

IN THE MATTER OF the Resource Management Act
1991

AND

IN THE MATTER OF various applications by the Central
Plains Water Trust to the
Canterbury Regional Council.

Section 41C Report : Review of Nutrient and other Contamination Issues

Date of Hearing: 12 – 16 October 2009

Report of Vince Bidwell & Ned Norton

1. This report is written in response to a request made by the Commissioners for the Central Plains Water Hearing in accordance with section 41C(4) of the Resource Management Act.
2. This review refers to the proposed scheme described in the evidence from Mr Tipler (7 September 2009) for the revised scheme without storage. This scheme is for an additional 30,000 ha of irrigated land within an area of 105,349 ha in the Central Plains. The included existing area of irrigated land is 30,000 ha. We have taken account of some uncertainty in the area of new irrigation and its management, which arises from Mr Tipler's evidence:
 - The original proposal included 24,000 ha of existing irrigation, but this has been increased to 30,000 ha "... *as it more accurately reflects the current situation ...*" (Tipler; paragraph 72).
 - Management of the new irrigated area would be managed according to the reduced reliability of the run of river supply (Tipler; paragraph 7).
 - This assumption about reliability may change because "... *CPWL intends to consider aquifer recharge if and when the scheme is consented. That will be the time to consider effects such as mounding, lowland stream flows and water quality.*" (Tipler; paragraph 8).
3. We have communicated with Mr Lewthwaite (on behalf of Mr Tipler) about these aspects of area and land use. Mr Lewthwaite assures us that the present irrigated area is understood to be 30,000 ha.
4. We have decided to consider the increase in area to be 30,000 ha of irrigated pastoral agriculture and also to consider effects of the existing 30,000 ha irrigated area that may not yet be apparent. This is because the existing irrigated area has been developed since 1990, and the time lag of complete environmental effects is longer than this recent history.
5. The structure of the review follows the set of questions in Paragraph 12 of Minute 8 (reproduced in Appendix 1), and takes account of issues outlined in Paragraph 19 of the Minute. Evidence and reports considered for this review are listed in Appendix 2.

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Figure 1. Groundwater flow map, from the evidence of Mr Weir, showing a typical groundwater flow path (blue arrow) inserted by the authors.

Figure 2. Map from Hanson and Abraham (2009) showing Transect 1 (green line) approximately along a groundwater flow path.

Figure 3. Vertical cross section along a groundwater flow path showing (a) groundwater flow, (b) relative contaminant concentration and (c) groundwater age.

Figure 4. Cross-sections along the transect shown in Figure 2, showing the distribution of (a) chloride and (b) nitrate (Hanson and Abraham, 2009; Figures 4.5 and A3.4).

Figure 5. Copy of slide presented by Mr McIndoe at the Selwyn Science Symposium, 29-30 March 2007.

Figure 6. Guidelines table copied from executive summary of Hickey and Martin (2009).

Figure 7. Copy of Figure 1 from the supplementary evidence of Ms Hayward.

Figure 8. Copy of Figure 2 from the supplementary evidence of Ms Hayward.

Figure 9. Copy of Figure 2 from the second supplementary evidence of Dr Burrell.

Appendix 1: Minute 8 of Commissioners setting out directions relating to an independent review of nutrient and other contamination issues

Appendix 2: Evidence considered in this review

Appendix 3: Comments on phosphorus provided by Dr Bob Wilcock (NIWA Hamilton) and Dr Scott Larned at the request of the authors

Appendix 4: Recommended Table WQL5 (Hayward et al. 2009)

Summary

Nitrate discharge from soil drainage to groundwater

6. A comparison between the dominant pastoral land use under dryland and irrigated scenarios shows there is no conclusively established difference in nitrate concentration of the soil drainage. However, the quantity of soil drainage for irrigated pasture (500 mm/yr) is larger than for dryland pasture (200 mm/yr). The corresponding mass leaching rates for nitrate-nitrogen are: 17 kg/ha/y for dryland pasture; and 42 kg/ha/yr for irrigated pasture.
7. The proposed CPW irrigation would discharge to groundwater an additional 750,000 kg/yr of nitrate-N from the CPW area of 105,349 ha. The existing irrigated area discharges about 750,000 kg/yr. The current discharge from the whole CPW area, including both dryland and irrigated areas is about 2,550,000 kg/yr. Thus, the nitrate discharge to groundwater from implementation of CPW irrigation would result in a 30% increase over the estimated current total discharge from existing consented use for the CPW area.

Groundwater

8. The concentration and distribution of nitrate in groundwater of the Central Plains aquifers are important factors contributing to an assessment of health and ecological issues.
9. Our assessment of the evidence, as well as other available model predictions, suggests that an increase in the median nitrate-N concentration of soil-water drainage (and therefore groundwater) is possible, but cannot be conclusively supported because of the inherent uncertainties in model prediction of nitrate concentrations from the range of landuses.
10. Prediction of the increase in volume of the contaminated groundwater flow from the CPW area is more reliable. The volume and thickness of the nitrate-contaminated groundwater plume is likely to increase by about 30%. The full development of this plume may take decades and would also incorporate the nitrate contamination from the development of existing irrigation in the CPW area since 1990.

Health

11. There is an existing (before CPW) health risk to bottle-fed infants from occurrences of nitrate-nitrogen concentration above the maximum acceptable value (MAV = 11.3 mg/L nitrate-nitrogen) in groundwater used for human consumption. The risk is higher for shallow wells (with respect to the groundwater surface) and may be confounded by occurrences of microbial contamination, which may also affect health. The nitrate component of the risk is associated primarily with intensive agriculture. The effect of the proposed CPW scheme is that this risk could become more widespread, because the increase in thickness of the nitrate plume may result in interception of high-nitrate groundwater by more wells. The severity of the health effect of contamination is unlikely to increase, because the maximum nitrate concentration is limited by agricultural processes similar to those in existing areas of intensive farming in Central Plains. We conclude that the existing risk of using water from shallow wells for infants may already be unacceptable, and that alternative sources of water should be used, such as from deep community wells.

12. There is a potential health risk that could arise from the effect of increased groundwater levels on the performance of existing wastewater infrastructure. This risk could be addressed by technological solutions, but the issues are economic cost of the solutions and agreement about liability.
13. Access to high-quality groundwater (originating from the alpine rivers) by deep community wells might be affected by the increase in thickness of the nitrate-contaminated plume. The effect from CPW irrigation would be additional well drilling and pumping costs for about a 15 m increase in depth required to reach high quality water. The time-lag effect of nitrate plume development means that recent irrigation development (since 1990) is likely also to contribute to the increasing depth of the interface, and the future total increase, including CPW, may be up to about 30 m. This effect would apply to wells or proposed wells at depths close to the current location of the interface between the two types of groundwater.

Surface water

14. Nitrate is one of the main contaminants of interest for the contribution from groundwater discharge to surface waters in Central Canterbury. This is because nitrate does not degrade significantly in the Central Plains aquifer and because it is the dominant nutrient from land use activities that is transported by groundwater. Nitrate has toxic effects on aquatic biota and may, in combination with other nutrients such as phosphorus, enhance growth of aquatic plants (periphyton and macrophytes), with adverse consequences for ecological, recreation and aesthetic values.
15. The effects of nitrate on surface waters must always be considered in relation to phosphorus, the second major plant nutrient. Phosphorus is transported by groundwater as well as overland processes. The applicant concluded that phosphorus would not increase as a result of the CPW scheme but our opinion is that the quantity and transport processes of phosphorus were insufficiently investigated. Even very small increases in dissolved reactive phosphorus (DRP) (i.e. in the order of 0.001 - 0.1 mg/L) can have ecological consequences. Such concentrations are small compared to concentrations of nitrate nitrogen that are of interest as a nutrient (~0.01 - 1 mg/L), as a toxicant for aquatic species (~1 - 4 mg/L) and as a toxicant for humans (MAV = 11.3 mg/L). No numbers were provided by the applicant for phosphorus.
16. The nitrate concentrations of some surface waters are likely to increase because the increase in thickness of the nitrate plume in groundwater results in a higher proportion of contaminated groundwater inflow to surface waters. The timing of this effect is related to development of the nitrate plume over a time scale of decades. The final steady state would also include the effect of recent existing irrigation development. A comparison with nitrate concentrations observed in lowland surface waters in Mid-Canterbury (Hinds-Ashburton area) suggests that median nitrate-N concentration in lowland streams of Central Canterbury could ultimately increase by up to about 2 mg/L. The applicant predicted that CPW's contribution would, on a median basis, be about 1.2 mg/L for the original proposed scheme and 0.5 mg/L for the revised (September 2009) proposal that assumes a less productive, partially irrigated mixed farming system. The reason for the present difference in surface water nitrate concentrations between Mid-Canterbury and Central Canterbury is likely to be that the former area has a longer history of developed irrigated agriculture.
17. Te Waihora is the major surface water feature that is unique to Central Canterbury. The CPW area occupies about half of the Te Waihora catchment area. The increase in

drainage resulting from the proposed CPW irrigation would be about 90 MCM/yr of pasture soil drainage plus additional 70 MCM/yr of low nitrate water from upper plains streams and (Rakaia and Waimakariri) water entering groundwater via the CPW races. This 160 MCM/yr of additional water would flow to Te Waihora primarily via groundwater feeding the springs and lowland streams. The additional nitrate-N mass load to Te Waihora would be about 750,000 kg/yr. The present state of the lake is probably not yet affected by the full nitrate mass loading from existing irrigation in the catchment (including CPW area) because of the time-lag phenomenon of groundwater transport.

Overall approach to ecological assessment

18. There is little doubt that contaminant loads (e.g., nitrogen and phosphorus) will increase as a result of CPW, and further environmental degradation will occur in lowland streams and Te Waihora at some unquantified level. The effects will add to effects of current land use and will be cumulative. The applicant's assessment of the ecological consequences of water quality changes is qualitative. By this we mean that no attempt has been made to quantitatively predict the ecological response to contaminant increases (e.g. nutrients) in terms of environmental outcomes of interest, such as for example the quantity of nuisance periphyton growth in rivers and phytoplankton growth in Te Waihora, and associated effects on ecological values. The applicant has relied largely on comparisons with water quality guidelines and other available desktop information to argue that incremental additive effects of CPW will be insignificant.
19. Qualitative environmental assessments may be sufficient where the amount of resource use is small and well within the capacity of the environment to support that use. However quantitative predictions have become critical when the cumulative effects of multiple diffuse discharges approach the assimilative capacity of the receiving environment. ECan has recognised that the capacity of groundwater and surface waterbodies to assimilate nutrients may be approaching limits in some areas, including the Canterbury Plains (e.g., Ford and Taylor 2006). For several years ECan has been developing methods to establish quantitative limits for managing cumulative effects on water quality. Some of these limits have been incorporated into the Proposed Natural Resources Regional Plan (PNRRP) and these are discussed in more detail later in this report.
20. In our opinion the scale and significance of potential effects of CPW justifies a quantitative assessment of the ecological consequences of water quality changes. The existing assessment does not do this. Notwithstanding this conclusion we have assessed ecological effects on lowland streams, groundwater and Te Waihora, based on information available for this review as follows.

Lowland streams ecology

21. We have applied three tests to assess the significance of predicted increases in nitrate loads and concentrations. The first test, against provisions of the PNRRP, was inconclusive because the applicant did not provide quantitative predictions of periphyton and macrophyte growth for comparison with Objective WQL1. Methods are available for making such predictions. The second test, against nitrate toxicity guidelines, showed that the increase in nitrate is significant in the context of toxicity for aquatic biota in lowland streams, particularly when compared to the very recently revised (Hickey and Martin 2009) nitrate toxicity guidelines. CPW will increase the risk

of guideline breaches in some streams - further detail is provided later in this report. The third test, against nutrient enrichment guidelines, was inconclusive due to the absence of reliable quantitative predictions of phosphorus increases.

22. It seems likely that nitrate, acting both as a toxicant and a nutrient, has contributed to a decline historically in aquatic biodiversity in Central and Mid-Canterbury lowland streams, to an extent that most current remaining communities have some resilience to elevated nitrate concentrations. The increase in nitrate loads and concentrations predicted under CPW would add to historic cumulative effects, may reduce biodiversity further in some areas, and would hinder efforts to rehabilitate some of the more sensitive biodiversity in lowland streams. These adverse effects should be considered along with the positive effect of CPW in increasing flow to some lowland streams, an effect that would provide a greater area and more favourable habitat for some enrichment and nitrate-tolerant species. For example, the applicant predicted approximately double the habitat area for adult brown trout. Weighing these positive and negative effects will involve a value judgement. Best practice mitigation measures to reduce nitrate losses would be justified to minimise, but probably not avoid, further losses of sensitive aquatic biodiversity.

Groundwater ecology

23. There are major knowledge gaps in this field generally and in New Zealand specifically. These concern i) the existing state of groundwater biodiversity (e.g., microorganisms and small invertebrates that live in groundwater), ii) the role these organisms play in assimilating contaminants and thus maintaining aquifer porosity and groundwater quality, and iii) the sensitivity of these organisms to contaminant overload (e.g. nitrate toxicity). There is nothing that this review can do about these knowledge gaps specifically, however we have considered the available information and suggest that the revised guidelines (Hickey and Martin 2009) are the best tool available for assessing the risk of nitrate toxicity effects on groundwater ecology. Similar to our assessment for lowland streams, increased nitrate concentrations and loads under CPW could shift community composition, favouring tolerant groundwater species over sensitive ones. The consequences of this for contaminant assimilation and groundwater quality are unknown. For these reasons there is an argument for a precautionary approach that uses the more conservative of the Hickey & Martin (2009) guideline values.

Ellesmere / Te Waihora ecology

24. There is insufficient information to quantitatively predict the ecological consequences of further degraded water quality on Te Waihora. It is clear from the information available that Te Waihora is already a highly disturbed ecosystem, and that additional contaminant loading from intensified landuse will add to existing cumulative effects. This situation, combined with the large scale of the CPW application, justifies a quantitative assessment of effects that identifies the assimilative capacity of Te Waihora. There are precedents for such assessments that include other waterbodies vulnerable to the effects of intensified land-use in New Zealand. We have described the information that is missing and the type of quantitative assessments which are possible in this report.

Mitigation

25. There is no doubt that agriculture degrades surface water quality. There are limits to what can be done to reduce loadings onto land or to intercept contaminants in runoff pathways through the use of best management practices (BMPs). Agricultural landscapes are inherently “leaky” and there are limits to land use intensification that will be tolerated without breaching measures of acceptable environmental outcomes, such as regional plan objectives and policies, regional plan receiving water quality standards and/or national water quality guidelines.
26. The Sustainability Protocol and design for farm plans proposed by the applicant contain many measures that are sound practice for reducing contaminant losses from agricultural land. There is a need for greater specificity in the farm plans, workable systems identified for implementing the actions, monitoring and enforcement. We have described some additional BMPs in this report. However BMPs will not achieve 100% removal of pollutants in farm drainage and runoff. They are simply the best means available for partial mitigation. Removal efficiencies for nitrogen and phosphorus under BMPs are likely to be much lower than 100% (i.e. in the order of less than 50%).

1. Potential contaminant levels in groundwater

27. The contaminants considered in the evidence are microbes, pesticides, and the nutrient elements phosphorus and nitrogen. Nitrogen leached to groundwater is primarily in the chemical form of nitrate, and is referred to as such.

Microbes

28. Mr Close (for applicant) concludes that microbes undergo significant die-off to the extent that microbial contamination can have localised effects but not a cumulative effect. There is minimal leaching of microbes from well-managed pasture irrigation; a higher degree of management is required for irrigation of dairy shed effluent; point sources such as septic tanks provide a significant risk to local shallow groundwater. Mr Hanson (ECan) generally agrees that the level of risk of microbial contamination from irrigated dairy farming is low.
29. Given the localised nature of the microbial risk, our conclusion is that any increase in the area of irrigated animal farming would simply increase the area within which a microbial risk might impact on individual human receptors. There is no cumulative effect that might increase the risk at a particular location or would provide a risk outside the general area of irrigated farming.

Pesticides

30. Mr Close (for applicant) reports an assessment of pesticide leaching which shows that concentrations in groundwater from normal farm practice would be low, less than maximum acceptable values (MAV). The risk from other inappropriate use and storage would not change. Groundwater quality surveys report generally low levels of pesticide, with a few that exceed MAV. Mr Hanson (ECan) agrees that the risk of significant pesticide contamination from CPW would be low. He also confirms that any detections in Canterbury have been mostly below any drinking-water standard.

Phosphorus

31. Mr Hanson (ECan) agrees with a conclusion from the URS assessment that the risk of significant phosphorus contamination, as a result of CPW, would be low. He reports that groundwater quality survey results show dissolved reactive phosphate (DRP) samples for Canterbury Plains to be generally less than 0.01 mg/L. He reports that these results suggest that DRP is affected more by aquifer geology than land use.
32. We sought further advice from Dr Bob Wilcock (NIWA Hamilton). He has assisted us in reviewing the CPW evidence and has provided a discussion on the likely effects of CPW on phosphorus in lowland streams and Te Waihora (see Appendix 3). A key conclusion from Dr Wilcock's review is that phosphorus is likely to increase in lowland streams and Te Waihora as a result of CPW. The likely consequences are discussed further in our sections on lowland streams and Ellesmere/Te Waihora.

Nitrate

33. Nitrate is the primary contaminant of interest with respect to effects on the quality of groundwater and surface water (in association with phosphorus) arising from increases in area and intensification of agricultural land use. The nitrate concentration of soil-water drainage from agricultural land uses that enters the groundwater surface can exceed the maximum acceptable value (MAV) for drinking water (11.3 mg/L nitrate-nitrogen) and is usually above the ecological guideline values for surface waters.

34. Mr Close (for applicant) concludes that there is very little reduction in nitrate concentration by denitrification within the vadose zone or groundwater, in the Canterbury Plains aquifers. This means that dilution of soil-water drainage within the underlying groundwater is the only process for reducing nitrate concentration in receiving waters. As a consequence, nitrate has a cumulative effect within groundwater. This contrasts with microbes, for example, which die off near their locality of origin.
35. Mr Tipler (for applicant) assessed the nitrate discharge from the proposed scheme area by means of a concept that involves mixing the total mass of leached nitrate from the scheme area into a groundwater flow equivalent to the total soil-water drainage from this area (land surface recharge) plus low-nitrate recharge to groundwater from upper plains streams and leakage from the scheme distribution network. The result of this computation is a single bulk value of long-term average nitrate concentration in groundwater leaving the scheme boundary.
36. The uncertainty of this single value of nitrate concentration was quantified by use of a statistical procedure that takes account of the variability inherent in all the information contributing to the computed value, such as the estimates of soil-water drainage and nitrate mass leached from each combination of land use, soil and climate. The result is presented as a probability distribution of the computed value of nitrate concentration.
37. The probability distribution of this computed value for the existing (pre-scheme) land use is compared with the probability distribution for observations of groundwater nitrate concentration from 152 wells in the Central Plains area. These two probability distributions match quite well. However, they do not describe the same measure.
38. The computed value is the (uncertain) nitrate concentration of the completely mixed contribution to groundwater flow from soil-water drainage and the specified low-nitrate recharge. In contrast, the observations from the wells are samples from groundwater flow that has spatially varying (with horizontal location and depth) nitrate concentration. These observations reflect the additional vertical variation caused by dispersion processes in groundwater flow.
39. This difference in measures of nitrate concentration is the basis for some of the questions raised by Mr Hanson (ECan) about the depths in groundwater to which elevated nitrate concentrations would penetrate post-scheme. Mr Hanson also raised questions about the magnitudes of variabilities assumed for inputs to the statistical procedure, such as nitrate leaching rates and recharge from rivers.
40. Mr Tipler presents a probability distribution for the post-scheme scenario, in comparison with the distributions of pre-scheme model estimates and observations from wells. His estimated increase in computed median concentration for the original proposed scheme was about 1.2 mg/L, which is about a 30% increase over the pre-scheme computed value of 3.7 mg/L. Mr Hanson suggested that the increase might be 50%, based on his calculations from similar assumptions. In Mr Tipler's second supplementary evidence (September 2009) he revised his prediction to 0.5 mg/L for the revised proposal that assumes a less productive "partially irrigated mixed farming system" (paragraph 81).
41. The estimated increase in median groundwater nitrate concentration is not a good indicator of the increase in the high-value end of the probability distribution. These high values are relevant to health risk and groundwater contributions to surface waters. Although the maximum likely value of nitrate concentration is constrained by bio-

physical processes related to agriculture, there may be an increase in the localities and occurrences of high values.

42. The occurrence of high values of groundwater nitrate concentration near intensive land use depends also on the processes of transport and dispersion that involve low-nitrate groundwater from less intensive land use and leakage from local surface waters. Mr Tipler's modelling method does not purport to address these processes at the local scale.
43. There is some degree of uncertainty about the relevance of sources of low nitrate water for dilution within the CPW scheme area. This uncertainty depends on the source, for example: upper catchment streams are not distributed at a fine scale throughout the area; the proposed distribution system provides some leakage at the property scale but this system operates only during the irrigation season, which is out of phase with leaching induced by winter rainfall.
44. The uncertainty about the contribution of the low-nitrate recharge to dilution, for effects on health, can be put aside by considering only the effects of the contribution from soil-water drainage (land surface recharge) originating from the increased area of irrigation. However, the contribution of this diluting water can be relevant to nutrient effects on surface water bodies
45. Mr Tipler (evidence, 7 September 2009) has taken account of the nitrate discharge database recently developed by ECan. We have also taken account of this database, including some very recent modelling results that were not available to Mr Tipler at the time of submitting his evidence. Our analysis in the following discussion is based on consideration of the two pieces of evidence from Mr Tipler (1 February 2008 and 7 September 2009) as well as the ECan nitrate discharge database.
46. We have conducted our nitrate discharge analysis for pastoral land use, which is the major proposed land use as well as existing land use. The conclusion we have reached is that the average nitrate discharge from dryland pastoral land use is about 17 kg-N/ha/yr and is associated with average soil drainage of about 200 mm/yr in the CPW area. The resulting average nitrate-nitrogen concentration is about 8.5 mg/L. The corresponding result for irrigated pastoral land use is 42 kg-N/ha/yr in 500 mm of drainage, to yield a nitrate concentration of about 8.5 mg/L.
47. The uncertainty of modelling results is such that this value of average nitrate-N concentration in soil drainage could be in the range of 7 mg/L to 12 mg/L. Much of the uncertainty seems to lie in estimation of soil drainage itself, even for the case of dryland agriculture. Within these bands of uncertainty, our calculations of nitrate discharge are consistent with those of Mr Tipler for the revised scheme. Mr Tipler presents his results (his paragraph 79) after low nitrate water sources have been included.
48. The main result of our analysis, for the following discussion, is that the average nitrate-N concentration does not conclusively increase with a change from dryland pastoral to irrigated pastoral agriculture. However, the mass rate of nitrate discharge (kg/ha/yr) for this land use change does increase by a factor of about 2.5. For the proposed new irrigation of 30,000 ha in the 105,000 ha of the CPW area (29% of land area), the total nitrate-N mass would increase by about 30%. The absolute increase in total nitrate-N would be about 750,000 kg/. The groundwater flow from the scheme area would increase by about 32%, excluding recharge from the alpine rivers.

49. The nitrate-enriched soil water drainage enters the top surface of the groundwater where it can be diluted by lower concentration recharge from other land uses and sources such as the water distribution system proposed for the CPW scheme. Dilution occurs through dispersive mixing of various sources of groundwater recharge that occur at a range of scales.

Dispersion of nitrate discharge into the environment

50. The relationship between nitrate leached from land and the consequent concentrations in groundwater and surface waters can be explained by considering the process of nitrate transport in groundwater along a typical flow path. Figure 1 shows a flow path superimposed on the groundwater flow map provided in the evidence of Mr Weir (for applicant).
51. This groundwater flow path also approximately coincides with a transect of groundwater chemistry observations that are the subject of a report by Hanson and Abraham (ECan, 2009) published in July 2009. Figure 2 shows this transect. These observations will be considered in relation to an illustration of nitrate transport generated by an author (of the present review) from a mathematical model.
52. Figure 3 (a) shows a vertical-slice view, from the mathematical model, along the groundwater flow path of the pattern of groundwater flow from recharge to discharge. Groundwater flow from land surface recharge is shown in green, and groundwater from river recharge is blue. The respective quantities of recharge are typical for Central Plains and the illustrated simulation is for equal total quantities of river recharge and land surface recharge. The central dashed line in Figure 3 marks the location of maximum total groundwater flow. At this location, the groundwater flow, in proportion to the respective recharge contributions, is 50% of each (for illustration purposes).
53. Figure 3 (b) shows the associated pattern of contaminant concentration for a uniform concentration of 10 units in the land surface recharge and zero in the river recharge. The multi-coloured bands (values given in the legend) illustrate the gradation of contaminant concentration in groundwater caused by the dispersive processes of groundwater flow (dispersive interface).
54. This general pattern of contaminant concentration is supported by the groundwater chemistry observations of Hanson and Abraham (2009) for the vertical transect along the flow path in Figure 2. Figure 4 (reproduced from Hanson and Abraham, 2009) shows the observed pattern of (a) chlorides and (b) nitrates.
55. Figure 3 (c) shows the pattern of groundwater age associated with this example. The absolute values of age are uncertain because of uncertainties about aquifer properties, but the relative values are realistic. Groundwater age is a useful concept because it can be combined with the groundwater flow [Figure 3 (a)] and contaminant dispersion pattern [Figure 3 (b)] to assess the time lag of nutrient effects.
56. The simple message from Figure 3 (c) is that there is a time lag of decades between discharge of nitrate from the upper plains (left side of the “recharge zone”) and transport to deep in the aquifer. It is even longer for transport to the “discharge zone” where groundwater discharges to surface waters.
57. Almost all the existing irrigated agriculture in the CPW area has been developed since about 1990. Our Figure 5 is a copy of a graph presented by Mr McIndoe to the Selwyn

Science Symposium, which shows the rate and magnitude of this development for the Rakaia-Selwyn zone of the Central Canterbury Plains. Our opinion is that the nitrate leached during the period of this development (1990 to the present) has not yet been completely transported to surface waters.

58. The proposed CPW scheme is in the upper plains, the left end of the recharge zone in Figure 3(b). The effect of the increase in groundwater flow (by 0.32 to 0.41) without significant change in nitrate concentration would be to increase the proportion of groundwater flow from land surface recharge with respect to that from the alpine rivers. The contaminated plume illustrated in Figure 3(b) would increase in thickness and the dispersive interface would move deeper into the aquifer.
59. Mr Blake-Manson (submitter, Selwyn District Council) questions the degree of mixing of these groundwater bodies before interception by community and private water supply wells. His evidence reports a 2005 record of nitrate-nitrogen concentration in community water supplies, which showed values up to 6.6 mg/L (Armack Drive) and 6.55 mg/L (Edendale). He states that these locations in the Central Plains are less likely to benefit from dilution effects.
60. The Armack Drive and Edendale wells (Mr Blake-Manson evidence; Fig. 1, Fig. 2) are over 50 m below ground level and have groundwater ages of 40 to 50 years. Therefore, these high nitrate levels are the result of past land use practices in Central Plains.
61. These groundwater ages are consistent with observations reported by Stewart et al. (2002) for groundwater age and chemistry in Canterbury Plains. Their Appendix 1 (p. 42), for Waimakariri-Rakaia Plains, shows observations of nitrate-N greater than 5 mg/L associated with groundwater ages greater than 30 years.
62. This reflection of past and existing land use effects is illustrated by Mr Hanson's Powerpoint presentation to the Commissioners of a map of observations of groundwater nitrate concentrations which shows some values greater than 14 mg/L (MAV is 11.3 mg/L). A time-series in the same presentation demonstrates the possible variation with time of nitrate concentrations at a particular well, above and below the MAV.
63. Our interpretation of the evidence is that the CPW scheme would increase the number of locations at which the groundwater nitrate MAV might be exceeded as well as the frequency of occasions of exceedance. The reason for this conclusion is that thickening of the contaminant plume from agricultural land use moves the distribution of nitrate concentration deeper into the aquifer. This distribution has the higher concentrations near the groundwater surface and the lower values in the dispersive interface near low nitrate alpine river recharge. The maximum value of groundwater nitrate concentration is unlikely to change because the same types of land use as in existing areas of intensive agriculture would simply be extended over a larger area of Central Plains.
64. The relevant issue is access to drinking water with shallow wells. The existing occurrences of groundwater nitrate above MAV means that this access is not currently guaranteed everywhere anyway, and this situation would deteriorate even further with scheme implementation.

2. Consequent health risks

65. Community and Public Health (CPH) provided a Health Impact Assessment (HIA) of the CPW scheme. Water quality (for drinking) is one of the three key determinants identified in the HIA. Within the context of the Drinking Water Standards for New Zealand (DWSNZ2005), the MAV for nitrate is exceptional in that it is based on *short-term exposure* rather than lifetime. The population group of concern is infants up to age 6 months. Consumption of water with nitrate above MAV for approximately one month would be sufficient to cause methaemoglobinaemia.
66. One case of methaemoglobinaemia has been reported in New Zealand but the true occurrence may be masked by other conditions. Bacterial conditions may play a role, and this can confound the issue because bacteria and high nitrate are both associated with private wells which may be contaminated by human or animal sources.
67. The HIA addresses other health outcomes considered linked to nitrate, such as cancer, diabetes, adverse reproductive health, and some other chronic health effects. For all of these, the scientific evidence is reported as being inconclusive at present.
68. Given that ECan observations (Mr Hanson's presentation) show existing occurrences of groundwater nitrate above MAV, including short-term events, there is clearly an existing risk to infants bottle-fed with water from shallow wells in rural areas for which microbial contamination is also a possibility. This risk is likely to be more widespread if there is more intensified agriculture, partly due to more widespread elevated nitrate levels and partly due to the possibility of associated increases in sources of microbial contamination.
69. The risk to infants, whether existing or potential future, seems to be avoidable by sourcing alternative small quantities of water for the critical six-month period from deep community wells, for example. The remaining risk to other sectors of the population, from elevated nitrate levels, cannot be conclusively identified.
70. The HIA mentioned the increased risk from microbial contamination due to raised groundwater levels and increased groundwater flow velocities. These factors can reduce the transport time available for microbial die-off between source and receptor. In areas with existing groundwater levels near to the land surface, flooding and septic tank failure may contribute to health risk. These risks can be addressed by technological measures but the associated costs of mitigation and agreement about liability would be significant issues.

3. Other potential adverse effects on groundwater

Access to high quality groundwater

71. Although a health risk from shallow drinking water wells exists in some locations of the Central Plains, high quality water can be accessed by means of deeper wells. Deep wells are expensive in terms of the cost of a drinking water supply for an individual property, but justifiable for a larger community.
72. The source of this high quality groundwater is recharge from the rivers, especially the two alpine rivers which have very low nitrate concentrations. This river recharge

groundwater forms a layer beneath the groundwater that is sourced from land surface recharge, as illustrated in Figure 3 (a).

73. The thickness of each of these groundwater layers is in proportion to the respective groundwater flows. Therefore any change in these proportions, such as increasing land surface recharge by means of irrigation, can be expected to increase the depth of the interface between the two groundwater layers. This interface is a zone of dispersion between the respective groundwater qualities, resulting in a gradation of decreasing nitrate concentration with increasing depth. The increase in depth of the interface, with reference to the land surface, is partly compensated by rising groundwater levels due to the additional recharge.
74. Mr Tipler (main evidence) recognises an increase (unspecified) in “mixing depth” as part of his discussion about surface water quality. Mr Hanson (main and supplementary evidence) estimates that the depth interface would increase by about 15% to 20%, which is equivalent to about 15 m for assumptions about aquifer thickness in the URS reports. Mr Tipler (supplementary evidence) agrees.
75. The time-lag effect of groundwater transport, illustrated in Figure 3 (c), means that the nitrate plume from the existing irrigation in the CPW area is not fully developed. This is because this irrigation has developed since about 1990, and the groundwater ages at the likely interface depth are larger. We estimate that the future increase in interface depth, from the combined effects of all irrigation, could reach about 30 m.
76. In summary, there may be an economic cost increase for future access to high quality water in some locations due to an increase in well drilling depth and pumping energy.

4. Contaminant levels in surface water

77. Nitrate is one of the main contaminants of interest for the contribution from groundwater discharge to surface waters in Central Canterbury. This is because nitrate does not degrade significantly in the Central Plains aquifer and because it is the dominant nutrient from land use activities that is transported by groundwater. The effect of nitrate on surface waters must be considered in relation to phosphorus, the second major plant nutrient. Phosphorus is transported by groundwater as well as overland processes. Our opinion is that the quantity and transport processes of phosphorus from the CPW scheme to surface waters are insufficiently investigated and we discuss the reasons for this later (from paragraph 121).
78. For an area of alluvial plains, such as Central Canterbury, the catchment area of a particular spring or stream is determined by the interaction of groundwater flow, geology, surface topography, and constructed drainage works. The catchment boundary is not easily identifiable as in the case for hill country catchments. Therefore, only general conclusions can be made about the relationship between the quality of a particular water body and the contaminants leached from land use in its catchment.

The contaminant plume effect

79. Figure 3(b) illustrates the nature of the nitrate-contaminated plume in groundwater flow that discharges from agricultural land use. The concentration at the groundwater surface is usually similar to that of the soil-water drainage and decreases with depth due to dispersive mixing with low nitrate groundwater from other recharge sources. The quality of surface waters (excluding high flow events) is determined by the location

of the surface water body with respect to the contributing groundwater discharge. For example, in Figure 3 (b), a spring located near the left of the discharge zone would be more contaminated than one further to the right of the diagram. A stream that received groundwater discharge over a significant proportion of the discharge zone would have a quality that reflected the mix of contaminant concentrations.

80. A change in thickness of the nitrate plume would mean that the nitrate concentration in some surface waters could increase even if the median nitrate concentration from increased irrigation does not change. This is because the surface water qualities represent a blend of groundwater flows with different origins. Any increase in the proportion of contaminated groundwater flow, caused by increase in plume thickness, shifts the “blend” towards increased concentration. This is because most surface waters receive at least some of their groundwater inflow from groundwater nearest the groundwater surface. This process is a sampling of the groundwater plume that is biased towards the higher concentrations.
81. The proportional change in thickness of the nitrate plume from the CPW area can be estimated from relative total flows of the soil-water drainage from the 105,349 ha of the scheme area. For the purposes of our following discussion about the time-lag effect, we consider the drainage from the scenarios of no irrigation, 30,000 ha irrigation (existing), and 60,000 ha irrigation. The results are shown in Table 1.

Table 1. Characteristics of a nitrate plume from the CPW area under various irrigation scenarios. Dryland drainage is 200 mm/yr; irrigated drainage is 500 mm/yr.

Irrigated area (ha)	Soil-water drainage flow (MCM/yr)	Relative plume thickness %
0	211	100
30,000	301	143
60,000	391	185

82. Mr Tipler presents an argument (evidence 1 February 2008; paragraphs 96-101) that the lowland streams flowing into Te Waihora have a geochemical signature similar to the local shallow aquifers and that there does not seem to be a significant discharge of deep groundwater directly to the springs. One implication is that the deeper groundwaters would originate in part from the CPW area. Mr Tipler suggests that aquitards limit the vertical flow of groundwater close to the coastal zone. We believe that the presence of aquitards, as part of the coastal geology, is the dominant cause of the emergence of groundwater in these lowland springs.
83. The supplementary evidence of Ms Hayward’s (ECan) Figure1 (reproduced as our Figure 7) shows the range of observed nitrate concentrations in lowland streams of Central Canterbury. The median values of nitrate/nitrite-nitrogen concentration are up to about 5 mg/L. It is significant that the value for the Selwyn River lies at the upper end of this range (5 mg/L). This river has the largest flow and hence its catchment area provides a correspondingly large sample of land use effects in Central Plains, including the CPW area. The Selwyn River is the largest contributor of streamflow to Te Waihora.

The time-lag effect

84. The nitrate concentrations of the lowland streams represent a sample of land use effects from many locations at a range of times in the past up to several decades.

These long time lags are a feature of the dynamics of contaminant transport in groundwater. It is not feasible to relate nitrate concentrations in surface waters to a snapshot of land use at a particular time. Therefore, effects of land use scenarios on surface waters are usually compared on the basis of long term (steady state) predictions.

85. Ms Hayward (supplementary evidence) presents graphs of the time series of nitrate concentration for several lowland streams. Our Figure 8 reproduces her Figure 2 for the Selwyn River. The Selwyn River provides a sample of groundwater that includes the effects from some of the CPW area. Inspection of this graph suggests an increasing trend in median and peak values of nitrate concentration for the period 1993 to the present.
86. Dr Burrell (supplementary evidence; paragraphs 23-24) refers to the nitrate status of lowland streams and drains in the Hinds-Ashburton area, which is associated with a longer history of intensive (and irrigated) agriculture. He refers to the report of Meredith et al. (2006) which shows high levels of nitrate concentration (median 5.65 mg/L) associated with the ecological scores described in his evidence. We note that Table 3.2 in Meredith et al. (2006) shows nitrate-N concentrations observed in six drains during 2000 to 2005 had median values of 4.20 mg/L to 7.75 mg/L. We think that these observations are indicative of the likely nutrient state to be expected in Central Canterbury surface waters when nitrate transport has reached a long-term steady state.

Summary of likely changes in nitrate status of surface waters

87. The increase in groundwater flow from the proposed additional 30,000 ha of irrigation in the CPW area would increase total discharge to surface waters by about 30%, equivalent to 160 MCM/yr. This change in volume would occur within a few years of irrigation development, based on the dynamics of groundwater flow.
88. The increase of nitrate-N mass loading to groundwater, associated with the 30,000 ha of irrigation, is about 750,000 kg/yr. The nitrate discharge to surface waters may take decades to reach steady state. During this period, the nitrate discharge of a similar magnitude from the existing irrigated area will also be on a trend to steady state. The total steady-state nitrate-N discharge from the CPW area, from existing land use plus the additional irrigated area, could then reach about 3,300,000 kg/yr
89. Full development of the nitrate-contaminated groundwater plume from the CPW area would also be on a time scale of decades. When this has reached steady state, nitrate concentration of some surface waters are likely to increase due to groundwater inflow from the more concentrated portions of the nitrate-contaminated plume. Comparison of recent observations of the nitrate status of lowland streams in Central Canterbury with those in Mid-Canterbury suggest that an increase in median value of up to 2 mg/L is possible. The applicant predicted that CPW's contribution would, on a median basis, be about 1.2 mg/L for the original proposed scheme and 0.5 mg/L for the revised proposal that assumes a less productive partially irrigated mixed farming system. The Selwyn River currently has peak values of nitrate-N near 7 mg/L. It would be feasible for this value to reach estimates for the mean value for soil-water drainage, which is 8.5 mg/L.
90. Te Waihora is the major surface water feature that is unique to Central Canterbury. The CPW area occupies about half of the catchment area. The increase in drainage resulting from the proposed CPW irrigation would be about 90 MCM/yr of soil drainage plus additional 70 MCM/yr of low nitrate water. This 160 MCM/yr of additional water

would flow to Te Waihora primarily via the springs and lowland streams. The total contribution of water to Te Waihora from land surface recharge is 750 MCM/yr, calculated from Mr White's technical assessment (submitter evidence for Ngai Tahu; Table 5.10). The additional nitrate-N mass would be about 750,000 kg/yr. The present state of the lake is probably not yet affected by the full nitrate mass loading from existing irrigation in the catchment (including CPW area) because of the time-lag phenomenon of groundwater transport.

5. Introduction to effects on aquatic ecosystems

91. The purpose of this section is to address several general issues that are relevant for assessing effects on aquatic ecosystems in lowland streams and Te Waihora. We will then address potential effects on lowland streams and Te Waihora separately in the two following sections.

Predicting effects on aquatic ecosystems depends on predictions made upstream

92. The applicant's assessment of effects on aquatic ecosystems (Mr Kennedy and Dr Burrell) has necessarily relied heavily on the predictions (made by others) on effects on groundwater and consequent effects on flows and contaminant levels in lowland streams (e.g. Mr Tipler). Uncertainty associated with groundwater predictions flows through to assessments on aquatic ecosystems. The remainder of our assessment is on the basis that increases in stream flows, and loads and concentrations of nitrate-N, are likely to be as described in the previous section.

Ecological consequences of increased flow

93. There is a consensus that groundwater-dependent streamflow would increase in some streams downstream of the proposed irrigation supply area, although there is a high degree of uncertainty about the size of the increase. We agree with the summary of effects of increased flow on lowland streams provided in the Section 42A Officer's Report by Ms Hayward (her paragraphs 8 and 9). In particular she agreed with the applicant's witnesses that increased flow may have some beneficial effects by improving aquatic habitat, but concluded that other adverse effects such as increased contaminant loads on water quality may offset this benefit. For the remainder of this report we will focus on the effects of degraded water quality as these effects are the subject of disagreement between witnesses and of considerable uncertainty.

Ecological consequences of degraded water quality – lack of quantitative assessment

94. The applicant's assessment of the ecological consequences of water quality changes has been done only on a qualitative basis. By this we mean that no attempt has been made to quantitatively predict the ecological response to contaminant (e.g. nutrient) increases in terms of environmental outcomes of interest, such as for example the quantity of nuisance periphyton growth in rivers and phytoplankton growth in Te Waihora, and associated effects on ecological values. Methods are available to make such predictions. Mr Kennedy and Dr Burrell have relied largely on comparisons with water quality guidelines and other available desktop information. They have relied on the assumption that nitrogen is not growth-limiting and that phosphorus will not increase and cause problems. We will return to these assumptions and guidelines later. Our purpose here is to make the point that there is a considerable difference between the applicant's effort to make quantitative predictions of groundwater changes (quantity

and quality) and the effort required and made to predict the ecological response to those changes. This has limited the confidence that can be placed on the ecological predictions.

95. In general there is significantly greater uncertainty about ecological effects than the groundwater quantity and quality predictions on which they are based. In our opinion the scale and significance of potential effects of CPW justifies a quantitative assessment by the applicant of the ecological consequences of water quality changes.

Effects on water quality and ecosystems are additive and cumulative

96. There seems little doubt that contaminant loads (e.g., nitrogen and phosphorus) will increase as a result of CPW, and further environmental degradation will occur in lowland streams and Te Waihora at some unquantified level. The applicant's witnesses acknowledge that lowland streams already breach national guidelines for the nutrients dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) (i.e., Biggs [MfE] 2000 and ANZECC 2000) and Lake Ellesmere is already nutrient enriched i.e., in a eutrophic state. Mr Kennedy and Dr Burrell concluded that adding more nitrogen will not cause significant increased risk of adverse ecological effects but they acknowledged that adding more nutrients will not improve ecosystem health and they recommended implementation of the Sustainability Protocol and Farm Management Plans to reduce risk. Several other witnesses disagreed that effects would be insignificant and/or concluded that there was insufficient information to predict these effects with any confidence (e.g., Ms Hayward, Prof Hamilton, Dr Larned, Dr White, Dr Hughey and Mr White). In essence it appears there is consensus that CPW would add to cumulative effects that degrade aquatic ecosystems but there is disagreement over the significance of this addition.

ECan's approach to managing cumulative effects on water quality

97. Qualitative assessments of environmental effects that focus on arguing the insignificance of incremental additive effects may have been sufficient for managing situations where the amount of resource use is small and well within the capacity of the environment to support that use. However quantitative predictions have become critical when the cumulative effects of multiple point-source and diffuse discharges approach the assimilative capacity of the receiving environment. ECan has recognised that the capacity of groundwater and surface waterbodies to assimilate nutrient contaminants may be approaching limits in some areas including the Canterbury Plains (e.g., Ford and Taylor 2006). For several years ECan has been developing methods to establish limits for managing cumulative effects on water quality, as described below.
98. Relevant for lowland streams and Te Waihora is the inclusion of quantitative objectives and receiving water quality standards in the Proposed Natural Resources Regional Plan Chapter 4: Water quality (PNRRP). Objective WQL1 of the PNRRP includes numerical outcomes for the cover of the streambed with macrophytes and filamentous algae, and states that water quality shall be maintained or improved so that there are no toxic or nuisance algal blooms in coastal lakes such as Te Waihora. The PNRRP contains policies and rules that include receiving water quality standards for nitrogen and phosphorus designed to achieve the objectives. There are scientifically derived relationships that relate different levels of nutrient concentrations to different levels of environmental outcome (e.g. extent of streambed cover with nuisance algae).
99. The PNRRP objectives and receiving water quality standards provide a basis for testing the significance of additions to cumulative water quality effects, although the

PNRRP is not yet operative. The most recent development is recommendations made by ECan officers to the NRRP hearing Commissioners in May 2009, in particular revised numerical objectives (i.e. Table WQL5) contained in Hayward et al. (2009). The recommendations table from Hayward et al. (2009) is provided in Appendix 4. There are also a number of relevant national guidelines that provide numerical criteria or thresholds that can be used to consider the significance of additions to cumulative effects. We will consider all these potential 'tests' for the significance of additions to cumulative effects shortly.

100. Ford and Taylor (2006) stated that "*Future management will need to consider the linkages between different types of water bodies, and to identify those water bodies that are most vulnerable to nitrate inputs. It may be that nitrate management will require the establishment and implementation of maximum loadings for particular catchments, and the allocation of discharge permits in a way that is analogous to the current allocation of water for abstractive use.*" Managing nitrate in this way would require a significant step beyond just defining quantitative objectives and receiving water quality standards (as concentrations) in the PNRRP. This would require a thorough quantitative understanding at the catchment scale, of the links between catchment land use changes, associated nutrient loads to streams and lakes, in-stream and in-lake processes, ecological consequences and objectives chosen to protect identified values. The CPW evidence provided quantitative predictions for the first of these linkages (i.e., catchment land use changes and associated nutrient loads to groundwater and to streams) but has not provided a quantitative analysis of the latter linkages (i.e., consequences of increased nutrient loads on stream and lake processes, and on ecological values).
101. In recent years ECan has made progress with several catchment-scale nutrient assessment studies designed to assist decision-making on proposals for land-use intensification. One example is studies in the upper Waitaki catchment. In 2005 ECan presented the Waitaki Allocation Board (WAB) Hearing Commissioners with results of a scoping level study that quantitatively predicted the effects of several future land use scenarios on nutrient loads and consequences for algae growth and associated ecological health in rivers and in Lake Benmore (WAB 2005 evidence of Mr Glennie, Dr Meredith and Mr Norton).
102. More recently ECan has commissioned a detailed modelling study that has identified a series of options for measurable objectives for water quality for Lake Benmore, and nutrient load limits (in kg per year of nitrogen and phosphorus) that could be set to achieve each of the objective options (Norton et al. 2009). Once objectives and related nutrient load limits have been chosen, this could establish the "line in the sand" basis for testing the significance of proposals that add to cumulative water quality effects. This approach is similar to that proposed by Environment Waikato for managing nutrients in lake Taupo (i.e., Waikato Regional Plan Variation 5) and by Environment Bay of Plenty for managing nutrients in lakes around Rotorua (i.e., EBOP's Rule 11), although in these North Island examples the nutrient load limits act as targets for nutrient reduction rather than tests for new intensification proposals, because it has been recognised that the capacity of those lakes to assimilate nutrients has already been exceeded. These types of approaches are also the subject of research programmes such as NIWA's programmes funded by the Foundation for Research Science and Technology.
103. Our purpose in describing these approaches to managing cumulative water quality effects is to illustrate the type of quantitative assessment that we would recommend today as a minimum for a proposal as significant as CPW. We recognise that there has been an increase in understanding of the effects of land-use intensification during the

period that CPW applications have been in process. However some other significant irrigation proposals that are similar in scale to CPW have employed quantitative assessments of this type. For example at hearings in 2007, applicants for the Hunter Downs Irrigation Scheme (HDI) in South Canterbury (approximately 40,000 ha irrigated area) provided a quantitative analysis of nutrient effects on nuisance algae growth in rivers and in Wainono Lagoon (a shallow coastal lake that is much smaller than Te Waihora). Similarly applicants for irrigation water in the upper Waitaki catchment (approximately 25,000 ha irrigated area) provided quantitative predictions of effects on ecosystems in rivers and Lake Benmore for hearings that are due to occur later in 2009.

Conclusion on deficiencies in available information

104. Our general conclusion is that there is insufficient information to quantitatively predict the ecological consequences of degraded water quality on lowland streams or Te Waihora. It is clear from the information available that lowland streams and Te Waihora are already highly disturbed ecosystems and additional pressure from intensified landuse will add to existing cumulative effects. This situation, combined with the large scale of the CPW application, justifies a quantitative assessment of effects on ecosystems that identifies the assimilative capacity of the affected waterbodies. There are precedents for such assessments that include other waterbodies vulnerable to the effects of intensified land-use in New Zealand. Notwithstanding this conclusion we provide the following assessment of effects on lowland streams and Te Waihora based on information available for this review.

6. Potential ecological effects on lowland streams

Consequences of increased nitrate loads and concentrations

105. There is consensus that nitrate loads and concentrations will increase as a result of CPW. There is uncertainty and disagreement about the size of this increase and the spatial and temporal variability of the increase as discussed previously. Following on from conclusions in paragraph 89, the key question is: Is a median increase of 0.5 to 1 mg/L nitrate-nitrogen (applicant's predictions for the revised and original CPW schemes respectively), with a range of up to approximately 2 mg/L (when the time lag for existing land use 'load to come' is allowed for) significant?

The answer to this question depends on:

- i) the existing nitrate-nitrogen concentration in any particular waterbody, and
 - ii) the absolute threshold concentration that the increase is tested against to assess the significance of cumulative effects.
106. Existing nitrate/nitrite nitrogen concentrations for lowland streams are shown in Figure 1 of Ms Haywards supplementary evidence (a copy is attached as our Figure 7). Existing median concentrations range from less than 1 mg/L (Avon) to around 5 mg/L (Selwyn) so a 0.5 mg/L median increase is an increase of 10% (e.g. Selwyn) to greater than 50% (e.g. Avon) depending on the waterbody in question. Because all of these numbers are medians, actual increases would vary with time and between locations in each surface-water catchment.

107. There are a number of threshold “tests” that could be applied to help assess whether these nitrate nitrogen increases are significant. These tests provide options for considering whether additions to cumulative effects would cross an unacceptable line. The tests are:
- i) The nitrate MAV for human health of 11.3 mg/L nitrate nitrogen
 - ii) Proposed regional plan (PNRRP) objectives (e.g. 30% filamentous periphyton cover), policies (e.g. Policy WQL4) and receiving water quality standards (e.g. no increase in soluble inorganic nitrogen (SIN or DIN) greater than 0.02 mg/L and no increase in soluble reactive phosphorus (SRP or DRP) greater than 0.002 mg/L)
 - iii) Nitrate toxicity criteria to protect aquatic biota (1.0 – 3.6 mg/L [chronic effects]; 20 mg/L [acute effects]) (i.e. from Hickey and Martin 2009)
 - iv) Nutrient enrichment guidelines for managing nuisance plant (viz algae) growth (e.g. ANZECC 2000 and Biggs [MfE] 2000) (i.e. in the order of less than 0.3 mg/L DIN and less than 0.025 mg/L DRP)
108. Mr Tipler addressed the nitrate MAV (11.3 mg/L) for human health and concluded (possibly in the context of that test) that the predicted increase in nitrate-nitrogen concentration under CPW is insignificant. He did not assess the significance of nitrate-nitrogen increases in the context of the three other tests listed above. Other CPW witnesses assessed some aspects of these tests. We consider the other three tests as follows.

Tests for evaluating the significance of predicted increases in nitrate nitrogen

1. Proposed NRRP objectives, policies and receiving water quality standards

109. Mr Kennedy addressed the PNRRP (Schedule WQL1) receiving water quality standards (for DRP and DIN) and concluded that such standards are “...a lofty and probably unattainable goal to apply to the entire CPW scheme, regardless of any proposed mitigation measures. This is because such water quality standards are usually applied to point-sourced discharges, with little consideration given to cumulative effects.” Overall he concluded that the PNRRP standards for DRP and DIN should not be applied to the CPW scheme. On the basis of a predicted median increase in nitrate-nitrogen of 1 mg/L under CPW, we agree that at least the DIN standard (no increase greater than 0.02 mg/L) is unattainable if applied to the entire CPW scheme. No quantitative predictions are available for DRP. We do not know if it is true that the PNRRP standards were intended to apply only to point-sourced discharges. Schedule WQL1 does not indicate this, stating: “*The standards apply to discharges of water or contaminants into surface water or discharges of contaminants onto land where they may enter surface water, and apply in the receiving water, immediately outside of the specified Maximum Allowable Non-Compliance Zone, calculated in accordance with Part 2 of Schedule WQL1.*” (Note: underlined words indicate latest changes recommended by ECan Officers to the NRRP hearing Commissioners in May 2009).
110. Even if the Schedule WQL1 standards are applied only to point-sourced discharges and not to the whole CPW scheme, then the relevant tests for CPW, in terms of the PNRRP, should include Objectives WQL1 and WQL2 and Policy WQL4. Objective WQL1 defines the water quality outcomes that the Schedule WQL1 standards are designed to achieve, so this objective is an obvious test if the Schedule WQL standards are to be dismissed. None of the material we reviewed mentioned the outcomes defined in Objective WQL1 or provided a quantitative assessment of effects

on the percentage cover of the streambed by periphyton or macrophytes that could be compared to the outcomes sought in Objective WQL1. Objective WQL2 states (amongst other things) that, for aquifers where the water quality is affected by human activities, the maximum concentration of nitrate-N shall not increase by more than 2 mg/L above the maximum concentration measured between 1996 and 2001 (reported in 2002) and shall not exceed 11.3 mg/L. None of the material we reviewed assessed this objective. Our assessment (see 63 and 89) suggests that CPW would not cause a breach of Objective WQL2, but combined with the 'load to come' from existing land use, may push closer to the WQL2 limit in some areas (the health consequences were discussed previously at paragraphs 65-70). Policy WQL4 is relevant because it is designed for managing non-point source discharges so as to achieve Objective WQL1. Policy WQL4 does not contain any direct tests that could be used to assess the significance of nitrate-nitrogen increases. However Policy WQL4 (2) and (3) provide for the management and prioritisation of rivers and lakes that do not currently meet Objective WQL1. Lowland streams affected by CPW are likely to fall into this category (see PNRRP Table WQL6).

111. We conclude that based on the information provided, it is not clear that the predicted increase in nitrate-nitrogen under CPW is insignificant in terms of tests in the PNRRP. We appreciate that the PNRRP is not yet operative and that submissions have been heard and revisions recommended by ECan Officers at hearings in May 2009 (see recommendations for Table WQL5 in Appendix 4). Other tests such as those described below may also be relevant for decision-making.

2. Nitrate toxicity criteria to protect aquatic biota

112. Dr Burrell, in his first supplementary evidence, dismissed the risk of nitrate toxicity in lowland streams as low because, in his view, the ANZECC 2000 trigger value for nitrate toxicity (updated by Hickey 2002) of 7.2 mg/L is "*conservatively high*". He stated a number of reasons for recommending that the revised (Hickey 2002) trigger should be applied cautiously. He referred to his own sampling of a number of streams in South Canterbury that support "*...healthy populations of juvenile trout, and provide good trout spawning habitat (both sensitive life stages), with concentrations of NO₃-N that well exceed the 7.2 mg/L toxicity trigger level.*" Data and stream details were not provided. Dr Burrell also referred to work by Meredith (2006) who found sensitive invertebrate species in a number of South Canterbury streams with nitrate concentrations that often exceeded the NO₃-N toxicity trigger level. Again no data or quantitative analysis was provided. Mr Kennedy also raised doubt about the accuracy of the ANZECC 2000 (and Hickey 2002) trigger level but did not provide any robust justification. Mr Kennedy concluded that "*It is evident that further work is required to define the likelihood of nitrate-nitrogen toxicity on freshwater fauna in Canterbury waterways (even in the absence of the irrigation scheme).*"
113. Ms Hayward, in her supplementary evidence, disagreed with Dr Burrell and, for a number of reasons that she provided, considered the 7.2 mg/L toxicity trigger level relevant for assessment of risks for lowland streams in New Zealand. She noted that nitrate/nitrite nitrogen concentrations already exceed 7.2 mg/L at times in Boggy Creek and Doyleston Drain and are approaching the trigger level in the Selwyn/Waikirikiriri and Irwell Rivers and in Hamner Road Drain. She concluded that "*...the risks of toxicological effects will increase with the increasing frequency and duration of high NNN concentrations in some of these lowland streams.*" We agree with Ms Hayward's conclusion. We consider that the burden of proof required to dismiss peer reviewed and published national guidelines is significantly greater than the few qualitative references made by Dr Burrell and Mr Kennedy in their original evidence without providing supporting data.

114. Since all of the above-mentioned evidence was written, ECan has published a report by NIWA titled *A review of nitrate toxicity to freshwater aquatic species* (Hickey and Martin 2009). ECan commissioned this report (and had it externally peer reviewed) to review the ANZECC (2000) and the 2002 revised freshwater guideline value for chronic nitrate-nitrogen concentrations (7.2 mg/L) in surface waters and groundwaters. The work was commissioned to support ECan's preparation of an amendment to the PNRRP to better manage the cumulative effects of non-point source discharges. A review of the international literature and toxicological databases was undertaken to compile a database of acute (short term exposure to toxin) and chronic (long term exposure to toxin) toxicity data suitable for deriving revised guidelines. Hickey and Martin (2009) recommended that freshwater guidelines suitable for application to freshwaters of Canterbury are:

- | | |
|---|---------------------------------|
| • Acute | 20 mg NO ₃ -N/L |
| • Chronic - high conservation (99% protection) | 1.0 mg NO ₃ -N/L |
| • Chronic - slight to moderate disturbed (95% protection) | 1.7 mg NO ₃ -N/L |
| • Chronic - highly disturbed (80 to 90% protection) | 2.4-3.6 mg NO ₃ -N/L |

115. A copy of the guidelines from the executive summary of Hickey and Martin (2009) is attached in Figure 6. Even the revised chronic guideline for highly disturbed systems (80% protection = 3.6 mg/L) is less than half the previous guideline value of 7.2 mg/L. Data medians are appropriate for comparison with chronic guideline values because median values reflect long term exposure concentrations. Thus, looking at Figure 1 of Ms Hayward's supplementary evidence (see copy in our Figure 7), of the thirteen streams sampled, four streams down-gradient of the CPW area (Selwyn/Waikirikiri, Boggy Creek, Doyleston Drain and Harts Creek) already exceed the 3.6 mg/L guideline value. Six streams exceed the 2.4 mg/L guideline value, nine streams exceed the 1.7 mg/L value and 11 streams exceed the 1.0 mg/L value. An increase in nitrate-N of between 0 and 2 mg/L would increase breaches of the guideline values.

116. For assessing acute toxicity it is appropriate to compare maximum or 95 percentile data with the revised acute guideline (20 mg/L). This shows that none of the streams down-gradient of the CPW area are currently at serious risk from acute nitrate toxicity and this risk would remain low under CPW.

117. The applicant's consultants were informed of the revised guidelines at our meeting on 25 August 2009. Dr Burrell in his second supplementary evidence (September 09) acknowledged the revised lower guideline values but maintained his opinion that "*the CPW scheme presents a low risk of causing nitrate toxicity in lowland streams*" (paragraph 27). To support his opinion he provided ECan data that shows 22 streams in the Mid-Canterbury (Hinds-Ashburton) area have an average QMCI score (an index of stream health used nationally) of 5.08 (range 3.5 to 7.0) which is significantly higher (better) than the average QMCI score of 4.5 from data for 58 lowland streams across Canterbury (his Figure 2 is reproduced in our Figure 9). His key point was that Hinds-Ashburton lowland streams achieved these stream health scores despite all streams having median dissolved inorganic nitrogen (DIN) concentrations exceeding the revised nitrate toxicity guidelines (he used DIN concentration as a proxy for nitrate-N concentration which is reasonable). We agree this data shows that many invertebrate communities found in the Hinds-Ashburton streams are tolerant of high nitrate-N concentrations but we don't agree with the conclusions. The data also show that lowland streams across Canterbury in general have by far the lowest stream health

QMCI scores (see Figure 9) i.e. they are already degraded. It is highly likely that land use effects throughout the Canterbury plains (including nitrate toxicity effects) have been a dominant contributor to the degradation that now means QMCI scores are lowest in lowland streams compared to all other river types (Figure 9). While the degradation is widespread, some parts of some lowland streams may still harbour more sensitive taxa and these may be vulnerable to further increases in nitrate-N concentrations. The changes to NRRP Table WQL5 recommended by Hayward et al. (2009) include an objective to achieve a QMCI score of 5.0 for lowland streams (see Appendix 4). Approximately half of the Hinds-Ashburton streams referred to by Dr Burrell would meet this objective (i.e. MCI score range of 3.5 to 7.0).

118. We conclude that the applicant's predicted increase in nitrate nitrogen concentrations by a median 0.5 mg/L (1.2 mg/L for the original CPW scheme) and with a possible range of up to 2 mg/L when combined with the 'load to come' from existing landuse, is a significant increase in the context of toxicity for aquatic biota in lowland streams. The increase has become more significant as a result of the recently revised (Hickey and Martin 2009) nitrate toxicity guidelines. The increase adds to cumulative effects and would increase breaches of nitrate toxicity guideline values. Best practice mitigation measures to reduce nitrate losses would be justified to minimise, but probably not avoid, further losses of sensitive aquatic biodiversity.

3. Nutrient enrichment guidelines for managing nuisance plant and algae growth

119. Mr Kennedy and Dr Burrell argued that the effects of additional nitrogen on aquatic ecosystems will be minor, based on the observation that nitrogen is already present in lowland streams at concentrations that exceed guideline levels for avoiding nuisance plant (viz algae) growth (i.e. ANZECC 2000 and Biggs [MfE] 2000) and the assumption that growth is currently limited by phosphorus (the other major plant nutrient). They argue that phosphorus will not increase under CPW and therefore further increases in nitrogen will not cause significant additional nuisance growths.
120. The first assumption made by Mr Kennedy and Dr Burrell, that phosphorus availability currently limits plant growth in lowland streams, was primarily based on a rough guide that uses the ratio of DIN and DRP concentrations to predict which nutrient is limiting. They also referred to a pilot nutrient limitation experiment conducted in the Selwyn River by Larned (2007).
121. Their second assumption, that phosphorus loads and concentrations will not increase under CPW, was based on the evidence of others (e.g. Dr Francis) and on the assumption that mitigation measures such as restoration of riparian margins and stock exclusion from streams will control losses of phosphorus from the CPW area (Mr Kennedy's evidence). Information provided to support this assumption was limited to undefined categorical statements. Dr Francis included only the following sentences on phosphorus. For dairy farming: "*The risk of P leaching was estimated to be low in most scenarios. When excess irrigation was applied, the risk of P leaching was estimated to be medium*" (paragraph 22). For sheep and beef farming: "*The risk of P leaching was estimated to be low in all scenarios*" (paragraph 23). For arable/vegetable farming: "*The risk of P leaching was estimated to be low and this agreed with published literature values*" (paragraph 24). Mr Kennedy also does not provide any numbers on phosphorus losses. It is not clear what 'low' and 'medium' risk means in the context of the fact that even very small increases in dissolved reactive phosphorus (DRP) (i.e. in the order of 0.001 - 0.1 mg/L) can have ecological consequences as a nutrient. Such concentrations are very small compared to the concentrations of nitrate nitrogen that are of interest as a nutrient (~0.01 - 1 mg/L), as a toxicant for aquatic species (~1 - 4 mg/L) and as a toxicant for humans (MAV = 11.3 mg/L).

122. The two assumptions about phosphorus are a concern to us and they are critical to the assessment of effects of nutrient enrichment both for lowland streams and Te Waihora. This concern has also been raised in the evidence of others (e.g. Dr Larned, Ms Hayward and Prof Hamilton). On the first assumption, we agree with Ms Hayward and Dr Larned that it is an oversimplification to rely on nutrient ratios and a one-off limitation experiment in one river to conclude that phosphorus availability limits growth in all lowland streams at all times. We agree with Ms Hayward that it is “...*likely that at times macrophyte or algal biomass could increase as a result of increased nitrate nitrogen concentrations but this may only occur infrequently.*”
123. On the second assumption, we sought further advice from Dr Bob Wilcock (NIWA Hamilton) and Dr Scott Larned (NIWA Christchurch) as specialists on this topic. Dr Larned’s experience is described in the evidence he presented for Fish and Game and the Department of Conservation. Dr Wilcock’s experience is described in Appendix 3. Dr Wilcock and Dr Larned have assisted us in reviewing the CPW evidence and have provided a discussion on the likely effects of CPW on phosphorus in lowland streams and Te Waihora (see Appendix 3). A key conclusion is that phosphorus is likely to increase in lowland streams and Te Waihora as a result of CPW and this raises questions about the validity of the conclusions drawn by Mr Kennedy and Dr Burrell.
124. Without a quantitative prediction of how much phosphorus might increase (as was done for nitrate-nitrogen) it is not possible for us to compare with guidelines (e.g. ANZECC 2000 and Biggs [MfE] 2000) or suggest an alternative prediction of how significant the increased risk of nuisance periphyton and macrophyte growth might be. Such a prediction would be necessary in order to test the extent to which Objective WQL1 of the PNRRP can be achieved. Predictions were made for another recent proposal (the HDI scheme), under different circumstances, that intensified land-use would increase both nitrogen and phosphorus loads to waterways. It was predicted this would lead to approximately a 60% increase in maximum periphyton biomass and an increase in the frequency of periods when Objective WQL1 would not be achieved (HDI 2007 evidence of Mr Norton and Mr Fraser). This negative effect was expressed to be weighed along with the positive effects of the irrigation scheme.

Conclusion for ecological effects on lowland streams

125. We have applied three tests to assess the significance of predicted increases in nitrate loads and concentrations under CPW that add to cumulative effects. The first test, against provisions of the PNRRP, was inconclusive because the applicant did not provide quantitative predictions of periphyton and macrophyte growth for comparison with Objective WQL1. Methods are available for making such predictions. The second test, against nitrate toxicity guidelines, showed that the increase in nitrate is significant in the context of toxicity for aquatic biota in lowland streams, particularly when compared to the very recently revised (Hickey and Martin 2009) nitrate toxicity guidelines. The third test, against nutrient enrichment guidelines, was inconclusive due to the absence of reliable quantitative predictions of phosphorus increases.
126. It seems likely that nitrate, acting both as a toxicant and a nutrient, has contributed to a decline historically in aquatic biodiversity in lowland streams, to an extent that current remaining communities have some resilience to elevated nitrate concentrations. The increase in nitrate loads and concentrations predicted under CPW would add to historic cumulative effects, may reduce biodiversity further in some areas, and would hinder efforts to rehabilitate some of the more sensitive biodiversity in these streams. These adverse effects should be considered along with the positive effects of CPW in

increasing flow to some lowland streams, an effect that would provide a greater area and more favourable habitat for some enrichment and nitrate-tolerant species. For example, the applicant predicted approximately double the habitat area for adult brown trout (Burrell supplementary evidence paragraph 10).

7. Potential effects on groundwater ecology

127. There are major knowledge gaps in this field generally and in New Zealand specifically. We sought further advice on this topic from Dr Graham Fenwick (NIWA Christchurch). The important knowledge gaps concern i) the existing state of groundwater biodiversity (e.g., microorganisms and small invertebrates that live in groundwater), ii) the role these organisms play in assimilating contaminants and thus maintaining groundwater quality, and iii) the sensitivity of these organisms to contaminant overload (e.g. nitrate toxicity). Although there is nothing that this review can do about these knowledge gaps specifically, it would be negligent to ignore the available information from New Zealand and overseas.
128. Using current knowledge of New Zealand's alluvial aquifer ecosystems and international knowledge of equivalent systems, we understand that the Canterbury Plains aquifers function as huge biofilters, within which the biodiversity (bacteria to invertebrates up to 25 mm long) is integral to natural bioremediation processes that maintain aquifer porosity and groundwater quality (Fenwick et al. 2004; Graham Fenwick pers. comm.). Much of the invertebrate biodiversity comprises crustaceans, which are among the more sensitive species to some chemical contaminants (Fenwick et al. 2004; Hickey and Martin 2009). While Hickey and Martin (2009) noted their guideline derivation lacked chronic nitrate toxicity data for these groundwater organisms, the revised guidelines are the best tool available for assessing the risk of nitrate toxicity effects on groundwater ecology in Canterbury. Similar to our assessment of lowland streams, increased nitrate concentrations and loads under CPW could shift community composition, favouring tolerant groundwater species over sensitive ones. The consequences of this for contaminant assimilation and groundwater quality are unknown. For these reasons there is an argument for a precautionary approach that uses the more conservative of the latest nitrate-nitrogen toxicity guidelines (Hickey & Martin 2009).

8. Potential effects on Lake Ellesmere/Te Waihora

129. There is consensus that Te Waihora is currently enriched in terms of both nitrogen and phosphorus. There also appears to be consensus that at least nitrogen loads to the lake will increase under CPW, even though there is disagreement about the scale of the increase, whether concentrations would also increase, whether phosphorus would also increase, whether there would be an adverse ecological response to increases, and the uncertainty associated with all increases. Many witnesses have commented on these matters including Mr Kennedy, Dr Burrell, Ms Hayward, Mr White, Dr Larned, Prof Hamilton and Prof Hughey.
130. In summary, Dr Burrell and Mr Kennedy have concluded that the effects of any increases in nitrate concentrations on aquatic ecosystems would not be significant. This conclusion was largely based on their assessment, using the available literature, that phytoplankton growth (which is the dominant plant form in Te Waihora) is currently

light limited and there is already surplus nitrogen available within the lake, such that additional nitrogen will not stimulate any major increase in phytoplankton growth.

131. Ms Hayward summarised the differing views in paragraph 14 of her supplementary evidence, stating: "*Dr Larned disagreed with this [Dr Burrell and Mr Kennedy] conclusion and commented that in his view, phytoplankton growth could be nutrient limited at times of high water transparency (calm weather conditions). Professor Hamilton's modelling work indicated that phytoplankton growth in Lake Ellesmere/Te Waihora were nitrogen limited 37% of the time. He considered it 'unwise to risk the magnitude of increase in dissolved inorganic nitrogen concentrations with CPW inflows, without more information.'* I agree with both Dr Larned's and Professor Hamilton's conclusions." We also agree with these conclusions.
132. Both Dr Burrell and Mr Kennedy stated that adding more nitrogen is unlikely to make the situation any better (i.e. unlikely to lessen the risk of phytoplankton blooms). We interpret from this that they acknowledge that increases in nitrate would contribute to cumulative effects in a negative direction, albeit in their opinion to an insignificant degree.
133. Both Dr Burrell and Mr Kennedy recommended that "*...integrated management of nutrients within the lake's entire catchment should be a priority*", and they recommended mitigation in the form of the Sustainability Protocol and measures to be implemented in farm plans. They relied heavily on the success of those mitigation measures, particularly to avoid phosphorus losses from irrigated land. Mr Kennedy stated in his right of reply: "*These mitigation measures are achievable and consequently, as I have previously stated, I do not anticipate that phosphorus loadings in lake Ellesmere/Te Waihora will increase as a result of CPW.*" The assumption that these mitigation measures will be effective to the extent that there would be no increase in phosphorus loadings is of concern to us, particularly given that none of the literature Mr Kennedy referenced states phosphorus removal efficiencies of 100%. We consider that, on the basis of the discussion of phosphorus provided by Dr Wilcock (Appendix 3), it is likely that there would be an increase in phosphorus loading to the lake. We will discuss the effectiveness of mitigation using the Sustainability Protocol and farm plans in the final section of this report.
134. We agree with Dr Burrell's description of historically alternating states in Te Waihora (i.e. flipping between macrophyte-dominated and phytoplankton-dominated states) in section 11 of his evidence. We also agree that returning the lake to a macrophyte-dominated state from its current phytoplankton-dominated state would be very difficult, even though as he stated "*I do agree with submitters that greater macrophyte dominance in the lake is a desirable management goal for the lake, and therefore that nutrient management within the entire lake catchment should be a priority.*" Prof Hamilton also expressed the view that restoration of Te Waihora would be "*...extremely challenging*". Nonetheless he concluded and we agree: "*I consider this [CPW-predicted] increase in dissolved inorganic nitrogen is likely to be counter-productive in efforts by Te Runanga O Ngai Tahu to restore Te Waihora.*"
135. We also agree with Ms Hayward's paragraph 15 in her supplementary evidence: "*I consider the area of greatest uncertainty is the consequences of any increases in phytoplankton production. Professor Hughey described the complex nature of lake Ellesmere/Te Waihora and many witnesses have commented on the difficulty of predicting the effects of changes in water quality and phytoplankton growth on the overall ecology of the lake*".

136. The uncertainty referred to by Ms Hayward above is unnecessarily high due to lack of a robust quantitative assessment of the effects of water quality changes on phytoplankton growth. Assessing the effects of land-use intensification necessarily involves a series of linked steps that build sequentially on each-other i.e., land use pattern changes affect nutrient loss rates, which in turn affect groundwater quality and consequently surface water quality in rivers flowing to the lake, which in turn affects phytoplankton growth and consequently a range of other ecological, amenity and recreation values. The more robust quantitative methods that can be employed at each of these steps the greater will be the confidence in estimates of effects at the end of the chain. The assessment undertaken by the applicant employed quantitative methods only for steps up to the point of predicting water quality changes. There are tools available for making quantitative predictions at the next step (i.e. phytoplankton response) that would increase confidence in estimates of effects at subsequent steps. One of these tools is the model used in an indicative way by Prof Hamilton. This tool could be improved significantly, as Prof Hamilton himself states, by undertaking additional field and experimental studies to confirm or adjust the model parameters so that it is more specific to the Te Waihora situation.
137. Overall we consider that the available information is inadequate for predicting the effects of increased nitrogen and phosphorus on ecological values (and related values) of Te Waihora. Some of the reasons are:
- The applicant provided no quantitative predictions of loading rates to Te Waihora but Mr White (in his report for Ngai Tahu) predicted that CPW would cause nitrogen and phosphorus loading to the lake to double or more. Robust estimates for load increases are needed for making robust predictions of ecological responses.
 - The applicant provided no quantitative assessment of the ecological response (e.g. phytoplankton growth) to predicted increases in nutrient loads, despite methods being available to make such predictions. The only semi-quantitative assessment is the one provided by Prof Hamilton (in his evidence for Ngai Tahu) but he describes this as indicative at this stage and not to be relied on for "...quantitative values". Prof Hamilton is a lake specialist and has considerable experience with modelling the effects of nutrient changes on lake trophic state and associated ecological condition. We note his view, based on his indicative modelling exercise, that "... there is a strong possibility that lake water quality will become further degraded." He cautioned that at this stage "...there is almost no information adapted into the model that is specific to Te Waihora in relation to phytoplankton physiological responses to light and nutrients" and: "The values of selected parameters in the model should not be regarded as fixed at this stage and additional studies to measure phytoplankton responses to light and nutrients should be undertaken under controlled environmental conditions".
 - The assumption that mitigation measures will be sufficiently effective to ensure no increase in phosphorus loadings to Te Waihora has not been adequately justified. We think this assumption is incorrect and this could influence conclusions about the phytoplankton response and associated effects on ecosystems. Changes to phosphorus predictions could alter the outputs from Prof Hamilton's model.
 - There is considerable uncertainty about the risk of toxic blooms and whether changes to the nutrient status and operating regime (i.e. frequency of lake openings) could alter salinity patterns that might lead to increased risk of toxic blue-green algal blooms. The risk of toxic blooms is an important prediction in

terms of testing the effects of CPW against the provisions of the PNRRP because Objective WQL1.2(2)(c) states that water quality shall be maintained or where it is necessary, improved so that there are no toxic or nuisance algal blooms.

- The current level of knowledge about nutrient cycling and phytoplankton-nutrient relationships in Te Waihora is rudimentary. Most of the quantitative work on Lake Ellesmere nutrients has been based on nutrient budgets, using the ECan monitoring dataset. That is the case for the recent ECan report on phytoplankton (Larned & Schallenberg 2006) and the evidence of Prof Hamilton. These reports and all previous work were not experimental. They only provide information about patterns, not the underlying processes. The level of understanding about the actual processes occurring in the lake is minimal. For example, denitrification has never been measured. Prof Hamilton's estimate for denitrification was based on a nutrient budget model and the observation that a large quantity of nitrate is not accounted for in nitrogen budgets. Nutrient uptake or release by phytoplankton has never been measured, and nutrient efflux from sediments has never been measured. In general, there is only a weak basis to predict responses of the lake nutrient pools to changes in loading.

Conclusion for effects on Te Waihora

138. We reiterate our earlier conclusion (paragraph 78) that there is insufficient information to quantitatively predict the ecological consequences of degraded water quality on Te Waihora. It is clear from the information available that Te Waihora is already a highly disturbed ecosystem and additional pressure from intensified landuse will add to existing cumulative effects. This situation, combined with the large scale of the CPW application, justifies a quantitative assessment of ecological effects.

Examples of work required for a quantitative assessment of effects on Te Waihora

139. The following list of existing reports and required information have been compiled from our reading of the available evidence and following advice we sought from Dr Larned and Dr Schallenberg.

Existing reports that addressed nutrient pools and patterns (but not cycling) in Te Waihora

1. Hawes & Ward 1996
2. Larned & Schallenberg 2006
3. Schallenberg et al. in revision
4. Taylor 1996
5. Ward & Taylor 1993

High priority studies for Te Waihora and its tributaries to assist with a quantitative assessment

- A. Analysis of nutrient and light-limited growth of periphyton and macrophytes in a range of Lake Ellesmere tributaries, over an annual cycle. The range of tributaries will

provide the range of ambient nutrient concentrations, shade and turbidity levels, hydraulic conditions, and species composition needed to draw strong inferences.

B. Analysis of nutrient and light-limited growth of phytoplankton in a range of Lake Ellesmere sites. The range of sites will provide the ambient nutrient concentrations and species composition needed to draw strong inferences (e.g., Schallenberg & Lill, in revision).

C. Analysis of other potentially limiting factors including micronutrients, salinity and grazing. These may overwhelm or interact with nitrogen and phosphorus and/or light limitation (e.g. Downs et al. 2009).

D. Analysis of internal loading in Lake Ellesmere, including sediment efflux and uptake.

E. Analysis of denitrification in Lake Ellesmere sediments

F. Analysis of nutrient exchange (uptake and release) between Lake Ellesmere phytoplankton and water column.

G. Analysis of the factors influencing the risk of toxic algal blooms. The Ministry for the Environment has just recently prepared draft guidelines (MfE 2009) that could assist with this.

140. A common aim for all of these studies should be quantitative relationships between nutrient loads or concentrations, and the responses (i.e., denitrification, algal growth, uptake, efflux). These relationships are needed to predict responses to changes in loading caused by developments such as CPW. These relationships could inform development of models such as the one described by Prof Hamilton.

141. A previous list of research priorities for Lake Ellesmere was recommended by Gough and Ward (1996), and it is consistent with the preceding list:

1. the identification of the critical factors controlling phytoplankton production,
2. and determination of whether different factors are important at different times;
3. the effects of various nutrient control measures on the lake nutrient concentrations;
4. the relative contribution of nutrients from different sources in the catchment;
5. the seasonal variation in nutrient input to the lake;
6. the role of sediments in recycling nutrients;
7. the nutrient process occurring in the inflowing rivers and streams; and
8. the trends in nutrient loading of the lake (i.e. the rate of eutrophication).

9. Effectiveness of mitigation using Sustainability Protocol and Farm Plans

142. We sought further advice on this topic from Dr Wilcock (NIWA Hamilton). Dr Wilcock's experience relevant for this topic is described in Appendix 3. He has assisted us in reviewing the CPW evidence and has provided the following discussion.
143. Large-scale irrigation development often causes rapid changes in water quality that may not be easily tied back to their source. That is, irrigation causes groundwater changes that may be manifested as surface water quality changes some distance from the site of irrigation.
144. There is no doubt that agriculture degrades surface water quality and that there are limits to what can be done to reduce loadings onto land or to intercept contaminants in runoff pathways, through the use of best management practices. Agricultural landscapes are inherently "leaky" and there are limits to land use intensification that will be tolerated without breaching measures of acceptable environmental outcomes, such as regional plan objectives and policies, regional plan receiving water quality standards and/or national water quality guidelines. Water quality changes from large-scale irrigation could be quite profound and happen quickly and, seemingly, irreversibly. There needs to be built in to the protocols some capacity to react and halt undesirable actions; i.e. contingency planning that is acceptable to ECan. Current thinking within the dairy industry is to focus on best management practices (BMPs) that relate to specific regional/local water quality issues. That requires an accord between the industry, landowners/managers and local (regional) government. This would mean consideration of macronutrient forms of N and P, faecal indicator organisms (viz. *E. coli*), and sediment. Riparian and stream habitat management should be considered as well.
145. BMPs are not a way of achieving 100% removal of pollutants in farm runoff. They are simply the best means available for mitigation. For example, research on grass filter strips indicates that where they are located at the down-slope margins of intensively grazed fields, they achieve 20-70% reductions in SS and TP concentrations (McKergow et al. 2007).
146. Focus in the Sustainability Protocol (Claire Mulcock evidence 20a, section 4.2.3) on achieving an annual application efficiency of 80% is sound practice because controlling the volume of water leaving irrigated areas is the best way of minimising pollution of non-targeted receiving waters.
147. BMPs tend to fall into two groups: those that reduce or manage land loadings so that the risk of runoff losses is also reduced; and interception methods that mitigate losses by intercepting contaminants along hydrological pathways from land to waterways.

Examples of land loading BMPS include:

- Matching fertiliser to meet agronomic optimal targets and timing applications to minimise runoff;
- Identifying and not applying P fertiliser to critical source areas for P runoff;
- Withholding irrigation for a set period after P fertiliser applications;
- Not applying fertiliser within riparian zones.

- Using riparian filter strips comprising fenced of pasture grass;
- Livestock exclusion from riparian zones.
- Ensuring irrigation rates do not cause surface runoff to occur (i.e. monitoring soil moisture and soil permeability)
- Minimising stock damage to wet soils through the use of feed pads and by avoiding high stocking rates
- Sound wet weather grazing practices;
- Use of nitrification inhibitors and slow-release (P) fertilisers;
- Making sure that effluent irrigation is at a rate that minimises rapid drainage losses and that there are adequate holding facilities for deferring wastewater irrigation when soils are wet.

Examples of interception BMPS include:

- Permanent riparian fencing and vegetation;
- Natural and constructed wetlands for denitrification and stripping P;
- Trapping and removing sediment and faecal matter from surface runoff; P adsorption methods (e.g. alum, fly ash, slag) for land and drains; denitrification walls; (McKergow et al. 2007).

148. Management practices that reduce losses of sediment and nutrients from cropped lands are described by Francis (2003). Mitigation of N leaching from cropped soils can be achieved by: changing the time of tillage from autumn to spring; reducing the intensity of tillage (so as to reduce the accumulation of nitrate in the soil profile); matching N and P applications to plant needs and applying fertilisers to avoid losses in drainage. Soil losses can be achieved by reducing the intensity of tillage to lessen the potential for wind erosion; contour planting and planting trees to minimise soil loss.
149. The work done at Lincoln University indicates 'potential' reductions in nitrate leaching, as well as gains in pasture production and product from the use of the nitrification inhibitor, DCD (Kennedy, Para 189). The 75% reductions in nitrate leaching achieved by the Lincoln University group may be a maximum value under optimal or ideal management conditions. Trials conducted under typical farm management conditions by AgResearch showing that nitrate leaching losses are more typically reduced by 25-50% (Ledgard et al. 2008; Monaghan et al. 2009).
150. For dairy farmers, it might be useful for the Code to add representation of an appropriate number of Dairy Action Team Leaders (roughly one per every 25 dairy farms). The DATs are an initiative of Dairy NZ and utilise farm leaders to keep their peers apprised of BMPs and sustainable farming, generally. They target is to have about 500 DAT leaders throughout NZ. If a large new dairy farming development (conversion or intensification) occurs as a result of the CPW scheme then it would be desirable that these farmers set the example for best practice farming.

Summary

- Agriculture cannot be isolated from adjacent waterways and this connectivity must be recognised by the applicants in their sustainability protocol by addressing land loads at source, and identifying key pathways connecting irrigated land with (surface and subsurface) water resources.
- Best management practices should be addressed more specifically by the applicants. BMPs should be targeted to address specific water resource issues identified by the regional council (ECan).
- There is a range of BMPs available to dairy farmers and implementation of these may best be done with appropriate advice from outside agencies (e.g. DairyNZ) or via farmer groups (e.g. DAT leaders).
- Contingency planning should be incorporated, such as adequate storage of effluent during wet weather for withholding disposal by land irrigation.
- BMPs are not a way of achieving 100% removal of pollutants in farm runoff. They are simply the best means available for mitigation. Removal efficiencies are likely to be much lower than 100% (i.e. in the order of less than 50%).

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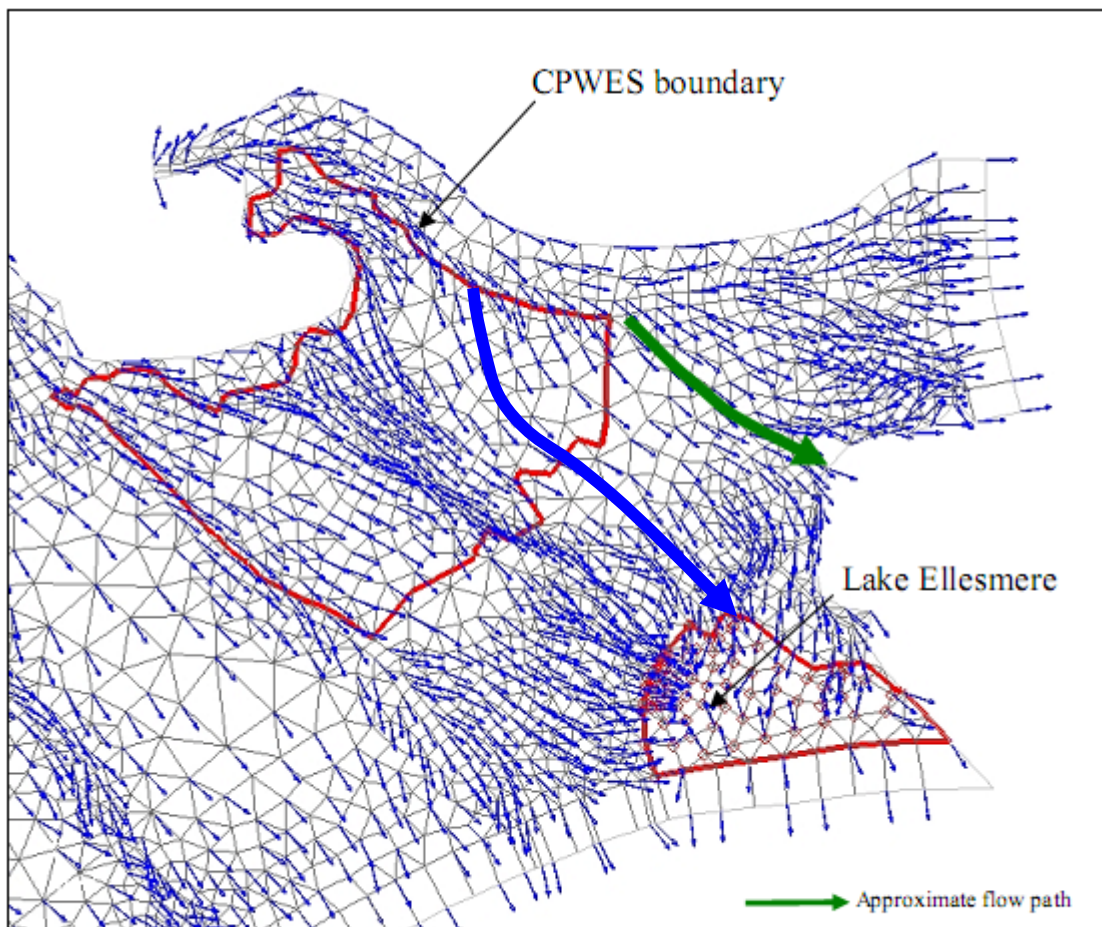
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Status quo average period (1 March 1994) – shallow aquifer

Figure 1. Groundwater flow map, from the evidence of Mr Weir, showing a typical groundwater flow path (blue arrow) inserted by the authors.

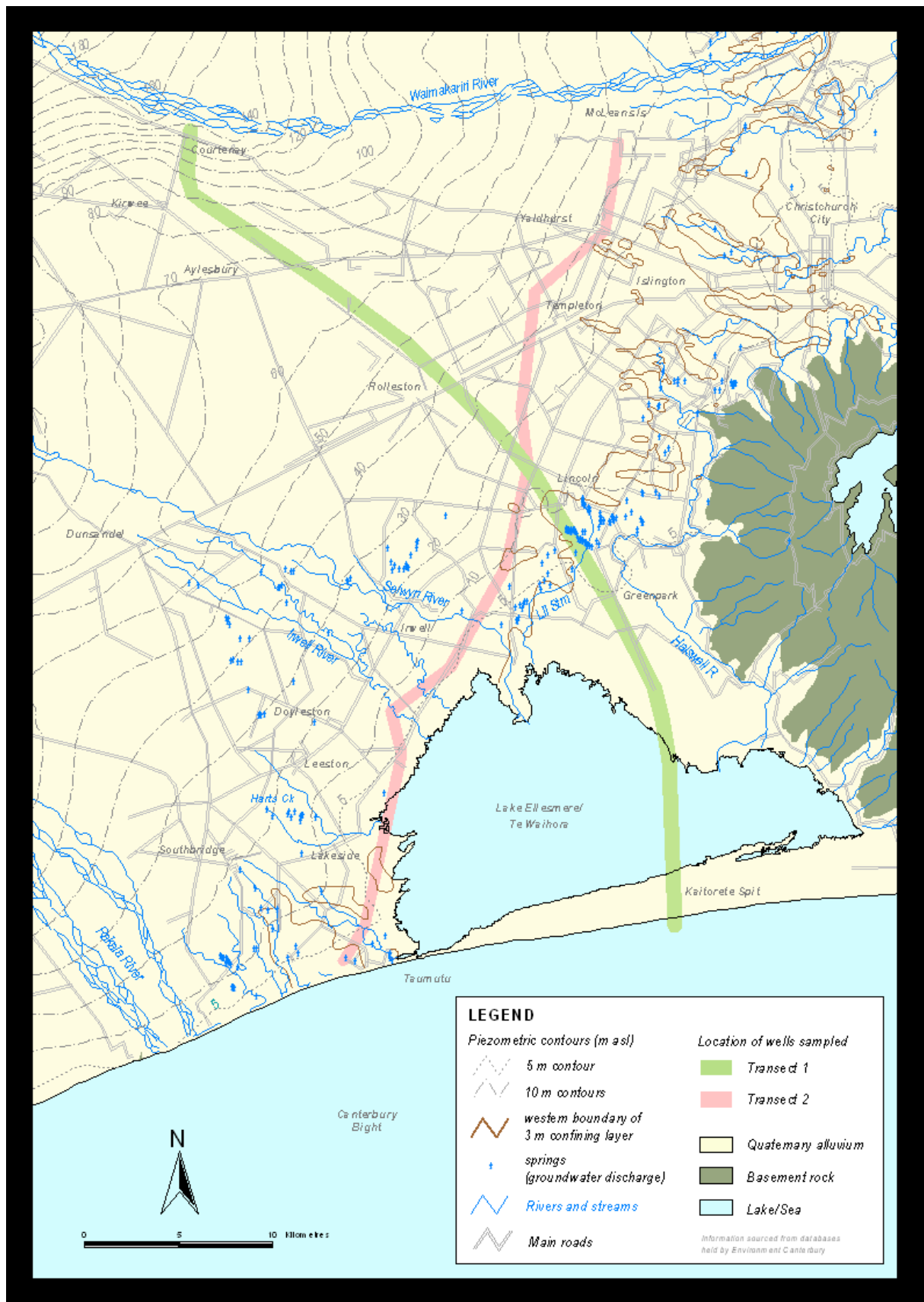


Figure 2. Map from Hanson and Abraham (2009) showing Transect 1 (green line) approximately along a groundwater flow path.

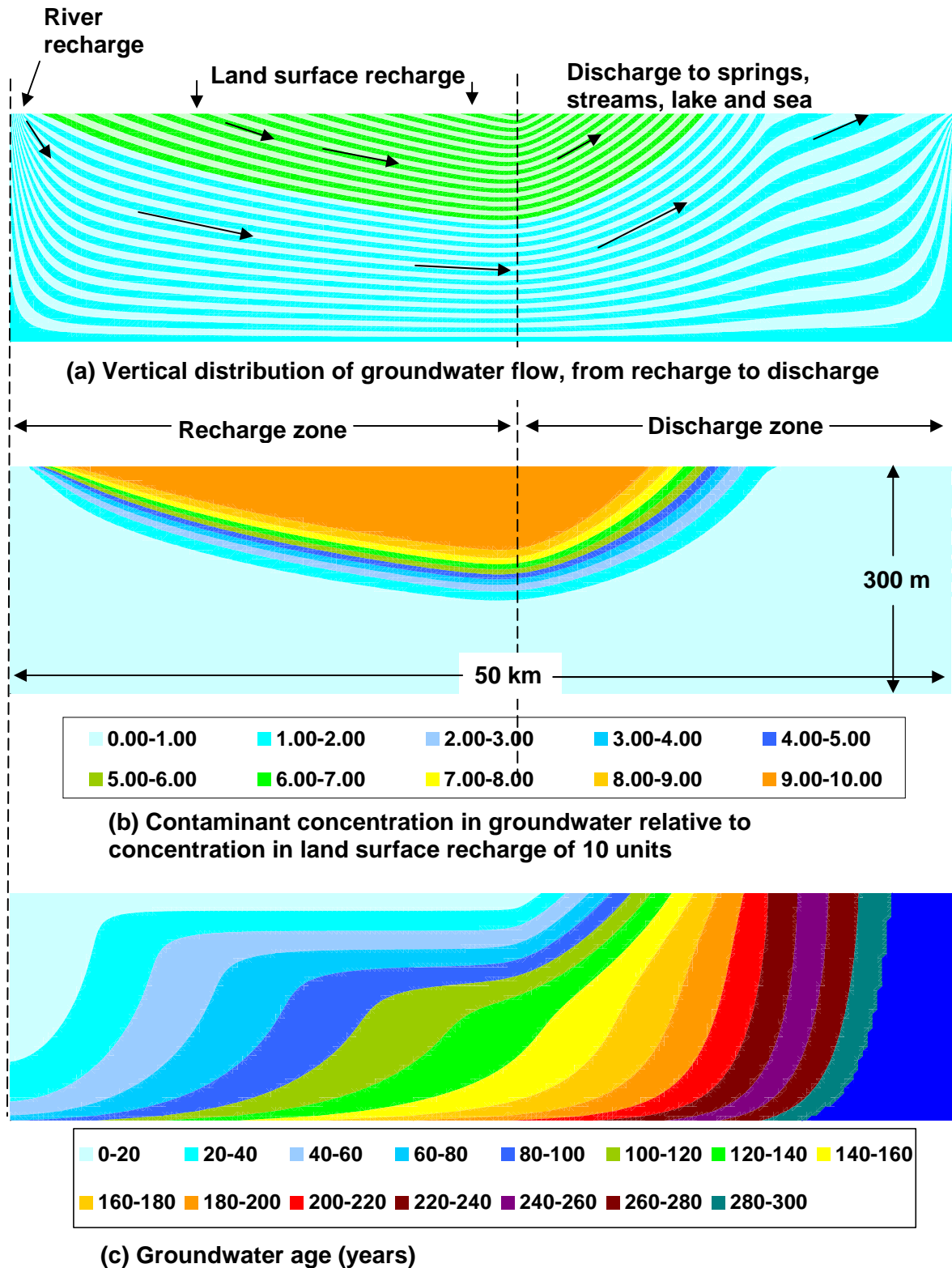


Figure 3. Vertical cross section along a groundwater flow path showing (a) groundwater flow, (b) relative contaminant concentration and (c) groundwater age. This example illustration is produced by the authors' mathematical model for typical values of groundwater recharge and aquifer properties in Central Canterbury Plains.

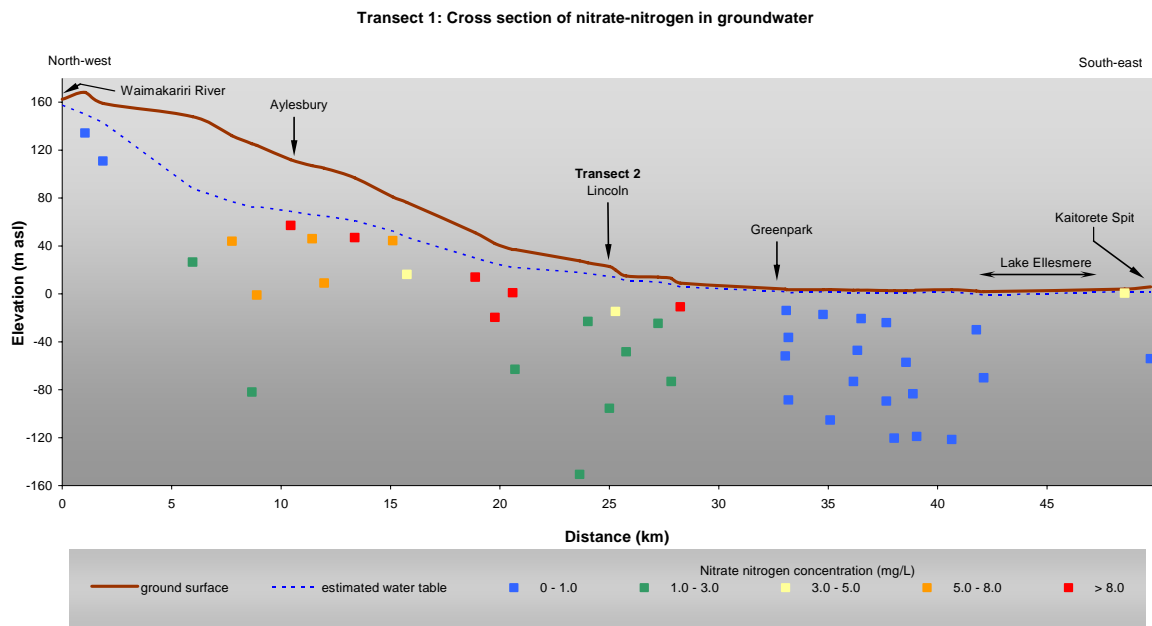
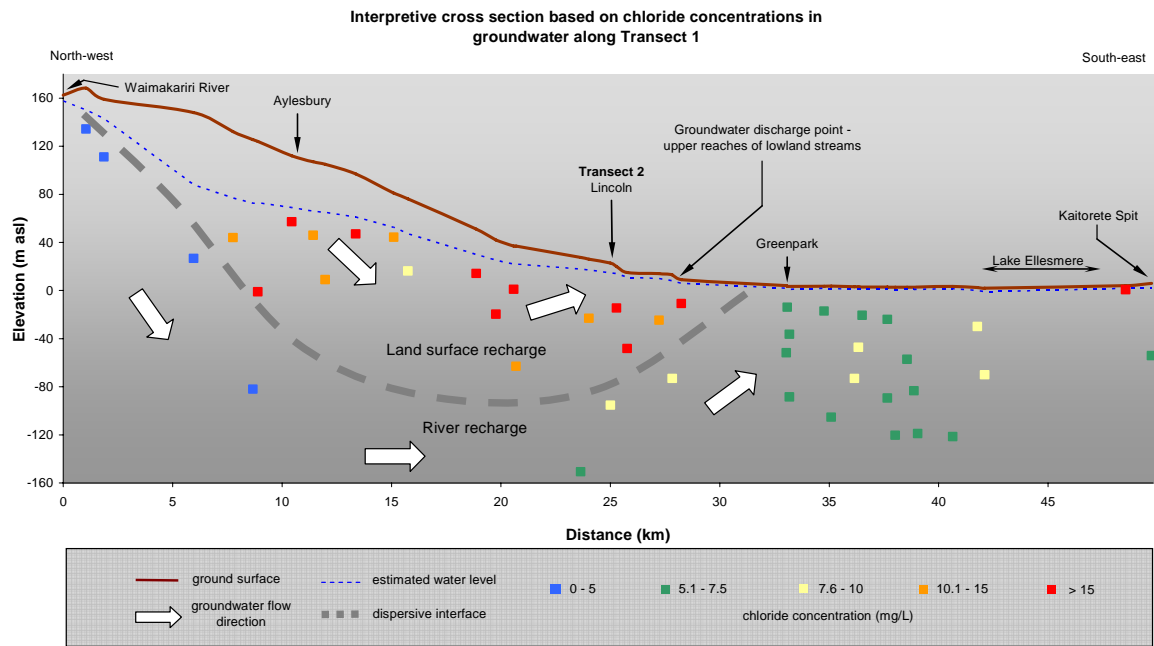
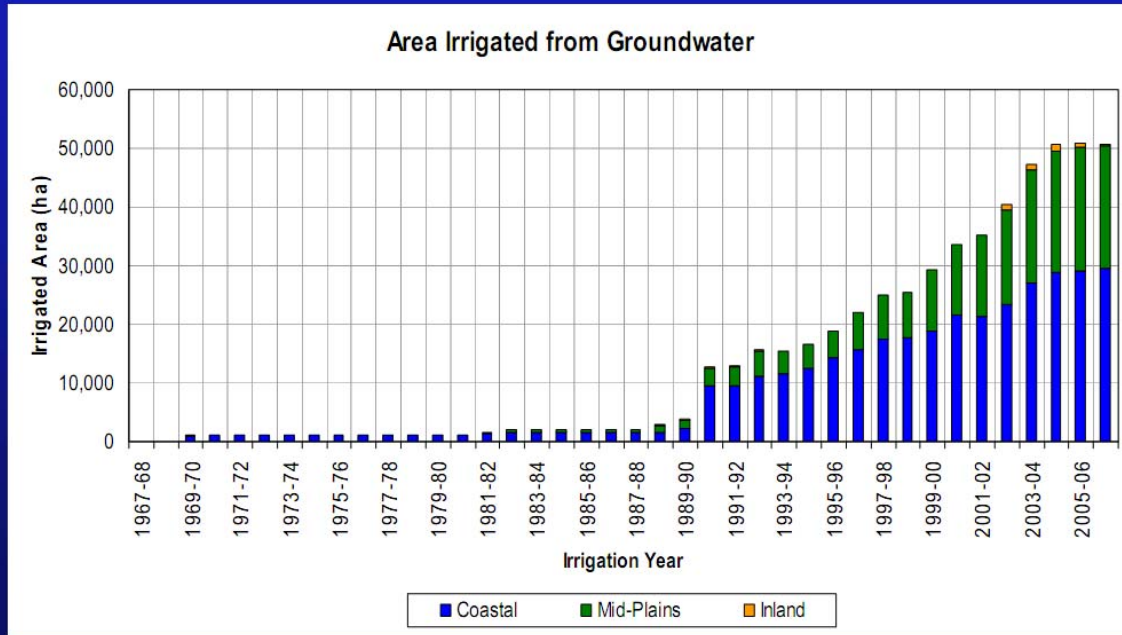


Figure 4. Cross-sections along the transect shown in Figure 2, showing the distribution of (a) chloride and (b) nitrate (Hanson and Abraham, 2009; Figures 4.5 and A3.4).

Consented irrigated area in RS



AQUALINC

Figure 5. Copy of slide presented by Mr McIndoe at the Selwyn Science Symposium, 29-30 March 2007.

Guideline type	Application to:	Guideline value (mg NO₃-N/L)^a
Acute	Very localised point source discharge.	20 mg NO ₃ -N/L
Chronic – high conservation value systems (99% protection)	Pristine environments with high biodiversity and conservation values.	1.0 mg NO ₃ -N/L
Chronic – slightly to moderately disturbed systems (95% protection)	Environments which are subjected to a range of disturbances from human activity.	1.7 mg NO ₃ -N/L
Chronic – highly disturbed systems (80 to 90% protection)	Specific environments which: (i) either have measurable degradation; or (ii) which receive seasonally high elevated background concentrations for significant periods of the year (1-3 months).	2.4 – 3.6 mg NO ₃ -N/L
Chronic – site-specific (species-specific protection)	Collection of specific data for representative species and life-stages with calculation of site-specific guideline values.	No data

^a Multiply by conversion factor of 4.43x to convert to NO₃

Figure 6. Guidelines table copied from executive summary of Hickey and Martin (2009).

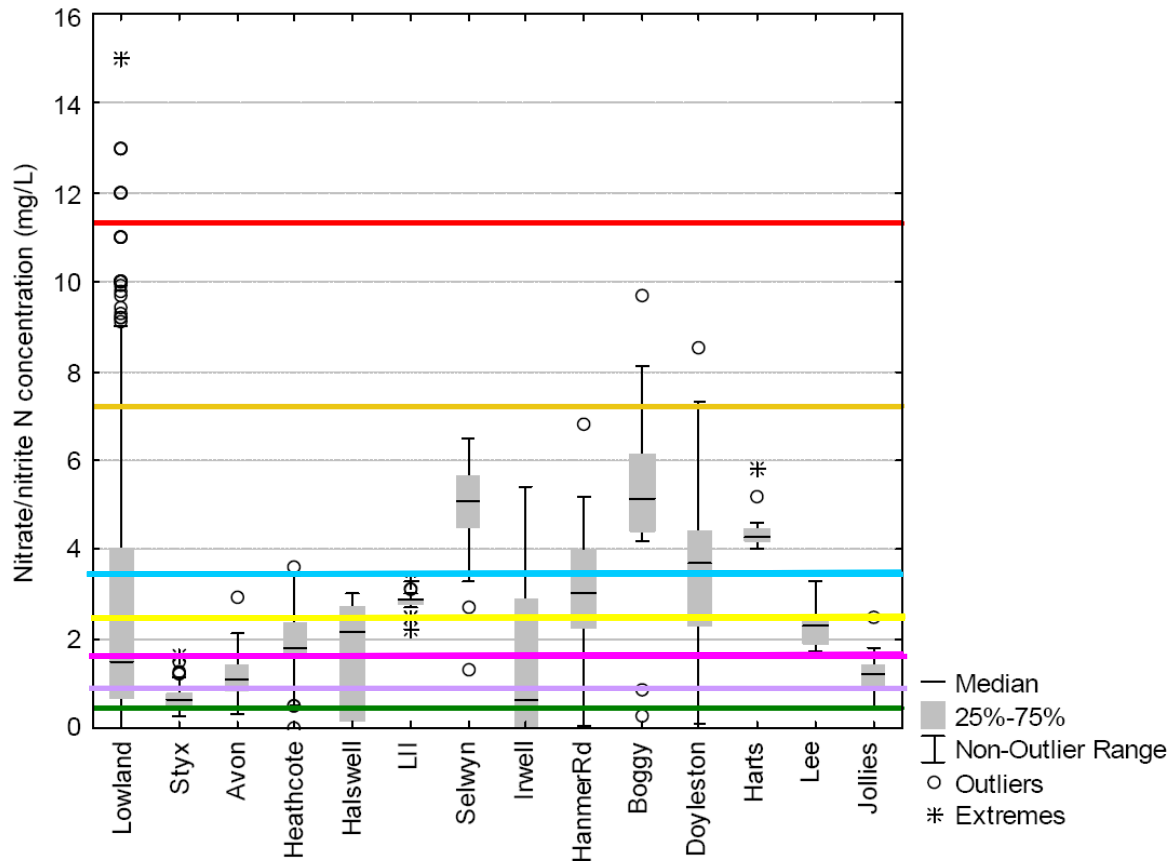


Figure 1 Range of nitrate/nitrite nitrogen concentrations for the five year period (2002-2006) in lowland streams down gradient of the Central Plains proposed irrigation area compared to lowland streams in other parts of Canterbury (42 sites). The streams are ordered from north to south. The green line indicates the nutrient enrichment trigger value from ANZECC 2000; orange line indicates the aquatic toxicity trigger value (95% level of protection) from ANZECC 2000 (modified by Hickey 2002); red line indicates the NZ drinking-water standard for nitrate nitrogen.

Figure 7. Copy of Figure 1 from the supplementary evidence of Ms Hayward. We have added four new coloured lines to indicate the revised (Hickey and Martin 2009) chronic toxicity guidelines. The blue line indicates the guideline for 80% protection for highly disturbed systems (3.6 mg/L). The yellow line indicates the guideline for 90% protection for highly disturbed systems (2.4 mg/L). The pink line indicates the guideline for slightly to moderately disturbed systems (1.7 mg/L). The purple line indicates the guideline for pristine high conservation value systems (1.0 mg/L)

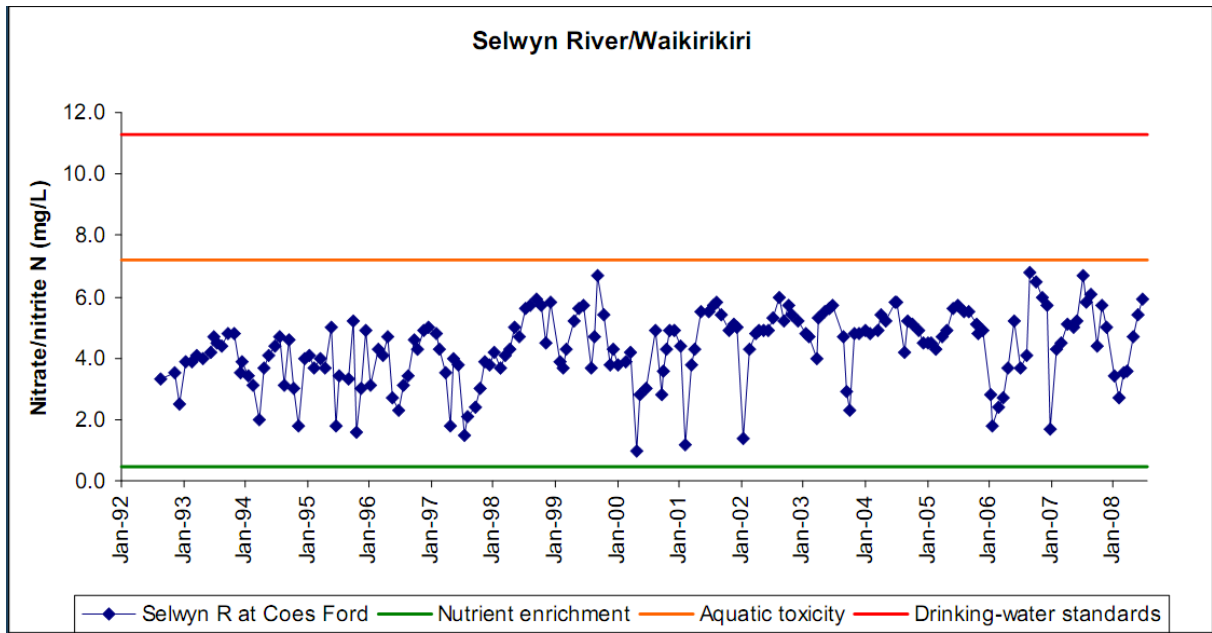


Figure 8. Copy of Figure 2 from the supplementary evidence of Ms Hayward.

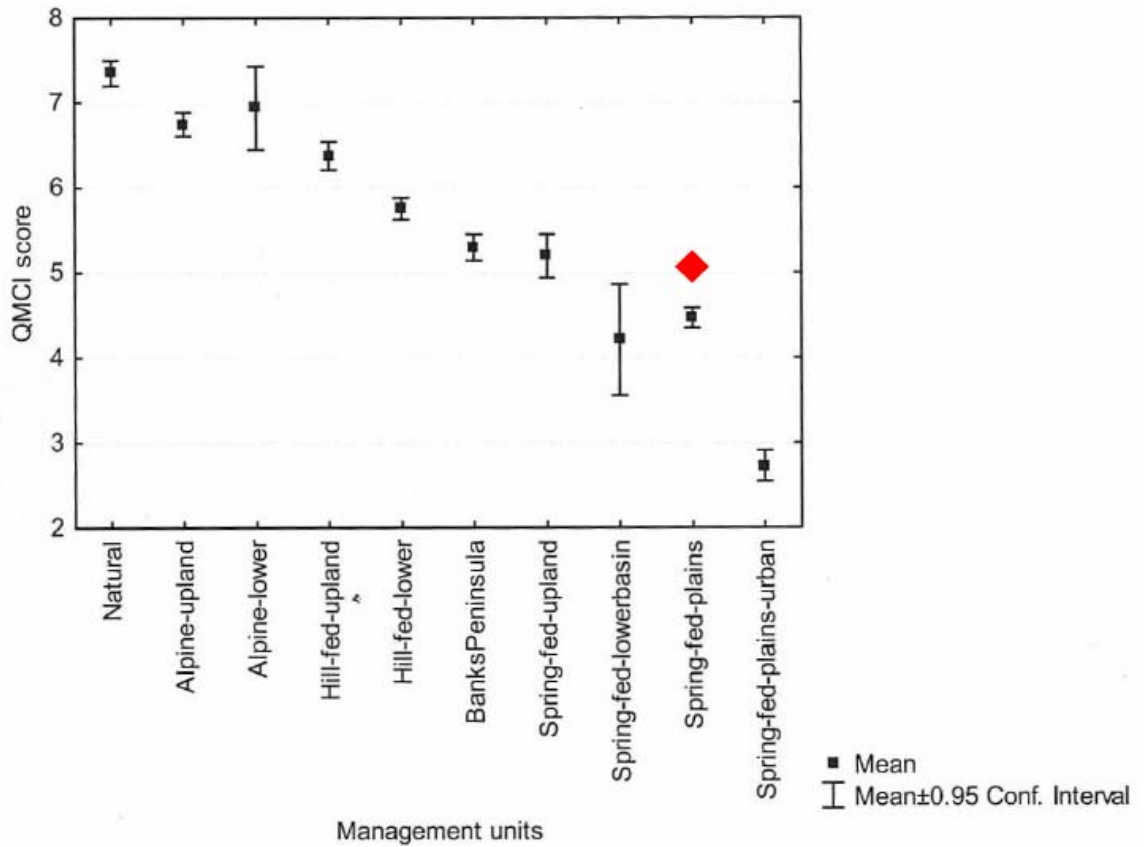


Figure 2: Mean and 95% confidence intervals of QMCI scores for all sites sampled as part of ECan's Ecosystem Health monitoring programme since 1999 (reproduced from Hayward et al. 2009). I have added the red diamond, which indicates the mean QMCI score from 22 streams in the Ashburton-Hinds area, based on data from Meredith et al. (2006).

Figure 9. Copy of Figure 2 from the second supplementary evidence of Dr Burrell (September 2009).

Appendix 1:

Minute 8 of Commissioners setting out directions relating to an independent review of nutrient and other contamination issues

IN THE MATTER OF the Resource Management Act 1991

AND

IN THE MATTER OF a joint application by Central Plains Water Trust and Ashburton Community Water Trust to:

Canterbury Regional Council for resource consents to take water from the Rakaia River for use by the Central Plains Water Enhancement Scheme and the Rakaia Terrace Hydro Scheme

IN THE MATTER OF applications by Central Plains Water Trust to:

Canterbury Regional Council for resource consents to take and use water from the Waimakariri River and to use water from the Rakaia River for the Central Plains Water Enhancement Scheme and for associated consents required for the construction and operation of the Central Plains Water Enhancement Scheme; and to

Selwyn District Council for resource consents to construct and operate the Central Plains Water Enhancement Scheme

AND

IN THE MATTER OF a notice of requirement by Central Plains Water Limited to:

Selwyn District Council for the designation of land for works associated with the construction and operation of the Central Plains Water Enhancement Scheme

IN THE MATTER OF applications by Ashburton Community Water Trust to:

Canterbury Regional Council for resource consents to use and divert water from the Rakaia river for the purposes of hydro electricity generation and associated consents required for the construction and operation of the Rakaia Terrace Hydro Scheme.

Minute 8 of Commissioners setting out directions relating to and independent review of nutrient and other contamination issues

22 June 2009

Introduction

1. The hearing is resuming on 5 October 2009 to consider the implications of a scaled back scheme. One of the issues which we will need to give further consideration to is the matter of nitrate contamination. In particular the potential effects of the amended scheme on:
 - Potential contaminant levels in ground water and in particular in drinking supply bores
 - Any consequent health risks of such contamination

 - Any other potential adverse effects on groundwater
 - Contaminant levels in surface water
 - Potential ecological effects on lowland streams
 - Potential effects on Te Waihora
2. We already have extensive evidence on these matters, however risks of adverse effects may be different with a scaled back scheme.
3. These issues are a matter of considerable public interest. For example:
 - The District Health Board has claimed that the proposal will pose a significant public health risk. (but did not provide any quantitative risk assessment to support that claim)
 - Ngai Tahu and others raise concerns regarding potential effects on Te Waihora and efforts which may be made to improve the ecology of the lake.
 - A number of submitters have raised concerns regarding potential adverse effects on the ecology of lowland streams.

4. Leaving aside the issues associated with the dam and reservoir which we have already addressed, the contamination issues and the question of effects on in-stream values in the Waikakariri are the two most significant remaining issues. While there are a raft of other issues, these two matters are of critical importance and public interest.
5. Both issues are quite complex. We are about to release a minute setting out our preliminary views on the take issue, however we have not yet reached any conclusions on the water quality issues. The evidence is complex and conflicting.
6. We have concluded that we require some assistance on this matter. None of the panel are ecologists or health risk experts. We have some preliminary views but given the public interest in these matters we have concluded that it would be appropriate to seek some independent assistance on these issues. That will both assist us with our decision making and provide the public with greater confidence that these issues have been thoroughly considered.
7. Section 41C enables us to commission a person or persons employed for that purpose, to prepare a report on any matter on which the authority requires further information if the activity that is the subject of the application is likely to have a significant adverse environmental effect, provided that the applicant does not refuse to agree to that.
8. We have concluded that the evidence suggests that the proposal does have the potential to significantly increase at least nitrate levels in groundwater and surface water. Whether or not that is a significant adverse effect can not be determined at this stage. The applicant is not opposed to the commissioning of a report.
9. We have sought advice from Regional Council officers and they have consulted with the applicant as to suitable people to provide the report. Those people are Dr Vince Bidwell of Lincoln Ventures Limited and Mr Ned Norton of NIWA who have agreed to be engaged for this purpose. We have also consulted with the officers and they have also consulted with the applicant regarding an appropriate brief which is set out below.
10. Accordingly pursuant to section 41C of the Act we direct that Messrs Bidwell and Norton be engaged to provide a report covering the following:

11. A review of information regarding, the environmental effects of irrigating land as a result of whatever amended scheme is advanced by CPW.

The consultants should:

12. Review of all existing evidence which is before the panel relating to:
 - Potential contaminant levels in ground water and in particular in drinking supply bores
 - Any consequent health risks arising from such contamination
 - Any other potential adverse effects on groundwater
 - Contaminant levels in surface water
 - Potential ecological effects on lowland streams
 - Potential effects on Te Waihora
13. Discuss with the applicant the details of its amended proposal and in particular any likely changes to the location or rates and volumes of irrigation or the time when that will occur and any ground water recharge proposals which it may have.
14. Review the further evidence provided by the applicant for the October hearing and any evidence in response from other parties relating to these matters.
15. Take into account the applicants proposals for mitigation including the on farm protocol.
16. Liaise with the relevant regional council officers, and the applicants and any submitter experts in relation to the above issues.
17. Take into account any other published or unpublished reports on the relevant issues, including any evidence provided in other hearings (eg the hearings into the PNRPP).

18. Liaise with the commissioners regarding the panels preliminary views of the evidence.
19. Synthesise this information and so far as is possible draw their own independent conclusions regarding:
 - The likely magnitude, temporal variation and spatial variation of any increase in nitrate and phosphate concentrations in groundwater resulting from the revised scheme.
 - Any potential health risk implications of increased nitrates or pathogens in bore water
 - Any potential effects on rivers, drains and streams down-gradient of the command area
 - Any potential effects on Lake Ellesmere (Te Waihora)
 - Any perceived deficiencies in the information before us pertaining to these issues;
 - Any areas of uncertainty in terms of their conclusions
 - Any suggested changes to conditions or the farm protocol to address water quality issues.
20. These conclusions should take into account:
 - proposed mitigation measures (including possible conditions);
 - the increased dilution arising from the scheme
 - recent decisions in relation to other irrigation schemes in Canterbury
21. We emphasise that this is a desktop exercise and we do not envisage any additional modelling work being carried out. However the consultants may informally suggest further work that the applicant may wish to carry out.
22. The methodology and scope of work should as far as possible be agreed with the applicant. The final scope of work should be agreed with the Regional Council before work commences. If the reviewers, staff or applicant have any queries or

suggestions regarding the scope of work or the form of the report they should be addressed to us directly

23. We note that this report will not be determinative of our conclusions on the matters concerned. However we are hopeful that report will provide us with considerable assistance and that ideally parts of it could be utilised in our final decision to avoid us having to re traverse matters. Accordingly it would be appreciated if the writing style in the report was in a form where the relevant parts of the report could be reproduced in our decision along with such comments from us as are appropriate.
24. Section 41c(5) RMA requires that a copy of this initial report be made available to the applicant and any party who made a submission. ECan staff will make that initial report available on the website by 21 September 2009. A copy will be provided to the Commissioners at that time. The applicant, submitters and the Reporting Officers have the right to provide comment on the initial report at the resumed hearing on 5 October 2009. The initial report should then be updated as required following the resumed hearing. The authors of the report will need to present the report at the resumed hearing. If necessary we will seek clarification of particular matters. They should also be available to assist us as necessary with our deliberations on the relevant matters.
25. Although we encourage collaboration with the applicant's experts relevant submitter experts and council officers, it is essential the reviewers approach this task in an independent manner.



Philip Milne
Chair

Dated: 22 June 2009

Appendix 2: Evidence considered in this review

Applicant's Evidence

- Cliff Tipler
- Murray Close
- John Bright
- Glynn Francis
- Paul Kennedy
- Greg Burrell
- Claire Mulcock?

Submitter Evidence

- Antony Stevens
- Christchurch City Council
- Community and Public Health
- Department of Conservation
- Fish & Game/DOC
- Greens Party
- Guardianz
- Molloy, Sue
- National Council of Women
- Ngai Tahu
- Raizis, Anthony
- Selwyn District Council
- Waihora Ellesmere Trust
- Water Rights Trust
- Williams, Florence and Earl

S42a Reports

- Leo Fietje – would include a brief summary of effects and planning matters
- Carl Hanson – GW quality
- Shirley Hayward – SW quality
- Vince Bidwell
- Howard Williams – GW flows and effects on lowland streams/Te Waihora

Appendix 3:

Comments on phosphorus provided by Dr Bob Wilcock (NIWA Hamilton) and Dr Scott Larned at the request of the authors

Dr Wilcock is a specialist at NIWA in land-water interactions. He has been studying environmental aspects of dairy catchments since 1995 and is currently coordinating the water resource component of the long-term "Best Practice Catchments for Sustainable Dairying" study that also involves the design and testing of best management practices. He has written over 100 scientific papers and several book chapters, including "Land-Water Interactions: Impacts on the Aquatic Environment", in Environmental Impacts of Pasture-Based Farming (ed. R.W. McDowell, published by CABI, UK.), (Wilcock 2008). Dr Larned's experience is described in the evidence he presented for Fish and Game and the Department of Conservation.

24 August 2009

Little is made of the impact of phosphorus (P) caused by runoff from irrigated land. The main emphasis is on increased nitrogen (N) loads, largely in the form of nitrate. Phosphorus is a well known key water pollutant produced by intensive dairy farming and there is a notion that P will not travel through soil from irrigated land.

Consideration of the potential effects of CPW on stream and lake phosphorus loading or concentrations in Mr. Kennedy's evidence is limited to three sentences:

- "Phosphorus concentrations may increase in receiving waters due to surface runoff from intensive agriculture" (paragraph 169).
- "Restoration of riparian margins including stock exclusion will mitigate sediment, phosphorus and faecal indicator bacteria inputs to streams" (paragraph 195).
- "Control of phosphorus runoff from the CPW area will be achievable, and therefore I do not anticipate effects on lake phosphorus loadings of concentration" (paragraph 200)."

Dissolved reactive phosphorus (DRP) is a form of P that promotes rapid plant growth in waterways and concentrations found in dairying streams are high by comparison with other rural streams and are a high proportion (about 50%) of the total phosphorus (TP). Typically, DRP comprises 30-60% of total P in streams within dairying catchments. It is almost inevitable that intensive dairy farming under irrigation on the Canterbury Plains will result in streams with mean dissolved reactive P concentrations of 30-70 mg m⁻³ ($\mu\text{g/L}$), based on extensive monitoring of dairying catchments throughout New Zealand (Wilcock et al. 2007). Fig. 8 of Mr Kennedy's evidence indicates that lowland streams entering Lake Ellesmere are already within this range.

Losses of P to groundwater occur when the percolation rate is greater than the rate of retention (of P) by soils, and when preferential flow occurs via macropores or soil cracks (McDowell et al. 2004). Factors that enhance P mobility in soils include soil texture (P is more mobile in sandy soils), soils with low P retention capacity, waterlogged soils where P is mobilised under reducing conditions, and the application of P above plant requirements (McDowell et al. 2004). Many of these conditions are likely to be encountered in irrigated dairy farms on the Canterbury Plains.

Mention is made of Mr Kennedy's evidence that the CPW scheme is not expected to affect phosphorus concentrations downgradient, because of the flat topography and the ability of CPW to mitigate potential runoff effects (Para 10.2). The Canterbury soils are known to be quite permeable and free-draining. Surface runoff P concentrations from flood-irrigated lands can be up to 1 mg P/L and we might expect there to be high P concentrations in shallow groundwaters if irrigation occurs within a week or two of P fertiliser being applied, or after heavy grazing by livestock. The assumption that P is bound to soil and therefore 'stripped out' as it moves downwards is based upon the notion that water percolates through soils with close contact being made so that phosphate is bound to polyvalent cations (viz. Al^{3+} , Fe^{3+} and Ca^{2+}). It is more likely that there will be enhanced P concentrations in lowland streams fed by groundwater with irrigation inputs.

It is clear from the preceding compilation of statements about phosphorus, that the applicants gave minimal consideration to the potential effects of CPW on phosphorus dynamics. This neglect is a matter of concern. There are implicit assumptions in Mr Kennedy's evidence statement that surface runoff is the only significant source of phosphorus input to streams or Lake Ellesmere, and that farm management practices will prevent runoff (paragraphs 168 and 169). Both of these assumptions are unsupported, and likely erroneous, for the following reasons. There is a growing body of evidence indicating that phosphorous leaching from New Zealand agricultural land occurs at ecologically significant rates, including the Canterbury Plains (Toor et al. 2004a, b; Parfitt et al. 2008). Clearly, surface run-off is not the only pathway by which phosphorus moves to streams and Lake Ellesmere. The rationale that surface runoff is minor and will be prevented, according to Mr Kennedy's evidence, is that most of the irrigated area is flat, and that small-scale run-off can and will be eliminated by establishing "permanent pasture" and "restoring riparian margins". The statement that "flat topography" makes surface runoff insignificant is unfounded and misleading. At the scale of surficial runoff flowpaths, the Canterbury Plains are not flat. There is substantial uncertainty about requirements for or enforcement of any farm practices, including riparian restoration.

Based on the information provided by the applicants, it is impossible to conclude that phosphorus enrichment of streams and Lake Ellesmere will not occur as a result of CPW. There are recent estimates available for phosphorus loading to Lake Ellesmere (Larned and Schallenberg 2006), and it is not clear why the applicants have not considered potential effects of CPW on phosphorus inputs to streams and the lake.

Summary

- The applicant's evidence downplays P losses from irrigated lands, putting the main emphasis on N losses.
- Irrigated intensive agriculture generates high P concentrations in surface runoff that present a threat to surface waters.
- The assumption that flat land will not generate surface runoff is unjustified. The rate of application of irrigation water, amount of P on the surface from previous land use, soil permeability and topography will all determine whether there is a risk to surface waters presented by irrigation excess.
- It is overly simplistic to assume that P adsorbs to soil (clay) particles as it drains, with little subsequent effect on groundwater quality. Rapid drainage from surface to groundwater can occur as a consequence of many factors, viz. high rate of drainage in permeable soils; low P retention by soils; soil cracks and root holes and reducing conditions (low dissolved oxygen in the soil water).

- Dairy farming under irrigation will effectively increase soil P loadings and present a risk of enhanced P concentrations in groundwater, and in surface waters receiving groundwater inflows.
- There may also be some surface runoff with high P concentrations.

References

See references for main report.

Appendix 4: Recommended Table WQL5 (Hayward et al. 2009)

Review of proposed NRRP water quality objectives and standards for rivers and lakes in the Canterbury region

Table 7.1 Recommended water quality objectives for Canterbury rivers (Table WQL5)

Recommended management units	Sub-unit	Map names	Purposes for management	Critical values	Ecological health indicators			Macrophyte indicators		Periphyton indicators		Visual quality indicator	Sedimentation indicator	Microbiological indicator
					QMCi	Dissolved oxygen (%saturation)	Temperature (°C)	Emergent macrophytes - % cover of stream bed	Total macrophytes - % cover of stream bed	Chlorophyll a - mg/m ²	Filamentous algae - % cover of stream bed			
Natural state		Natural		High biodiversity, High amenity, Natural character				shall not be changed						
Alpine - upland		Alpine-upland	1,2,3,4,6,7	High biodiversity, salmonid fishery, amenity						50	10	1.6	10	Good
Alpine - lower		Alpine-lower	1,2,3,4,6,7,8	Salmonid fishery, amenity						120	20			Good-Fair
Hill-fed - upland		Hill-fed-upland	1,2,3,4,6,7	High biodiversity - salmonid fishery	6					50	10		15	Good
Hill-fed - lower		Hill-fed-lower	1,2,3,4,6,7,8	Amenity, contact recreation						200	30	4		Good-Fair
Hill-fed - lower-urban	urban	Hill-fed-lower-urban	1,2,3,5,6,7,8	Amenity	4				n/v				20	Fair or MAC=C or Fair for identified recreational areas only
Lake-fed		Lake - fed	1,2,3,4,6,7,8	Salmonid fishery, high biodiversity	6	>90	<19			200	30	3	10	Good
Banks Peninsula		Banks Peninsula	1,2,3,4,6,7,8	High biodiversity	5					120	20	2	20	Fair
Spring fed streams of inland basins and valleys		Spring-fed-upland	1,2,3,4,6,7	High biodiversity - salmonid spawning	6				20%	50	10		20	Good
Spring fed streams of lower basins		Spring-fed-lower-basin	1,2,3,4,6,7	High to moderate biodiversity	5				30%	200	30	3		Fair
Spring fed streams of the plains		Spring-fed-plains	1,2,3,4,6,7,8	Moderate biodiversity, locally/regionally important trout fisheries	5				30%	200	30		40 / 30	Fair
Spring-fed-plains-urban	urban	Spring-fed-plains-urban	1,2,3,5,6,7,8	Amenity, moderate biodiversity	4	>80			30%	200	30	2	40 / 30	Fair or MAC=C or Fair for identified recreational areas only

Purposes of management:

1. Ensure diverse and abundant aquatic ecosystems of indigenous flora and fauna
2. Protect significant habitat of salmonids (trout or salmon)
3. Maintain amenity values
4. Ensure water quality is safe for contact recreation
5. Ensure water quality is safe for secondary contact recreation
6. Safeguard Nga Tahu cultural values including mahinga kai, wahi tapu and wahi taonga
7. Ensure water is suitable for stock drinking-water supply
8. Support the functioning and health of estuaries and coastal lagoons

Narrative statements are required to describe objectives for the following:

- Fish health
- Toxic algae
- Colour

Table 7.2 Recommended water quality objectives for lake types in Canterbury (Table WQL5)

Lake management units	Map name	Purpose for management	Critical value	Ecological health indicators			Eutrophication indicator	Visual quality indicator	Microbiological indicator
				Dissolved Oxygen (% sat.)	Temperature (°C)	Lake SPI category			
				Hypo-limnion					
				Epi-limnion					
Natural state	Natural			Shall not change					
Large high country lakes	Large-HC	1,2,3,4,5,6	High amenity, high biodiversity, salmonid fishery.			Excellent	2	*	Good
Small to medium sized high country lakes	Small-medium-HC	1,2,3,4,5,6	High amenity, high biodiversity, salmonid fishery		19	High	3	*	Good
Coastal lakes and lagoons	Coastal	1,2,3,4,5,6	Biodiversity, High cultural values	>70	>90	Moderate	4	*	Fair
Artificial lakes - on-river	Artificial-on-river	1,2,3,4,5,6	High amenity			High	3	*	Good
Artificial lakes - others	Artificial	Specific to each lake	Should not become a public nuisance	>20	*	*	4	*	*

* indicates that a narrative statement is recommended for this objective

Purposes of management

1. Ensure diverse and abundant aquatic ecosystems of indigenous flora and fauna
2. Protect significant habitat of salmonids (trout, salmon or char)
3. Maintain amenity values
4. Ensure water quality is safe for contact recreation
5. Safe-guard Ngāi Tahu cultural values including: mauri, mahinga kai, wahi tapu and wahi taonga
6. Ensure water is suitable for stock drinking-water supply

Narrative statements are required to describe the objectives for the following:

- Visual clarity and colour
- Objectives lakes in the Artificial- others management unit