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*in the matter of:* the Resource Management Act 1991

*and:* submissions and further submissions in relation to proposed Variation 1 to the proposed Canterbury Land and Water Regional Plan

*and:* **Various submitters as set out in Annexure 1**

Joint rebuttal evidence of Nicholas Conland, Michelle Sands,  
Phillip Jordan and Richard Cresswell

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Dated: 8 September 2014

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**Annexure 1**

This brief of evidence is provided on behalf of a number of submitters including:

Central Plains Water Limited

Horticulture New Zealand Limited

Irrigation NZ Limited

DairyNZ

The Foundation for Arable Research

Dairy Holdings Limited

Beef & Lamb NZ

NZPork

Canterbury Grasslands Limited

Camden Farm Limited

**JOINT REBUTTAL EVIDENCE OF NICHOLAS CONLAND, MICHELLE SANDS, PHILLIP JORDAN AND RICHARD CRESSWELL**

**INTRODUCTION**

***Nicholas Conland***

- 1 My name is Nic Conland, I am an Environmental Scientist. I have worked for Sinclair Knight Merz (now Jacobs) as an Environmental Consultant since 2010. My full qualifications and experience were outlined in our Evidence in Chief (EIC).

***Michelle Sands***

- 2 My name is Michelle Sands, I am an Environmental Scientist. I have worked for SKM (now Jacobs) since 2004 as an Environment Scientist. My full qualifications and experience were outlined in our EIC.

***Phillip Jordan***

- 3 My name is Phillip Jordan. I have worked for SKM (now Jacobs) as a Senior Hydrologist since January 2003. I am the Jacobs Practice Leader for Modelling Catchment Processes. My full qualifications and experience were outlined in our EIC.

***Richard Cresswell***

- 4 My name is Richard Cresswell. I have worked for SKM (now Jacobs) as a Senior Hydrogeologist since 2011 and lead the groundwater team in the Sydney office. Previously, I was a Principal Research Scientist with CSIRO Land and Water in Brisbane. My full qualifications and experience were outlined in our EIC..

**SCOPE OF EVIDENCE**

- 5 In this evidence we address the EIC from the submitters selected in section 7:
- 5.1 We both raise point in support and disagreement in regards to specific points made by these witnesses
- 5.2 We briefly detail the findings from our calibrated Source model discussed in our EIC. This is primarily in response to submitters and to conclude our EIC.
- 6 As with that evidence I confirm I have read the Environment Court practice note and have complied with it in preparing this rebuttal evidence.

## **SUBMITTER REBUTTAL**

7 In this evidence we have considered the evidence of the following submitters:

7.1 Fish and Game (Pearson);

7.2 Fish and Game (Cooke);

7.3 Fish and Game (Dewes);

7.4 Ngai Tahu (Wilcock);

7.5 Ngai Tahu (Begley);

7.6 Ngai Tahu (Mckerchar);

7.7 Central Plains Water (McIndoe).

### **Fish and Game (Pearson)**

8 We have reviewed the EIC of Scott Pearson who proposes an alternative approach to managing the catchment based on “determining the ‘current state’ of the environment and the goal of returning this catchment back to ‘ecosystem health’.” We agree with the assertion that a better understanding of the current state is required to make good decisions and our EIC makes note of several assessments made by our experts from the existing observed data to estimate the load to the lake and the function of denitrification in the baseflows around the large margins.

### ***General Approach to modelling***

9 We agree with Pearson that there is a high level of uncertainty in the current modelling framework for the reasons discussed in our EIC. There is also a high reliance on OVERSEER for determining the potential nitrogen loading rates to the shallow groundwater.

10 We also agree that a lack of time series and flow proportional monitoring makes it challenging for model calibration and predicative analysis. Any conclusions drawn from the current data are limited to the areas where the existing data sets are available.

11 In his EIC Pearson recommends a dual nutrient approach and while we agree with an adaptive management approach for determining the performance of regulatory measures it is equally challenging to apply an enforceable limit to catchment areas where the processes aren’t well understood and there is poor monitoring.

12 We agree with E-can that the phosphorus limits and loads are best managed as a lake load and the outcome managed through the recommended TLI range for the lake. However, this could change as

cause and effect relationships are established and monitoring data improves to support these conceptual and numerical models.

- 13 We find that while Pearson suggests that the most reliable measure of progress is against 'current state', we argue that decisions which require changes in peoples livelihoods and a cost benefit analysis require predictive modelling to answer questions about the outcomes for different regulatory options proposed. The suggestion that interim limits will provide certainty for regulators or landowners is flawed and will not solve issues with over-allocation.
- 14 We do agree that the variation 1 plan would benefit from clear review methods, monitoring and an adaptive management approach.

#### **Fish and Game (Cooke)**

- 15 Dr Cooke raises some important issues regarding nutrient load impacts on surface waters in the Selwyn Te Waihora catchment and we agree, in principle, with two of the three critical conclusions of his evidence, namely (Dr Cooke's paragraph 9):

"– there is justification in including phosphorous load limits in Selwyn-Waihora" considerations, thus applying a dual nutrient control approach for future assessments, and

"– an improved methodology is required to monitor progress towards meeting the objectives of variation 1 and Policy A2 of the NPS-FM that the water quality of streams, rivers and Te Waihora should improve by 2037 (relative to current state)".

- 16 We do not, however, agree with Dr Cooke's third element of evidence, namely his approach to "load limit setting of nitrogen".
- 17 Specifically, the approaches adopted by both ECan and Dr Cooke will over-predict nitrogen loads to Te Waihora compared to currently observed loads from gauge data, or predicted by our revised modelling.

#### ***Review and critique of current work on load limit setting***

- 18 Dr Cooke presents a relationship between flow and load and draws the incorrect conclusion that the power relationship illustrates that nitrate concentration increases with increasing flow.
- 19 Indeed, the relationship shown in Dr Cooke's Figure 1 demonstrates that the actual relationship involves a decrease in concentration with increasing flow, as the multiplier to convert flow to load is less than 1 (0.8972). This would need to be greater than 1 for concentration to increase under this relationship.

- 20 Further, examination of actual data from Coes Ford reveals there are likely three (not two as Dr Cooke surmises) flow regimes as illustrated in the figure below.

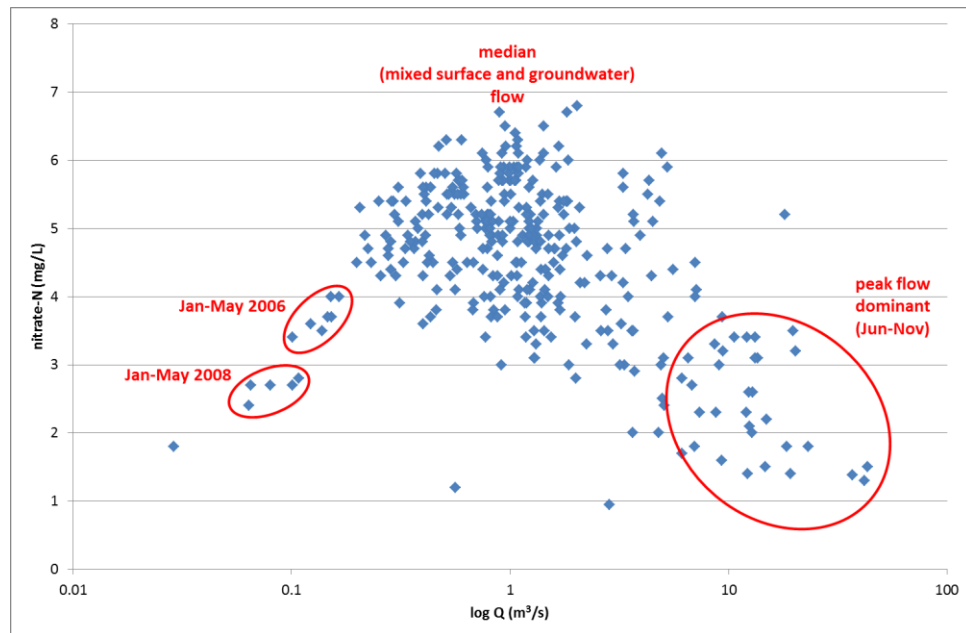
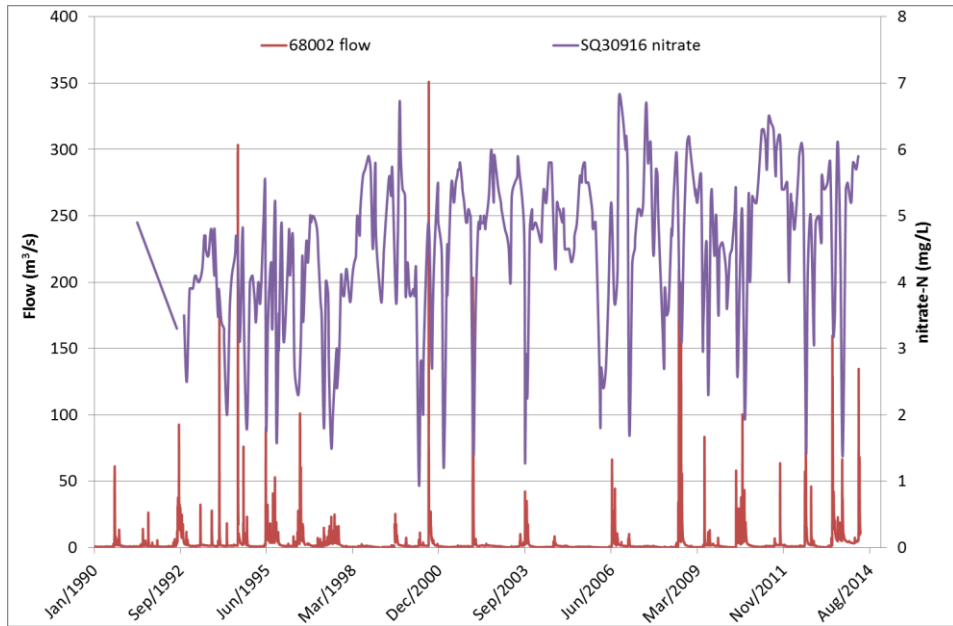


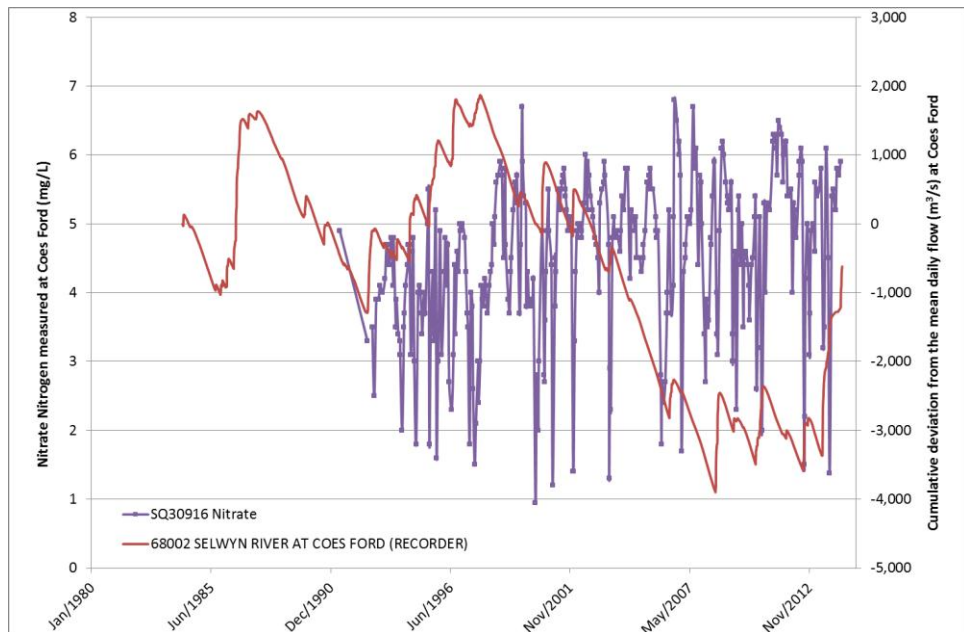
Figure 1 – Nitrogen concentration vs flow relationship at Coes Ford gauge on the Selwyn River

- 21 The data demonstrate why the curve generated by Dr Cooke deviates at low and high flows from the expected relationship. Thus, under median or normal flow conditions, there is a mix of nitrate derived from local surface water and groundwater sources. During high flow events (such as during winter and spring melt events) only surface water is seen, presumably dominated by surface water from high in the catchment and hence with low nitrate composition. During very low events (during dry summers), surface flow reduces almost to zero and flow is dominated by groundwater inputs that trend locally to ~3-4 mg/L nitrate N, as is seen in local bores in this area.
- 22 The relationship can also be seen when the time series of flow is plotted against nitrate concentration (figure below). Peak flows correspond to distinctly reduced nitrate concentrations in the stream while very low flows have elevated nitrate concentrations.



**Figure 2 – Time series of flow passing gauge 68002 at Coes Ford and samples from collector SQ30916 also at Coes Ford.**

- 23 Interestingly, there is a distinct increase in the average nitrate concentration after 1998. This can be explained by a shift in flow regime from a generally drying trend prior to 1992 to a wetting trend through to 1997 which kept nitrate concentrations lower than the long-term average and generated a greater number of peak flows than the long-term average. The figure below illustrates this by comparing the cumulative deviation from the long-term average daily flow to measured nitrate-N concentration at Coes Ford. Rising trends in the cumulative deviation curve represent wetter than average conditions (i.e. greater flow); falling trends represent drying conditions.



**Figure 3 – Cumulative deviation curve for flow at Coes Ford compared to nitrate concentration at the same location**

- 24 There is an apparent return to wetting conditions over the past year and this should be assessed against nitrate at Coes Ford to corroborate the previous observation of lower nitrate during wetter climate phases.

***Changes in water quality conditions for lowlands streams***

- 25 Regardless, ECan has assumed N concentrations in tributaries are independent of flow, while we can demonstrate that N concentrations are dependent on flow (specifically a decrease in concentration as flows increase). Hence, there will be lower concentrations in tributaries and the lake than those currently predicted by the ECan model and by Dr Cooke.
- 26 As Dr Cooke points out (paragraph 70): “The current ZCSP limit setting exercise is based on a top down (paddock to the lake) approach and because of lag and attenuation issues there has been no attempt to verify predictions with [*comparison to the*] current state of spring-fed tributary stream [*sic*] flowing into Te Waihora.”
- 27 To produce reliable predictions of nutrient loads for scenarios that result in changes to groundwater recharge and surface runoff, the nutrient loads and concentrations transmitted via these different flow pathways should therefore be simulated in their own right.
- 28 The Source model simulates both surface and groundwater transmission pathways and attributes different concentrations to nutrients generated via both pathways.



***Is phosphorous an issue: the McDowell Paper on phosphorous transport in alluvial environments***

- 29 In general, we agree with Dr Cooke's summary and concerns regarding phosphorous transport in the Selwyn-Te Waihora catchment.
- 30 We would point out, however, that the presence of (low levels of) phosphorous is conducive to nitrate up-take by plants (including phytoplankton) and levels up to those currently observed do not pose a risk to the environment.
- 31 Further, phosphorous will tend to remain fixed in plant material, and will be buried as the plants die and sink to the lake floor during sedimentation. Hence, phosphorous (together with nitrate) will be removed from the water column under normal lake processes and will not be "recycled" as Dr Cooke states in paragraph 51.
- 32 Indeed, the addition of phosphorous to degraded (acidified) lakes in the northern hemisphere has been shown to aid in nitrate reduction, albeit at lower levels of phosphorous than is observed in Selwyn-Te Waihora, and this has been shown to aid in the restoration of endemic lake communities, which commonly does not happen using other remediation methods (such as liming) to fix nitrate and phosphorous.
- 33 The strongly correlated relationship between nitrate and phosphorous in ecosystem function and response emphasises the need to apply a combined nutrient control approach to future assessments.
- 34 Dr McDowell's research into phosphorous pathways between surface and groundwater systems is a focus of Dr Cooke's evidence and highlights a potential legacy for P enrichment for lowland spring-fed streams for decades to come.
- 35 As noted for nitrate, elevated levels (0.03 mg/L) of dissolved reactive phosphorous is observed in mid-catchments. Lower levels (<0.01 mg/L) are observed in bores near the lake.
- 36 Further investigations are therefore required prior to introducing P limits at farms as well.

**Fish and Game (Dewes)**

- 37 Alison Dewes (Dewes) in her EIC makes statements about the assessment for nitrogen allocation for the catchment and in particular Central Plains Water (CPW).
- 38 The land use and nitrogen load assumptions we have made in our modelling differs slightly from those assumed by Environment Canterbury and discussed by Dewes in table 1. (Tables 2-7 EIC)

- 39 Our assessment of the existing nitrogen allocation for CPW at 2014 of 1884 tonnes is based on best available information landuse and Lilburne et al (2013) loads, and therefore the calculated average leaching rate is consistent to the loads calculated elsewhere within the catchment.
- 40 It is worth noting that Dewes assertion in paragraph 20 is incorrect. 1500 tonnes over 45000 ha would equal an average of 33kg/ha/yr, rather than the 44kg/ha/yr calculated by Dewes. Furthermore, the CPW area is 60,000 ha and in the existing situation approximately half of the land is irrigated.
- 41 The existing load we calculated for the remaining load is 2730 tonnes; this is less than Environment Canterbury's assumed load of 2910 tonnes. Our load calculation was based on Lilburne et al (2013) leaching rates and landuse data supplied by Environment Canterbury, with minor modifications made for land use change. Our assumptions do not allow for intensification of existing land above the existing baseline for the respective landuses.
- 42 In paragraph 22 Dewes discusses the additional load allocated to CPW. Our calculations indicate the additional load allocated to CPW is less than assumed by Environment Canterbury. The existing load is 1884 tonnes and the proposed load at 2017 is 1928 tonnes. The load following the clawback provisions is estimated at 1769 tonnes.
- 43 In reference to Dewes paragraph 24, we disagree that CPW land is allowed to leach more than existing users under the proposed variation 1. Under Policy 11.4.14 where properties convert from dry land to irrigated, the nitrogen loss rates from the outset shall be managed in accordance with the proposed reductions in policy 11.4.14. Contrary to Dewes assertion, policy 11.4.17 requires a stricter level of land management to be adopted in CPW before it is required elsewhere in the catchment.
- 44 In paragraph 156 Dewes states "For the Canterbury Plains aquifers, denitrification processes are unlikely to significantly reduce nitrate concentrations as drainage water moves down through the soil profile and gravels are overlying the aquifers" Dewes provides no analysis to support this assertion. We disagree with this statement.
- 45 Our analysis of nitrate state indicates that denitrification is occurring, in the Canterbury Plains, particularly around the lake. Our understanding of the denitrification process is detailed in our EIC.
- 46 In paragraph 157, Dewes goes on to assert the zone committee solutions package will result in the nitrate levels in groundwater and

shallow wells rising by 20-25% as a result of the additional CPW load. Dewes provides no analysis to support this assertion.

- 47 We have developed a calibrated model to assist in determining what impact the proposed plan would have on nitrate levels, and contrary to Dewes assertions we have concluded as outlined below.

**GROUNDWATER QUALITY AND LIKELIHOOD OF EXCEEDANCE OF MAXIMUM ACCEPTABLE VALUES OF NITRATE IN DRINKING WATER**

- 48 Our EIC discussed a Monte-Carlo simulation approach, based upon observed Nitrate concentrations in groundwater bores, to estimate the likelihood of exceeding the Maximum Acceptable Value (MAV) for drinking water quality of 11.3 mg/L of Nitrate Nitrogen. The Monte-Carlo simulation approach also provided an estimate of the likelihood of exceeding 6.6 mg/L of Nitrate Nitrogen, approximately half the MAV.
- 49 The Monte-Carlo simulation approach was applied at bore L36/0871 which is located 5 km to the north-west of Te Waihora/Lake Ellesmere and is in an area with shallower groundwater levels, where the low observed Nitrate concentrations in the bores reveal that denitrification of the groundwater is occurring. On the basis of observed median nitrate concentrations in many observation bores, statistics estimated from Nitrate concentrations at bore L36/0871 would be representative of groundwater quality in a zone located up to about 10 km from the lake boundary.
- 50 The Source model was used to estimate the mean Nitrate Nitrogen concentration in groundwater across the climatic period in the model run from 1 July 1980 to 14 May 2014, for each modelled scenario. The Monte-Carlo simulation approach was then used to estimate the likelihood (on any given day) of exceeding 11.3 mg/L and 6.6 mg/L.
- 51 Table 14 shows that under all scenarios modelled the likelihood of exceeding the MAV in the shallow groundwater in the zone where denitrification is very low is approximately 0.1%. There is a very small simulated increase in the likelihood of exceeding the MAV under Scenario 2b (with CPW), although this change in probability is extremely low. Implementation of the proposed caps on TN leaching rates as set out in Variation 1 (modelled Scenario 3a) results in reductions in the likelihood of exceeding the MAV, although once again the reductions in probability are very small.
- 52 The likelihood of exceeding MAV for Nitrate Nitrogen concentrations in groundwater is higher under existing conditions further away from the Lake. At greater than about 10 km from the lake, the water table is beneath the land surface and most groundwater

movement is either down or laterally towards the lake and hence there is limited capacity for denitrification to occur. The Source model was not able to provide reliable mean annual predictions on Nitrate Nitrogen concentrations in the groundwater more than about 10 km from Te Waihora / Lake Ellesmere. We have therefore not provided an estimate of the likelihood of exceeding the MAV for Nitrate Nitrogen for areas where groundwater flux is not upwards which corresponds to areas more than about 10 km away from the lake.

- 53 There are currently over 1,000 bores located within the shallow aquifer in the de-nitrification zone near the lake that we would argue would not undergo any significant nitrate increase.

**Ngai Tahu (Wilcock)**

- 54 We have reviewed the EIC of Dr Wilcock and strongly endorse the recommendations (near-lake wetlands and increased riparian vegetation) made in his evidence.
- 55 In particular we welcome the opportunity to improve the outcomes discussed in our EIC for increased denitrification and provide reductions in nitrogen loads to the lake.
- 56 We do note in Wilcock EIC at para's 21,22 and 34 he assumes the E-Can groundwater lag times of 10 to 30 years will apply. Our own work to develop a conceptual model for the groundwater system indicated much quicker travel times. These indicate from the observed data that the mean groundwater travel times for nitrates are closer to 10 years or less
- 57 This would imply that measures to manage nutrients through a matrix of good management practices and through catchment interventions may have a more rapid effect on improving the lake TLI than Wilcock currently assumes.
- 58 We also note that Wilcock acknowledges that the predominant driver for lake TLI is the existing legacy nutrient cycling.

**Ngai Tahu (Begley)**

- 59 Begley's submission outlines a number of proposed changes to objectives policies and rules with an emphasis on reflecting Ngai Tahu cultural values and a long term vision for the receiving environments. We support the general concepts within the evidence, but we have not undertaken specific analysis to determine the effects of the Begley's proposed changes to rules and policy.

**Catchment Load**

- 60 Begley supports principle of catchment load. One should have a reasonable degree of confidence that, whatever the catchment load

is, it is adhered to (para 70), we agree with this statement, and we consider the uncertainty in the methodology adopted by of the assess the effects of Variation 1 by Environment Canterbury of the load, does not provide sufficient confidence that variation 1 will have effects that consistent with those outlined in the Section 32 report.

- 61 We agree with Begley’s statement setting the proposed clawback in policy 11.4.14 prior to Environment Canterbury understanding the benefits of GMP,” is not good planning”. (para 80). We recommend that a catchment load is set to account for Good Management Practice and is calculated in manner that enables on farm calculations of leaching to be compared to the catchment load.

**Ngai Tahu (McKerchar)**

- 62 We support in general the EIC provide by Dr McKerchar.

***General Approach to modelling***

- 63 McKerchar (EIC) presents a regression model that demonstrates a temporal trend in seasonal (90 day) low flows in the Selwyn River at Coes Ford that is additional to the signal presented in estimated recharge to groundwater and recorded seasonal flow at Whitecliffs. McKerchar identified an apparent trend of 32 L/s/year reduction in 90 day low flow across a 22 year period (1984-2006).
- 64 McKerchar makes the assumption that the reduction in seasonal flows is caused by increases in irrigation within the catchment, hence causing an increase in evapotranspiration and reduction in long-term recharge to groundwater. However, the model used is purely statistical – there is no causative process reflected in the model. It is possible that some or all of the reduction in flow with time in the observed data is caused by a factor other than increase in irrigated water use in the catchment.

**CENTRAL PLAINS WATER MODELLING**

**Evidence of Mr Ian McIndoe**

- 65 We support in general the EIC provide by Mr McIndoe, in particular his comments on the previous review of the E-Can modelling work.
- 66 As stated in our Evidence in Chief (EIC), we have established a Source integrated catchment model of the Selwyn-Waihora catchment area. The Source model simulates surface and groundwater transmission pathways for both flows and nutrients. The Source model also simulates irrigation and the extraction of water from surface and groundwater to irrigated parts of the catchment.

- 67 As a single, integrated, model, Source has a considerable advantage over the modelling approach adopted by ECan, which relied upon integrating modelling from four separate models. ECan's modelling approach utilised separate models for modelling of the water balance within soils in the catchment, groundwater flow modelling, modelling of stream flows and hydrological modelling of water quality.
- 68 At the time we presented our EIC, we were still in the process of calibrating the Source model to observations in the catchment. The Source model calibration has now been completed and we present in this statement of evidence a summary of the outputs from the Source model.
- 69 We agree with the criticisms of the ECan approach in the evidence of McIndoe that the adoption of separate models for each component of the water and nutrient balance in the catchment leads to potential inconsistencies in assumptions between models. We agree with McIndoe's criticisms that the potential inconsistencies then result in incorrect predictions and conclusions made from the overall modelling suite.
- 70 In particular, we agree with McIndoe's (EIC paragraphs 34-37) in that the ECan approach appears to have double counted the quick flow component of flow and that the approach use does not allow for the quick flow component to change as the modelled area under irrigation changes.
- 71 We also agree with the criticism of McIndoe (EIC paragraph 58) that there is inconsistency with the land surface recharge rates estimated by Lilburne et al. (2013) for different soil types and landuses with the recharge rates to groundwater that were used in R14/11.
- 72 The Source model that we have developed does not suffer from these limitations, as the integrated model estimates the water required for irrigation water use, generates quick flow, generates drainage to groundwater and simulates transmission of groundwater flows in a single model that maintains the overall water balance.
- 73 The Source model simulates the water balance in the soil profile on a daily time step for the period between 1972 and 2014, using the Soil Moisture Water Balance Model (SMWBM). The Source model simulates the water stored in the soil profile on a daily basis using rainfall and potential evapotranspiration time series on a daily basis. For irrigated landuses, the Source model estimates the depth of irrigation water likely to be required by the soil and adds this to the soil profile.

- 74 The Source model was run to estimate the mean annual rate of groundwater recharge in each subcatchment of the Source model, for irrigated and dryland landuses and for "lighter soils" (soil classifications XL, VL and L) and "heavier soils" (M, H, Pd and PdL). For each of the four combinations of irrigated / dryland and lighter / heavier soils, the outputs from the Source model were used to estimate the mean annual recharge rates for the modelling period for mean annual rainfall bands of 650, 750 and 850 mm.
- 75 The mean annual rates of recharge estimated by the Source model are presented in Table 4. When compared with the mean annual rates of recharge estimated by Lilburne et al. (2013), the rates from the Source model on virtually all combinations are larger, typically between 30% and 150% larger than the estimates from Lilburne et al. (2013).
- 76 The Source model also estimated the mean annual load of TN from each landuse in each model subcatchment, which was the sum of the load generated via both surface and groundwater flow pathways. Some of the TN load generated and transmitted into the groundwater remains in the groundwater system, travelling beneath Te Waihora and out to sea. Some of the TN load that is generated as drainage and goes into the groundwater system is de-nitrified in the shallower layer of the groundwater system and the loads of Nitrate and TN transmitted into the lowland streams, for both reasons, are lower than the loads as they are generated in the catchment.
- 77 Table 1, Table 2 and Table 3 present the mean annual volumes of total surface runoff and drainage and mean annual TN loads generated for the Rakaia-Selwyn, Selwyn-Rakaia and Selwyn-Waimakariri zones respectively for the existing conditions scenario (Scenario 1). The loads and total runoff and drainage generated represent the mean values across each zone: the Source model internally simulates variability in the flow and TN load generated due to climatic variation between subcatchments within each zone.
- 78 The mean annual generation rates per unit area simulated in the Source model (as presented in the tables) may be slightly higher than the rates indicated in Lilburne et al. (2013) for two reasons. Firstly, the estimates from the Source model include both surface runoff and drainage to groundwater whereas Lilburne et al. (2013) only documents the drainage to groundwater and the TN load associated with drainage to groundwater). Secondly, the Source model simulates the rainfall signal occurring on each subcatchment in the model and there are some subcatchments with higher mean annual rainfall (and hence higher total flow and TN load generation) than the three rainfall categories that were considered by Lilburne et al. (2013). Having stated those two qualifications, the mean annual

TN loading rates across the three zones calculated by the Source model for the existing conditions scenario (Scenario 1) are comparable with those documented by Lilburne et al. (2013).

- 79 The mean annual TN loading rates per unit area estimated from the Source model demonstrate consistency with loading rates that would be expected (on average) with rates that would be expected from other models, such as Overseer. For the same landuse type in the Source model, irrigated land produces higher total flow generation and higher mean annual TN load per unit area than dryland. The highest loading rates per unit area are produced by dairy and dairy support landuse categories, with grazing, arable and horticulture in the mid-range and very low loading rates produced from native and plantation forests.

### **SCENARIOS RUN USING THE SOURCE MODEL**

- 80 The Source model was run for five different scenarios discussed in our EIC in table 14:

### **FLOWS IN LOWLAND STREAMS**

- 81 The Source model was used to estimate a daily time series of flows for each scenario. These daily time series of flows from the model run were used to estimate the mean daily flow (MDF) and mean annual 7-day low flow (7dMALF). Although the Source model was run for the period from 1 January 1972 to 14 May 2014, the analysis of flow statistics was restricted to the period between 1 July 1980 and 30 June 2013 to allow for adequate warm up period for the Source model to be accurately representing flows.
- 82 The MDF and 7dMALF for Scenario 1 are comparable, as a means of testing the model calibration, against gauged flow data for sites where it is available. MDF and 7dMALF flow statistics were computed from gauged flow data for the entire period of record, whilst the flow statistics were computed from the Scenario 1 outputs for the period between 1 July 1980 and 30 June 2013. Some of the differences in flow statistics between modelled and gauged may be attributable to differences in climatic conditions between the periods used for analysis of gauged data and model output – these differences are potentially more considerable where the gauged data record is shorter.
- 83 During the Source model calibration process, other criteria to establish calibration of the model were also used, including the correlation in the time series between gauged and modelled flows, the probability distribution (or flow duration curve) of gauged and modelled flows, the relative prevalence of generation of surface runoff from irrigated and dryland areas and mean annual drainage



rates to groundwater (as discussed in paragraphs 72 to **Error! Reference source not found.**).

- 84 Table 5 presents a comparison between the mean daily flows estimated from the Source model for the existing conditions scenario (Scenario 1), gauged flows and the equivalent ECan Scenario 1. The comparisons vary between gauging sites, in some cases with the Source model over-estimating the mean daily flow and in some cases under-estimating. Given the potential inconsistency in the periods used for calculating the statistics from the gauged data and the model, these differences are acceptable.
- 85 Table 6 presents a comparison between the 7dMALF statistics estimated from the Source model for the existing conditions scenario (Scenario 1), gauged flows and the equivalent ECan Scenario 1. The comparisons vary between gauging sites but in general the Source model is producing lower estimates of 7dMALF for the existing conditions scenario than revealed by the gauged data or ECan's equivalent model run. The Source model is apparently not sustaining baseflows in the lowland streams for the existing conditions scenario to an equivalent level as was observed in the gauged data. However, given the match in the mean daily flows, the Source model is representing flow conditions across moderate and high flow ranges that are comparable with gauged flows.
- 86 Table 7 compares the modelled mean daily flows between the Source model simulations for the Scenarios. The naturalised scenario results in an increase in mean daily flow compared with the existing scenario in the Halswell River, Harts Creek and the LII River but a minor decrease in mean daily flow for the Selwyn River and the Hanmer Road drain. The removal of irrigation extractions under the naturalised scenario also results in reduction in recharge to groundwater in some parts of the model and this redistribution of baseflow in the interconnected groundwater system represented in the Source model results in the variation in the impact of the naturalised scenario on mean daily flows. Table 8 shows that under the naturalised scenario 7dMALF is projected to increase substantially in the lowland streams from existing conditions, particularly for the lowland streams with smaller surface water catchments and hence a larger proportion of their flow contributed via groundwater.
- 87 As shown in Table 7, implementation of the proposed Schedule 10 limit on extractions provides no modelled improvement in mean daily flows under existing conditions. The Source model finds that implementation of the proposed Schedule 10 limit would actually reduce 7dMALF from existing conditions in most of the lowland streams (by between -1% and -5%), as artificial recharge from

irrigation would be reduced in drier years and this more than offsets the reduction in extractions from groundwater.

- 88 Implementation of the CPW scheme (Scenario 2b) increases both MDF and 7dMALF from existing values in almost all of the lowland streams that were modelled.

### **WATER QUALITY IN LOWLAND STREAMS**

- 89 The Source model was used to simulate Dissolved Inorganic Nitrogen (DIN) concentrations in the lowland streams on a daily timestep. The analysis of DIN concentrations was restricted in all simulations to the climatic period between 1 July 1980 and 30 June 2013. During the calibration process, the probability distribution of DIN concentrations from the Source model were compared to the probability distribution of DIN concentrations from in-stream water quality monitoring data.
- 90 Results from simulation of in-stream DIN concentrations are presented for the modelled scenarios – with median simulated concentrations presented in Table 9 and 95<sup>th</sup> percentile simulated concentrations presented in Table 10.
- 91 The naturalised landuse scenario results in substantial reductions in simulated DIN concentrations in the lowland streams. As would be expected, removal of all irrigated landuse and the associated conversion of landuse from those with higher TN leaching rates to lower TN leaching rates (assumed to be dryland arable farming) substantially reduced DIN concentrations.
- 92 Modelled in-stream DIN concentrations increase under Scenario 2a from the Scenario 1. Median DIN concentrations increase by between 2% and 18% while 95<sup>th</sup> percentile DIN concentrations increase by 1% and 15%. The increase in DIN concentrations were due to an assumed increase in TN load to 15 kg/ha/year for those landuses that were below this threshold in the Scenario 1 model.
- 93 Simulated changes for in-stream DIN concentrations for the CPW (Scenario 2b) were relatively similar to those simulated for Scenario 2a. Median in-stream DIN concentrations in the lowland streams increase between Scenario 1 and Scenario 2b by between 1% and 17%, with the exception of Harts Creek, where there was a projected reduction in median DIN concentration of 4%.
- 94 Implementation of the proposed caps on TN leaching rates as set out in Variation 1 (modelled Scenario 3a), results variable changes in DIN concentrations between the lowland streams from existing conditions (Scenario 1). Increases in median DIN concentration of 6-7% were simulated for Scenario 3a in the Selwyn and Halswell

Rivers but reductions of between 3% and 16% in median DIN concentrations were simulated for the LII River, Harts Creek, Lee River, Boggy Creek, Hanmer Road Drain and Doyleston Drain.

- 95 Changes in DIN concentrations between scenarios vary between the lowland streams due to spatial variation in the generation and transmission of surface runoff and groundwater-fed baseflow, the differential impact of where the changes in TN loading rates are projected to occur in the catchments and the soil types upon which the TN loading rates are simulated to change.

#### **TOTAL NITROGEN AND NITRATE NITROGEN LOADS DELIVERED TO LAKE ELLESMERE / TE WAIHORA**

- 96 The Source model was used to simulate the total flow of water, TN load and Nitrate load delivered to Lake Ellesmere / Te Waihora. The flows and loads were delivered in the Source model via the lowland streams draining to the lake, with those flows coming via a combination of surface and groundwater flow pathways.
- 97 Table 11 shows the simulated contributions to the DIN load to Lake Ellesmere / Te Waihora from each stream flowing into the lake for the existing conditions scenario (Scenario 1). The DIN mean annual DIN load is currently estimated to be slightly less than 1000 t/year.
- 98 Table 12 shows the simulated Source model estimates of TN generated by zone between scenarios. The naturalised scenario (Scenario 0) results in between -21% and -30% reduction in TN load, varying by zone. Implementation of restrictions on seasonal volumes results in minimal change in TN loads from existing conditions. Scenario 2b results in relatively small increases in TN loads from existing conditions.
- 99 The reduction in DIN load to Te Waihora / Lake Ellesmere under naturalised flow conditions is a relatively modest -6%. If irrigation were no longer undertaken in the catchment, while inputs of TN load would be substantially reduced there would also be a reduction in groundwater mounding (and hence shallow groundwater levels), which would reduce the relative impact of denitrification in the catchment, hence the more muted reduction in DIN load delivered to the lake.
- 100 The projected TN load generated increases in the Rakaia-Selwyn and Selwyn-Waimakariri zones are 8% and 10% respectively under Scenario 2a, due to the assumed increase in TN load to 15 kg/ha/year for those landuse classes that were below this threshold in Scenario 1. This results in a simulated increase of 13% in mean annual DIN load to Te Waihora / Lake Ellesmere from Scenario 1.

- 101 The projected TN load generated increases in the Rakaia-Selwyn and Selwyn-Waimakariri zones are 13% and 14% respectively under Scenario 2b, due to the combined effects of implementation of the ultimate effect of CPW and the assumed increase in TN load to 15 kg/ha/year for those landuse classes that were below this threshold in Scenario 1. This results in a simulated increase of 16% in mean annual DIN load to Te Waihora / Lake Ellesmere from Scenario 1. The incremental impact on mean annual DIN load from implementation of CPW (between Scenarios 2a and 2b) is a relatively small 30 tonnes per year or 3% of the mean annual DIN load to Lake Ellesmere / Te Waihora.
- 102 The increase in DIN load delivered to the lake is muted by some proportion of the additional recharge induced by increased area irrigated travelling via deep groundwater flow pathways, and not reaching the lake, and also by denitrification occurring in shallow groundwater within approximately 10 km of the lake.
- 103 The Source modelling simulates a relatively modest 1% increase in TN load generated in the Little Rakaia zone for Scenario 2b over existing conditions but the accuracy of the change for the Little Rakaia zone is less reliable as less detail was available on existing and proposed future landuse for parts of this zone to the west of the Little Rakaia River.
- 104 Implementation of the proposed caps on TN leaching rates as set out in Variation 1 (modelled Scenario 3a) results in a modest overall increase of 3% in TN load generated in the Selwyn-Waimakariri zone but a 0.2% reduction in the Rakaia-Selwyn zone and 11% reduction in the Little Rakaia zone from existing conditions. The overall net effect of the reduction in loads is a 6% increase in mean annual DIN load to Lake Ellesmere / Te Waihora, or a reduction of approximately 10% in load to the lake when compared to Scenario 2b.

### **CONCLUSIONS**

- 105 We present further arguments that the approaches adopted by both ECan and Dr Cooke will over-predict nitrogen loads to Te Waihora compared to currently observed loads from gauge data, or predicted by our revised modelling.
- 106 We agree, however, that the strongly correlated relationship between nitrate and phosphorous in ecosystem function and response emphasises the need to apply a combined nutrient control approach to future assessments.

- 107 Our modelled scenarios as a generalisation of the catchment have answered some of the key questions raised by our review of the initial modelling by E-Can:

**WHAT IS THE PROJECTED N LOAD TO TE WAIHORA/LAKE ELLESMERE?**

- 108 The Source model predicts that the current load is around 973 (t/year) to the lake. This number is likely to increase in 2017 to 1103 (t/year) and peak in 2022 prior to a clawback mechanism at 1132 (t/year).
- 109 The proposed clawback mechanism will reduce the lake load back to close to the present value at 1033 (t/year).
- 110 The Source model simulations demonstrated that the further reductions in TN load per unit area (as a clawback mechanism) proposed in Variation 1 would result in changes for in-stream DIN concentrations that vary between streams –
- 111 With DIN concentrations simulated to increase in some streams and reduce in others, depending upon the assumed location of changes in TN loading rates in the catchment and the relative contributions of surface and groundwater flow in each of the lowland streams.

**WHAT ARE THE EFFECTS ON REGIONAL GROUNDWATER QUALITY?**

- 112 The Source model predicts that there is a very slight increase in risk of exceedance of the MAV (<0.02%) this risk is reduced to the current probability under the clawback scenario.
- 113 Under all scenarios modelled the likelihood of exceeding the MAV in the shallow groundwater in the zone where denitrification is very low – approximately 0.1%. There is a very small simulated increase in the likelihood of exceeding the MAV under Scenario 2b (with CPW), although this change in probability is extremely low.
- 114 The Source model was not able to provide reliable mean annual predictions on Nitrate Nitrogen concentrations in the groundwater more than about 10 km from Te Waihora / Lake Ellesmere. We have therefore not provided an estimate of the likelihood of exceeding the MAV for Nitrate Nitrogen for areas where groundwater flux is not upwards, which corresponds to areas more than about 10 km away from the lake.

**WHAT ARE THE EFFECTS ON SURFACE WATER QUALITY (AS DISSOLVED INORGANIC NITROGEN)?**

- 115 The Source model predicts that in 2017 when the 15kg/ha/year permitted activity rule is in place and the landuse lifts to the baseline values and a matrix of good management practices is developed the median and 95<sup>th</sup> percentile stream concentrations will increase by up to 18% from the current state.
- 116 The Source model predicts that in 2022 prior to a clawback mechanism and with a fully implanted CPW in place the median and 95<sup>th</sup> percentile stream concentrations will increase by a similar amount from the current state (up to 17%).
- 117 The introduction of the proposed clawback mechanism will cause an increase in the median concentration on Selwyn and Halswell Rivers of 7% and a decrease of up to 16% for the other tributaries to the lake.

**WHAT IS THE EFFECT ON MEAN ANNUAL LOW FLOW (MALF)?**

- 118 The Source model predicts that proposed Schedule 10 approach to seasonal allocation will provide no improvement to the mean daily flows to the lake. it also suggests that the Schedule 10 will would actually reduce the MALF in most of the lowland streams by up to 5%.
- 119 The introduction of the CPW scheme into the catchment increases both the mean daily flows and the MALF in the majority of the lowland streams to the lake.

Dated: 8 September 2014

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## TABLES AND FIGURES

**Table 1 Mean annual total volume of runoff and load of TN generated via groundwater drainage and surface runoff pathways for landuses represented in the Source model within the Rakaia-Selwyn zone under Scenario 1**

Landuse Type	Area (ha)	Mean Annual Total Generated (mm/year)	Mean Annual TN Total Load (tonnes/year)	Mean Annual TN Total Load (kg/ha/year)
Arable Dryland	554	469	8.8	15.9
Arable Irrigated	9679	469	166.9	17.2
Beef Dryland	2321	390	58.4	25.2
Beef Irrigated	2085	454	66.2	31.8
Dairy 3 cows per ha	9872	486	327.9	33.2
Dairy 4 cows per ha	19341	583	1073.9	55.5
Dairy 5 cows per ha	2093	495	111.6	53.3
Dairy Support Dryland	4291	424	193.3	45.1
Dairy Support Irrigated	4526	527	223.4	49.3
Deer Dryland	4095	620	54.3	13.3
Deer Irrigated	263	464	4.9	18.6
Forestry	6163	565	11.3	1.8
Lifestyle	3208	321	34.0	10.6
Miscellaneous	659	753	8.0	12.2
Native Forest	2415	568	3.6	1.5
Orchard	306	504	2.5	8.3
Pigs	555	355	18.2	32.8
Sheep Dryland	10762	517	127.5	11.8
Sheep Irrigated	3070	523	57.6	18.7
Sheep and Beef 10% Dryland	7438	660	197.6	26.6
Sheep and Beef 10% Irrigated	3364	648	109.8	32.7
Sheep and Beef 20% Dryland	4404	452	105.2	23.9
Sheep and Beef 20% Irrigated	2267	545	72.6	32.0
Urban	548	337	4.3	7.8
Vegetables	129	387	2.8	21.6
Viticulture	63	320	0.5	7.7
Water	1350	0	0.0	0.0
<b>Totals for Zone</b>	<b>105819</b>	<b>521</b>	<b>3045.1</b>	<b>28.8</b>

**Table 2 Mean annual total volume of runoff and load of TN generated via groundwater drainage and surface runoff pathways for landuses represented in the Source model within the Selwyn-Waimakariri zone under Scenario 1**

Landuse Type	Area (ha)	Mean Annual Total Generated (mm/year)	Mean Annual TN Total Load (tonnes/year)	Mean Annual TN Total Load (kg/ha/year)
Arable Dryland	603	292	5.8	9.7
Arable Irrigated	16295	580	353.8	21.7
Beef Dryland	4061	355	104.3	25.7
Beef Irrigated	2001	480	70.6	35.3
Dairy 3 cows per ha	9434	489	314.9	33.4
Dairy 4 cows per ha	6780	590	383.2	56.5
Dairy 5 cows per ha	1100	510	59.2	53.9
Dairy Support Dryland	5111	345	176.5	34.5
Dairy Support Irrigated	4564	512	218.7	47.9
Deer Dryland	3471	457	44.2	12.7
Deer Irrigated	943	448	17.6	18.7
Forestry	5991	451	11.3	1.9
Lifestyle	12116	316	129.6	10.7
Miscellaneous	237	669	2.8	11.9
Native Forest	1955	384	3.4	1.7
Orchard	356	510	3.1	8.7
Pigs	1040	298	26.4	25.4
Sheep Dryland	16570	366	165.8	10.0
Sheep Irrigated	4120	545	84.7	20.6
Sheep and Beef 10% Dryland	10822	437	234.0	21.6
Sheep and Beef 10% Irrigated	3522	573	106.8	30.3
Sheep and Beef 20% Dryland	9948	377	205.7	20.7
Sheep and Beef 20% Irrigated	3231	473	86.0	26.6
Urban	4467	316	32.9	7.4
Vegetables	595	483	20.9	35.2
Viticulture	226	328	1.7	7.6
Water	1899	0	0.0	0.0
<b>Totals for Zone</b>	<b>131459</b>	<b>436</b>	<b>2864.0</b>	<b>21.8</b>



**Table 3 Mean annual total volume of runoff and load of TN generated via groundwater drainage and surface runoff pathways for landuses represented in the Source model within the Little Rakaia zone under Scenario 1**

Landuse Type	Area (ha)	Mean Annual Total Generated (mm/year)	Mean Annual TN Total Load (tonnes/year)	Mean Annual TN Total Load (kg/ha/year)
Arable Dryland	2287	321	25.1	11.0
Arable Irrigated	4660	502	87.1	18.7
Beef Dryland	307	357	7.5	24.3
Beef Irrigated	181	503	7.0	38.9
Dairy 3 cows per ha	5279	408	143.3	27.1
Dairy 4 cows per ha	2248	612	124.0	55.2
Dairy 5 cows per ha	2003	515	116.5	58.2
Dairy Support Dryland	674	360	25.0	37.1
Dairy Support Irrigated	1886	576	106.4	56.4
Deer Dryland	248	548	4.2	16.8
Deer Irrigated	16	723	0.5	29.1
Forestry	842	315	1.3	1.6
Lifestyle	343	308	3.6	10.6
Miscellaneous	0			
Native Forest	2420	255	2.5	1.0
Orchard	28	467	0.2	7.9
Pigs	5	338	0.2	31.1
Sheep Dryland	1105	388	12.0	10.9
Sheep Irrigated	1014	549	21.5	21.2
Sheep and Beef 10% Dryland	364	612	9.7	26.7
Sheep and Beef 10% Irrigated	47	669	1.5	32.0
Sheep and Beef 20% Dryland	659	356	13.0	19.8
Sheep and Beef 20% Irrigated	1359	518	41.1	30.2
Urban	239	294	1.6	6.9
Vegetables	132	540	5.7	43.2
Viticulture	0			
Water	4032	0	0.0	0.0
<b>Totals for Zone</b>	<b>32380</b>	<b>390</b>	<b>760.4</b>	<b>23.5</b>

**Table 4 Comparison of estimated mean annual rates of recharge to groundwater from farm systems and soil types from the Source model and from Lilburne et al. (2013)**

Mean Annual Rainfall (mm/y)	650	750	850	650	750	850	650	750	850
	Source Model Estimated Recharge Rates (mm/y)			Lilburne Estimated Recharge Rates (mm/y)			Ratio of Source Model / Lilburne et al. (2013)		
Irrigated, XL, VL, L soils	519	562	606	208	272	339	2.49	2.07	1.79
Irrigated, M, H, Pd, PdL soils	306	359	413	188	244	303	1.63	1.47	1.36
Dryland, XL, VL, L soils	320	366	412	140	232	323	2.29	1.58	1.28
Dryland M, H, Pd, PdL soils	179	231	283	125	208	290	1.43	1.11	0.98

**Table 5 Mean daily flows estimated from Source Model for Existing Conditions Scenario (Scenario 1, for model period 1980-2103), compared with estimate from gauged flows (for available record) and ECan Scenario 1**

<b>Stream Name</b>	<b>Site Name</b>	<b>Source Model Scenario 1 (L/s)</b>	<b>Gauged (L/s)</b>	<b>ECan Scenario 1 (L/s)</b>	<b>% Difference to Observed</b>	<b>% Difference to ECan Scenario 1</b>
Harts Creek	Timberyard Road	1930	1379	1696	40%	14%
Kaituna River	Kaituna Valley Road	848	593	Not Stated	43%	
Selwyn River	Coes Ford	3681	3204	2975	15%	24%
Boggy Creek	Lower Lake Road	92	Not Gauged	188		-51%
Halswell River	Ryans Bridge	1290	784	1186	65%	9%
Hanmer Road Drain	Lower Lake Road	252	Not Gauged	216		17%
LII River	Pannets Rd	1317	2366	2307	-44%	-43%
Doyleston Drain	Lake Road	139	173	159	-20%	-13%

**Table 6 Mean annual 7 day low flows (7dMALF) estimated from Source Model for Existing Conditions Scenario (Scenario 1, for model period 1980-2103), compared with estimate from gauged flows (for available record) and ECan Scenario 1**

<b>Stream Name</b>	<b>Site Name</b>	<b>Source Model Scenario 1 (L/s)</b>	<b>Gauged (L/s)</b>	<b>ECan Scenario 1 (L/s)</b>	<b>% Difference to Observed</b>	<b>% Difference to ECan Scenario 1</b>
Harts Creek	Timberyard Road	400	897	987	-55%	-59%
Kaituna River	Kaituna Valley Road	118	38	Not stated	215%	
Selwyn River	Coes Ford	224	627	289	-64%	-22%
Halswell River	Ryans Bridge	198	418		-53%	
LII River	Pannets Rd	114	1391	1544	-92%	-93%
Doyleston Drain	Lake Road	13	2	2	591%	539%

**Table 7 Mean daily flow compared between scenarios in lowland stream flow sites (for 1980-2013 climatic period)**

Stream Name	Site Name	Mean daily flow (L/s)				% Difference in Mean Daily Flow to Scenario 1		
		Scenario 1	Scenario 0	Scenario 2a	Scenarios 2b and 3a	Scenario 0	Scenario 2a	Scenarios 2b and 3a
Harts Creek	Timberyard Road	1930	2019	1920	2041	5%	0%	6%
Selwyn River	Coes Ford	3681	3569	3669	3720	-3%	0%	1%
Boggy Creek	Lower Lake Road	92	92	92	95	0%	0%	3%
Halswell River	Ryans Bridge	1290	1414	1288	1323	10%	0%	3%
Halswell River	Hodgens Bridge	1734	1901	1731	1777	10%	0%	3%
Halswell River	Neils Road	1487	1628	1484	1524	10%	0%	3%
Hanmer Road Drain	Lower Lake Road	252	232	251	268	-8%	0%	6%
Irwell River	Lake Road	96	96	95	104	0%	0%	9%
LII River	Pannets Road	1317	1521	1313	1344	15%	0%	2%
Doyleston Drain	Lake Road	139	139	138	143	1%	0%	3%

**Table 8 Mean annual 7 day low flow (7dMALF) compared between scenarios in lowland stream flow sites (for 1980-2013 climatic period)**

Stream Name	Site Name	7dMALF (L/s)				% Difference in 7dMALF to Scenario 1		
		Scenario 1	Scenario 0	Scenario 2a	Scenarios 2b and 3a	Scenario 0	Scenario 2a	Scenarios 2b and 3a
Harts Creek	Timberyard Road	400	463	391	467	16%	-2%	17%
Selwyn River	Coes Ford	224	243	213	236	8%	-5%	5%
Halswell River	Ryans Bridge	198	346	195	207	75%	-1%	4%
LII River	Pannets Road	114	295	111	121	159%	-2%	6%
Doyleston Drain	Lake Road	13	37	13	13	187%	-2%	4%

**Table 9 Median Dissolved Inorganic Nitrogen (DIN) concentration simulated in Source model within lowland streams for different scenarios**

Stream Name	Site Name	50 <sup>th</sup> Percentile DIN Concentration (mg/L)					% Difference in DIN Concentration Scenario 1			
		Scen 1	Scen 0	Scen 2a	Scen 2b	Scen 3a	Scen 0	Scen 2a	Scen 2b	Scen 3a
Harts Creek	Timberyard Road	4.66	3.35	4.75	4.49	3.93	-28%	2%	-4%	-16%
		4.40	4.40	5.83	5.83	5.25	0%	32%	32%	19%
Selwyn River	Coes Ford	2.59	2.37	2.92	3.04	2.76	-9%	13%	17%	6%
Boggy Creek	Lower Lake Road	4.19	3.10	4.36	4.33	3.93	-26%	4%	3%	-6%
Halswell River	Ryans Bridge	3.23	2.78	3.82	3.75	3.47	-14%	18%	16%	7%
Halswell River	Hodgens Bridge	2.90	2.52	3.41	3.38	3.11	-13%	18%	17%	7%
Halswell River	Neils Road	3.12	2.69	3.68	3.63	3.35	-14%	18%	16%	7%
Hanmer Road Drain	Lower Lake Road	3.06	2.51	3.19	3.26	2.83	-18%	4%	7%	-8%
Irwell River	Lake Road	2.26	2.10	2.40	2.43	2.17	-7%	6%	7%	-4%
Lee River	Te Moana	3.60	3.12	3.68	3.69	3.32	-13%	2%	2%	-8%
LII River	Pannets Road	2.14	1.44	2.28	2.26	2.07	-33%	7%	6%	-3%
Doyleston Drain	Lake Road	3.92	2.41	4.05	3.95	3.60	-38%	3%	1%	-8%

**Table 10 Dissolved Inorganic Nitrogen (DIN) concentration not-exceeded on 95% of days simulated in Source model within lowland streams for different scenarios**

Stream Name	Site Name	95 <sup>th</sup> Percentile DIN Concentration (mg/L)					% Difference in DIN Concentration Scenario 1			
		Scen 1	Scen 0	Scen 2a	Scen 2b	Scen 3a	Scen 0	Scen 2a	Scen 2b	Scen 3a
Harts Creek	Timberyard Road	6.53	4.67	6.58	6.22	5.55	-28%	1%	-5%	-15%
		4.93	4.93	5.99	5.99	5.40	0%	22%	22%	9%
Selwyn River	Coes Ford	4.03	3.18	4.35	4.71	4.17	-21%	8%	17%	3%
Boggy Creek	Lower Lake Road	4.93	4.24	5.17	5.07	4.55	-14%	5%	3%	-8%
Halswell River	Ryans Bridge	3.89	3.19	4.46	4.42	4.02	-18%	15%	14%	3%
Halswell River	Hodgens Bridge	3.40	3.00	3.85	3.81	3.52	-12%	13%	12%	4%
Halswell River	Neils Road	3.69	3.10	4.19	4.15	3.79	-16%	14%	13%	3%
Hanmer Road Drain	Lower Lake Road	5.00	3.14	5.03	4.99	4.27	-37%	1%	0%	-15%
Irwell River	Lake Road	3.67	2.92	3.89	3.67	3.25	-20%	6%	0%	-11%
Lee River	Te Moana	5.46	3.60	5.55	5.38	4.69	-34%	2%	-1%	-14%
LII River	Pannets Road	3.64	2.10	3.75	3.73	3.42	-42%	3%	2%	-6%
Doyleston Drain	Lake Road	4.95	3.99	5.10	5.01	4.46	-19%	3%	1%	-10%



**Table 11 Total contribution of flow and Dissolved Inorganic Nitrogen load to Te Waihora / Lake Ellesmere for existing conditions scenario (Scenario 1)**

<b>Stream Name</b>	<b>Mean Annual Flow to Lake (GL/year)</b>	<b>Mean Annual Flow to Lake (m<sup>3</sup>/s)</b>	<b>Mean Annual NNN Load (tonnes/year)</b>	<b>Mean Annual Ammonium Load (tonnes/year)</b>	<b>Mean Annual DIN Load (tonnes/year)</b>
Selwyn River	118.5	3.75	171	12	183
Waiekekewai Creek	2.8	0.09	8	1	10
Harts Creek	60.9	1.93	227	36	263
Doyleston Drain	4.4	0.14	13	2	15
Boggy Creek	2.9	0.09	9	1	11
Irwell River	3.0	0.10	4	1	6
LII River	41.6	1.32	58	19	77
Halswell River	74.6	2.36	215	28	243
Kaituna River	26.8	0.85	93	9	102
Prices Stream	15.5	0.49	54	5	59
Waikoko Stream	1.5	0.05	4	0	5
<b>Total of All Inflows to Lake</b>	<b>352.4</b>	<b>11.17</b>	<b>857</b>	<b>115</b>	<b>973</b>

**Table 12 Comparison of mean annual Total Nitrogen (TN) loads generated in each zone for each scenario simulated by the Source model**

Zone	Mean Annual TN Load Generated (t/year)					% Change From Scenario 1			
	Scenario 1	Scenario 0	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 0	Scenario 2a	Scenario 2b	Scenario 3a
Rakaia-Selwyn	3045	2282	3296	3449	3040	-25%	8%	13%	-0.2%
Selwyn-Waimakariri	2864	2269	3144	3274	2952	-21%	10%	14%	3%
Little Rakaia	760	529	788	765	674	-30%	4%	1%	-11%

**Table 13 Comparison of mean annual Dissolved Inorganic Nitrogen (DIN) load delivered to Te Waihora /Lake Ellesmere simulated by the Source model**

Component of DIN	Mean Annual TN Load Generated (t/year)					% Change From Scenario 1			
	Scenario 1	Scenario 0	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 0	Scenario 2a	Scenario 2b	Scenario 3a
NNN	857	789	971	993	908	-8%	13%	16%	6%
Ammonium	115	120	132	139	125	4%	15%	21%	8%
<b>Total DIN</b>	<b>973</b>	<b>910</b>	<b>1103</b>	<b>1132</b>	<b>1033</b>	<b>-6%</b>	<b>13%</b>	<b>16%</b>	<b>6%</b>

**Table 14 Estimation from Source Model simulations of mean Nitrate Nitrogen concentration in the shallow groundwater layer and the probability of exceeding the Maximum Acceptable Value under the New Zealand Drinking Water Guidelines**

<b>Source Model Scenario</b>	<b>Mean Nitrate Concentration (mg/L) simulated in Source Model run in shallow groundwater layer</b>	<b>Probability of Nitrate Concentration exceeding 11.3 mg/L (MAV)</b>	<b>Probability of Nitrate Concentration exceeding 6.6 mg/L (half MAV)</b>
1	2.59	0.10%	1.2%
0	2.10	0.07%	0.9%
2a	2.80	0.12%	1.4%
2b	2.79	0.11%	1.4%
3a	2.50	0.10%	1.2%