and surface water resources appears to be most pronounced in the Valetta GWAZ.

62. Groundwater allocation limits based on net land-surface recharge for Mayfield-Hinds and Valetta should have (but have not) been updated to account for new information and understanding (such as newer climate records, irrigated areas, and water usage). This would assist in confirming the over-allocation issues, particularly in Valetta, whereas Mayfield-Hinds may or may not be fully allocated.

63. Replacement of stream depletion and surface water takes from spring-fed streams is likely to benefit flows in these streams. However, the over-allocated groundwater resource in Valetta is less likely to be able to accommodate the additional takes, particularly given the current state of spring-fed stream flows and declining groundwater levels. Moving users to surface water schemes in Valetta may be a better option given the current resource over-allocation.

64. Replacements of shallow groundwater and surface water takes with deep groundwater may need additional measures to ensure a sufficiently low hydraulic connection with streams is achieved once the take is moved to the aquifer system. This could include a minimum depth requirement, “adaptive management” type measures and/or targeted allocation block approaches. I recommend that any replacement wells be drilled to depths deeper than 50 m to minimise connectivity across the groundwater strata and the shallow aquifer system that supports the spring-fed streams.

65. Alternative options to address the over-allocation issues could be considered such as reviewing individual consent allocation requirements, creating more specific allocation blocks for groups of users with tailored measures, and setting aside sufficient groundwater to maintain environmental spring-fed stream flows. Such measures could include sinking lids, requirements for

precise irrigation methods, targets for irrigation efficiency and demand reliability when calculating annual volumes, moving existing users onto surface water irrigation schemes and taking less groundwater.

66. I agree that MAR has the potential to assist in addressing part of the water allocation issue in the Hinds/Hekeao Plains, and perhaps a small part of the groundwater quality issue. However modelling provided to date does not yet adequately represent the potential benefits and challenges, and the source of water for MAR is not clear.

67. Targeted augmentation of streams may be a more effective option of supplementing surface water flows. MAR and augmentation options are uncertain at this time and require fuller investigation to determine the volume and distribution method(s) and more robust water source arrangements before it can be included in the water balance for allocation purposes.

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