Before the Canterbury Regional Council

IN THE MATTER OF the Resource Management Act 1991

AND

IN THE MATTER OF Water permit applications by Simons Pass Station Limited and Simons Hill Station Limited.

Evidence in Reply of Ian McIndoe

INTRODUCTION

1. My full name is Ian McIndoe.

2. My qualifications and experience were outlined in my earlier evidence.

CODE OF CONDUCT

3. 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 agree to comply with it when giving oral evidence. This evidence is within my area of expertise.

SCOPE OF EVIDENCE

4. I have prepared this evidence at the request of Simons Hill Station Limited and Simons Pass Station Limited ("the Applicants").

5. My evidence has been prepared in response to concerns raised by submitters and ECan officers about the conclusions reached by GHD Ltd in the Water Quality Study (WQS) and by me in my earlier evidence relating to groundwater flow directions and groundwater / surface water interactions in the Pukaki Flats.

6. My evidence addresses these concerns by describing the field investigation programme that was undertaken to gain a better understanding of the Pukaki Flats groundwater system and discusses the results of the investigations.

7. Two reports have been provided to ECan and to the Hearing Panel describing the Pukaki Flats Groundwater Investigations. These are a Summary Report[1] which outlines the key conclusions and an Appendix Report[2] containing full details of the investigations and monitoring.

REVIEW OF INFORMATION

8. In addition to the Groundwater Summary Report C09073/1 and associated Appendix to the Summary report, I have reviewed the following documents and information when preparing this evidence.

- The submitter brief of evidence of Peter Callander on individual farm properties.

---

[1] "Groundwater Investigation – Pukaki Flats, Mackenzie District" Summary Report. Aqualinc Report Number C09073/1, prepared for Simons Hill Station Ltd and Simons Pass Station Ltd, April 2010

[2] "Groundwater Investigation – Pukaki Flats, Mackenzie District" Appendix to Groundwater Summary Report. Aqualinc Report Number C009080 prepared for Simons Hill Station Ltd and Simons Pass Station Ltd, April 2010

- The submitter brief of evidence addendum of Peter Callander on cumulative water quality effects.
- The submitter brief of evidence of Richard Turner on individual farm properties.
- The submitter 1st supplementary of evidence of Richard Turner on individual applications.
- The S42a addendum report of Maria Bartlett.

BACKGROUND

9. Simons Hill and Simons Pass Stations have applied for resource consent to take water to irrigate up to 4,022 ha of land known as the Pukaki Flats, located between the Pukaki River and the Mary Range.

10. In September 2008 the Water Quality Study (WQS) prepared by GHD Limited for Mackenzie Water Research Limited (MWRL) concluded that the effect of the proposed water use on the Tekapo River and Lake Benmore would be minor.

11. This conclusion was mainly premised on the assumption that the majority of groundwater from the Pukaki Flats passes underneath the Tekapo River and flows directly to Lake Benmore. This assumption was supported by the MODFLOW groundwater modelling undertaken by GHD.

12. The conclusion that groundwater passes underneath the Tekapo River is highly significant, because it follows that the water quality impacts on the Tekapo River itself, as a result of irrigating the Pukaki Flats, would be less than minor.

13. The WQS concluded that the Northern Arm of Lake Benmore has sufficient assimilative capacity to accommodate nutrient losses from the Pukaki Flats, and that effects on the water quality of Lake Benmore would remain within prescribed acceptable limits.

14. The conclusions in the WQS were supported by some field measurements, including river gaugings, bore information from the Twizel area and from a production bore owned by Rosehip Orchards New Zealand Limited. The Rosehip Orchards bore is located on the flats between the Twizel and Pukaki Rivers. However, no detailed on-site information was available at the time that related directly to the Pukaki Flats.

INITIAL INVESTIGATIONS

15. The Applicants recognised that the WQS conclusion relating to the Pukaki Flats could be challenged on the basis of insufficient on-site supporting data. They began an investigation and monitoring programme to obtain additional information to better understand the movement of groundwater from the Pukaki Flats and to find out if the conclusion reached by GHD was consistent with the additional information.

16. In March 2009, twelve shallow piezometers were installed along the Tekapo River between the southern end of the Mary Range and the Tekapo Iron Bridge, and about half way up the dry riverbed of the Pukaki River. Water levels were measured and water quality testing was carried out. In addition, the Tekapo River and the Lower Tekapo River were gauged in three locations.

17. This information was supplied to GHD, who incorporated it into their modelling. They concluded that their original assumptions could still be supported, i.e. that the majority of groundwater from the Pukaki Flats passes underneath the Tekapo River and flows directly to Lake Benmore. Updated versions of the WQS Reports were issued in August 2009.

18. Water level and water quality information has continued to be gathered from these shallow piezometers.

19. The monitoring information, along with the GHD modelling, provided the basis for the evidence I presented to the Hearing Panel on 19 November 2009. I concluded that the effects of irrigating the

Pukaki Flats on surface water quality in the Tekapo River and Lower Tekapo River is likely to be minor, but that some interaction with the Tekapo River could not be completely discounted. I also concluded that the majority of groundwater from the Pukaki Flats would pass under the Tekapo River into Lake Benmore or beyond.

SUBMITTER CONCERNS

20. ECan officers and submitters (in particular Peter Callander for Meridian), raised concerns about the conclusions reached by GHD and my conclusions presented in my evidence relating to groundwater direction and groundwater-surface water interactions.

21. In summary, the opinions of the Officers and submitters was as follows:

- There is a high degree of uncertainty associated with partitioning between flow into surface water resources and groundwater (due to lack of reliable field data to calibrate GHD's MODFLOW groundwater model).
- The GHD groundwater model was unable to be calibrated for the Pukaki Flats, as no data existed.
- There is uncertainty in groundwater paths and final destination of groundwater, specifically groundwater flow to Lake Benmore. No groundwater contour map was presented.
- The groundwater system is anisotropic and horizontal preferential flow paths could occur, leading to increased nutrient discharge to the Tekapo River.
- There is possible inconsistency between model outputs and actual measurements.
- The issues of timing of cause and effect relationships and seasonal patterns had not been considered.
- The impact of an increase in groundwater levels on flows into neighbouring rivers had not been properly considered.
- There were possible flow variations in rivers between gauging points that had not been identified because the gaugings undertaken were not "close" enough to ensure that water was not being gained in the locations where gauging had not occurred.
- There was no groundwater level data from deep bores on the Pukaki Flats itself.
- There were issues raised in respect of an area of approximately 1 km^2 directly at the very northern end of the Haldon Arm.
- There was insufficient information regarding key groundwater parameters under the Pukaki Flats, e.g. hydraulic conductivity and travel times.

22. Overall, the clear view presented by submitters and ECan officers was that the analysis was not conservative enough and that lack of data created significant uncertainty about the conclusions.

23. However, the evidence that I presented to the Hearing Panel used realistic parameters based on the best available information at the time. The base information was obtained from field measurements available at the time, and when used to determine aquifer through-flow for example, produced numbers that were lower (more conservative) than those provided by the GHD model. In my view, a sufficiently conservative approach had been taken. However, I acknowledged that further field measurements would be required to strengthen that position.

FURTHER INVESTIGATIONS IN RESPONSE TO CONCERNS

24. In order to be in a position to respond to the concerns that I have described, the Applicants embarked on further field work to reduce uncertainty and risk to the environment. The approach was twofold:

- To carry out further fieldwork and analysis to better understand the groundwater system, groundwater-surface water interactions and nutrient pathways.

- To develop a staged farm development and monitoring plan that incorporated a mitigation/ adaptive management process to reduce any risk still further.

25. The staged adaptive management plan involves extensive monitoring with planned feedback loops back to farming development.

FIELDWORK REQUIRED

26. The key gaps in knowledge were groundwater level changes and groundwater quality changes in the Pukaki Flats proposed irrigation area, and the path that drainage from that area will take. The following fieldwork was proposed to fill the gaps:

- Continue monitoring groundwater levels in the existing piezometers and continue to carry out water quality testing (limited to key parameters).
- Install and test four deep monitoring bores in the Pukaki Flats to develop an improved piezometric surface, establish the aquifer type (unconfined or semi-unconfined) and determine aquifer properties.
- Drill a small cluster of bores at different depths to find out whether there are downward or upward hydraulic gradients in the lower Pukaki Flats.
- Undertake additional flow gaugings at closer intervals along the Tekapo River to more accurately establish gaining and losing reaches.
- Drill temporary shallow piezometers in the Tekapo riverbed from the Mary Burn to Lake Benmore to determine piezometric surface and direction of groundwater flow.
- Revisit the possibility of doing a step-test on the Rosehip deep irrigation bore to refine the piezometric surface and to determine aquifer transmissivity to the west of the Pukaki River.

27. Field investigations were carried out within and near the Pukaki Flats during February 2010. The field work consisted of the following:

    - Further stream gauging on the Tekapo and Lower Tekapo Rivers.
    - Installation of four 150mm diameter bores on the Pukaki Flats (between 15 and 62 m deep).
    - Installation of 15 shallow piezometers within or near the bed of the Tekapo, Pukaki and Twizel Rivers (permanent observation and monitoring bores were installed with bentonite seals).
    - Measurement of groundwater level from 27 piezometers.
    - Measurements of river stage height at or near to relevant piezometers.
    - Two step-discharge tests, and one constant-discharge aquifer test on the Pukaki Flats deep bores.
    - Groundwater sampling from 15 piezometers.
    - Surface water sampling from three sites on the Tekapo River.

28. A map showing the locations of the monitoring sites is included in Appendix A of my evidence.

29. The locations and elevations of all but four of the monitoring sites were surveyed using a Real-Time Kinematic GPS system (RTK GPS). The indicative accuracy of RTK GPS is ± 0.03 m in both the horizontal and vertical directions.

30. The field results from the above investigations were circulated to all parties on 06 March 2010.

AQUIFER TYPE

31. Based on drillers bore logs, measured groundwater levels, and on aquifer tests, the upper (most shallow) aquifer, which will receive the land-surface recharge from the proposed irrigation, appears to be:

- Possibly unconfined in the upper-mid areas of the Pukaki Flats. If not unconfined, it will be semi-unconfined.
- Unconfined in the vicinity of the Tekapo riverbed around the Mary Burn/ Tekapo River confluence.
- Semi-unconfined in the lower areas of Pukaki Flats and Tekapo River.

32. The implications of this aquifer type are that horizontal hydraulic conductivity is likely to be significantly higher than vertical conductivity and that horizontal flow will predominate in the lower Pukaki Flats and under the Tekapo River.

AQUIFER PERFORMANCE

33. Step-discharge tests were conducted on two deep bores on the Pukaki Flats. Constant-discharge tests could not be performed on these bores due to the lack of observation bores. The step-tests were carried out according to best-practice guidelines for aquifer testing, and were analysed using the method derived by Eden and Hazel (1973) to calculate aquifer transmissivity and well efficiency.

34. Analysis of the step-test results provided an aquifer transmissivity of 650-1,000 m^2/d for bore H38/0261 (the northernmost deep bore, 62 m deep) and 4,460 m^2/d for bore I38/0103 (42 m deep). A range of values is reported for bore H38/0261 because the full set of test data could not be matched with a single transmissivity value. The range of values for bore H38/0261 is regarded as low-average for alluvial gravel. The values for bore I38/0103 are high.

35. Well efficiency was calculated from the test results and was found to be very low. The analyses found that 83- 97% of the measured drawdown was due to losses in the well. Water level recovery was rapid however, implying that aquifer transmissivity may be higher than calculated. The low well efficiency may be related to the use of 150 mm diameter bores.

36. A constant discharge test was conducted on bore I38/0104. This bore is near the Tekapo-Pukaki River confluence and is approximately 25 m deep. Groundwater levels in five observation bores were monitored before, during and after testing. Bore I38/0104 was pumped continuously for 13.1 hours at an average rate of 16.3 ℓ/s. Water from the pumped bore was discharged into the Tekapo River, 450 m away. The constant discharge test was carried out according to best-practice guidelines for aquifer testing.

37. Corrections for barometric pressure variations and a linear antecedent trend were applied to the data. The corrected data has been analysed using methods suitable for confined, unconfined and semi-confined aquifers. Results from the test were analysed using the methods of Theim (1906), Theis (1935), Cooper-Jacob (1946) and Boulton (1973) to give aquifer transmissivity, specific yield, storage and leakage. Results from the analyses were averaged to give single values for the aquifer parameters. Full details of the aquifer test set-up and results are given in the Appendix Report.

38. Analysis of the constant discharge test results provided an average transmissivity of 2,799 m^2/d, a specific yield of 0.0495, and a leakage value L of 400. Specific yield is low, consistent with a semi-confined or semi-unconfined leaky aquifer. Transmissivity is moderate to high, indicating that the aquifer has the ability to transmit high quantities of water. The leakage value is indicative of an aquifer with moderate leakage into the pumped aquifer.

39. In one of the monitoring bores, I38/0105, a semi-confining layer (aquitard) of claybound gravels was identified from the bore-log. The vertical hydraulic conductivity of the 4.9 m aquitard was calculated to be 0.07 m/d.

GROUNDWATER FLOW DIRECTION

40. The surveyed elevations of the monitoring bores were used to convert water level measurements to elevations above mean sea level. This information was then used to plot piezometric contours (lines connecting points with static water levels at equal heights above mean sea level).

41. Piezometric contour lines were based on water levels from 24 bores on the Pukaki Flats and in the Tekapo and Pukaki River beds.

42. Groundwater flow directions were mapped by drawing lines perpendicular to the piezometric contour lines. Beyond the extent of the contoured area, lines were extrapolated to indicate the possible direction of groundwater flow. A map showing the piezometric contours and flow directions is included as Appendix B of my evidence.

43. Key points of the flow direction analysis are:

- At the confluence of the Tekapo and Pukaki Rivers, groundwater from the Pukaki Flats flows south towards Lake Benmore or beyond.
- Between the 400 and 440 m topographic contour lines north-east of the Tekapo/Pukaki River confluence, groundwater flows in a direction roughly parallel to the Tekapo River. It appears that leakage from the Tekapo River into groundwater is influencing groundwater flow direction by pushing the Pukaki Flats groundwater in the direction of the Tekapo/Pukaki confluence.
- Between the 400 and 380 m topographic contour lines, groundwater flows in a more southerly direction compared to the Tekapo River. A small amount of groundwater from the Pukaki Flats may be returning to the Pukaki River above the Pukaki/Tekapo River confluence, or shallow subterranean flow from beneath the Pukaki River bed may be returning to the surface.
- Although not shown on the piezometric contour map, groundwater levels relative to the Pukaki River indicate that water from the Pukaki River or from subterranean flow from beneath the river is moving into the Pukaki Flats in the upper reaches.

HORIZONTAL HYDRAULIC GRADIENTS

44. In the Pukaki Flats, groundwater levels are falling by approximately 4m/km in a southerly direction from the top of the Flats to the Tekapo-Pukaki River confluence. Gradients tend to be slightly steeper in the upper flats, flatter in the mid-lower flats, with a steepening gradient in the vicinity of the Tekapo River.

45. The high transmissivity coupled with limited recharge to the Pukaki Flats due to low rainfall (leakage from Lake Pukaki may also be contributing to a groundwater baseflow) are likely to be the cause of the relatively flat horizontal gradients, as water is flowing towards Lake Benmore. Steep gradients indicate either low transmissivity or high recharge, neither of which is present in this region.

VERTICAL HYDRAULIC GRADIENTS

46. Vertical hydraulic gradients and cross-sections showing groundwater levels relative to river levels and the land surface were determined from the piezometers and land survey data. The cross-sections and a map showing their locations are included as Appendix C of my evidence.

47. Data from the shallow (approximately 5 m deep) piezometers in the Tekapo riverbed identified downward hydraulic gradients in all sites, i.e. the free-surface elevation of the river is higher than the groundwater level below the river bed. It shows that the Tekapo River is leaking to groundwater, rather than groundwater leaking to the river.

48. Tight material was described in most of the piezometer bore logs. This material is likely to be forming an aquitard, which is causing the Tekapo River to be perched above the groundwater system over most of its length between the southern end of the Mary Range and Lake Benmore. The

information indicates that groundwater is flowing from the Pukaki Flats underneath the Tekapo River in a southerly direction towards Lake Benmore.

49. This result is also consistent with a groundwater system that has moderate to high horizontal hydraulic conductivity underlying aquitards beneath the Tekapo River. If vertical hydraulic conductivity and leakage was high, water levels in the groundwater system and river would be the same within a depth of 5 m. However, the actual field results from the river bores show that this is not the case.

50. One site (Hole 1a) near the Mary Burn showed little or no head difference between shallow groundwater and river level. The riverbed at that site consisted of gravel and sand, but not tight. A logical interpretation is that there is a close connection between groundwater and the Tekapo River at that location. However, another site (Hole 1b) about 50 m away from Hole 1a showed a downward hydraulic gradient, with tight material identified in the log.

51. Another site (Hole 9, Cross-sections C1 and C2) near to the Tekapo-Pukaki River confluence, showed a smaller difference in water levels between the Tekapo River and 5 m deep groundwater. There is some evidence of seepage in this area with the presence of wet marsh areas immediately above the Tekapo/Pukaki confluence. As no flowing water is evident in these marsh areas, the shallow flow contribution is minimal.

52. At Lake Benmore, little or no gradient between shallow groundwater and lake level was identified. It shows that Lake Benmore is acting as a constant head boundary. This is consistent with the original GHD modelling assumption.

53. As only step tests could be completed on the two deep bores further up the Pukaki Flats due to there being no observation bores available, vertical hydraulic gradients from bore information in the Pukaki Flats cannot be determined. However, the elevation of water levels in the two deep bores on Pukaki Flats is below that of the Pukaki riverbed, and the groundwater surface in cross-section B slopes away from the river. It follows that Pukaki River water (during times when water is being spilled into the River from Lake Pukaki), or subterranean flow from the riverbed is moving eastwards into the Pukaki Flats.

RIVER GAUGING

54. A gauging run was carried out on the Tekapo River in February 2010. A map showing the locations of the gaugings sites and the measured flow at each site is included as Appendix D of my evidence.

55. The key results from the gauging run are:

    - An overall decrease in flow of 1.4 m^3/s in the Tekapo River from the confluence with the Mary Burn down to Lake Benmore.
    - A small (approximately 0.5 m^3/s) increase in flow in the mid reaches of the Tekapo River above the Iron Bridge, followed by an equivalent decrease in flow.
    - A small flow of water (0.3 m^3/s) discharged from the Pukaki River immediately upstream of the Tekapo River confluence. This flow is groundwater–fed, as the Pukaki River is dry 1 km upstream of the confluence.
    - A progressive decrease in flow downstream from the Iron Bridge in the lower Tekapo River to Lake Benmore.

56. Except for the small increase in flow in the reach immediately above the Iron Bridge, the Tekapo River is losing flow from Mary Burn to Lake Benmore. At the southern end of the Mary Range the flow is 7.2 m^3/s, while at Lake Benmore the flow is 5.8 m^3/s after including a contribution of 0.3 m^3/s from the Pukaki River. During these gauging measurements the Tekapo River was losing 1.7 m^3/s between the southern end of the Mary Range and Lake Benmore, if the Pukaki River contribution is subtracted.

57. The increase in flow above the Iron Bridge, between gauging sites T3 and T4, is unlikely to be caused by groundwater discharge from the Pukaki Flats as there is no evidence of groundwater discharge in that area. In addition, water chemistry results show no evidence of a change in chemical signature.

58. The increase is most likely caused by Tekapo River water moving into the riverbed gravels (noting that there are downward gradients below the Mary Burn) and then reappearing above the Iron Bridge as the downward gradients reduce.

59. Mr David Boraman, who undertook the flow gauging, noted that there were large gravel deposits in the river bed immediately upstream of gauging site T3, which was the site with the lowest recorded flow upstream of the Iron Bridge. It is therefore likely that the lower flow measured at this site was due to a higher proportion of shallow sub-surface flow (i.e. flow beneath the river bed that could not be measured by gauging) than at the adjacent sites.

WATER CHEMISTRY

60. Water samples were taken from 16 groundwater bores and three surface water sites on the Tekapo River in February 2010. The water samples were analysed by Hill Laboratories for the major anions and cations, dissolved reactive phosphorus and pH.

61. All samples complied with the ANZECC (2000) guidelines for fresh water quality. All samples also complied with the Ministry of Health (2005) drinking water standards apart from four that had pH slightly outside of the recommended range.

62. All samples had Nitrate-N concentrations that were less than the Ministry of Health maximum acceptable value of 11.3 mg/l. Total Nitrate-N + Nitrite-N for all samples was less than the ANZECC (2000) recommended value of no more than 0.444 mg/l.

63. No samples exceeded the ANZECC (2000) guideline value of 0.01 mg/l for dissolved reactive phosphorus.

64. Ion concentrations from the February 2010 water samples were combined with results from water samples taken in May, August and October 2009, and averaged.

65. The Stiff Plot method (Stiff, 1951) was used to characterise and group water samples based on a graphical comparison of ion concentrations. A map showing the spatial distribution of Stiff Plot patterns is included as Appendix E of my evidence.

66. The key result from the Stiff Plot analysis is that the water samples from the Tekapo River and the riverbed piezometers (the yellow Stiff Plots in Appendix E) have a hydrochemical signature that is distinct from the water samples from bores on the Pukaki Flats (the blue Stiff Plots in Appendix E). This supports the assumption that groundwater from the Pukaki Flats is flowing underneath the Tekapo River.

GROUNDWATER THROUGH-FLOW

67. Aquifer test results and horizontal hydraulic gradients from measured groundwater levels were used to provide the parameters required to estimate the volume of water flowing through the Pukaki Flats aquifer.

68. The transmissivity calculated for each of the three aquifer tests was divided by the saturated aquifer thickness above the screen of the pumped bore. The values from the three aquifer tests were then averaged to give a representative hydraulic conductivity of 233 m/d for the Pukaki Flats aquifer.

69. The hydraulic gradient was calculated as the difference in water level elevation between bore H38/0261 (the northernmost deep bore) and Hole 9 (near the Tekapo / Pukaki confluence) divided by the horizontal distance between them. This gave an average hydraulic gradient of 0.0037 m/m.

70. The average width of the Pukaki Flats is 6,000 m. The remaining parameter required to estimate the aquifer through-flow is the aquifer thickness. Given that no precise information on aquifer thickness is available, through-flow was calculated for a range of thickness values. The results, which are shown in Table 1, range from 270,000 m^3/day (approximately 3 m^3/s) to 1,080,000 m^3/day (approximately 12 m^3/s).

Table 1 Range of values for groundwater through-flow.

Q (m^3/day)	K (m/day)	dh/dl (m/m)	W (m)	B (m)
269,115	233	0.00385	6,000	50
538,230	233	0.00385	6,000	100
807,345	233	0.00385	6,000	150
1,076,460	233	0.00385	6,000	200

71. The through-flow values in the table are consistent with the range of flows provided by GHD (8 m^3/s) and in my earlier evidence (4 m^3/s). It shows that the original estimates are supported by field measurements.

72. If a significant proportion of this water was entering the Tekapo River, either directly through upwelling in the riverbed or via springs or streams along the river banks, spring-fed streams should be able to be located, or significant increases in river flows should have been able to be measured. Neither has been found.

73. Also, the chemical signature of the Pukaki Flats groundwater as shown on the Stiff Plots is not found in the Lower Tekapo River.

CONTAMINANT TRANSPORT RATES

74. Contaminant transport rates for the Pukaki Flats were estimated using equations that describe movement of contaminants in groundwater by advection, mechanical dispersion and molecular diffusion.

75. The average hydraulic conductivity value of 233 m/d from the aquifer tests was used in the advection equation.

76. Table 2 shows expected transport times for nutrients to travel various distances in groundwater beneath the Pukaki Flats. The travel times in Table 2 are based on an initial contaminant concentration of 0.1 mg/l. For comparative purposes the analysis was repeated with an initial concentration of 40 mg/l. The results were found to be relatively insensitive to the significant increase in initial concentration.

Table 2: Travel times for a contaminant in Pukaki Flats groundwater based on a K value of 233 m/d

Distance down-gradient from the point at which the contaminant was released into the groundwater (m)	Time	
	Months	Years
3,000	8	0.65
6,000	14	1.15
9,000	21	1.75
12,000	26	2.2

77. Some contaminants could travel more quickly than indicated in Table 2 for two main reasons. The first is that the 233 m/d hydraulic conductivity is an average value determined from aquifer tests and

does not take into account that contaminants can travel through preferred channels in the strata at up to 10 times the rate determined using average hydraulic conductivity (Dann et al 2008).

78. The second reason is that the Table 2 analysis is based on times for the concentration of nutrient equal to the leached concentration to travel the prescribed distance. In practice, some nutrient will travel much more quickly and some more slowly than it takes for the average amount of nutrient to travel the prescribed distance.

79. For this reason the travel times in Table 2 are likely to be an overstatement of the times necessary to detect an increase in nutrient concentrations above baseline levels at the specified distances downstream of the contaminant source.

GROUNDWATER- SURFACE WATER PARTITIONING

80. The field measurements have shown that the interaction between groundwater from beneath the Pukaki Flats and surface water (the Tekapo River and the small area of marsh above the confluence in the Pukaki River) is very limited.

81. At the Mary Burn confluence, groundwater is closely connected to surface water. However, there is no evidence of a measurable flow of groundwater moving into the Tekapo River between the Mary Range and Lake Benmore.

82. With respect to the Pukaki Flats, I consider that the majority of groundwater is travelling underneath the Tekapo River. In addition, it is also highly likely that there is a small contribution to Pukaki Flats groundwater from the Pukaki River in its mid-upper reaches. Some of this water may reappear in the Pukaki River in the region of the Tekapo/Pukaki River confluence. However, the water chemistry, flow gauging and lack of significant upward hydraulic gradients show that if it occurs at all, it is minor.

83. It follows that the majority of the Pukaki Flats groundwater should be partitioned to travel as groundwater to Lake Benmore and only a very small proportion, if any, partitioned to the Tekapo River in the vicinity of the Pukaki River/ Tekapo River confluence.

GHD MODEL CALIBRATION

84. The calibration of the GHD groundwater model was done using all information available at the time. It assumed constant head boundaries at Lake Pukaki and Lake Benmore, and included the Tekapo River as a boundary condition.

85. The model output indicated that the majority of groundwater from the Pukaki Flats was moving directly to Lake Benmore and that the quantity of groundwater entering the Tekapo River was very small. The GHD modelling predicted a groundwater contribution of 0.2 m^3/s to the Tekapo River, with an increase of 0.013 m^3/s after irrigation development. The groundwater contribution to the Tekapo River is about 2.5% of the total estimated groundwater through-flow of 8 m^3/s (as estimated by GHD), or 5% of 4 m^3/s (as estimated by me in my earlier evidence) i.e. 0.2 m^3/s.

86. The recent fieldwork has confirmed that Lake Benmore is a constant head boundary, or that groundwater at the head of the lake and lake water levels are coincidentally the same, consistent with the GHD modelling.

87. It has also shown that the interaction of groundwater with the Tekapo River is less than that assumed in the GHD model, as the Tekapo River is losing water to groundwater. On that basis, it is likely that the GHD model has in fact overestimated the connection of groundwater with the Tekapo River and is therefore conservative.

GROUNDWATER PATHS AND FINAL DESTINATION OF GROUNDWATER

88. The recent fieldwork shows that groundwater is moving from the Pukaki Flats in a southerly direction towards Lake Benmore. Water lost from the Pukaki River and from the Tekapo River is modifying the groundwater flow paths and directing groundwater flow in the direction of the Tekapo/Pukaki River confluence before it turns in a southerly direction towards Lake Benmore.

89. The absence of measurable spring flows and gains in the Tekapo River flows relative to groundwater through-flow shows that the majority of groundwater is not flowing into the Tekapo River, but flowing underneath the Tekapo River to Lake Benmore or beyond.

90. There is no evidence to suggest that significant quantities of groundwater are flowing into the Tekapo River downstream of the southern end of the Mary Range.

91. The exact destination of groundwater is not known. What is known is that the majority of groundwater is not entering flowing surface waterways. The field measurements strongly indicate that it is at least reaching the northern end of Lake Benmore if not (more probably) further south of that area.

92. Although Lake Benmore is clearly a hydrological boundary, it is not a geological boundary. It is extremely unlikely that all groundwater is entering Lake Benmore at the Tekapo River/ Lake Benmore confluence. The reason for that is that there are no hydrogeological controls to force groundwater up at that location.

93. Before the Benmore Dam was constructed, groundwater would have presumably moved through the alluvial gravels towards the present Benmore Dam location where narrowing of the valley may have forced groundwater to the surface. Today, the presence of the lake may force groundwater to the surface sooner, but it is unlikely to all appear in the lake at the northern end simply because of the presence of the lake.

94. A small (1 km square) area at the very northernmost end of the Haldon Arm of Lake Benmore has been identified as at risk of contamination from the effects of irrigation from the Pukaki Flats. Because nutrients in groundwater are expected to be fully mixed to a depth of 20-30 m or more by the time groundwater reaches Lake Benmore, and because there are no hydrogeological controls to force groundwater up in the particular 1 km square area, there is no reason to conclude that the area in question will be adversely affected by irrigation of the Pukaki Flats.

AQUIFER TYPE AND POTENTIAL FOR NUTRIENT DISCHARGE TO THE TEKAPO RIVER

95. The groundwater system is anisotropic, semi-unconfined, with moderate to high transmissivity.

96. The existing connection between groundwater and the Tekapo River is clearly minor, based on lack of spring-fed stream flow entering the Tekapo River, downward hydraulic gradients through most reaches of the Tekapo River downstream of the southern end of the Mary Range, measured flow loss of about 1.5 cumecs in the Tekapo River itself relative to at least 3 cumecs flowing through the groundwater system, and water chemistry.

97. There may be a degree of preferential path flow based on the difference between horizontal and vertical hydraulic conductivities.

98. With an increase in drainage from irrigation of the Pukaki Flats, the moderate to high transmissivity will allow rapid movement of additional water through the groundwater system. The rapid movement provides the ability to monitor contaminant discharge concentrations in the groundwater sooner and apply feedback actions to farming development and practices.

99. The main areas of irrigation will occur over recharge areas of the groundwater system and the majority of nutrient will disperse and enter deeper layers, travelling to Lake Benmore or beyond.

100. Based on the assumption that in Canterbury aquifers, Nitrate-N is rarely found in groundwater deeper than 50 m below the water table, estimates of travel distances for full mixing to 50 m have been determined to be 13 km from the source. In reality, mixing will occur throughout the Pukaki Flats and become progressively deeper with distance from the source. The estimates show complete mixing to 10 m depth within 500 m, to 20 m depth within 2 km and to 30 m depth within 5 km.

101. If irrigation was planned along the river margins, it is possible that partially mixed nutrients could enter the Tekapo River in a small area close to the Tekapo/ Pukaki River confluence. However significant setback distances from the River boundaries are proposed. The distance from the nearest part of the irrigation command area to the confluence of the Pukaki/ Tekapo rivers (and borehole H6) is 1.2 kms. Parts of the irrigation command area reach up to 2 kms from the Tekapo River in other locations.

102. Also, no part of the irrigation command area is on the lower terrace. The mixing depth estimates show that the setback distances are consistent with full mixing to 15-20 m, which will reduce nutrient concentrations and significantly lower the risk of significant quantities of nutrients entering the Tekapo River.

INCONSISTENCIES BETWEEN THE MODEL OUTPUTS AND ACTUAL MEASUREMENTS

103. Although the GHD model was based on very little field data, from a hydrological perspective the GHD model outputs are consistent with the interpretation of recent field data.

104. The model indicated that the contribution of groundwater to the Tekapo River was limited and that the majority of groundwater would flow directly to Lake Benmore. In fact, the model, by assuming that the Tekapo River was directly connected to groundwater, has probably overestimated the connection between the groundwater flow and the Tekapo River.

105. The recent field measurements support the GHD analysis. There is no evidence of a significant gain in flow in the Tekapo River. In most places in the Tekapo River downstream of the southern end of the Mary Range, the Tekapo River loses flow to groundwater. It does not gain flow from groundwater.

106. The groundwater system has relatively high transmissivity, which allows water to easily flow through deeper layers. The majority of the Pukaki Flats is a recharge zone and the semi-unconfined nature of the aquifer in the Pukaki Flats area means that land surface recharge will almost certainly move into deeper layers, despite the high horizontal hydraulic conductivity.

107. It needs to be remembered that Lake Benmore has been artificially created and that there are no hydrogeological features that would cause groundwater to rise and flow into the Tekapo River downstream of the southern end of the Mary Range. Field measurements support that fact.

ISSUES OF TIMING

108. The relatively high hydraulic conductivities of the groundwater system under the Pukaki Flats will allow rapid movement of contaminants through the system. Changes in nutrient concentrations downstream of the source, if they occur, will be seen within months or, in the worst case, within one or two years of the activity occurring.

109. It is almost certain that the effects of current land-use will be reflected in current measurements in the deeper bores. The effects of land use intensification will be seen in groundwater within months

and if significant increases in nutrient concentrations are detected close to surface water bodies, there will be time to modify the activity and mitigate the effects.

110. In addition, the rapid response of the groundwater system to changes in land-use will mean that if changes in contaminant concentrations occur, they will be flushed through the system quickly.

111. Fears that if the groundwater system is contaminated, potentially large contaminant concentrations will take decades to be detected are unfounded and are not supported by the groundwater investigations undertaken.

EFFECTS OF INCREASING GROUNDWATER LEVELS

112. The GHD modelling showed that an increase in recharge (i.e. by irrigation) over the Pukaki Flats would have very little impact on flows in the Tekapo River.

113. Given that there is a good match between the GHD modelling and the field measurements, there is very little reason to believe that the model would not reproduce the effects of increased land surface recharge equally well.

114. The model showed that increasing land surface recharge would have little impact on groundwater levels and on the Tekapo River. The model results were conservative in that they assumed a direct connection with the Tekapo River. This assumption was not borne out by field measurements.

115. On balance, it is unlikely that increased land surface recharge will have more than a minor effect on the groundwater levels or on the Tekapo River.

VARIATIONS IN FLOWS IN THE TEKAPO RIVER

116. Gauging of the Tekapo River has conclusively shown that there is no significant increase in flow in the reaches between the southern end of the Mary Burn and Lake Benmore. Measurements showed an overall decrease in Tekapo River flows of about 1.7 m^3/s over that reach.

117. An increase in flow was measured in the reach above the Iron Bridge. However, that followed a rapid decrease in flow in the reach above that point. There is no evidence of substantial quantities of groundwater from the Pukaki Flats entering the Tekapo River and then leaving the Tekapo River between gauging points.

STAGING PROGRAMME

118. In my primary evidence, I concluded that from the measured data and the GHD modelling that the majority of drainage from Pukaki Flats is not entering the Tekapo River between the Mary Range and the Iron Bridge. I also concluded that most, if not all, groundwater from Pukaki Flats is passing underneath the Tekapo River into Lake Benmore or beyond. Mr Heller, for CRC, came to a similar conclusion.

119. I also acknowledged that there was some uncertainty in the conclusions, although field work completed recently has added further strength to my conclusions.

120. Although my view is that irrigation drainage resulting from the proposed irrigation of the Pukaki Flats will primarily pass under the Tekapo River into Lake Benmore or beyond, there remains a risk (very small in my view) that nutrients will enter the lower Tekapo River resulting in adverse environmental effects. To cover this risk, a staged farm development programme, a monitoring programme and adaptive management process is proposed to track changes in water levels and water quality so that actions can be taken to avoid and/or mitigate the risk of significant quantities of nutrients from entering the lower Tekapo River.

Hydrological processes

121.In general terms, the process for nutrients to move from the proposed irrigated area to waterways is as follows.

- Existing farm land is developed, intensified and irrigated.
- Water and nutrients (N & P) drain through the upper soil profile into the vadose zone. This is expected to occur over a relatively short time-frame – hours or at most a few days. Some reduction in nutrients may occur in this profile.
- Water and nutrients make their way into the groundwater aquifer. Due to the open/ free nature of the gravels, this will happen in a few days or at most a few weeks. Because the irrigated areas are at least 1.2 – 2 km away from flowing streams, quick flow to streams is extremely unlikely.
- Some reduction in nutrients could occur in the vadose zone, eg dentrification.
- Water and nutrients mix with groundwater in the aquifer diluting concentrations.
- Groundwater levels may rise, increasing the hydraulic gradient slightly.
- Groundwater will move south towards the Tekapo River. Mixing depth is expected to be significant due to the dispersivity of the aquifer. (Need to provide figures).
- The majority of groundwater will pass under the Tekapo River and either enter Lake Benmore or continue into deeper groundwater. Some groundwater could enter the lower Tekapo River.
- Groundwater entering the Lower Tekapo River will mix with river water, possibly increasing nutrient concentrations in the river.

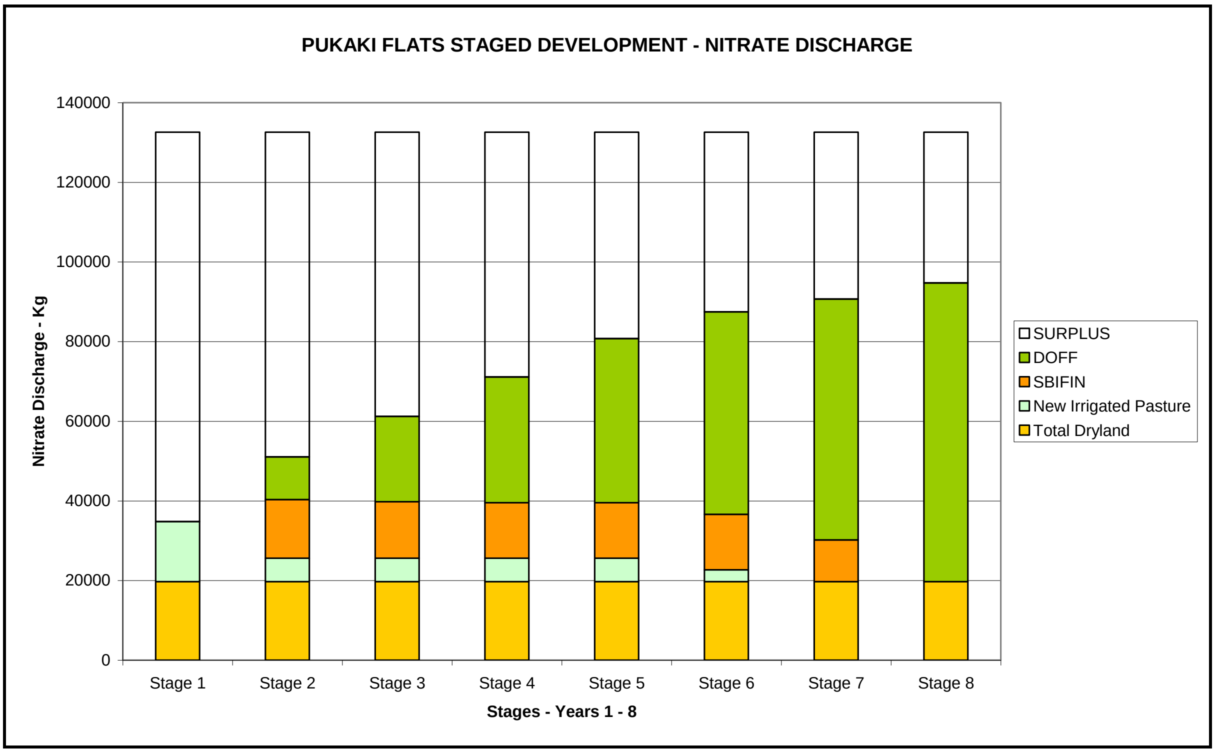
122.Because groundwater can be measured at strategic points along the groundwater flow paths, contaminant concentrations and travel times will able to be checked against predicted values to determine variances. If the variances are found to be significant, the farm development programme will be adjusted accordingly.

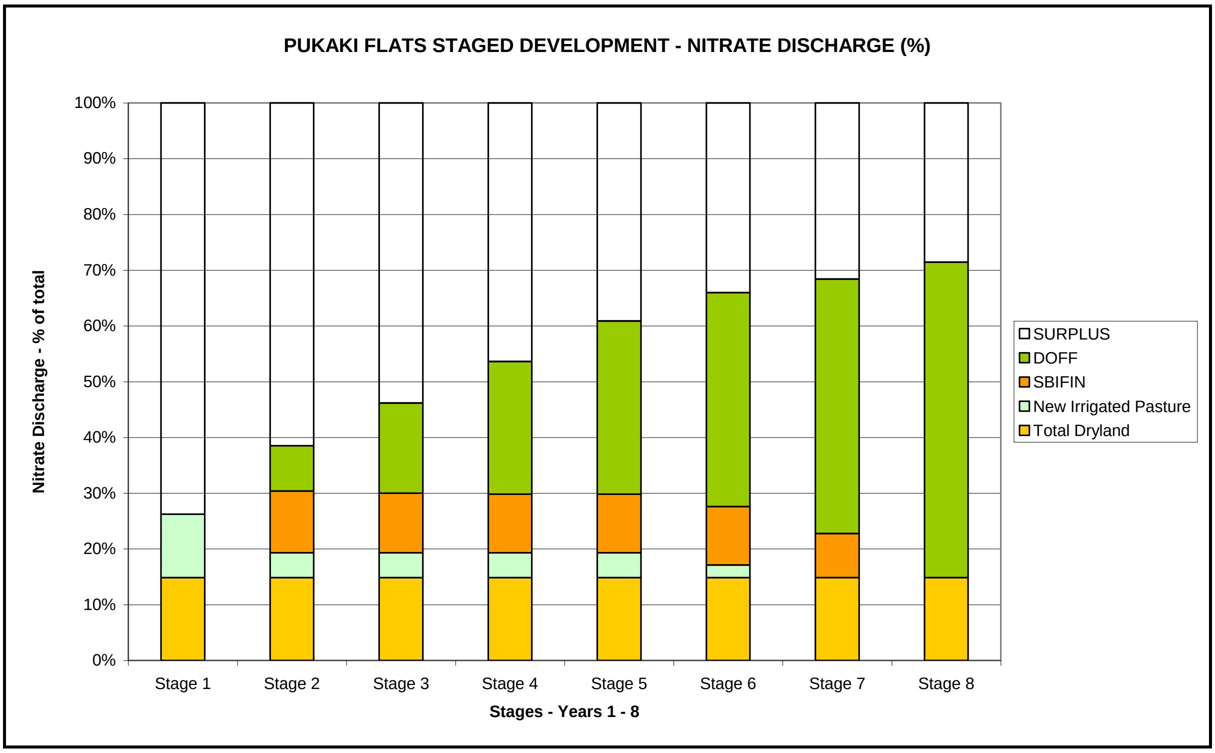
Development Programme

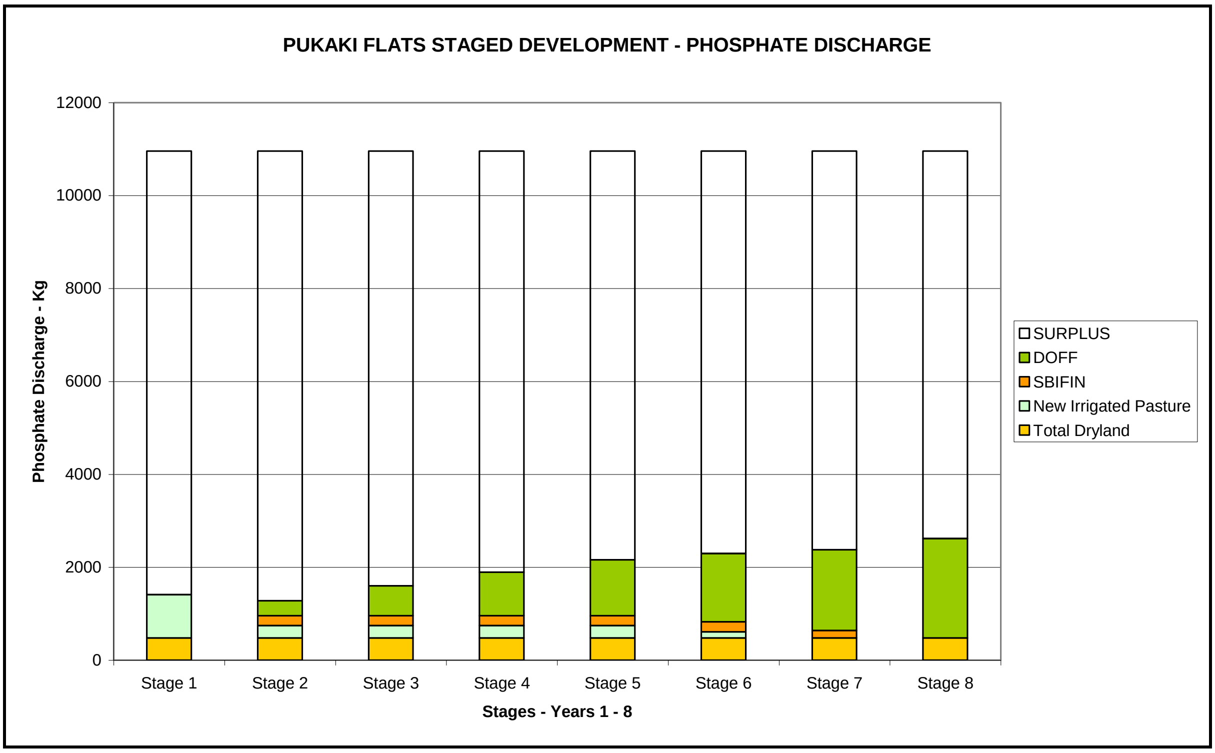
123.The initial farm development will be an annual increase in irrigated pasture progressively over the total area of 4022 ha, possibly with dairy farming proposed to expand on the Pukaki Flats over a period of seven years (approximately one-seventh per year). The initial land use development will be at the top (northern end) of the Pukaki Flats.

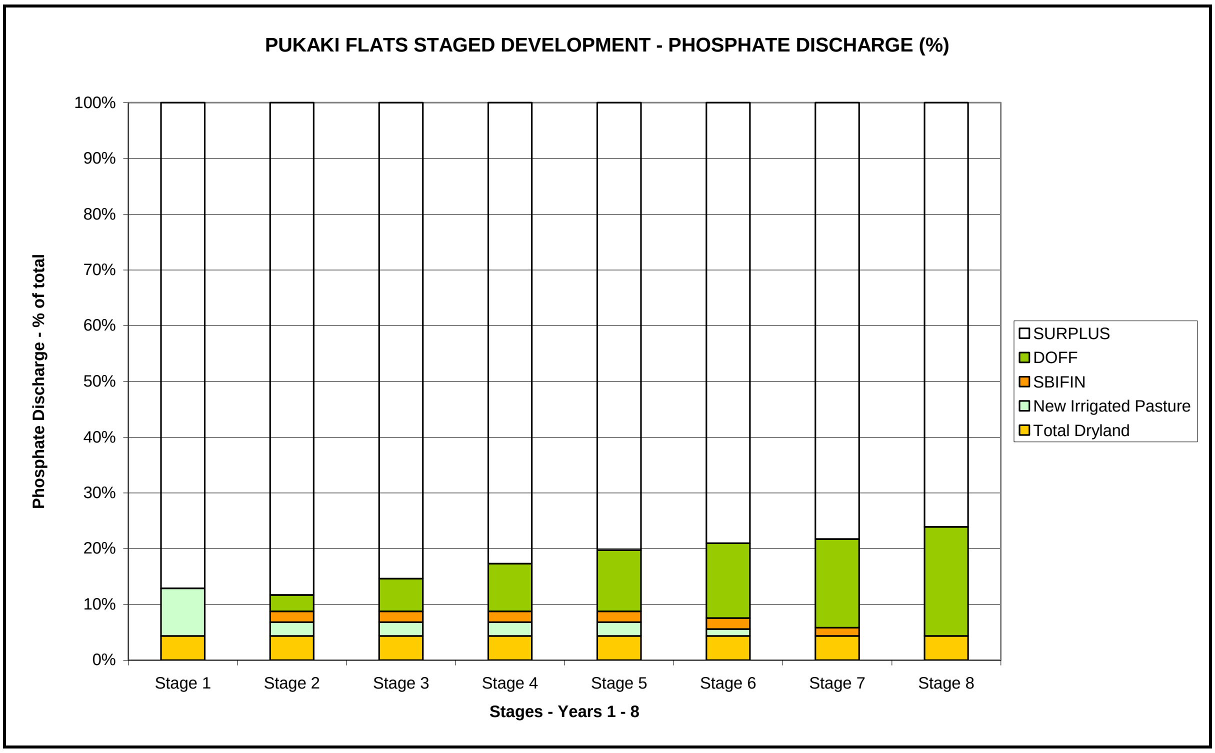
124.The balance of irrigated pasture will be used for intensive sheep and beef and/or cut and carried. It should be noted that the adaptive management regime allows a particular N and P discharge up to a maximum level, rather than permitting only a specific land use (such as dairying). It is irrelevant whether the N and P discharge originates from a dairy cow or a sheep, it is the land use intensity and the level of resultant N and P which is important to the environmental outcome.

125.Charts of the development programme are presented below. These charts provide the targets for N and P discharge for each year of the development programme.


PUKAKI FLATS STAGED DEVELOPMENT - NITRATE DISCHARGE
Nitrate Discharge - Kg
140000
120000
100000
80000
60000
40000
20000
0
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
Stage 6
Stage 7
Stage 8
Stages - Years 1 - 8
SURPLUS
DOFF
SBIFIN
New Irrigated Pasture
Total Dryland


PUKAKI FLATS STAGED DEVELOPMENT - NITRATE DISCHARGE (%)
Nitrate Discharge - % of total
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
Stage 6
Stage 7
Stage 8
Stages - Years 1 - 8
SURPLUS
DOFF
SBIFIN
New Irrigated Pasture
Total Dryland





MONITORING PROGRAMME

126.The proposed NDA targets and monitoring programme are based on measuring and monitoring through the hydrological cycle from the farm level through to the Tekapo and Pukaki Rivers and ultimately into Lake Benmore.

Proposed targets

127.The fundamental NDA targets that must be met are defined by the WQS. Nutrient targets as set by the WQS and described in the development plan have been adopted (units of P & N/ha). Note that for Pukaki Flats, the targets are based on maintaining N concentrations in groundwater below 1 mg/l. Key localised targets relate to on-farm nutrient balance targets, groundwater level changes, groundwater quality changes and surface water quality changes.

128. The targets proposed below are interim targets that if exceeded will initiate a response. With on-going monitoring and analysis, these targets will be refined either up or down to ensure that water quality effects remain at acceptable levels.

129. Decisions relating to changes in nutrient concentrations and water levels will be based on three-year moving averages calculated using all available data. This is to remove anomalies due to short-term spikes.

130. On-farm nutrient targets will be those defined by the WQS. Overseer will be the key tool used to manage those targets.

131. Groundwater level targets are difficult to predict without further work. Hydrological modelling will be based on water balance modelling inputs (e.g. Irricalc) into a simple transient groundwater model (probably MODFLOW). Extensive investigation and monitoring carried out by the applicant has provided excellent data for calibrating such a model. The groundwater model will provide predicted groundwater levels, changes in flow and predicted nutrient concentrations at pre-defined monitoring points.

132. On-going groundwater level monitoring will determine natural water level fluctuations in the system. As these fluctuations are currently unknown, if water level increases cause the hydraulic gradients to increase by 50% (equivalent to a 50% increase in groundwater through-flow), the potential for increased discharge to surface water bodies will be examined. This should not be regarded as a hard and fast trigger, as increasing groundwater levels are not an adverse effect. Rather it is a warning that further investigation may be required.

133. Although the NDA targets are based on a change in groundwater quality, an increase in nutrients in groundwater at the low levels expected, even it they exceed 1 mg/l, is not an adverse effect. The applicants will continue to monitor groundwater quality and will use the modelling described above to track actual values against predicted values.

134. Based on current investigations and monitoring, it is extremely unlikely that changes in flow in surface water bodies will be at a detectable level. For that reason, there are no specific targets proposed for surface water flows.

135. The change in nutrient concentrations in the Tekapo River and lower Tekapo River reaches will be monitored. As groundwater quality is being tracked and adaptively managed, it is extremely unlikely that an increase in the difference in nitrate concentrations between the upper and lower sites due to irrigation of the Pukaki Flats.

136. We expect drainage water and associated nitrate nitrogen to move through the various components of the hydrological cycle quite quickly, based on the estimated travel times described in my evidence above. We predict changes in nutrient concentrations in the Pukaki Flats monitoring bores to occur within months of outcomes at various points in the hydrological system.

137. The farm development plan proposed by the applicant is based on long-term steady state nutrient discharges in line with WQS requirements. Likewise groundwater modelling is based on steady-state groundwater modelling, which is acceptable for long-term predictions.

138. All predictions, including the long-term Overseer predictions, will be updated annually, using the latest available monitoring information. This refinement will improve the accuracy of the predictions.

Monitoring

139. Consistent with the Farm Environment Management Plan and consent condition requirements, and to track water and nutrient movement from the proposed irrigated areas to determine whether targets are being met, an extensive monitoring programme is proposed.

140. The monitoring and analysis is based on the premise of identifying potential problems early in the process, so that in the longer term, key targets are met. Although monitoring is proposed at the bottom of

the catchment, I expect that targets at the bottom, e.g. in the piezometers along the Tekapo and Pukaki Rivers or in the rivers themselves will not be exceeded because remedial action will have already been taken.

141.The inputs required for Overseer will be recorded. The climate station on Simons Hill will be used to provide climate data for the model. Should climate data not be available, NIWA daily data from their virtual climate station network will be used. The models will be updated annually.

142.Lysimeters will not be installed in the initial stages of development because Overseer has been run on its highly developed setting to take a conservative approach. However, they may be installed for future monitoring, should circumstances arise where lysimeter data may be beneficial.

143.Water levels in the four deep bores and the 15 permanent piezometers will be monitored monthly to determine natural water level fluctuations and once development begins, to detect changes in the water table.

144.Water quality sampling will occur at the sites shown in Figure 1. Water samples from H38/0261, I38/0103, I38/0104, I38/0105 I38/0090, I38/0092, I38/0095 and I38/0245 will be taken and tested for nutrients 3-monthly in first 3 years, 6-monthly in next year and annually thereafter.

145.River sampling to test for nutrients in the Tekapo River will be carried at the southern end of the Mary Range (Site 1), at the Iron Bridge (Site 2) and above Lake Benmore (Site 3) gauging site. Measurements will be taken 3-monthly in first 3 years, 6-monthly in next year, and annually thereafter. These measurements will be used to determine the change in nutrients in the Tekapo River between the southern end of the Mary Range and the Tekapo/ Pukaki confluence and between the Tekapo/ Pukaki confluence and Lake Benmore.

146.Although changes in nutrient status between the southern end of the Mary Range and the Iron Bridge will indicate a potential effect from irrigating the Pukaki Flats, a change in nutrient status between the Iron Bridge and Lake Benmore will be influenced by activities on other properties. For that reason, Site 3 will be used as a warning to investigate further.

Adaptive management

147.If the measured effects are equal to or lower than predicted, then the next stage can proceed. If not, further analysis using the updated models will be carried out to determine the cause of the problem and to assess the implications for meeting overall WQS targets.

148. If the targets can still be met despite the initial targets not being met, the next stage will proceed. If not, the process will be adaptively managed by making adjustments to the development plan and reassessing the effects.

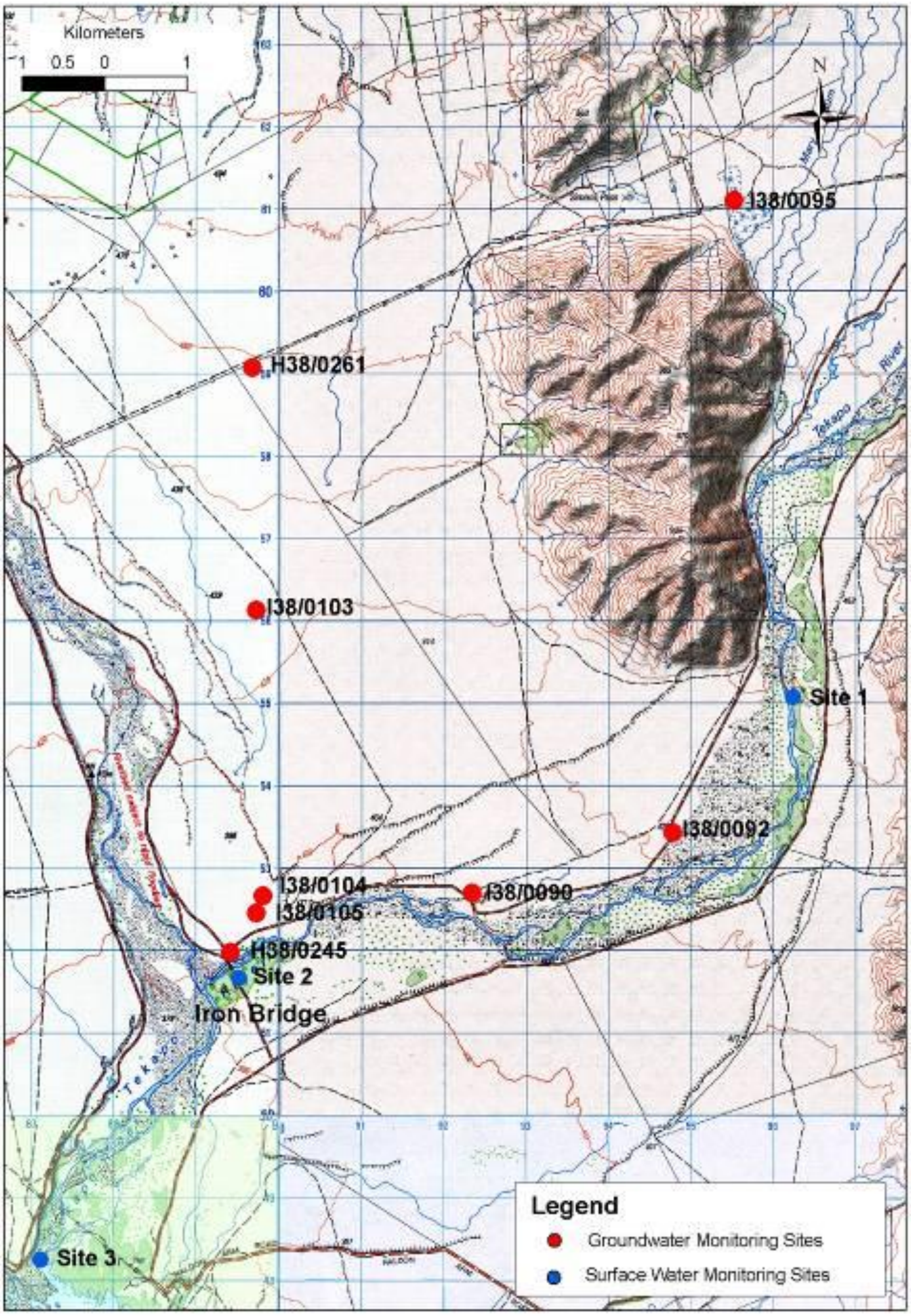


Figure 1: Groundwater and river monitoring sites

149.If results are less than the target, the development plan will continue. If values are greater than the target, the source will be investigated and if due to the applicants' development, the on-farm operation will be modified to bring nutrients back to the target.

150.Visual observations for unusual ponding and nutrient-enhanced growth in the lower Pukaki and Tekapo Rivers will be made. In particular, a photographic record of seepage areas along the Tekapo and Pukaki River will be made three-monthly.

151.If there is no discernable change, the development process will continue. If there is discernable change, the cause will be identified and if due to irrigation development by the applicant, earlier targets will be recalculated and adjustments made to the development plan.

152.Because groundwater can be measured at strategic points along the groundwater flow paths, contaminant concentrations and travel times will able to be checked against predicted values to determine variances. If the variances are found to be significant, the farm development programme will be adjusted accordingly.

CONCLUSIONS

153. My response to the CRC Officers and other submitters is that the conclusions I had reached and expressed in my previous evidence were correct. The field work and analysis has confirmed that most if not all of the groundwater from the Pukaki Flats is not discharging into the Tekapo River, but is passing underneath the river into Lake Benmore or beyond. The partitioning between flow into surface waters and groundwater predicted by the GHD modelling is largely correct.

154. The issues raised by CRC Officers and submitters are largely unfounded. In my opinion, there is now a high degree of certainty about groundwater flow paths and discharges. All of the field work – bore installations, aquifer tests, groundwater levels, water chemistry, and flow gauging – add strength to my previous conclusions.

155. In my view, irrigation development on Simons Hill Station and Simons Pass Station will not result in significant discharges of groundwater into the Tekapo River. As a further precaution, the applicants have offered to implement a staged development plan with detailed monitoring and adaptive management to ensure that there are no adverse effects of the proposed development on the Tekapo River and Lake Benmore.

I. McIndoe.

Ian McIndoe
28 April 2010