Before the commissioners appointed by the Canterbury Regional Council

In the matter of	The Resource Management Act 1991
and	
In the matter of	60 water permit applications to take and use water, 29 land use consent applications and 21 discharge permit applications, for agricultural and horticultural activities in the upper Waitaki catchment

Section 42A Report – Cumulative Water Quality Assessment

Date of hearing: September 2009 – February 2010

Addendum Report of Thomas Brendan Heller

INTRODUCTION

1. This report deals with a limited number of matters that have arisen during the course of the hearing that I provide comment on in addition to the material contained within my original section 42A report.

2. This report has been prepared in accordance with the Minute of Commissioner Rogers dated 21 August 2009 that provides for addendum section 42A reports and takes into account the hearing evidence provided by Mackenzie Water Research Limited (MWRL) experts, and the evidence provided by Meridian Energy experts. This report has also benefitted from caucusing discussions between Environment Canterbury (ECan) reporting officers and experts acting for MWRL, Meridian and other parties.

3. This report is limited to:

   a) Only matters contained in my original section 42A report that I consider are still outstanding; and

   b) Addressing any additional matters that have arisen with additional information provided by the applicant's consultants during the course of the hearing or since my original section 42A report was prepared.

QUALIFICATIONS

3. My qualifications are detailed in my original section 42A report.

SCOPE OF REPORT

4. The following is a summary of the key technical issues that are only required to be addressed in relation to all of the matters raised in my original S42A report. I am comfortable that the following matters and discussion covers all/any of the outstanding issues:

   a) Phosphorus mass balances and surface water routing

   b) Lake Benmore residence times

   c) Overall water quantity mass balances for sub-catchments and Lake Benmore in respect of nitrogen loading

   d) Nitrogen loading upon surface water sub-catchments at low flows (MALF).

5. In preparing this report, I have examined all additional evidence and have attended caucusing with GHD/applicant, Meridian and other ECan experts which mainly resulted in developing an understanding of the spreadsheet toolkit used in deriving the mass balances for the GHD study/reports. Additionally, I have been provided with further technical information which includes:

   (a) Spreadsheet information concerning phosphorus mass balance calculations

   (b) Spreadsheet calculations for nitrogen and water quantity mass balances including groundwater and surface water hydrology

   (c) Additional water quality data and analyses for specific stream sub-catchments.

COMMENT ON OUTSTANDING MATTERS

Phosphorus Mass Balances

6. In my original S42A report I was unable to comment on phosphorus (P) mass balances or check the methodology used by the applicant's consultants as critical information was absent from the GHD study reports. I can now make comment on this as I had received sufficient P mass-balance spreadsheets from the applicant's consultants after some brief caucusing with Dr Robson.

7. The methodology used to derive P concentrations in surface waters and Lake Benmore is a simple combination of land use area and P-loss factors (contained within the GHD Summary Report) using GIS mapped areas to route P into sub-catchments (and effectively by-passing groundwater) then to the relevant arm of Lake Benmore. This has been achieved for the current base case landuse and for future scenarios presented by the applicant's consultants. Calibration to measured P concentrations was achieved for the base case scenario.

8. I have checked all of the sub-catchment P loss loads and agree that they have been apportioned correctly, albeit there are some small conversion errors within the GHD reports when comparing the mass balance flow diagrams and individual modelled P concentrations at some stream nodes. However, I see those inconsistencies as a minor issue and not of concern for cumulative assessment of lake impacts.

9. I consider that for P, a mean flow assessment is the correct methodology to employ, and that otherwise, no low-flow analysis is warranted. I also acknowledge that there is a limited amount of data on which to compare existing P-loss and resulting loads in surface waters.

10. The results of the P mass balances indicate that for the base case a maximum P-loss used was 1.1 kg/ha/annum and the average value was 0.083 kg/ha/annum for the whole of the contributing catchment to Lake Benmore. The scenario 2 P mass balance suggests that an additional 1.3 kg//ha/annum P had been allowed for new irrigation practices within the GHD reported assessment. This equates under scenario 2 to the base case, of a 67% increase in overall P-load to Lake Benmore.

11. I consider that such an assessment is rather conservative as significantly higher P-loss has been attributed to the developing catchment and that all P-loss is routed directly to surface waters. No consideration of P uptake within surface waters or Lake Benmore was allowed for in the analyses. As the methodology does not account for P interaction with soil or groundwater, the developing scenario is the same as the fully developed scenario in the GHD analyses.

12. I am now satisfied that phosphorus mass balances and the subsequent provision of mean flow P-loads in surface waters and in Lake Benmore is correct and is based on sound methodology, albeit reasonably conservative.

13. The stream and lake P concentrations arising from the P mass balance spreadsheet results are discussed in evidence of Dr Meredith and Dr Schallenberg respectively.

Lake Benmore Residence Times

14. The applicant's consultants have indicated that a "bucket type" approach has been used to define N and P concentrations in either arm of Lake Benmore under the irrigation development scenarios given. Under this type of analysis there has been no account of mixing between the two arms of the lake and no sensitivity tests are given for the predictions, despite requests for such having been made by council experts.

15. Dr Spigel in his evidence indicated that there was most likely a thermal hydraulic mixing of waters at depth between the Haldon and Ahuriri arms of Lake Benmore. In my original S42a report I had indicated that this may be the case, and as such, the GHD methodology (which considers a discrete "bucket" approach) is likely to be conservative in that instance.

16. I consider that the estimates given for lake residence times in evidence of Dr Gamage are different to that indicated in NIWA (2009). However, I consider that his estimates may not be as critical to lake hydraulic performance (mixing and through-flow) as previously indicated in my original S42A report.

17. Particularly given the evidence from Dr Spigel that shows the conservative nature of mixing in both arms of Lake Benmore.

18. Dr Gamage (in his evidence) predicts average residence times of approximately 37 days in the Haldon Arm and 48 days in the Ahuriri Arm. This compares to (NIWA, 2009) which provides a residence time of 57 days for the Haldon Arm and 75 days for the Ahuriri Arm at mean flow input.

19. Irrespective of the actual mean residence time for each arm of the lake, the variability during critical periods is also of significance in predicting nutrient impacts.

20. For Lake Benmore, I have compiled all inflows available within the GHD suite of reports and factored between months for residence times greater than 30 days in an attempt to audit the potential seasonality of residence times for each arm of the lake. The data used relates to monthly average inflows and is presented in **Appendix 1**.

21. The results of this analysis indicate that for a mean residence time for the Ahuriri Arm of 48 days, the minimum residence time of 34 days occurs during the November period with the maximum residence time of 60 days occurring during August. This tends to indicate that the critical residence time (longest residence time) is most likely to occur during winter months. Generally, the mean residence time is in good agreement with each monthly average flow.

22. However, within the applicant's consultant's mass balances, no account of new abstraction has been made in adjustment of lake inflows. Reduction of inflows due to abstraction is more likely to have a potential adverse effect during low flows than at mean flows. The most critical (irrigation season) residence time for the Ahuriri Arm occurs at or about March, which results in a longer residence time than the mean (56 days).

23. I have audited the amount of new abstraction sought and found that it may increase residence times by approximately a maximum of 5.8% for the Ahuriri Arm and 1.4% for the Haldon Arm (Ahuriri catchment new abstraction – 1,800 L/s and Haldon catchment new abstraction 4,700 L/s based on a 100 mm irrigation application in any month).

24. For the Haldon Arm, residence times vary from 30 to 42 days, with longer residence times during June-July and shorter residence times from February to April. Other months are at about the average residence time. Thus, for the purposes of the GHD assessment, I agree that the average flow scenario is appropriate for the hydrologic assessment of Haldon Arm lake conditions. It is unlikely that new abstraction would significantly alter the residence times given the small amount of new water abstracted in comparison to the large inflow.

25. Lake Benmore residence times in consideration of N and P concentrations given in mass balances indicated by the applicant's consultants appear to be reasonably well suited to the mean for the Haldon Arm. However, there is some doubt over residence times during the February to April low flow period for the Ahuriri Arm. During this period the GHD assessment does not account for new abstraction of water from the catchment.

26. I consider that based upon the amount of new abstraction applied for from the Ahuriri (arm) catchment, that there is potential for some variability in increased lake residence times which may then reflect variability in N and P concentrations predicted by the applicant's consultants. However, this may not necessarily be significant as inter-arm mixing of lake waters (as identified in Dr Spigel's evidence) during these critical periods (high thermal gradient between arms) may have a greater effect upon average lake nutrient concentrations. However, again no comparative or sensitivity analysis has been undertaken in respect of the work undertaken in NIWA, 2009.

27. Thus, overall, I consider that the "bucket type" approach undertaken by GHD to be reasonably appropriate in defining each arm's hydrologic state on an annual basis. It should be noted that more extreme drought events or flow management (including abstraction) may significantly alter the residence time in the Ahuriri Arm. Although, based on monthly average inflows, this may occur infrequently and for a relatively short duration.

28. Dr Schallenberg (in his S42A addendum evidence), addresses the potential environmental effects of the mean and estimated variability in N and P concentrations for each arm of Lake Benmore. This is with respect to the results of mass balances presented by the applicant's consultants and in consideration of estimates of potential seasonal variability in lake residence times for each arm of Lake Benmore.

Water Quantity - Nitrogen Mass Balances

29. I have completed an additional audit of the applicant's consultants mass balances on the basis of evidence presented to the panel and in assessment of spreadsheet data provided by Dr Mzila. At this point I wish to indicate that whilst the additional spreadsheet data was critical to my understanding of the methodology employed by GHD experts, I considered that the spreadsheets were a "work in progress" as very few components and overall results exactly matched information contained within GHD reports for the cumulative water quality effects assessment. However, there were general similarities in spreadsheet data and reported information in all cases.

Groundwater Recharge and Discharge

30. The application of highland recharge to groundwater for sub-catchments has been made on the basis of the methodology contained in Kingston-Morrison (1999). Whereby, a proportion of upland runoff is provided as additional recharge to a down-land groundwater basin.

31. I agree with the overall methodology used to derive highland recharge, although the applicant's consultants have not undertaken this explicitly consistent with the method outlined in the Kingston-Morrison report. The Hawea Basin area (identified in the KM report - which is part of the Otago Region) is a good example of potential highland recharge addition to a lowland groundwater basin. I accept that there are similarities between the Hawea Basin and the upper Waitaki with respect to the calculation of highland recharge.

32. I have checked highland recharge and other recharge sources for groundwater sub-catchments utilised in the applicant's consultant's mass-balance calculations. Overall, I believe that the recharge values are generally consistent with previously reported or expected recharge rates or volumes. I did note that the Ahuriri highland flow rate has been reduced significantly in line with comments I made in my original S42A report and I now agree with the current value (now 63.7 Mm^3/annum). Furthermore, when I account for highland recharge, land surface recharge and expected surface water gains, the overall through-flow for groundwater sub-catchments is as generally expected.

33. Stream recharge to individual groundwater sub-catchments has been taken as the balance of total groundwater recharge minus land surface and resulting (net) highland recharge. This component of recharge as indicated above, is plausible and accepted for each groundwater sub-catchment. Individual values and locations of stream recharge are not given within GHD reports or mass-balance spreadsheets.

34. However, there is still an outstanding issue of the apportioning of aquifer discharge to surface waters, and what volume of groundwater may then occur as deep groundwater flow to Lake Benmore.

35. On review of the applicant's consultant's mass-balance spreadsheets I am unable to specifically determine these proportions of groundwater discharge, although in key gaining stream reaches they are indicated in the GHD reported mass-balance diagrams.

36. It was indicated (in caucusing) that the apportioning of groundwater discharge within the GHD mass-balances was on the basis of reported surface water gains (and losses). However, as above I am unable to fully audit this flow component on the basis of a lack of clarity in reported GHD mass-balances and in spreadsheet calculations supplied by the applicant's consultants.

37. However, I do consider that whilst the overall groundwater sub-catchment through-flows are largely correct, there are specific (gaining) stream reaches that are susceptible to N-addition from groundwater sub-catchments, in which the cumulative effects assessment to date has not provided an adequate account of. These specific stream reaches are identified in the following section of evidence.

38. An additional matter that follows from the applicant's consultant's treatment of groundwater sub-catchment discharge is the potential diversion of N-load through increased deep groundwater discharge to Lake Benmore. I identify below, the critical areas where this is believed to occur within the GHD mass-balances.

39. Finally (for groundwater sub-catchments) whilst I believe as indicated in the overall N mass balance audit below that N-loss values and resulting N-loads are reasonably appropriate, there is an unexplained inconsistency in applying 0.015 kg/ha/annum N-loss from highland area recharge to groundwater. This N-loss value does not fit with the expected average for upland non-irrigated areas reported by GHD to be 0.5 kg/ha/annum. This implies significant denitrification and may serve to overly reduce groundwater sub-catchment N-concentrations.

40. Further comment on individual groundwater sub-catchment N balances and resulting concentrations is made in the S42A addendum evidence of Mr Hanson.

Overall N-mass Balances

41. As identified in my original S42A report, there was reasonable agreement with total inflows to each arm of Lake Benmore. However, given that critical information was not supplied or was not given in GHD reports, I was unable to validate the overall N-mass balances to the Ahuriri or Haldon Arm's.

42. For the continued audit of the applicant's consultant's overall N-mass balances, I have prepared summary catchment N-balances based upon GHD reported average N-loss values and those values assigned within supplied mass-balance spreadsheets. These summary N-balances are given in **Appendix 2**.

43. In summary, I have checked the N-loading and mass balances for the current base-case scenario and find that whilst there are discrepancies with the GHD reported information, I do get similar overall results from my audit/calculations to that presented by the applicant's consultants.

44. The audit (Appendix 2 – GHD N-loss values) indicates a total N-load to the Ahuriri Arm of 172,104 kg/annum and thus an N-reduction of 10.9% is required to calibrate to the current (GHD estimated) N-load of 153,363 kg/annum as being consistent with measured water quality results. This is in general agreement with the GHD model whereby approximately 7% denitrification has been applied to the overall N-mass balances. The resulting N-concentration as calculated for the Ahuriri Arm of 0.124 mg/L is consistent with mean flow and total N-load.

45. N-loads for the Haldon Arm derived from the adoption of GHD average N-loss rates are significantly higher than the resulting N-mass balance results reported by the applicant's consultants (higher load is 636,252 kg/annum). Based upon the potentially higher N-load derived from average N-loss rates reported by GHD (or as supplied in mass balance spreadsheets), a 19.6 % reduction in N-load is required under the current base case scenario to achieve the 511,347 kg/annum reported. However, N-concentrations in the Haldon Arm would only vary from 0.052 to 0.062 mg/L given that range of N-load, and they are both invariably low.

46. Appendix 2 also details a summary of my estimates of N-loading from major land use areas to each arm of Lake Benmore. The results for the Ahuriri Arm (150,312 kg/annum) are similar to that reported by GHD (153,363 kg/annum) for the current base case scenario (only 2% different). Comparative figures for the Haldon Arm show a 6.7% difference, in which I calculate slightly higher N-loads. However, the resulting lake N-concentration is invariably not dissimilar to that calculated by GHD.

47. On the basis of my audit of N-loads provided in evidence, reports and spreadsheet information by the applicant's consultants, I am comfortable that the current base case scenarios for N-load to each arm of Lake Benmore have been appropriately calculated by GHD experts.

48. However, I recommend that any additional N-load or modifications to N-load for the current base case scenario be fully accounted for on a farm-by-farm basis. This is because there are likely to be significant differences for replacement applications in relation to actively irrigated area, the type of land-use occurring and the nutrient management practices employed. The resulting N-loads from the replacement applications are indicated (from GHD FEMP spreadsheets) as being significantly

greater than for the estimated base case scenarios reported (refer to Dr Freeman's S42A addendum report).

49. Individual (farm) consent applications have been assessed by investigating officers and Mr McNae provides (in evidence), the results of his audit of proposed farming operations and resulting N-losses predicted from Overseer modelling.

Stream Sub-catchment N-mass Balances

50. I am in agreement (as above) that the N-mass balances are generally suitable for the mean flow analysis for Lake Benmore. However, I flag that some individual stream sub-catchments are subject to groundwater discharge and may be more sensitive to seasonal variation in N-concentrations.

51. The GHD model presents the groundwater sub-catchments is a receptor for N-load as a result of existing or proposed land uses. Thus, the interaction of groundwater with surface waters (for gaining reaches) is critical in assessment of surface water impacts.

52. There are two key stream reaches that (hydraulically) I consider are inconsistent with the presented GHD methodology and are likely to result in significantly more N-contribution than predicted. These are: the lower Ahuriri River (in mid to lower reaches) due to a larger proportion of groundwater entering the stream and not flowing direct to Lake Benmore; and the Wairepo Arm - Ohau canal/lower Ohau River where all groundwater from the Wairepo catchment is most likely to contribute to, and not flow directly to Lake Benmore.

53. In each of the above cases, I have considered aquifer saturated thicknesses and direction of groundwater flow presented by the applicant's consultants and the presence of no-flow boundaries identified within geologic mapping and the GHD groundwater model.

54. However, the N-concentrations in the Ohau canal/river are still expected to be relatively low based upon my recalculation of the GHD mass-balances. Although N-concentrations for the Wairepo Arm are unable to be re-calculated based upon information supplied by the applicant's consultants, in the absence of such data, I still confirm that N-concentrations would almost certainly increase from that indicated with increased groundwater input. I suggest that ongoing water quality monitoring be undertaken in the lower Wairepo Stream and/or the Wairepo Arm to verify the applicant's consultant's claims.

55. The lower Ahuriri River may be expected to have increased N-concentrations from groundwater contribution in that area. For each land use scenario reported by GHD, this is likely to be similar to or slightly less than the N-concentrations derived for the Ahuriri Arm of Lake Benmore.

56. In the following section of evidence, I indicate key stream reaches that are susceptible to N-addition from groundwater inflows that should be considered for a low flow nutrient analysis as part of the applicant's consultants approach to assessment of cumulative water quality impacts.

N-limit Threshold for the Ahuriri Arm

57. Within the GHD reports, a threshold N-limit for the Ahuriri Arm of Lake Benmore is presented as 154,185 kg/annum. At this point, and in consideration of the audited N-mass balances outlined above, I have concerns over how little additional catchment N-loss may be accommodated within this threshold N-limit.

58. I raise this issue of the threshold N-limit also in relation to the current estimated N-load and trophic status of the Ahuriri Arm. NIWA (2009) does present an increased N-load under the current land use scenario. However, a much increased N-limit is also suggested by NIWA to retain the Trophic Lake Index at less than 2.9.

59. It may be very difficult to accommodate additional N-loss into the threshold limit set by GHD, otherwise, there is an obvious error in the calculation of the threshold limit identified for the Ahuriri Arm.

Low Flow Assessment

60. Dr Mzila presented evidence to address the requirement for further analysis of nitrogen impacts on surface waters at low flow conditions (instead of at mean flow).

61. I have reviewed Dr Mzila's evidence and assessed the available stream water quality and flow data. Dr Mzila's plots of modelled and measured N concentrations provided in evidence do not allow for the apportioning of any N discharge during low flow periods. This is why the modelled N concentrations are significantly higher than the N concentrations measured during low flows. As noted, there are few data points on which to base these conclusions on and I maintain that critical gaining streams are most susceptible from N addition from groundwater sources during low flows.

62. Additionally in paragraph 62 of Dr Mzila's evidence he states that there is "not a strong relationship between flow and nitrate-N concentrations in surface waters……." I agree with that finding.

63. Upon review of the water quality data provided by Dr Mzila, I find that there are few data points on which to base any statistical certainty of a trend toward lower N concentrations in any gaining streams at low flow. I reiterate that N concentrations are likely to be correspondingly higher at low flow given the greater ratio of groundwater to surface waters present.

64. Rather than to try and provide meaningful statistical analysis of the limited dataset, I make comment on critical sub-catchment reaches that are susceptible to significant groundwater inflow and that are located down-groundwater gradient of additional proposed irrigation areas. These stream reaches are:

    (a) Grays River at the lower Tekapo confluence – With the limited data there is no correlation to suggest lower N concentrations at lower flows. Higher N concentrations are likely at low flows as the river in the lower reaches gains significant flow from groundwater sources.

(b) Wairepo Creek – No correlation of N concentrations to stream flow. However, the stream gains flow from Spring Creek, which is completely groundwater sourced.

(c) Omarama Stream – No correlation of N concentrations with stream flow. However, the stream gains flow from groundwater sources in mid reaches and in some lower reaches.

(d) Quailburn and lower Willowburn – No correlation of N concentrations with stream flows. Both streams gain flow from groundwater input in lower reaches.

(e) And the lower Ahuriri River – There is no water quality information available for this reach. Significant flow gains are expected to occur from groundwater discharging to the mid to lower reaches of the river.

65. Existing hydrogeologic information suggests (confirmed by the applicant's consultant's models) that the above reaches are susceptible to groundwater inflows and are down-groundwater gradient of proposed new irrigation development.

66. I suggest that all of the above streams require additional information to be provided in respect of potential adverse environmental effects of irrigation development upon water quality (stream concentrations for N) during low flows. Otherwise, I would recommend that a comprehensive monitoring programme be developed in which to assess cyclic or seasonal changes in N concentrations within the above surface water reaches.

67. I also make comment on the applicant's consultant's assessment of potential N addition to the lower Tekapo River, and why I consider that this stream reach is unlikely to be adversely affected by the additional proposed irrigation development.

68. I agree in principle to the by-passing of the majority of groundwater flow within the Twizel basin to the Haldon Arm of Lake Benmore. This is due mainly to the relative piezometric levels and direction of groundwater flow in the basin allowing the majority of groundwater to "undercut" the lower reach of the Tekapo River (below the Grays Hills Gorge to the confluence with the Ohau Canal discharge). The piezometric levels also indicate that this stream reach loses flow to groundwater. However, it is plausible that some groundwater may eventuate in the Tekapo River from sources located on the true right bank. Given this eventuality and in consideration of the available hydrogeologic data, I recommend that sufficient ongoing water quality monitoring be undertaken to support the applicant's consultant's claims.

SUMMARY

69. I am satisfied that phosphorus mass balances and the subsequent provision of mean flow P-loads in surface waters and in Lake Benmore is correct and is based on sound methodology, albeit reasonably conservative.

70. On the basis of my audit of N-loads provided in evidence, reports and spreadsheet information by the applicant's consultants, I am comfortable that the current base case scenarios for N-load to each arm of Lake Benmore have been appropriately calculated by GHD experts.

71. Overall, I consider that the "bucket type" approach undertaken by GHD to be reasonably appropriate in defining both the Ahuriri and Haldon Arm's hydrologic state on an annual basis. It should be noted that drought events or flow management (including abstraction) may significantly alter the residence time in the Ahuriri Arm. Although, based on monthly average inflows, this may occur infrequently and for a relatively short duration.

72. I consider that the groundwater recharge values presented by the applicant's consultants are generally consistent with previously reported or expected recharge rates or volumes. However, there is still an outstanding issue of the apportioning of aquifer discharge to surface waters, and what volume of groundwater may then occur as deep groundwater flow to Lake Benmore.

73. Critical sub catchment reaches that are susceptible to significant groundwater inflow and that are located down groundwater gradient of additional proposed irrigation areas are:

    (a) Grays River at the Lower Tekapo confluence

    (b) Wairepo Creek

    (c) Omarama Stream

    (d) Quailburn and lower Willowburn

    (e) And the lower Ahuriri River.

74. I suggest that all of the above streams require additional information to be provided in respect of potential adverse environmental effects of irrigation development upon water quality (stream concentrations for N) during low flows. Otherwise, I would recommend that a comprehensive monitoring programme be developed in which to assess cyclic or seasonal changes in N concentrations within the above surface water reaches.

75. Although N-concentrations for the Wairepo Arm are unable to be re-calculated based upon information supplied by the applicant's consultants, in the absence of such data, I confirm that N-concentrations would almost certainly increase from that indicated in the GHD mass balance results with expected additional groundwater input. I suggest that ongoing water quality monitoring be undertaken in the lower Wairepo Stream and/or the Wairepo Arm to verify the applicant's consultant's claims.

76. I also suggest that ongoing water quality monitoring of the lower Tekapo River (below Gray's Hills Gorge to the Ohau Canal confluence) be undertaken in order to verify the applicant's consultant's claims that groundwater is not a significant source of flow for that stream reach.

77. I also raise the issue of the threshold N-limit set for the Ahuriri Arm by the applicant's consultants. The current limit would restrict any additional catchment N-loss. Otherwise, there may be an obvious error in the calculation of the threshold limit identified.

Signed: Date: 11 January 2010

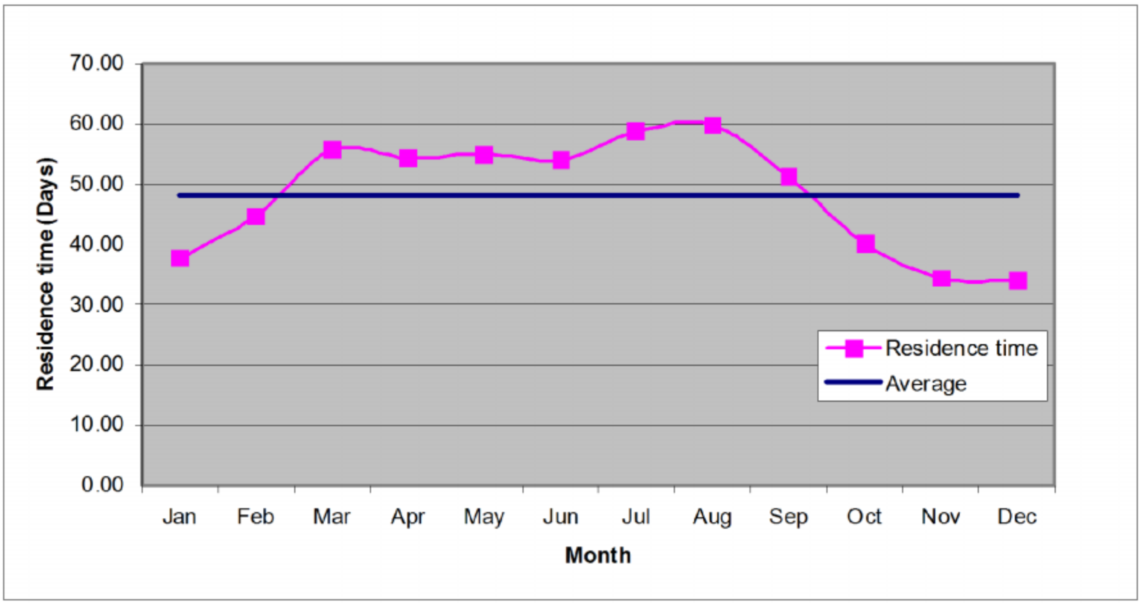
Thomas Brendan Heller
Director, Environmental Associates Ltd

REFERENCES

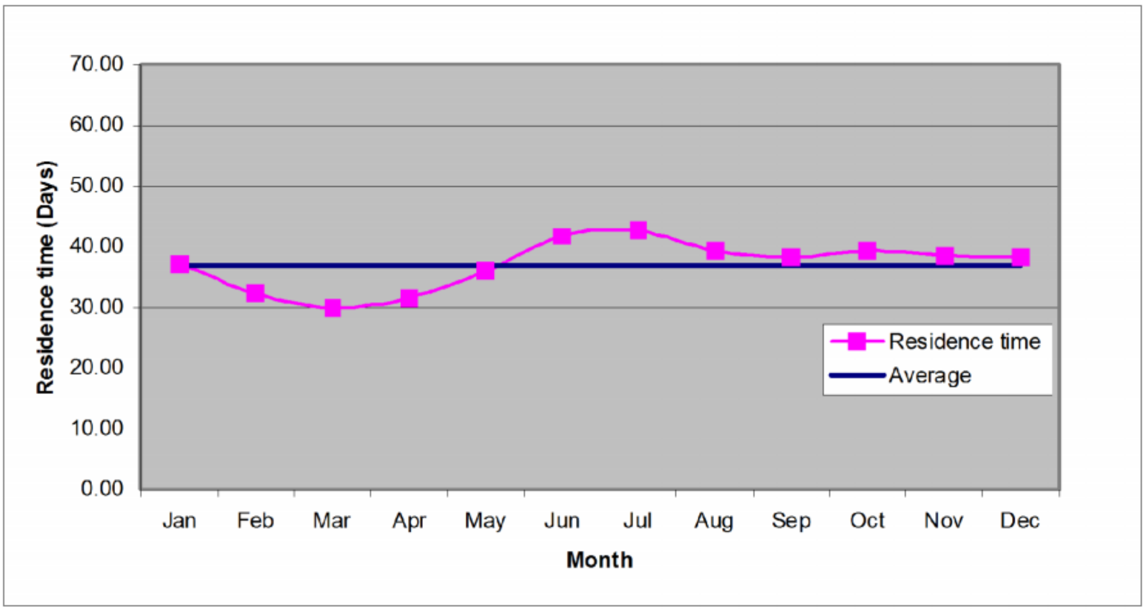
Kingston-Morrison (1999). Hawea Basin Groundwater Report. Report Prepared for the Otago Regional Council.

NIWA (2009). Lake Benmore Water Quality: A Modelling Method to Assist with Assessments of Nutrient Loadings.

Appendix 1 – Lake Benmore Residence Times



Estimated Residence Times for Ahuriri Arm (based on GHD average of 48.3 days)



Estimated Residence Times for Haldon Arm (based on GHD average of 37 days)

Appendix 2 – Catchment Based N-loss Estimates

N-loss for Ahuriri Arm catchment (current base case – GHD data)

Area[1]	Size (ha)	Average N-loss rate[2] (kg/ha/annum)	Total N (kg)	Mean lake in-flow (L/s)	Lake N concentration (mg/L)
Uplands	138,965	0.5	69,482.5		
Downlands – non irrigated	27,845.2	2.2	61,259.4		
Downlands - irrigated	4,595.8	9	41,362.2		
Total	**171,406**		172,104.1	38,947	0.139
GHD estimate			153,363	38,947	0.124
N Reduction %			10.9		

Notes: 1 Area obtained from GHD reports or from GIS mapping
2 Average N-loss rates obtained from GHD reports or from spreadsheet calculations

N-loss for Haldon Arm catchment (current base case – GHD data)

Area[1]	Size (ha)	Average N-loss rate[2] (kg/ha/annum)	Total N (kg)	Mean lake in-flow (L/s)	Lake N concentration (mg/L)
Uplands	513,291	0.5	256,645.5		
Downlands – non irrigated	155,146.1	2.2	341,321.4		
Downlands - irrigated	4253.9	9	38,285.1		
Total	**672,691**		636,252	310,942	0.065
GHD estimate			511,347	310,942	0.052
N Reduction %			19.6		

Notes: 1 Area obtained from GHD reports or from GIS mapping
2 Average N-loss rates obtained from GHD reports or from spreadsheet calculations

N-loss for Ahuriri Arm catchment (current base case – estimated n-loss data)

Area[1]	Size (ha)	Average N-loss rate[2] (kg/ha/annum)	Total N (kg)	Mean lake in-flow (L/s)	Lake N concentration (mg/L)
Uplands	138,965	0.25	34,741.3		
Downlands – non irrigated	27,845.2	2.5	69,613		
Downlands - irrigated	4,595.8	10	45,958		
Total	**171,406**		150,312.3	38,947	0.122
GHD estimate			153,363	38,947	0.124
Difference %			2.0		

Notes: 1 Area obtained from GHD reports or from GIS mapping
2 Based upon average N-loss rates reported in evidence in consideration of similar work undertaken in the Hakataramea catchment

N-loss for Haldon Arm catchment (current base case – estimated n-loss data)

Area[1]	Size (ha)	Average N-loss rate[2] (kg/ha/annum)	Total N (kg)	Mean lake in-flow (L/s)	Lake N concentration (mg/L)
Uplands	513,291	0.25	128,322.8		
Downlands – non irrigated	155,146.1	2.5	387,865.3		
Downlands - irrigated	4253.9	7.5	31,904.3		
Total	**672,691**		548,092.4	310,942	0.056
GHD estimate			511,347	310,942	0.052
Difference %			6.7		

Notes: 1 Area obtained from GHD reports or from GIS mapping
2 Based upon average N-loss rates reported in evidence in consideration of similar work undertaken in the Hakataramea catchment