Before the Commissioners appointed by Canterbury Regional Council

IN THE MATTER OF The Resource Management Act 1991

AND

IN THE MATTER OF Applications by the Central Plains Water Trust and Central Plains Water Ltd. to Take and Use Water for Irrigation in the Central Plains area.

Section 42A Officer's Report

Date of Hearing: 25 February 2008

Report of DAVID MICHAEL SCOTT

INTRODUCTION
Background

1. The Central Plains Water Trust has applied to the Canterbury Regional Council for resource consents to take water from the Rakaia and Waimakariri rivers and use it to irrigate 60,000 hectares of land between the two rivers. The irrigation scheme is called the Central Plains Water Enhancement Scheme ("the CPW scheme").

2. The proposed CPW scheme has the potential to affect groundwater conditions in the following ways:

- Mounding of groundwater levels, particularly below and down-gradient of the scheme area,
- Increased groundwater discharge to surface water bodies, particularly to lowland streams and to Lake Ellesmere,
- Modification of surface water/groundwater interaction in the Rakaia, Selwyn and Waimakariri Rivers,
- Modification of groundwater flow directions.

3. My evidence will provide information and advice related to the interpretation and evaluation of the groundwater flow modeling undertaken on behalf of the applicant to evaluate the above effects.

4. My evidence is supplementary to the Section 42A report prepared by the Canterbury Regional Council for the above consent application. Full details of the consent application are provided in that report.

Qualifications and experience

5. My full name is David Michael Scott. I am employed by the Canterbury Regional Council ("the Council") as a Groundwater Hydrologist, a position I have held since 1993. My work with the Council includes the development and application of groundwater models, providing technical input into the development of groundwater management policies and the preparation of technical evidence for resource hearings.

6. In previous jobs I was employed as a groundwater scientist working for the Geology and Geophysics Division of the Department of Scientific and Industrial Research and its predecessor the Hydrology Centre of the Ministry of Works and Development. I have also undertaken two 2-year assignments as a groundwater hydrologist working in the South Pacific – in the Solomon Islands under the NZ Bilateral Aid Programme and in Fiji under the Commonwealth Fund for Technical Cooperation. I hold a Master of Engineering (Agriculture) (with distinction), from Lincoln College and a Bachelor of Engineering (Civil) from the University of Canterbury.

7. I have worked as a groundwater scientist since 1976, specialising in the use of computer models for groundwater resource assessment, groundwater flow and transport modelling, analysis of surface water/groundwater interaction and groundwater management and planning. I have been the author (or co-author) of more than 20 published papers and reports on groundwater assessment and modelling, have contributed almost 30 conference and workshop presentations and completed more than 60 unpublished reports.

8. I acknowledge that I have read the code of conduct for expert witnesses contained in the Environment Court's Practice Note dated 31 March 2005. I have complied with it when preparing my written statement of evidence and I agree to comply with it when I give oral evidence.

Scope of my report

9. My evidence provides an assessment of the groundwater modelling undertaken to assess the potential effects of the proposed CPW scheme and focuses on groundwater quantity issues. In preparing my assessment I have considered the following reports and supplementary information:

- Weir, J.J. (2008): Brief of evidence.
- URS (2007a): Memorandum – Central Plains Water Enhancement Scheme s92 request regarding groundwater mounding. Response from W. Lewthwaite to L. Fietje, dated 14 December 2007.

- Merrick, N.P. (2007): Review of Canterbury Groundwater Model 2, New Zealand. Report prepared for Aqualinc Research Ltd by Heritage Computing. Project number HC2007/4, dated 19 August 2007.
- Aqualinc (2007): Canterbury Groundwater Model 2. Report number L07079/1, dated September 2007.
- URS (2007b): Memorandum – Central Plains Water Enhancement Scheme Request for further information. Response from C. Tipler and W. Lewthwaite to L. Fietje, dated 19 March 2007.
- URS (2006): Central Plains Water Enhancement Scheme: Assessment of Environmental Effects for Resource Consent Applications to Canterbury Regional Council. Report prepared for Central Plains Water Trust by URS New Zealand Ltd. (Christchurch). Report number 42156547.66140 \ AEE R001C, dated 23 June 2006.
- Aqualinc (2006): Central Plains Water Enhancement Scheme – Assessment of Effects on the Groundwater Environment. Report prepared for URS New Zealand, Ltd. by Aqualinc Research Ltd. Report number L05248/2, dated June 2006.

10. My evidence will consider the groundwater flow model and peer review, and the simulated effects of the CPW scheme. Such evidence is within the ambit of my expertise.

Summary of my conclusions

- Modelling results are reported in a way which may result in them being seen as more certain than they really are. For example, the peer review is presented as endorsing the reliability of the model even though the reviewer effectively stated that the model was not suitable for practical use and had not seen the predictions for the CPW scheme.
- Despite the non-uniqueness of the model calibration and the inherent difficulty of simulating surface water/groundwater interaction at this scale there is only limited consideration given to the uncertainty of the model prediction.
- The model illustrates the complex interaction of the expected effects of the CPW scheme and provides an indication of the timescales involved. The simulation of demonstrates that the onset of effects could occur over several years and that it may be difficult in future to distinguish the effects of climate from those of the CPW scheme. These factors have implications for the design of monitoring and mitigation measures if the consents are granted.
- The magnitude of simulated effects should be viewed with some caution and should not be accepted as being worst-case assessments. Water balance errors and concern regarding the plausibility of some water budget terms leaves doubt regarding the reliability of the model predictions. Limiting the prediction scenarios to the historic climate record is also likely to lead to underestimation of the potential for groundwater mounding.
- It should be noted that though additional work might improve the reliability of predictions and provide a better description of the uncertainties it could not eliminate the inherent uncertainty of model predictions for this type of application.

THE GROUNDWATER FLOW MODEL AND PEER REVIEW

Background

11. The analysis of environmental effects of the proposed CPW scheme has involved a series of groundwater modelling studies. The initial feasibility study (URS 2002) was undertaken using a MODFLOW model. The subsequent more detailed assessment has been based on an alternative model code (FEMWATER) as reported in Aqualinc (2006). The model used in that assessment was, to my knowledge, essentially the same as that presented at the Rakaia-Selwyn hearing. For convenience I will refer to that model as **Model 1**.

12. A number of shortcomings in Model 1 were highlighted during the Rakaia-Selwyn hearing. The revised version of the model, which I will call **Model 2**, is described in Aqualinc (2007) and addresses two of the issues (the model zonation and the representation of historic water use) and uses an updated climate record.

13. Weir (2008) refers to further changes undertaken to improve the reproduction of flows and to improve the calibration to groundwater levels in some localised areas of the model. This version, which I will call **Model 2A**, was used to simulate the CPW scheme effects as reported in Weir (2008).

14. Aqualinc Research Ltd commissioned a peer review of Model 2 from Dr Noel Merrick. The review (Merrick 2007) used the standard checklist provided in the Australian Flow Modelling Guideline (MDBC 2001)[1]. The peer review was limited to the information provided in a draft version of the Aqualinc (2007) report. Since that report contained no specific reference to the CPW scheme and no model prediction the review has omitted the standard section on model prediction. I understand that many of the review comments have been addressed in the final report. My comments are focused on the issues that remain unresolved.

Model overview

15. The simulation of groundwater behaviour has been based on two separate models:

- A crop-soil water balance model to calculate land-surface recharge[2] inputs and to estimate the groundwater abstraction rates required to meet irrigation demand, and
- A finite-element flow model (FEMWATER) which represents surface water/groundwater interaction and groundwater flow (both saturated and unsaturated) beneath the land surface.

16. Modelling has been undertaken using data for the period from 1967 to 2006 to represent three different situations:

- A history matching case using estimates of actual land-surface recharge and groundwater abstraction rates to calibrate and verify the model against observed groundwater levels and surface water flows. That case reflects the historic irrigation development over the simulation period and has been undertaken using Model 2.
- A ‘Status Quo’ scenario using estimates of the land-surface recharge and groundwater abstraction rates that might have occurred over the period if current land-use had prevailed prior to 1967, and
- A ‘CPWES’ scenario using estimates of the land-surface recharge and groundwater abstraction rates that might have occurred over the period if the CPW scheme had been in place prior to 1967.

17. The differences between the CPWES and Status Quo scenarios provides an estimate of the transient effects of the CPW scheme – in terms of changes to groundwater levels and to surface water flows. Three, supposedly representative, dates have been chosen to illustrate the expected range of effects. In addition a 10-year simulation has been undertaken to illustrate the rate of onset of effects. This Status Quo and CPWES scenarios have been simulated using Model 2A.

Model conceptualisation

18. Aquifer hydraulic properties are defined in the model in terms of a number of aquifer zones to represent a layered aquifer structure. The aquifer zonation and layered representation used in Model 1 received critical comment at the Rakaia-Selwyn hearing (Scott 2006). The shortcomings of the block zonation used in Model 1 have been addressed in the revised versions of the model though it appears to have been difficult to determine an optimum pattern of aquifer properties as illustrated by the permutations between Model 2 and Model 2A.

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[1] Murray-Darling Basin Commission.
[2] The term ‘land-surface recharge” refers to rainfall recharge plus the additional recharge that occurs as a consequence of irrigation.

19. The conceptual layered aquifer structure has been retained in the updated models as representing a distinct sequence of aquifers and aquitards. This interpretation has been dismissed by Schulmeister (2007) and his views are echoed in the evidence of my colleague Mr Carl Hanson. It is clear that a layered structure does exist in the coastal confined aquifer on the margin of Banks Peninsula. It is also conventional modelling practice to represent a 3rd aquifer dimension (depth) by using multiple model layers. In the coastal confined aquifer area some of the model layers do realistically represent aquitards however the vertical hydraulic conductivities (0.005% of the horizontal value) seem low. In my opinion the propagation of these low values over the rest of the model is not reasonable, though I understand from Mr Weir that they have been required to allow the model to match the observed vertical gradients in groundwater pressures.

20. I suspect that the need to invoke what appears to be a physically unrealistic conceptual model may be the result of aquifer hydraulic conductivity being very much greater in the primary flow direction than it is laterally or vertically. This is consistent with the view expressed by Davey (2007) who stated that "*My interpretation of the aquifers is that they are located within gravels deposited during glacial times, and are the result of primary permeability of those sediments, with some modification of the permeability by the passage of groundwater through them"*. This horizontal anisotropy is not easily represented in a numerical model and hence the aquifer/aquitard layered sequence may simply be a convenient mathematical device to represent the effects of vertical anisotropy on a regional scale. Regardless of the correctness of that hypothesis it is interesting to note that, despite the very low aquitard vertical hydraulic conductivities, the particle tracking calculations (Appendices J & K, Weir 2008) clearly show that vertical groundwater flow can be expected as has also been demonstrated using analytical models (Scott and Hunt, 2007).

21. The peer review raises another issue regarding the model conceptualisation. In his Table 3 (Model Review – Conceptualisation) Merrick (2007) records the view that the conceptual model is unnecessarily complex stating "*Groundwater timescale is overkill. Not convinced of need to simulate unsaturated zone. Result is long runtime*."

22. This is an important issue. The simulation of unsaturated flow requires very small time steps to achieve stable numerical solutions and, for a model of this scope, involves long model runtimes. This has implications for model calibration, ruling out automatic optimisation techniques and comprehensive sensitivity analysis and limits the scenario testing that can be undertaken with the completed model.

23. Elsewhere in his peer review Merrick (2007) comments that the lengthy runtime of 6 weeks is "*far too long for a useful model*". He recommends that "*steps must be taken to bring the runtime back to a manageable duration, in the order of a day or less*". I agree with this and would argue for even shorter run times. Hill (2006) who recommends a maximum model runtime of 30 minutes states that "..*only if models are designed to have a limited number of parameters and forward execution times less than about a half hour can the data and system characteristics be fully enough explored through sensitivity analysis and optimization to attain a reasonable level of model calibration*."

Calibration to observed groundwater levels

24. Despite his concerns about the model runtime and resulting constraints Merrick (2007) comments very favourably on the model calibration noting that "*the calibration statistics of 1-2% normalised RMS error are as good as could be expected of any model*". The reported RMS errors are low but it is important not to lose sight of the size of actual model errors incorporated within that statistic.

25. Figure 1 shows the match achieved between observed and simulated groundwater levels for well L36/0092 which is within the CPW scheme area. There are several aspects of this plot that give grounds for concern about the quality of the model calibration:

- The simulated groundwater levels show a seasonal fluctuation which is not apparent in the earlier half of the observed record. The later observed fluctuations are presumably the result of groundwater abstraction and the model does simulate increased seasonal amplitude over the later part of the record. The anomaly in the earlier part of the record, which is also evident in many of the hydrographs plotted in Appendix P of Aqualinc (2007), suggests that some of the storage terms adopted in the model are inappropriate.

- In some areas of the model the simulated groundwater level rise resulting from higher than average recharge is less than the observed range (particularly in model zone 18). Since the CPW scheme would result in increased land-surface recharge this aspect of the model's performance is of particular significance. The observed rise of groundwater levels in the late 1970's can be attributed to the higher than average rainfall which occurred over several years. The fact that in some areas the model under-estimates that response suggests that it is also likely to under-estimate the groundwater level rise resulting from the CPW scheme.
- The blue line in Figure 1 shows the groundwater level simulated using Model 2. The green line was calculated using Model 2A. The later model included modifications to improve the simulation of Selwyn River flows but this appears to have been achieved at the cost of some degradation of the ability of the model to match the response to longer timescale changes in land-surface recharge.

26. The adequacy of model calibration should ideally be assessed in terms of the particular prediction that it is to be used for. In this case, since the reviewer was not provided with any information relating to the CPW scheme it is perhaps not surprising that he has evaluated its performance in a less focused way.

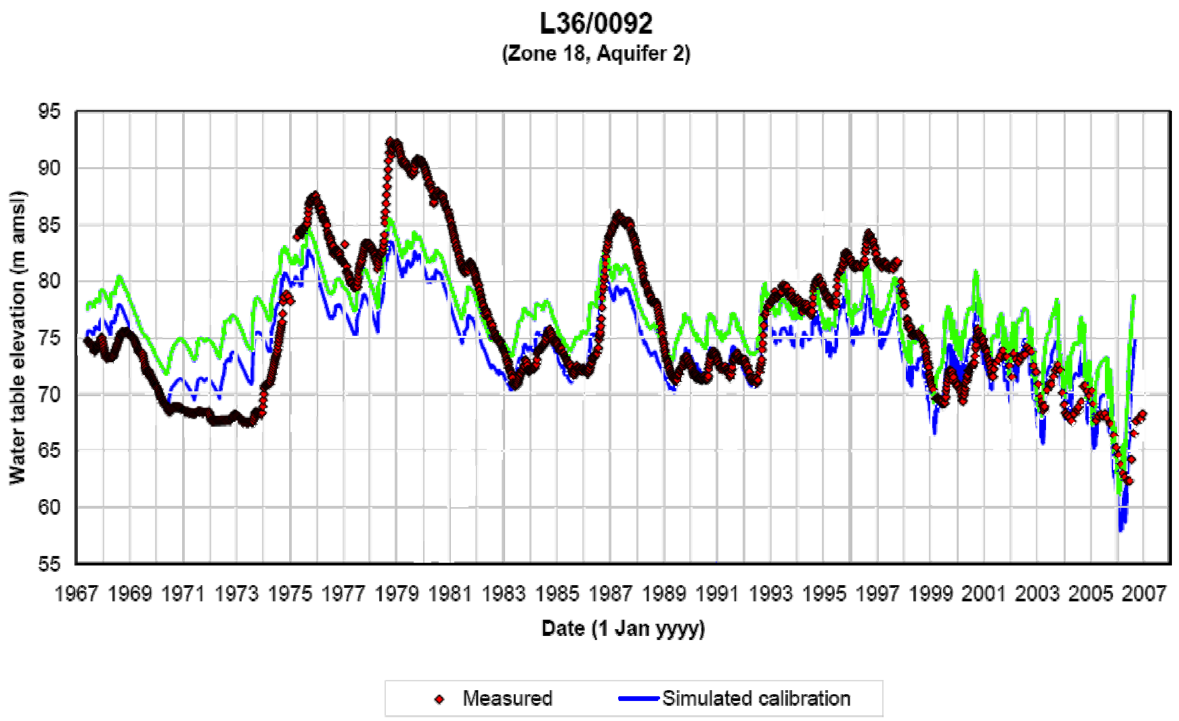


Figure 1: Observed and simulated groundwater levels for well L36/0092.
Blue line - Model 2 (from Figure 7-6, Aqualinc 2007)
Green line – Model 2A (from Figure 4, Weir 2008)

Calibration to observed stream flow

27. The reviewer's evaluation of the model calibration to observed stream flow acknowledges the difficulty of accurately reproducing that relatively fine scale behaviour in a regional model stating "*Some flow duration curves and cumulative flow curves show divergences. However, one could not expect matches to be better than this*." I think that this is a reasonable assessment and the predictions should be evaluated from that standpoint.

28. The CPWES scenario predicts very significant increases in the flow in the Selwyn River at Coes Ford so it is important to look more closely at this aspect of the model's performance. The Model 2 and Model 2A simulations of historic flow for that site are shown in Figures 2 and 3 respectively. Flow recording commenced at the Coes Ford site in 1984 and model calibration has attempted to match the flow record since that date. The Model 2 under-estimation of low flow is clearly evident in Figure 2. Figure 3 shows the significant improvement made to the Model 2A version in terms of matching the Selwyn River low flow.

29. The Council gaugings database contains records of spot flow gaugings at the Coes Ford site starting from 1971 and I have superimposed those on Figures 2 and 3. The observations prior to 1984 suggest that both models perform less satisfactorily when conditions are likely to lead to higher base flows and that the modifications made to improve the reproduction of very low flows has degraded the model performance at higher flows.

30. It is difficult to fully understand what interactions are at work here. On seeing these latest results I requested a copy of the stream package inputs referred to in Appendix A of Aqualinc (2007) but at the time of writing had not received that additional information. My provisional conclusion is that the model parameters may be set in such a way that groundwater drains too easily from storage when groundwater levels in some areas of the model are above some threshold. That would account for the under-estimation of groundwater level increases and over-estimation of higher than average baseflow.

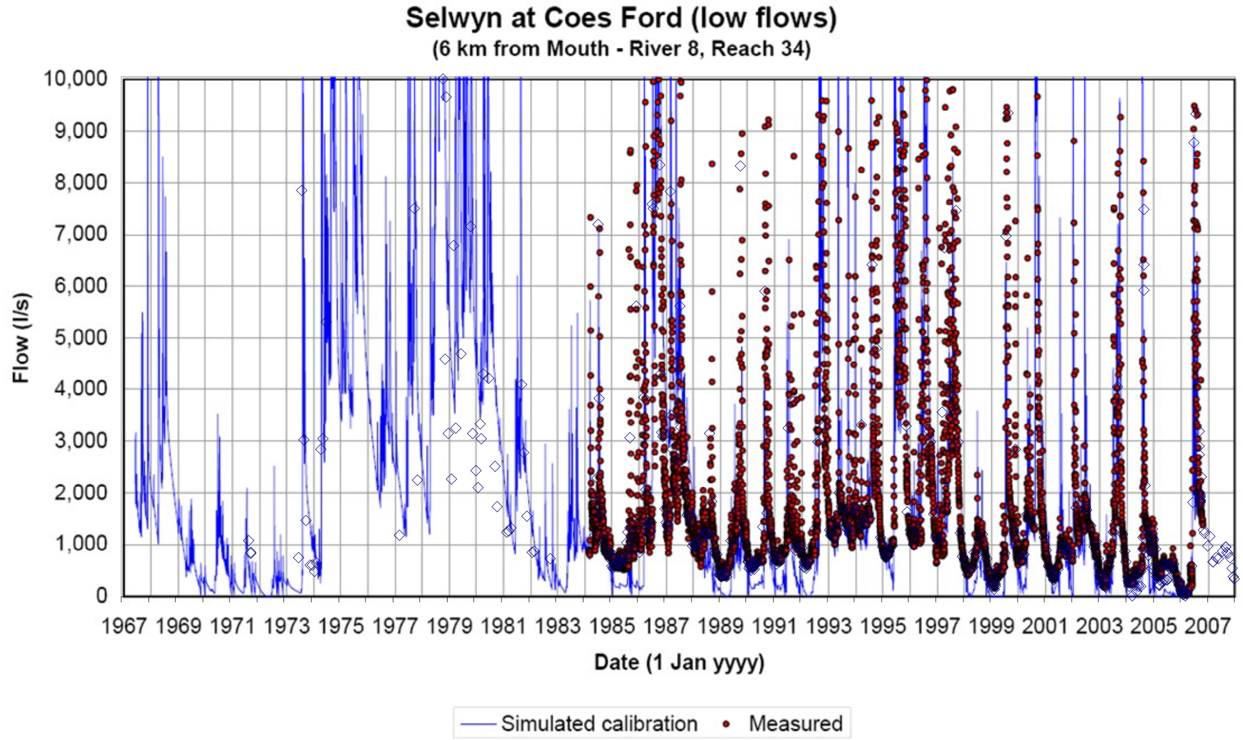


Figure 2: Model 2 Observed and simulated flow (from Appendix Q, Aqualinc 2007) plus spot gaugings (◊) from ECan database.

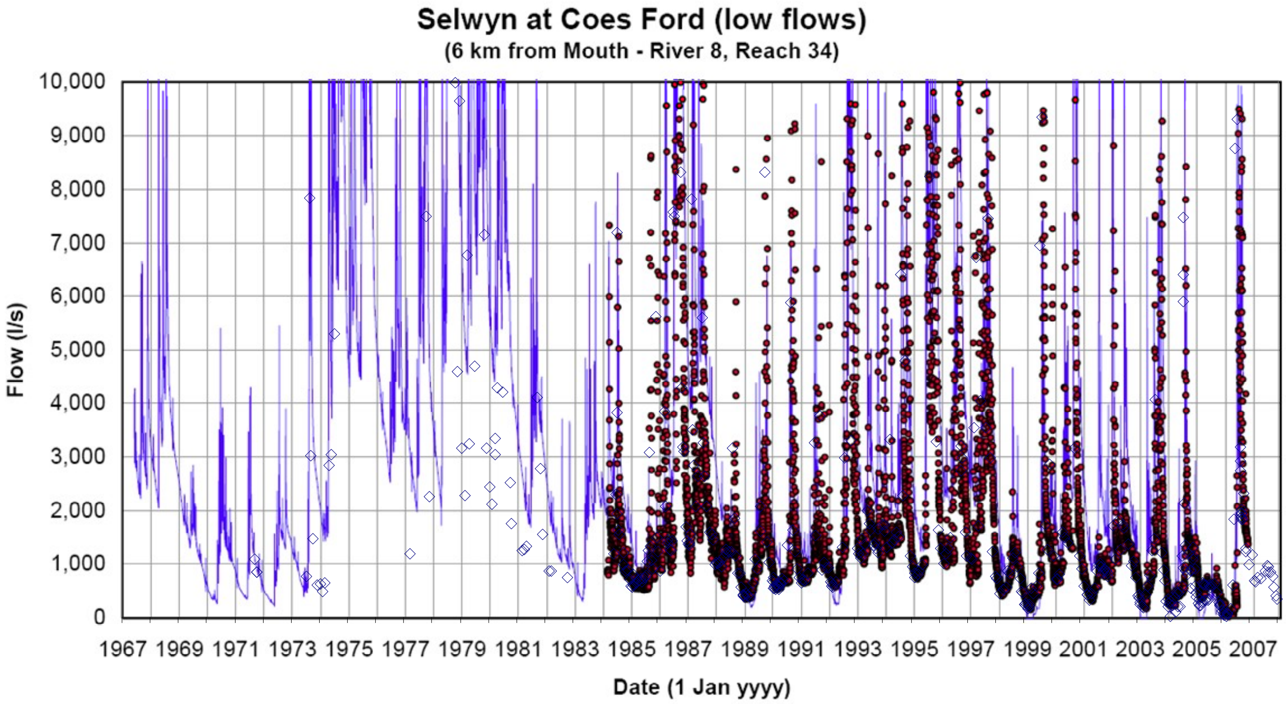


Figure 3: Model 2A Observed and simulated flow (from Figure 7, Weir 2008) plus spot gaugings (◊) from ECan database.

Model mass balance

31. The overall water budgets for the history matching case are summarised in Table 1 for the entire model domain and in Table 2 for the sub-area of the model between the Rakaia and Waimakariri Rivers. The values raise several issues which have a bearing on the reliability of the model.

Budget item	Model 2A	Model 2
Scheme distribution channels	2.5	2.5
Main channels	1.0	1.0
Land-surface recharge	65.5	65.5
Surface water	103.8	102.0
Stockwater	8.5	8.5
Total input	***181.3***	***179.5***
Irrigation abstraction	6.5	6.6
Non-irrigation abstraction	6.1	6.1
Surface water	69.6	69.0
Lake Ellesmere	12.6	12.3
Offshore	77.7	77.0
Total output	***172.5***	***171.0***
Input - Output (m^3/s)	**8.8**	**8.5**
Difference (%)	5.0%	4.9%

Table 1: Water budget items for the history matching case – entire model domain.
Notes: Model 2A values from Figure 11, Weir (2008)
Model 2 values from Figure 7-18, Aqualinc (2007)

Budget item	Model 2A	Model 1
Scheme distribution channels	0.2	0.0
Main channels	0.0	0.0
Land-surface recharge	29.0	30.2
Surface water	44.4	22.3
Stockwater	3.7	3.7
Total inflow	***77.3***	***56.2***
Irrigation abstraction	13.7	13.8
Non-irrigation abstraction	5.9	2.9
Surface water	29.5	14.0
Lake Ellesmere	11.2	
Offshore	9.5	
Offshore and Lake Ellesmere		27.5
Total outflow	***69.8***	***58.2***
Inflow - Outflow (m^3/s)	**7.5**	**-2.0**
Difference (%)	10.2%	-3.5%

Table 2: Water budget items for the Status Quo scenario - Rakaia-Waimakariri area
Note: Model 2A values from Appendix P, Weir 2008
Model 1 values from Appendix C, Aqualinc (2006)
Water budget details for the Rakaia-Waimakariri area were not reported for Model 2.
Lake Ellesmere and Offshore flows were aggregated in reporting of Model 1.

32. The reported mass balance errors exceed guideline standards and raise questions about the accuracy of the numerical calculations. The peer review records that mass balance figures are reported and notes that the FEMWATER code fails to report changes in storage. No further comment is provided regarding the significance of the reported difference – 4.9% error for the simulation included in the review – even though the MDBC guideline (used as the framework for the peer review) specifies that the value should be less than 1%. A low mass balance error is a pre-requisite for a model to potentially be considered reliable – it is analogous to requiring financial records to balance before evaluating financial performance. Its importance is reflected in other groundwater modelling guidelines:

- MfE (2002) specifies that the discrepancy between inputs and outputs should be less than 1% (and must be no greater than 2%) to ensure that the model calibration is not numerically unstable (for each stress period and cumulatively for the entire model).
- Reilly and Harbaugh (2004) propose that the error in mass balance should be less than 0.5% and note that even if the global mass balance error is small, the model solution may not be appropriate for the system under investigation.

33. Aqualinc (2007) and Weir (2008) discuss the mass balance errors in light of the MfE (2002) specification and note that, because of FEMWATER limitations, the mass balance totals are calculated externally, that storage changes are not included and hence the figures should be treated as indicative. This doesn't remove the possibility that the limits have been exceeded and leaves uncertainty about the numerical accuracy of the model calculations.

34. Table 2 suggest that even larger model mass balance discrepancies may exist for the Rakaia-Waimakariri sub-area of the model. Weir (2008) points out that groundwater management zone boundaries are not hydrological boundaries and I agree with that. The 10.2% difference between inputs and outputs for the Model 2A Status Quo scenario represents an unaccounted for discharge from the sub-area of 7.5 m^3/s. While it is quite feasible that there is a net groundwater outflow from the sub-area this figure seems surprisingly high.

Model water budget

35. The model results summarised in Tables 1 and 2 show simulated groundwater seepage to Lake Ellesmere ranging from 11.2 to 12.6 m^3/s. These rates are very much higher than the 0.08 m^3/s estimated by Horrell (1992) in his water balance model of water level fluctuations in Lake Ellesmere which reliably predicts the frequency of lake openings. Ettema and Moore (1995) have measured seepage in the lake bed and estimated a seepage flow of 0.44 m^3/s. All these estimates and inherently uncertain. Horrell (pers. comm.) accepts that the actual seepage may be larger than his earlier estimate but regards the model results as implausible.

36. The Model 2A result includes a surprisingly high rate of input from surface water sources to the Rakaia-Waimakariri sub-area of the model - the reported input of 44.4 m^3/s is significantly larger that the equivalent value of 22.3 m^3/s used in Model 1. The description of simulated surface water/groundwater interaction for the Rakaia and Waimakariri Rivers (Appendix N, Weir 2008) suggests that they loose approximately 25 m^3/s and 10 m^3/s to groundwater respectively. If 50% of the simulated Rakaia River loss and 100% of the simulated Waimakariri River loss are regarded as likely inputs to the Rakaia-Waimakariri sub-area then the reported input of 44.4 m^3/s leaves a balance of 21.9 m^3/s supposedly contributed from other surface water sources. The model report provides no comment on where this additional water might be derived from.

Model peer review

37. I have already referred to a number of matters raised in the peer review. Weir (2008) and Aqualinc (2007) highlight some of the many favourable comments made but it is important to note that the review identifies significant concerns. The review notes "*the strong performance of the model does not mean that it is suitable for practical use in its present form*." On the face of it this appears to be a very serious reservation and gives the impression that the reviewer expected that significant revision would be undertaken before the model was applied to a real problem.

38. There are other important aspects of the peer review which should also be noted:

39. No other documents other than the draft version of Aqualinc (2007) were inspected by the reviewer and apparently he was not advised of the specific concerns that had been raised regarding an earlier version of the model. In his opening remarks Merrick (2007) states that "*more information could have been given of the ways in which this version of the model has improved over earlier versions of the model in order to address apparent criticisms of earlier work of which this reviewer has no knowledge*." It is regrettable that this information was not provided as it would certainly have allowed a better-informed review. The earlier modelling report (Aqualinc 2006) and selected briefs of evidence for the Rakaia-Selwyn hearing would have provided useful background in this respect.

40. The lack of background information is also addressed in the reviewer's tabulated response to the questions posed in the MDBC (2001) groundwater flow modelling guideline:

- In response to the question "Have prior investigations been examined and acknowledged? He records the comment "*Very little information on previous model, especially shortcomings that have been addressed*."
- And the question "Has a literature review been completed?" is scored as being deficient with the comment "*little recognition of extensive studies*."

41. In light of this lack of adequate background information it is difficult to understand how the reviewer was able to reach the unqualified conclusion that "*the model is a faithful simulator of the behaviour of the aquifer system and its complex interactions with rivers and streams and land surface drainage resulting from irrigation and rainfall*." If he had been aware of the conflicting views on the overall water balance and on groundwater seepage to Lake Ellesmere I expect he may have been a little more circumspect.

42. The other important element missing from the peer review is any consideration of the application of the model to the prediction of effects of the CPW scheme. Merrick (2007) notes that "*the model report is limited to model development and calibration and has not attempted any predictive scenario analysis at this stage*." As a consequence, the standard section addressing model predictions (reproduced in my Appendix A) has been omitted from the review and the recommendations propose further improvements as a pre-requisite to practical use. It is arguably semantically correct to have informed the reviewer that this particular version of the model had not been used for predictive analysis. Nevertheless, given that a previous version of the model had already been applied to simulate the CPW scheme and that specific details of the planned application were available at the time of the review, it seems somewhat misleading. I will return to the question of a review of predictions later in my evidence.

SIMULATED EFFECTS OF THE CPW SCHEME

Overview of CPWES scenario

43. The CPWES scenario has been designed to simulate the groundwater levels and flows that might have happened over the period 1967 to 2006 had the CPW scheme already been in existence. Comparison with the Status Quo scenario provides an indication of the net differences resulting from the operation of the scheme.

44. The water budgets for these two scenarios are compared in Table 3. The Status Quo figures are the Model 2A values listed in Table 2 - the difference between that and the CPWES figures reflect the water budget changes resulting from the CPW scheme. The differences in scheme distribution channels, main channels, land-surface recharge and irrigation abstraction items reflect the scenario inputs – they depend on assumptions regarding the performance of the scheme infrastructure and the differences in land-use between the two scenarios. The table shows an increase in surface water inputs and surface water outputs – presumably largely a consequence of changes in surface water/groundwater interaction of the Selwyn River since net losses from the Rakaia and Waimakariri Rivers are expected to reduce. The proportion of unaccounted for outflow increases to 14.7% representing 12.1 m^3/s.

Budget item	Status Quo	CPWES	Difference
Scheme distribution channels	0.2	3.0	2.8
Main channels	0.0	1.0	1.0
Land-surface recharge	29.0	33.1	4.1
Surface water	44.4	47.3	2.9
Stockwater	3.7	3.7	0.0
Total inflow	***77.3***	***88.1***	
Irrigation abstraction	13.7	10.8	-2.9
Non-irrigation abstraction	5.9	5.9	0.0
Surface water	29.5	37.0	7.5
Lake Ellesmere	11.2	12.4	1.2
Offshore	9.5	9.9	0.4
Total outflow	***69.8***	***76.0***	
Difference (m^3/s)	**7.5**	**12.1**	
Difference (%)	10.2%	14.7%	

Table 3: Model 2A water budget for Status Quo and CPWES scenarios for the Rakaia-Waimakariri sub-area.

Prediction of groundwater mounding

45. Weir (2008) uses the Status Quo and CPWES simulations to describe the extent of groundwater mounding that could have been expected on three particular dates:

- 1 March 1970 – when groundwater levels were low and drier than average conditions would have led to high irrigation water use,
- 1 October 1978 – when groundwater levels were high and wetter than average conditions would have led to low irrigation water use, and
- 1 March 1994 – when conditions were average.

46. On the basis of these results Weir (2008) concludes that:

- Maximum mounding of approximately 10 m could be expected in the centre of the CPW scheme area during a dry year, in a location where the status quo depth to groundwater is about 25 m below ground level,
- An increase of 19,908 ha area where groundwater levels shallower than 5 m below ground level could be expected to occur, and
- An increase of 6,613 ha area where groundwater levels shallower than 1 m below ground level could be expected to occur.

47. It is difficult to interpret the predicted change in area where groundwater is shallower than 5 m since that may be of little consequence in some areas. The increase in the area where groundwater levels are expected to be within 1 m of the ground surface is a more easily understood figure and highlights the need for some contingency measures to deal with this potential effect. Aqualinc (2006), which evaluated the impacts using Model 1, presented equivalent results in terms of a depth to the water table that would be exceeded 80% of the time which is a more useful way of describing the effect.

48. I have a number of reservations about accepting the above estimates as reliable predictions of worst case conditions:

- As explained earlier, there are some areas of the model where historic water level rises have been under-estimated. The model may similarly under-estimate the effect of the CPW scheme.

- The groundwater mounding simulated to occur on March 1970 does not necessarily represent the maximum mounding throughout the model area (the exceedance probability reporting in Aqualinc (2006) would have been more helpful in this respect).
- The historic climate pattern, while obviously the appropriate one to use for the model development, does not allow for other climate patterns which could result in greater groundwater mounding. Climate change studies have suggested that the risk of drought in Canterbury is likely to increase. Hence a sequence of high irrigation water use years could occur.

49. Weir (2008) includes a simulation that illustrates the rate of onset of CPW scheme effects and suggests that "90% of the effects of the scheme will be seen within approximately 2-4 years, and the full effects of the scheme would be realised after approximately 3-5 years". Since this estimate is based on the proposition that the CPW scheme development would be complete in its first year of operation it is likely to underestimate the time required for the effects to fully manifest themselves. Issues around the model calibration may also mean that the simulated times are underestimates.

50. The significance of this to groundwater mounding is that it illustrates the difficulty in the future of clearly distinguishing CPW scheme induced changes from climate driven ones. The simulation results show that, even where the CPW scheme mounding is relatively large, it may still be difficult to prove that to be the case. This has important implications for the design of monitoring and mitigation measures.

Prediction of changes to lowland stream flows

51. Weir (2008) predicts that the CPW scheme would result in:
- increased median flows in all lowland streams, and
- increased mean annual low flows in most - the exceptions being the Doyleston Drain, Hanmer Drain and Irwell River.

(The CPWES scenario indicates a 1311% increase in the simulated Status Quo median of 9 L/s even though the simulated 7-day mean flow of zero is unchanged.)

52. The model report acknowledges the difficulty of accurately simulating groundwater discharge to streams and it is reasonable not to give too much weight to the exact magnitude of the predictions. Nevertheless, it is reasonable to expect that lowland stream flows would increase as a result of the CPW scheme and it is not obvious why mean annual low flows would not also increase in the Doyleston Drain, Hanmer Drain and Irwell River. The applicant argues that changes are likely to generally be favourable benefits and that the existing drainage infrastructure is likely to be able to accommodate the expected flow increases. As for the issue of groundwater mounding, the design of monitoring and mitigation of any unfavourable outcomes will be complicated by the long period over which changes may occur.

Prediction of effects on surface water/groundwater interaction

53. The CPWES scenario includes the effects of the proposed flow diversions from the Rakaia and Waimakariri Rivers by reducing the specified flow inputs to the model according to irrigation demand and the expected conditions governing the surface water takes. Weir (2008) predicts reductions in groundwater recharge rates of approximately 5% and 8% for the Waimakariri River and Rakaia River respectively. However these reductions in river recharge to groundwater are predicted to be offset by the increased land-surface drainage resulting from the additional irrigation under the proposed CPW scheme.

54. These predictions seem plausible but, given the significance of any potential for effects on recharge to the Christchurch groundwater system, it would have been desirable to have provided more detailed analysis and to have considered alternative scenarios. Questions that remain unanswered include:
- How sensitive are the predictions to uncertainties in the model parameters?
- How sensitive are the predictions to the assumptions made regarding irrigation efficiency?

- How are groundwater levels expected to change in the period between the commencement of flow diversions and the full development of groundwater mounding? Given that mounding effects are expected to develop more slowly closer to the coast there could be a period of many years during which river recharge and groundwater levels are low.
- What are the implications for groundwater levels and flows in the area to the north of the Waimakariri River where the offsetting effects of increased land-surface recharge will not occur?

55. The CPWES scenario also provides an indication of changes to surface water/groundwater interaction in the Selwyn River with substantial increases in median and low flows are predicted for the Selwyn River at Coes Ford. I have commented above on the possibility that the model may be overstating this effect. Nevertheless it is plausible that, since it flows through the proposed CPW scheme area, the Selwyn River flow would be affected to a significantly greater extent than the lowland streams.

Prediction of effects on groundwater flow directions

56. Weir (2008) describes the steady-state flow directions simulated for the Status Quo and CPWES scenarios. The simulated shallow groundwater flow directions indicate a groundwater divide that is comparable to that implied by the Groundwater Protection Zone proposed Variation 6 of the Natural Resources Regional Plan. The extent of that zone was based on a qualitative evaluation of shallow groundwater flow directions inferred from piezometric contours, supporting water quality data and geological mapping. In Figure 5 I have superimposed the protection zone on to the plot of flow directions (Status Quo average period). This provides only an approximate comparison since I did not have access to a geo-referenced version of the flow direction plot[3]. Nevertheless it supports the general contention that discharge from the CPW scheme will largely flow in the direction of Lake Ellesmere.

57. Comparison of the Status Quo and CPWES flow direction plots (Appendix I, Weir 2008) suggest that on a regional scale groundwater flow direction may be unchanged by the CPW scheme. This seems a reasonable assessment even though it might at first be seen as contradicting the statement that the loss of recharge from the Waimakariri River will be offset by increased land-surface recharge as a result of irrigation from the CPW scheme.

58. The modelled flow directions suggest that deeper groundwater under the CPW scheme area could be flowing more directly towards Christchurch (in model aquifers 4 & 5). The particle tracking calculations (illustrated in Appendices J & K, Weir 2008) show shallow groundwater from within the CPW scheme area flowing towards Lake Ellesmere and groundwater in the Christchurch water supply area as being predominantly originating from the Waimakariri River or from within the Groundwater Protection Zone. One of the particle tracks suggests the potential for groundwater flow from the upper plains area within the CPW scheme area to reach Christchurch.

59. Particle track calculations are dependent to a large extent on the pattern of hydraulic conductivities adopted in the model. It should be remembered that the model attempts to represent the complexity of the real world using a simplified description of hydraulic conductivity and there is considerable uncertainty involved in these descriptions as illustrated by the alternative versions adopted for Aquifer 4-5 hydraulic conductivity zones for Model 2 (Aqualinc 2007) and Model 2A (Weir 2008) – see Figure 4. I expect that very different particle tracks would result if the Aqualinc (2007) hydraulic conductivity pattern had been used and in my opinion the particle tracks provided in Weir (2008) should be regarded as speculative.

[3] I understand that a more accurate overlay of the proposed CPW scheme area and the Groundwater Protection boundary has confirmed that there is a small area of overlap.

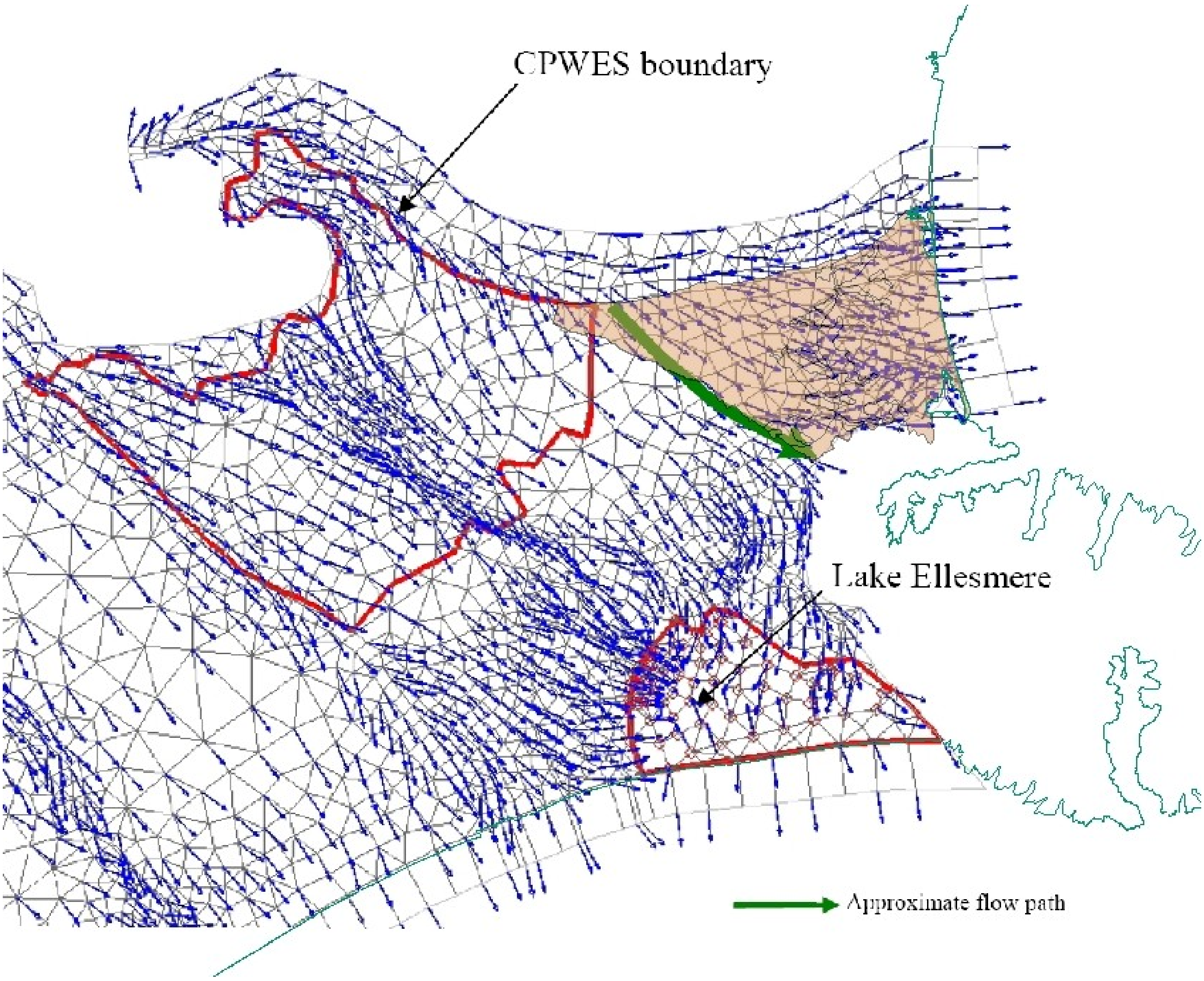
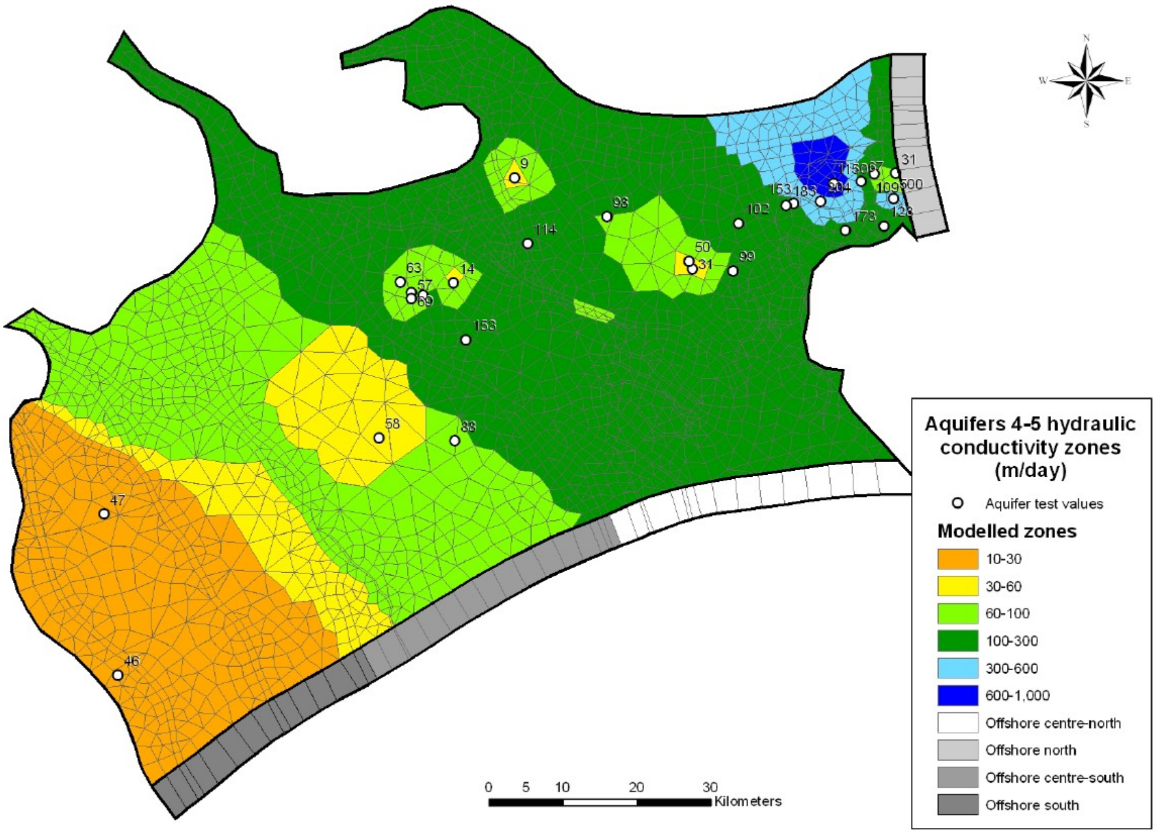
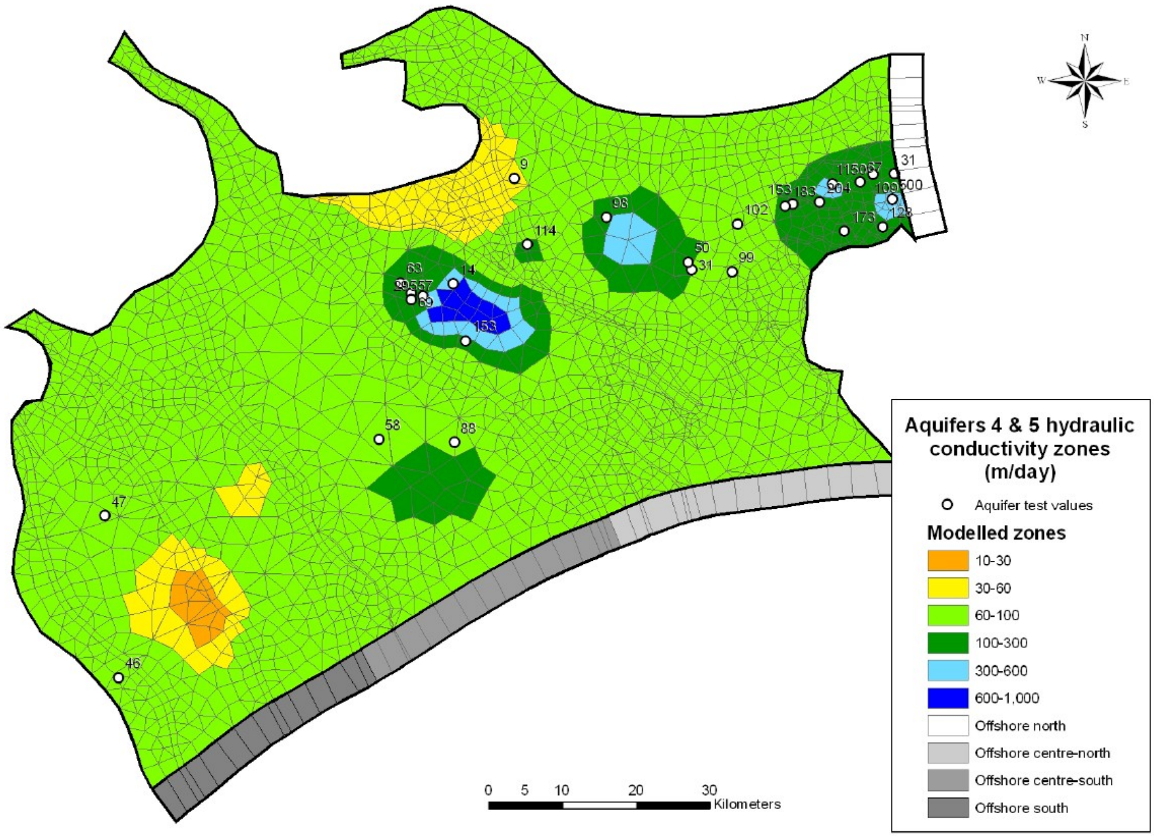


Figure 5: The Christchurch groundwater protection zone superimposed upon simulated flow directions (Weir 2008, Status quo average period (1 March 1994) – shallow aquifer).



(a) Model 2 (from Aqualinc 2007).



(b) Model 2A (from Weir 2008).

Figure 4: Alternative aquifer 4 & 5 hydraulic conductivities.
Model 2 is the version reviewed by Merrick (2007).
Model 2A is the version used for particle track calculations.

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[5] Available from http://www.ecan.govt.nz/Our+Environment/Water/Groundwater/Groundwater+Analysis+Tools/leakyAquiferBehaviour.htm

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
7.1	Is prediction made for steady state conditions?		Missing	No	Maybe	Yes			
7.2	Is prediction made for transient conditions?		Missing	No	Maybe	Yes			
7.3	Are the assumed stresses reasonable?		Missing	Deficient	Adequate	Very Good			
7.4	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			
7.5	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			
7.6	Have multiple scenarios been run for operational alternatives?		Missing	Deficient	Adequate	Very Good			
7.7	Are model predictions made at scales consistent with model space and time scales?		Missing	No	Maybe	Yes			
7.8	Are the model predictions plausible?		No	Maybe	Yes				
7.9	Are model predictions likely to be impacted by constraining boundary conditions?		Unknown	Yes	Maybe	No			
7.10	If boundary conditions affect the predictions, are the predictions defensible?		Unknown	No	Maybe	Yes			
7.	**TOTAL SCORE**								

Appendix: Model prediction table excluded from Merrick (2007) review – reproduced from MDBC (2001)

My response to these unanswered peer review questions

7.1 *Is prediction made for steady state conditions?*
No. But arguably a steady state simulation would be of little value given that the expected response is essentially a dynamic one.

7.2 *Is prediction made for transient conditions?*
Yes.

7.3 *Are the assumed stresses reasonable?*
Yes. The crop-soil modelling of rainfall recharge and irrigation demand is a reasonable approach. Limitation is that only one land-use pattern has been considered. Sensitivity analysis deals with in part.

7.4 *Is the time horizon for prediction comparable with the length of the calibration / verification period?*
Yes – it uses the same length of record.

7.5 *Have multiple scenarios been run for climate variability?*
No – yet climate change scenarios consistently indicate that drought risk (and irrigation demand) should be expected to increase.

7.6 *Have multiple scenarios been run for operational alternatives?*
No – yet there is considerable scope for different land use, application of different irrigation techniques, options for managing surplus allocated water and possibly options for using a higher proportion of the diverted water.

7.7 *Are model predictions made at scales consistent with model space and time scales?*
Yes

7.8 *Are the model predictions plausible?*
In part – it's notable that in many areas of the model the simulated groundwater levels exaggerate the observed annual pattern of fluctuations. Conversely, the historic high groundwater levels resulting from the higher than average rainfall recharge in the late 70's is under-estimated in some areas and simulated Selwyn River flow is over-estimated in the same period. These particular predictions are directly relevant to the CPW mounding prediction and so are most relevant to the consideration of plausibility.
Flow direction predictions are plausible, particle track could reasonably be regarded as being speculative.

7.9 *Are model predictions likely to be impacted by constraining boundary conditions?*
Possibly – river boundary conditions and constant head boundaries may impact on predictions

7.10 *If boundary conditions affect the predictions, are the predictions defensible?*
Potential impacts have been partially explored by sensitivity analysis.