13 May 2010

Environment Canterbury
PO Box 345
CHRISTCHURCH, CANTERBURY 8140

Attention: **Anita Warnock**
Consents Project Leader - Waitaki

Dear Anita,

Peer Review: Aqualinc, 2010, Groundwater Investigation - Pukaki Flats, Mackenzie District, C09073

The scope of this peer review is outlined in email correspondence (Anita Warnock - Simon East, 4 May 2010) and the Contract for Services between Canterbury Regional Council (ECan) and MWH (6 May 2010). Specifically the agreed scope includes:

> *"Review data gathered, (including stream gauging data, aquifer test data and groundwater level data), data analysis and conclusions drawn regarding groundwater flow paths and specifically, the conclusions regarding the flow path of the proposed irrigation drainage water and the receiving waters for that drainage water."*

The Aqualinc report "Groundwater Investigation – Pukaki Flats, Mackenzie District" (the report) was prepared for Simons Hill Station Ltd and Simons Pass Station Ltd (the applicants) and issued in April 2010. It comprises a summary report (summary report) a report (main report) and appendices (appendix).

The purpose of the report is to support resource consent applications made by the applicants to take water from either Lake Pukaki or the Pukaki Canal to provide water for irrigated agriculture on 4,022 ha of land on the Pukaki Flats between the Pukaki River and the Mary Range. These applications are currently part of the joint Upper Waitaki hearing, which is to hear and decide 110 resource consent applications in the Upper Waitaki Catchment.

The key issue addressed in the report is whether groundwater from the Pukaki Flats discharges to the Pukaki and Tekapo Rivers or flows beneath these features. Irrigated agriculture on the Pukaki Flats has the potential to increase nutrient concentrations in groundwater. Submitters and ECan staff are concerned about the potential for these increased nutrient concentrations in groundwater to impact upon water quality in the Tekapo and Pukaki Rivers. It appears to be generally agreed that the assimilative capacity of the Haldon Arm of Lake Benmore is sufficient that water quality impacts arising from discharge of nutrient enriched water from the Pukaki Flats would be less than minor. I have not explored the validity of this premise in my review.

GHD (2008) undertook preliminary numerical groundwater modelling to address these questions and concluded that the majority of groundwater from the Pukaki Flats would pass underneath the Tekapo River and discharge to Lake Benmore. Little field evidence was available for preparation and calibration of this model at the time. To address the uncertainties within this report additional field data was collected between March 2009 and March 2010. Analysis of this data in conjunction with the GHD (2008) report forms the basis for the report's conclusions.

Monitoring locations

The report assesses groundwater data from 28 wells in Pukaki Flats area. 23 of these wells are located adjacent to the Tekapo River, two adjacent to the Pukaki River, two in the central Pukaki Flats and one on the east side of the Pukaki River. There is a scarcity of data points with the central Pukaki Flats and this has implications for the determination of groundwater flow directions and aquifer parameter estimation.

Aquifer pumping tests

Step pumping tests were conducted on I38/0103 and H38/0261 and a constant rate pumping test on I38/0104.

The constant rate pumping test was relatively short (13.1 hours) and examination of the time-drawdown relationship suggests that a steady state drawdown condition was not reached during the test.

Water levels were monitored in the pumped bore and 5 observation bores. A drawdown response to pumping was observed in I38/0105 and possibly H38/0244. The remaining wells provided data on background groundwater levels.

Bore logs are available for wells I38/0105 (monitoring well at 39.5 m from pumped well) and I38/0104 (pumped well). A clay bound[1] gravel layer was identified in I38/0105 but this appears to be absent from I38/0104. This variation in stratigraphy over relatively small distances appears to be common within sediments of the Pukaki Flats[2] and is indicative of sediments within this geological setting.

A bore log isn't presented for H38/0244 (3.5 m deep, 152 m from pumped well). Due to the limited lateral extent of sediment layers it cannot be determined if the clay bound gravels identified in I38/0105 exist at H38/0244 and, if they do, whether the well is screened above or below them.

There are inherent uncertainties in describing sediments samples during bore drilling, however the sediments shown in Figure 2 of the report are clearly clay bound. It is possible that the bore log from I38/0104 isn't representative and the sediments described between 5 and 10 m depth to in fact have greater silt/clay content.

This makes the use of drawdown response data from H38/0244 for aquifer pumping test analysis uncertain. In addition the stratigraphic variation between I38/0105 and I38/0104 may make the selection of an appropriate conceptual model to steer the selection of aquifer pumping test analysis methods difficult.

Static water levels in the pumped well were within 30 cm of those recorded in I38/0105 and these differences are likely to be the result of well efficiency differences due to different well and screen construction techniques used in each well. Static water levels in H38/0244 were approximately 1 m lower than in the pumped well. This is partly explained by this well been down gradient of the pumped well, however well construction and stratigraphic differences may also have an influence.

It is apparent that only data from I38/0105 and the pumped well can be used reliably for aquifer pumping test analysis.

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[1] I have used the colloquial or drillers term "clay bound" but in reality these sediments are likely to have a silt rather than clay matrix.
[2] Refer to Section 8.9.1 of: 2009 GHD, Cumulative Water Quality Effects of Nutrients from Agricultural Intensification in the Upper Waitaki Catchment, Prepared for Russell McVeagh on behalf of Mackenzie Water Research Limited.

Drawdown response

During the constant rate test an instantaneous drawdown of approximately 5.17 m in the pumped well occurred and increased to approximately 5.27 m at the end of the test. Review of the graph on page 74 of the appendix reveals that a steady state condition was not reached during the test with drawdown continuing at a minor rate.

In well I38/0105 a maximum of 0.216 m of drawdown was observed. The total depth of the aquifer at the pumping test location is not described, however it is unlikely that the wells are fully penetrating. Well I38/0103, approximately 3.5 km north of the pumping test site was drilled to a depth of 41.7 m. Well H38/0035, approximately 4.8 km west of the pumping test site was drilled to a depth of 118 m. In the absence of other data we must assume the aquifer at the pumping test site maybe significantly deeper than the existing wells. In this case the Hantush (1964) condition for partial penetration is not met for monitoring well I38/0105. This may also explain the unusual drawdown response observed and in some circumstances can produce a very similar response to that observed due to delayed yield.

Analysis

It appears that the aquifer in the vicinity of the pumping test is variably leaky or confined due to the presence of laterally discontinuous impermeable layers. This makes the selection of an appropriate conceptual model for analysis problematic.

Late time data from I38/0105 appears to be influenced by delayed yield or partial penetration effects. There is uncertainty about the causation of the observed "drawdown" in H38/0244 and it would be appropriate to remove this well from the analysis. This leaves early time data from I38/0105 and the pumped well data. The Boulton (1969) solution for leaky aquifers is the most appropriate analysis method presented in the report, however it is important to keep in mind that it doesn't consider the laterally discontinuous nature of the low permeability layers. It is also uncertain from the report whether partial penetration of the wells has been considered. Table 9 of the report suggests transmissivity values of between 2,240 and 2,692 m^2/day derived from the Boulton solution. Based on the limitations of the aquifer pumping test these values are likely to be the most indicative of those presented in Table 9 of the actual aquifer transmissivity.

Rather than using an average value from the various analysis methods (Section 4.6 of the report) it is more appropriate to select the value from the analysis method which best fits the conceptual model of the aquifer. In this case it is clearly the Boulton solution.

The report has considered the aquifer thickness to be the saturated aquifer thickness above the well screen. In a leaky aquifer it is conventionally the saturated thickness above the bottom of the well screen that is considered the aquifer thickness (b). This would change the aquifer thickness values presented in Table 10 slightly, however not significantly.

An aquifer pumping test generally only provides information about aquifer properties for a discrete area. When looking at aquifer wide processes such as through flow aquifer parameters need to be selected that represent the aquifer as a whole. There appears to be little aquifer parameter data available for the Pukaki Flats apart from the results of the 3 tests presented in the report and for this reason it is essential that a broad range of values is used in any assessment to encompass the likely range of natural variability.

Transmissivity values determined from step pumping tests on wells H38/0261 and I38/0103 were approximately 1,000 and 4,500 m^2/day respectively[3]. When considered with the results of the constant rate

[3] These values were calculated with the Eden Hazel solution for confined aquifers. I have not assessed the suitability of this solution with respect to the conceptual model of the aquifer at this location. If the aquifer is in fact leaky as observed at the constant rate

test (~2,500 m^2/day[4]) we can suggest that bulk transmissivity of the Pukaki Flats may be within the range 1,000 to 4,500 m^2/day, however insufficient data is available to identify spatial trends in transmissivity and it cannot be excluded that the actual bulk transmissivity may be lower or higher.

Based on the range of transmissivity values from the aquifer pumping tests we would expect hydraulic conductivity to be slightly lower than presented in Table 10. A reassessment of these values is provided in the following table.

Well	Transmissivity (m^2/day)	Saturated aquifer thickness (m)	Hydraulic conductivity (m/day)
H38/0261	1,000	14	70
I38/0103	4,500	13.5	333
I38/0105	2,500	21.7	115

The assessment of aquifer through flow and contaminant transport has used a range of hydraulic conductivity between 233 and 2,330 m/day. Despite the uncertainty in converting the transmissivity values to hydraulic conductivity and the inherent uncertainty in applying results of discrete aquifer pumping tests to the assessment of aquifer scale processes, the range of hydraulic conductivity values adopted are highly conservative in terms of estimating the maximum rate of contaminant transport (i.e. the travel times presented in Table 14 and 15 are likely to be conservative).

However, lower permeability values may result in a decrease in dilution of irrigation drainage and therefore the change in contaminant concentrations (discussed at the end of Section 5.3.2 of the main report) may be underestimated.

The methodology used to assess contaminant mixing (Section 5.3.2 of main report) is highly sensitive to aquifer hydraulic conductivity and I suggest that it would be prudent to re-assess this analysis in light of the potentially lower aquifer hydraulic conductivity values I have described above.

Concurrent stream gauging

The report describes the results of concurrent stream gauging undertaken on the Tekapo and Pukaki Rivers in February 2010 (Section 2.3) and makes comparisons with data from three concurrent stream gauging runs undertaken March and October 2009.

Stream gauging is inherently uncertain due to measurement errors, flow variations during a gauging run and morphological changes in bed structure causing bed through flow and can often lead to errors in excess of 10% of the actual flow.

The gauging data presented in the report confirms that the Tekapo River generally loses water between the Mary Burn confluence and the Pukaki River confluence. However between gauging points T3 and T4 a flow gain of 0.7 m^3/s was recorded on 17 February 2010. It is uncertain whether this same trend was observed during the previous gauging runs or not. The report suggests that the recorded flow at T3 was lower than the actual flow because a proportion of the flow was present as bed flow (and following that if the actual flow at T3 was considered a flow loss would be reported between T3 and T4). This is a reasonable hypothesis but not easily confirmed with the available data. A cross section between D and C would be useful in making this assessment. Bed flow may also be present at other gauging sites, thus bringing into

pumping test site these results may not be representational. In addition, it is not apparent if the results have been corrected for partial penetration.

[4] Average of reported values

question the accuracy of those measurements. A river morphology survey maybe required to confirm the suitability of the gauging locations.

The available concurrent gauging data suggests that the Tekapo River predominantly loses water to groundwater, however; there is the possibility that there are spatial and or temporal variations to this general trend. With the available data it is not possible to estimate the magnitude of any potential flow gain. Complicating the analysis is the possibility that within a gaining reach of the river flow gains may occur on one bank and losses through the other, and that the river can move from losing to gaining conditions within very short distances. As concurrent stream gauging only examines the net flow differences between two points there is the potential for groundwater contribution from the Pukaki Flats to be underestimated.

No concurrent stream gauging is reported for the Pukaki River. A flow of 0.3 m^3/s was recorded on 17 February 2010, although it is not known if this is more or less than occurring upstream. Cross section B indicates that the groundwater table is at least 4 metres below river level at that point, however it is possible that the observed flow in the Pukaki River just upstream of the Tekapo River confluence when water is not been released from Lake Pukaki is the result of gains from groundwater downstream of cross section B. Additional cross sections downstream of cross section B would be useful in making this assessment.

The presence of at least some gaining reaches of the Tekapo River is confirmed by groundwater levels being higher than river levels in cross sections C1 and C2 although it is not known how far upstream the Tekapo River these conditions continue. Previous gauging runs showed an increase in flow downstream of the Pukaki River confluence of 0.7 m^3/s (15 October 2009), however it is not mentioned in the report if the Pukaki River contributed to this flow. The report also indicates that on 25 March 2009 a flow measured approximately half way between the Mary Burn Stream confluence and Iron Bridge was slightly higher than at Iron Bridge indicating the possibility of a flow gain from groundwater.

Cross sections and vertical hydraulic gradients

Section 2.2.2 of the main report discusses differences between proximal groundwater and surface water level elevation measurements. Table 1 indicates that generally groundwater is below the surface water level with exceptions occurring at Holes 1b, 8 and 9. If the elevation difference between groundwater and the river bed is considered these differences are somewhat less and in some cases groundwater could be shown to equal to or above river level.

Because Holes 8 and 9 are located some distance from the active channel of the Tekapo River cross sections C-1 and C-2 have extrapolated the groundwater level observed in Holes 9 and 8 to the river using the same hydraulic gradient observed between H38/0245 and Hole 9. I am unsure about the suitability of this methodology and would suggest that extrapolating the Tekapo River level towards Hole 9 would be an as equally valid approach. In either case it is clear that there is likely to be some groundwater discharge to the Tekapo River in this area.

I have reassessed the groundwater and surface water level data (Appendix E) used to construct cross section D and suggest that it is possible for groundwater to be discharging to the Tekapo River at this location. Bore I38/0089 shows a significant seasonal level variation of over 4 metres. Groundwater levels at I38/0090 are more constant and the report has assumed that this is the result of it intersecting a perched water table. Nonetheless, when water levels in I38/0089 are high there is potential for water to discharge to the Tekapo River. A lack of long term groundwater level monitoring data makes an assessment of this risk difficult. It is also not apparent whether the assessment in the report has considered the potential worst case increase in groundwater levels in the Pukaki Flats due to irrigation recharge. This has the potential to influence the spatial and temporal occurrence of groundwater discharge to surface water. Reanalysis of the data with consideration of seasonal groundwater and surface water levels fluctuations and increased groundwater levels due to irrigation recharge would be useful.

Through flow

Through flow calculations presented in the report are based on a hydraulic conductivity of 233 m/day. As described above this may not represent the potential low range of possible hydraulic conductivity and to ensure a conservative assessment a broader range of values should be used. The following table compares the aquifer through flow values calculated with a hydraulic conductivity of 233 m/day and 100 m/day.

			Hydraulic conductivity: 233 m/day		Hydraulic conductivity: 100 m/day	
dh/dl	W (m)	B (m)	Q (m^3/day)	Q (m^3/s)	Q (m^3/day)	Q (m^3/s)
0.0037	6,000	50	258,630	3	111,000	1
		100	517,260	6	222,000	3
		150	775,890	9	333,000	4
		200	1,034,520	12	444,000	5

If the actual bulk hydraulic conductivity of aquifer is lower than suggested by the report the calculated aquifer through flow will be less. As we can see, if the bulk hydraulic conductivity was in fact 100 m/day and the aquifer thickness only 50 m, the estimated through flow is approximately 1 m^3/s. Groundwater discharge to the Tekapo River may then may be a more significant component of the total through flow.

Groundwater flow direction

Groundwater flow directions have been estimated from the groundwater and surface water level data (Appendix G). Data points are concentrated around the Tekapo River with few available for the area surrounding the Pukaki River and the central area of the Pukaki Flats. For this reason, the orientation of groundwater flow in the central Pukaki Flats cannot be accurately determined. The available data confirms that groundwater flow is approximately to the south in the central Pukaki Flats and to the south west in the vicinity of the Tekapo River.

I disagree with some of Section 4.3 in relation to the inferred groundwater flow directions and suggest that additional groundwater level monitoring points are required adjacent to the Pukaki River and within the central Pukaki Flats to confirm the actual groundwater flow direction. Accurate determination of groundwater flow directions is essential in the selection of appropriate cross section locations and this may be a source of error in the comparison of surface and groundwater level data in the cross sections.

Summary

Pukaki Flats groundwater appears to be in variable hydraulic connection with the Tekapo and Pukaki Rivers. Based on broad scale topographical and geological controls I would expect the majority of groundwater from the Pukaki Flats to discharge directly to Lake Benmore. Based on the information presented in the report I consider it likely that there is some groundwater discharge from the Pukaki Flats to the Pukaki and Tekapo Rivers, however the magnitude of this flow gain cannot be quantified with the available information.

The actual bulk hydraulic conductivity of the aquifer may be lower than suggested in the report. In turn, aquifer through flow may also be lower. As the methodology used to calculate contaminant mixing (Section 5.3.2 of main report) is sensitive to the aquifer through flow value, I suggest that these calculations should be re-addressed with the potentially lower range of hydraulic conductivity I have described above. Overestimating the hydraulic conductivity value will underestimate the contaminant concentrations in any groundwater that does discharge to surface water.

It is apparent that a large proportion of aquifer through flow would have to discharge to surface water to have a significant effect on nitrate-N concentrations in the Tekapo and Pukaki Rivers if the reported mixing distance and groundwater contaminant concentrations (which are based on the estimates of hydraulic conductivity and aquifer through flow) are accepted. However, there is still potential for small scale effects on spring fed streams where groundwater discharge is not diluted by significant surface water flow.

The report suggests that groundwater levels are generally below the Tekapo and Pukaki River surface water level. I agree with this conclusion; however, I also stress that in any instance where groundwater levels are above the river level the potential for groundwater discharge to the river exists.

As a numerical groundwater model has already been prepared for this area by GHD, it would be prudent to re-run the model after the inclusion of the newly collected field data. A numerical groundwater model supported by adequate field data and an appropriate sensitivity analysis is perhaps the best means of estimating the likely range contaminant concentrations in groundwater resulting from the proposed irrigation drainage and the quantity of groundwater discharged to surface water.

Despite some uncertainties within the report, its broad conclusions appear to be correct, that is; the majority of Pukaki Flats groundwater passes beneath the Tekapo River and discharges directly into Lake Benmore.

Yours sincerely

Simon East
Hydrogeologist
MWH New Zealand Limited

Reviewed by: Lee Paterson