BEFORE CANTERBURY REGIONAL COUNCIL

IN THE MATTER of the Resource Management Act 1991

AND

IN THE MATTER of the Proposed Land and Water Plan (Variation 1)

EVIDENCE OF ROBERT JOHN WILCOCK FOR TE RŪNANGA O NGĀI TAHU

DATED 29 AUGUST 2014

BUDDLE FINDLAY
NEW ZEALAND LAWYERS

Barristers and Solicitors
Christchurch

Solicitor Acting: **Kerry Smith**
Email: kerry.smith@buddlefindlay.com
Tel 64 3 379 1747 Fax 64 3 379 5659 PO Box 322 DX WX11135 Christchurch 8140

Introduction

1. My name is Robert John Wilcock.

2. I was previously employed by the National Institute of Water and Atmospheric Research (NIWA) as a Principal Scientist and Programme Leader and, although now retired, am currently retained by NIWA as an Emeritus Scientist.

Qualifications and Experience

3. My qualifications are: BSc (Hons) in chemistry; PhD in physical chemistry, both from the University of Canterbury.

4. My work experience began with two years as a post-doctoral fellow at Wright State University, Dayton, Ohio, and five years in the Water Section of Chemistry Division, DSIR, Wellington, in 1975-1980. I joined the Hamilton Science Centre, Ministry of Work and Development (MWD) in 1980 and subsequently became Group Leader of the Catchments Group. I have been in Hamilton since 1980; during which time MWD was disestablished and the Centre incorporated into DSIR Marine and Freshwater in 1987, and then NIWA in 1992. My research and expertise has been in the areas of water chemistry, gas exchange across the air-water interface, interactions between aquatic plants and water quality in freshwaters, contaminant chemistry, and land use effects on water quality. During the past 20 years my research has focused on ways of making intensive dairy farming more environmentally sustainable through development, implementation and monitoring of good management practices.

5. I have written about 100 scientific publications (papers, book chapters and conference proceedings), and about 100 technical reports. I have been on several scientific management groups, such as the South Pacific Regional Environment Programme on marine pollution (SPREP-POL); National Representative for Commission on Soil and Water (International Union of Pure and Applied Chemistry (IUPAC), the Patea dam expert panel and the Waituna Catchment Management Group.

6. I have given evidence as an expert witness to several resource management hearings, the Environment Court and the High Court, viz.: the Horizons

Regional Council's One Plan, the Otago Regional Council's Proposed Plan Change 6A (Water Quality), Canterbury Land and Water Plan and the Tukituki Catchment Proposal.

7. I confirm that I have read the 'Code of Conduct' for expert witnesses contained in the Environment Court Practice Note 2011. My evidence has been prepared in compliance with that Code. In particular, unless I state otherwise, this evidence is within my sphere of expertise and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

8. The data, information, facts and assumptions I have considered in forming my opinions are set out in my evidence to follow. The reasons for the opinions expressed are also set out in the evidence to follow.

Scope of Evidence

9. I have been asked by Te Rūnanga o Ngāi Tahu to prepare evidence in relation to water quality management aspects of the proposed Variation 1 to the proposed Canterbury Land and Water Plan concerning Te Waihora/Lake Ellesmere. I have been asked to consider the following points, in particular:

   (a) The proposal in Variation 1 to have an annual average trophic level index (TLI) of 6.6 mid lake and 6.0 at the lake margins (Table 11 (b): Freshwater Outcomes for Selwyn Waihora Catchment Lakes);

   (b) The feasibility of setting a long-term TLI of 4.8, reflecting better water quality occurring during 1940-1960. The time-frame for such a change would be inter-generational;

   (c) The appropriateness of the proposed threshold of 15 kg of nitrogen per hectare per annum, as specified in rules 11.4.11-11.4.13, 11.5.6-11.5.9 of Variation 1;

   (d) The scientific basis for requiring properties to achieve a percentage reduction from 2009 levels (based on land use, e.g. dairy is 30%) to reduce nitrogen loss where the property does not meet the 15 kg nitrogen threshold (rule 11.4.14);

(e) The type of mitigation measures for reducing N, P and sediment inputs to Te Waihora that will need to be adopted in order to achieve the target TLI values and longer-term aspirational values favoured by Ngai Tahu.

10. In preparing this evidence I have reviewed:

(a) Selwyn Waihora ZIP Addendum. October 2013;

(b) Proposed Variation 1 to the Proposed Canterbury Land and Water Regional Plan;

(c) Section 32 Evaluation Report (2014);

(d) Norton, N.; Allan, M.; Hamilton, D.; Horrell, G.; Sutherland, D.; Meredith, A. (2014). Technical Report to support water quality and Water Quantity limit setting process in Selwyn Waihora Catchment. Predicting consequences of future scenarios: Te Waihora/Lake Ellesmere. Environment Canterbury Report No. R14/14.

Summary of findings

11. Sediment and phosphorus (P) loads to Te Waihora that originate from the catchment affect lake water primarily via suspended sediment. Nitrogen (N) inputs to Te Waihora are a complex mixture of surface water inflows deriving from groundwater, and re-suspended sediment. For that reason, the TLI is not directly related to catchment land use and mitigation measures.

12. A better way to manage directly Te Waihora is to weaken the effect of wind-driven suspension of lake sediment by maintaining higher summer water levels and by encouraging macrophyte growth.

13. Meandering channels and riparian areas near the lake margins will need to be set aside as a riparian buffer that are intermittently flooded.

14. The 15 kg N/ha/yr threshold for nitrogen leaching may be met by dairy farming on heavy soils near the lake but will mostly limit land use to less intensive forms of pastoral agriculture, such as unirrigated sheep/beef farming, as well as forestry and other less N intensive land uses.

15. In order to achieve improved water quality in Te Waihora in the longer term, it will be necessary to implement a suite of 'advanced mitigations' in addition to GMP as described in Variation 1. These include greater use of wetlands and riparian management, and in-lake measures (e.g. floating wetlands). Greater attention is needed to manage sediment and soil losses conveyed in farm drains.

Te Waihora Trophic Level Index (TLI)

16. TLI is normally calculated from water clarity, and by total nitrogen (TN), total phosphorus (TP) and chlorophyll-a concentrations. It is based around the assumption that the concentration of phytoplankton is primarily related to each of these variables, and thus that they are all correlated. Chlorophyll-a is a measure of phytoplankton biomass, which often contains most of the TN and TP in lake waters, so that these variables are often the main factor affecting clarity. When there is good reason to exclude one variable, for example in highly turbid lakes where clarity is hard to measure or driven by glacial flour, a TLI_3 is sometimes used that avoids clarity. The TL_3 is a trophic level index that is based only on TN, TP and chlorophyll-a concentrations (i.e. it does not include water clarity in the computation). This appears to be the case in Lake Ellesmere/Te Waihora.

17. TLI and TLI_3 assumptions of inter-correlation between the component variables are not well borne out in Lake Ellesmere/Te Waihora. TP and TN are very weakly related to concentrations of chlorophyll-a. This is because a major component of TP is in the form of suspended sediment that is a feature of large, shallow, exposed coastal lakes like Te Waihora. There is a slightly more predictive correlation between TN and chlorophyll-a, but the implication is that a substantial proportion of TN and TP is associated with non-phytoplankton material (i.e. sediment). Similarly, water clarity is largely determined by suspended sediments (SS) and not chlorophyll-a. The primary determinant of suspended sediments is wave action on the lake bed, which is determined by wind speed and water depth. This leads to the inference that management actions that target reduced N and P input loads may not target clarity, TN and TP (lake water concentrations).

18. TLI_3 in Lake Ellesmere/Te Waihora is strongly impacted by resuspension of bed sediment because of its exposed coastal location, its shallowness

(average depth less than 1.5 m) combined with an average lake depth of less than 1.5 m and its large surface area (198 km^2) (Gibbs & Norton 2013). Clarification of the long term objectives of water enhancement in terms other than those in TLI_3 may be helpful, and an aspirational water clarity level, translatable as suspended sediment concentration and load, may be a suitable inclusion. Reducing inputs of N and P to Te Waihora as is proposed will result in improved water quality, but will likely take a long time (decades) to occur because of the large reservoir on N and P within the lake sediment and the continuing interaction between suspended sediment and phytoplankton.

19. For the remainder of this evidence I refer to Te Waihora/Lake Ellesmere TLI_3 as TLI.

20. I understand that about 50% of sediment entering Te Waihora is via farm drain discharges (Professor Ian Hawes, University of Canterbury, pers. comm.). There is much scope therefore, for reducing sediment inputs by managing erosion and sediment loss better. Best practice for reducing sediment run-off, including wide, mixed-cover riparian strips and settlement zones, which could include re-established wetlands, should be required if the objective is sediment control for all drains that directly or indirectly enter the lake.

21. Longer term objectives could be expressed as TLI values, given that catchment inputs ultimately affect lake water quality, in addition to suspended sediments. For example, a short-medium (10-20 years, given groundwater lag times of 10 to 30 years) goal might be an average TLI that is less than 6. It would also be good to have a long-term goal (say, 30 to 50+ years) of having a TLI that supports traditional values (e.g. 4.8) that may reflect historical lake conditions in 1940-1960. For the Te Waihora TLI to change from its present average value of about 6.8 to a long-term objective of 4.8 would require major reductions in catchment emissions to the lake, as well as greatly reduced influence of suspended sediment on lake water quality and the establishment of extensive beds of macrophytes.

22. Managing nutrient inputs from the catchment so that they reduce over time is a good measure but will take a very long time to achieve an improvement in lake water quality. This is mainly because of the present levels of intensive

farming and the imminent establishment of the CPW scheme, but also compounded by the 10-30 year groundwater lags (Selwyn Waihora ZIP Addendum). Reducing inputs of N and P will be effective, but will take time for the benefits to be seen. If, as appears to be the case, a significant P load to the lake is associated with sediment run-off via drains, riparian management may be effective over the long term in reducing both sediment and TP.

23. Actions that reduce re-suspension of lake bed sediments will (a) lower the SS concentration and hence the particulate N and P concentrations, and (b) improve water clarity. These effects may cause a reduction in chlorophyll-a, although that is not guaranteed because greater light penetration in less-turbid waters may aid algae growth, including potentially toxic taxa as in nearby Wairewa/Lake Forsyth.

24. The historical record shows that TLI dropped below 6 when summer lake levels were higher than usual, suggesting in that case deeper water resulted in lower concentrations of SS and, by implication, TN and TP (Figs. 1 and 2). The low TLI (5.8) on 3rd August 2011 followed a period of sustained high lake levels over summer. The two year decline in TLI from 7.3 down to 5.8 occurred when the lake level was at extremely high levels during the summers of 2009/10 and 2010/11. An analysis of these extended summer levels places them at the second highest and highest in 42 years of lake height records. This is an extreme and uncommon event which may well have caused the TLI reduction (Graeme Horrell, NIWA, pers. comm.).

25. Freshwater inflows to Te Waihora are expected to increase as a result of increased drainage from land irrigated by alpine water in the Central Plains Water scheme. Coupled with a projected reduction in demand for groundwater, the additional water will lower concentrations of leached nitrate entering Te Waihora, by dilution. However, annual loads of N (kg/yr) will probably increase as more land is converted to irrigated, intensive dairy farming. Lake trophic state is affected by loads, rather than concentrations of inflows and will not improve as a result of lower inflow N concentrations *per se*. However, the additional water may benefit Te Waihora by raising lake levels and thereby weakening wind-driven resuspension of lake sediment and its associated N and P. Lowering N inputs to Te Waihora will reduce lake stores and improve water quality in the longer-term.

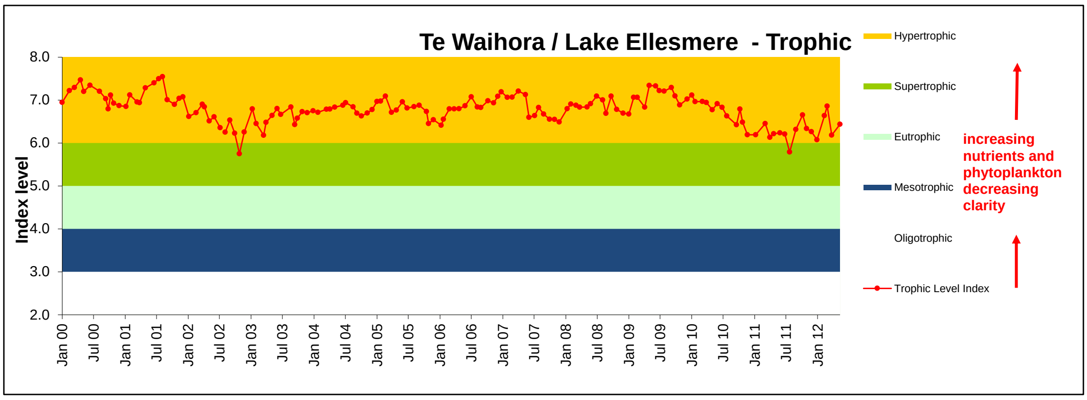

Figure 1 Trophic level index for Te Waihora (Graeme Clarke, ECan).

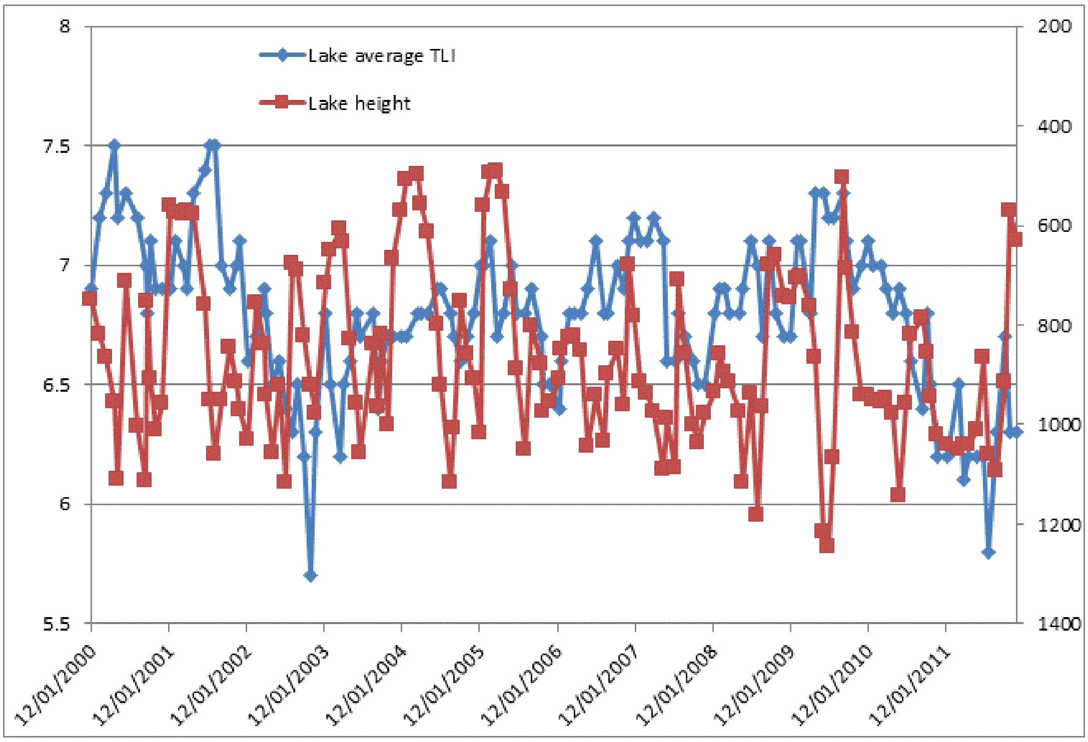

Figure 2 NIWA data (Graeme Horrell). NOTE: INVERTED depth scale.

26. Establishing macrophytes (large, rooted plants) around the lake margin would improve water clarity and drive the TLI down around the shallow margins of Te Waihora, but would be quite challenging to achieve. NIWA has a project underway as part of the Whakaora te Waihora initiative in which it is proposed to establish several brackish water-tolerant species behind wave barriers so that they are protected from wind and wave action. Macrophytes would definitely benefit from more stable water levels and clearer water, but would not do well if lake levels fluctuated a lot.

27. The establishment of macrophytes in conjunction with the need to maintain improved stability of lake levels is recommended. This may mean that some marginal land, including restoration of meandering channels, will need to be set aside as a riparian buffer that is intermittently flooded. Such wetland habitats will potentially enhance wildlife and mahinga kai values.

28. Solutions package 1 (Norton et al. 2014) mentions construction of a lake level control weir structure, along with restoration of macrophytes beds and lake-margin wetlands, and construction of floating wetlands. Additional irrigation return-flow from CPW will cause lake levels to rise, while rising sea level (on average 2.1 mm/yr, Bell 2001) will increase the likelihood of sea-water intrusion. Thus, a lake level control weir seems inevitable and could be used to maintain high lake levels during summer to lower the re-suspension of lake sediment and to prevent excessive salt water intrusion, as well as to release water from the lake to the sea when necessary (e.g. to aid migration of diadromous fish).

The Scientific Basis for a 15 Kg N Threshold

29. The term ‘grandparenting’ used in Variation 1 is ‘at current land use’ but with GMP, as detailed in the Variation 1 Plan Schedules. ECan proposes that if a land-user is exceeding 15 kg N/ha/yr, they are required to make further reductions on Good Management Practice (GMP) nitrogen loss rates from 2022 to achieve an ‘on average’ 15% reduction for the catchment, with everyone farming at GMP by 2017. The Selwyn Waihora ZIP Addendum October 2013 proposes that:

    (a) Land users with N losses greater than 15 kg N/ha/yr are required to make a percentage (ca. 15-20%) improvement on 2017 GMP by 2022 and, if they are not in CPW, can only intensify if this does not increase N loss;

    (b) Land users who are discharging less than 15 kg N/ha/yr can change (intensify) land management or land use provided they are operating at GMP and the change does not result in discharges exceeding 15 kg N/ha/yr;

    (c) Requires that any new land use that will discharge more than 15 kg N/ha/yr to operate at better than 2017 GMP from the start (as per a) above) and, if they are not in CPW, they are not to discharge more N than under the previous land use;

(d) Providing an N load of 850 t/yr to CPW to allow shareholders to change land use or intensify land management activities.

30. Irrigated intensive pastoral farming (viz. dairying) is likely to produce leaching rates of more than 100 kg N/ha/yr on lighter soils. In order to manage the total annual N loading to Te Waihora, there is the need to set a lower threshold, such as 15 kg/ha/yr.

31. A comprehensive review of N, P and sediment losses (yields) for different land uses (Table 1) showed that on average, 15 kg N/ha /yr is between the medians for mixed sheep and beef cattle, and dairy farming (McDowell & Wilcock 2008). The 'look up' tables (Lilburne et al. 2010) indicate that irrigated dairy farming on medium–heavy soils in the Lincoln area might meet the 15 kg N/ha/yr threshold for leaching, as well as unirrigated sheep, beef and sheep + beef farming on a range of soils throughout the Te Waihora catchment.

Table 1. Median yields of N, P and sediment (kg ha^{-1} yr^{-1}) for different rural land uses.

Land use	N	P	Sediment
Dairy	27	1.9	299
Deer	8	1.5	2034
Mixed sheep and beef	11	1.3	1156
Sheep	3	0.6	598
Trees (forest and bush)	2	0.2	174

32. Soils in the Selwyn Waihora management zone have a wide range of soil drainage behaviours and water holding capacity, and hence vulnerability to nitrogen leaching (Fig. 3). The range in leaching vulnerability is reflected in the estimates of nitrogen leaching from intensive dairying: nitrogen losses from stony, very light and light soils are estimated at 80 kg N/ha/yr or more, while those from heavy soils are estimated at 20 kg N/ha/yr or less. Over 40% of the high-productive agricultural soils in Selwyn Waihora are light soils with high vulnerability to nitrogen leaching (see map below). It is estimated

that 100% adoption of Advanced Mitigation[1] (this is mitigation in excess of GMP) would result in a 25% reduction of the load with GMP.

33. Dairy farms on the heavy soils around the lake may be able to achieve low leaching rates, of less than 20 kg N/ha/yr (i.e. approaching the 15 kg/ha/yr maximum value).

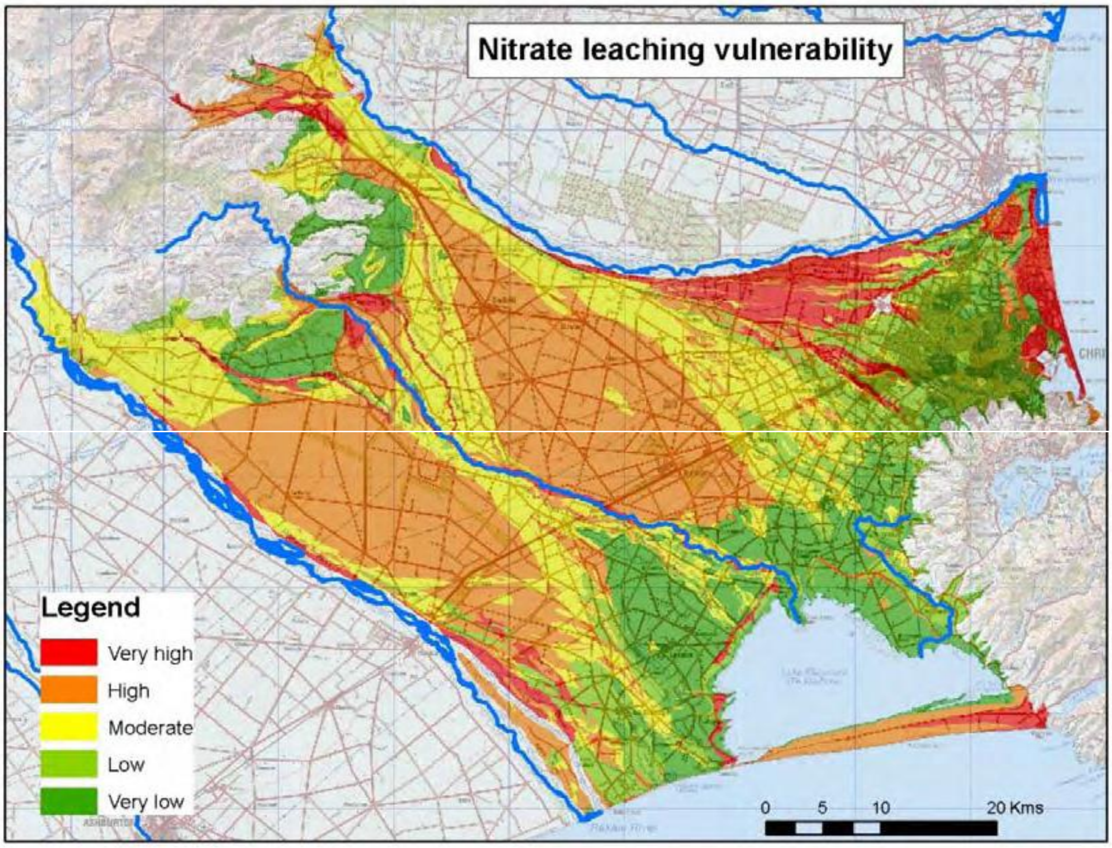

Figure 3 Soil N leaching potential in Te Waihora catchment.

Catchment Management of N, P and Soil Loss

34. Reduction in inputs of N, P and soil to Te Waihora will be beneficial but the benefits may not be seen for many decades. This is because of the 10-30 year lags in groundwater-bearing N loads and the large reservoir of sediment

[1] Advanced Mitigation is the maximum reduction in nitrogen that is technically feasible for a particular farming system/land use (without changing land use). The amount of reduction in nitrogen loss varies with land use, for example there are relatively few mitigation options available for dryland beef and sheep. Advanced mitigation does not consider affordability, only whether there are technically feasible mitigations. While 100% adoption of Advanced Mitigation would reduce nitrogen losses it would not reduce them to zero. It is estimated that 100% adoption of Advanced Mitigation would result in a 25% reduction of the load with GMP. (Selwyn Waihora ZIP Addendum October 2013, p33)

rich in P within the lake. They will, nonetheless, ultimately drive the TLI down and produce better lake water quality. A key factor will be ensuring that GMP and 'advanced mitigation' (Selwyn Waihora ZIP Addendum) are applied wherever necessary and that soil conservation and P mitigation methods are applied diligently in the catchment. Twelve lakes in the Rotorua district have TLI targets that are regularly assessed. Some have responded positively to mitigation practices (viz. sediment capping to retain P and reduced P inflows, in Lake Rotorua, and a combination of in-lake and catchment management practices to reduce nutrient inputs, in Lake Rotoehu)[2].

35. Variation 1 Plan Schedule 24 lists good management practices (GMP) for dairy that include:

(a) use of OVERSEER for monitoring losses

(b) abiding by the Spreadmark Code of Practice for fertiliser application, and

(c) for all intensive winter grazing adjacent to any river, lake, artificial watercourse (excluding irrigation canals or stock water races) or a wetland, a 5 m vegetative strip (measured from the edge of the bed of the river, lake, artificial watercourse, or wetland) from which stock are excluded, is maintained around the water body.

36. In my opinion, these practices are unlikely to greatly reduce N leaching losses on light soils, where leaching losses under irrigated dairy farming may be in excess of 80kg/ha/yr. In such free-draining soils, it is likely that attenuation of nitrate is likely to be much less than 50% so that inputs to Te Waihora from those soils will be greater than 40 kg/ha/yr (Webb et al. 2010). There will be appreciable reductions in P losses if riparian management is implemented. In my opinion, two additional important mitigations are:

(a) reduction of soil losses and associated P from the catchment, and

(b) minimizing anaerobic soil conditions that greatly increase soil-P loss.

---

[2] http://www.boprc.govt.nz/media/33640/RotoruaLakes-100827-LakeRotoehuReport.pdf

There is a possibility that over time sediment (and P) losses will reduce enough to make the lake P-limited and reduce the TLI, but the process will be slow because of the large reservoir of P-rich sediment within the lake.

37. A major land use in Te Waihora catchment is intensive dairy farming supported by irrigation. Leaching losses of N on very light soils are likely to be high (greater than 80 kg N/ha/yr)[3], even with adoption of GMP, requiring additional mitigation measures to achieve targeted reductions.

38. In addition to the Advanced Mitigations described in the Selwyn Waihora ZIP Addendum, a more complete set of state-of-the-art mitigation methods for mitigating pollutant losses to waterways from intensive agriculture are described in recent publications, viz.:

(a) Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems (McKergow et al. 2007);

(b) Assessment of Strategies to Mitigate the Impact or Loss of Contaminants from Agricultural Land to Fresh Waters (McDowell et al. 2013);

(c) Menu of practices to improve water quality: dairy farms (Waikato Regional Council 2013). Menus are also available for drystock farmers and cropping land.

39. The methods described in 37 (a) – (c) address management of land-loadings, water pathways and connectivity between land and water, and utilising natural processes such as denitrification. These processes are encapsulated in the following diagram (McKergow et al. 2007). A multi-faceted approach to mitigating pollutant inputs to Te Waihora is described in ECan Technical report R14/14 (Norton et al. 2014), which includes:

(a) Minimising nutrient losses at source by setting N and P limits;

(b) Capturing nutrients where possible down the catchment (i.e. intercepting pollutants along flow paths connecting land with water);

(c) Maximising flow in tributaries by setting flow and allocation limits;

[3] Selwyn Waihora ZIP Addendum October 2013, p33.

(d) Employing lake mitigation and restoration methods.

This a widely accepted strategy for reducing impacts of land use on receiving water quality.

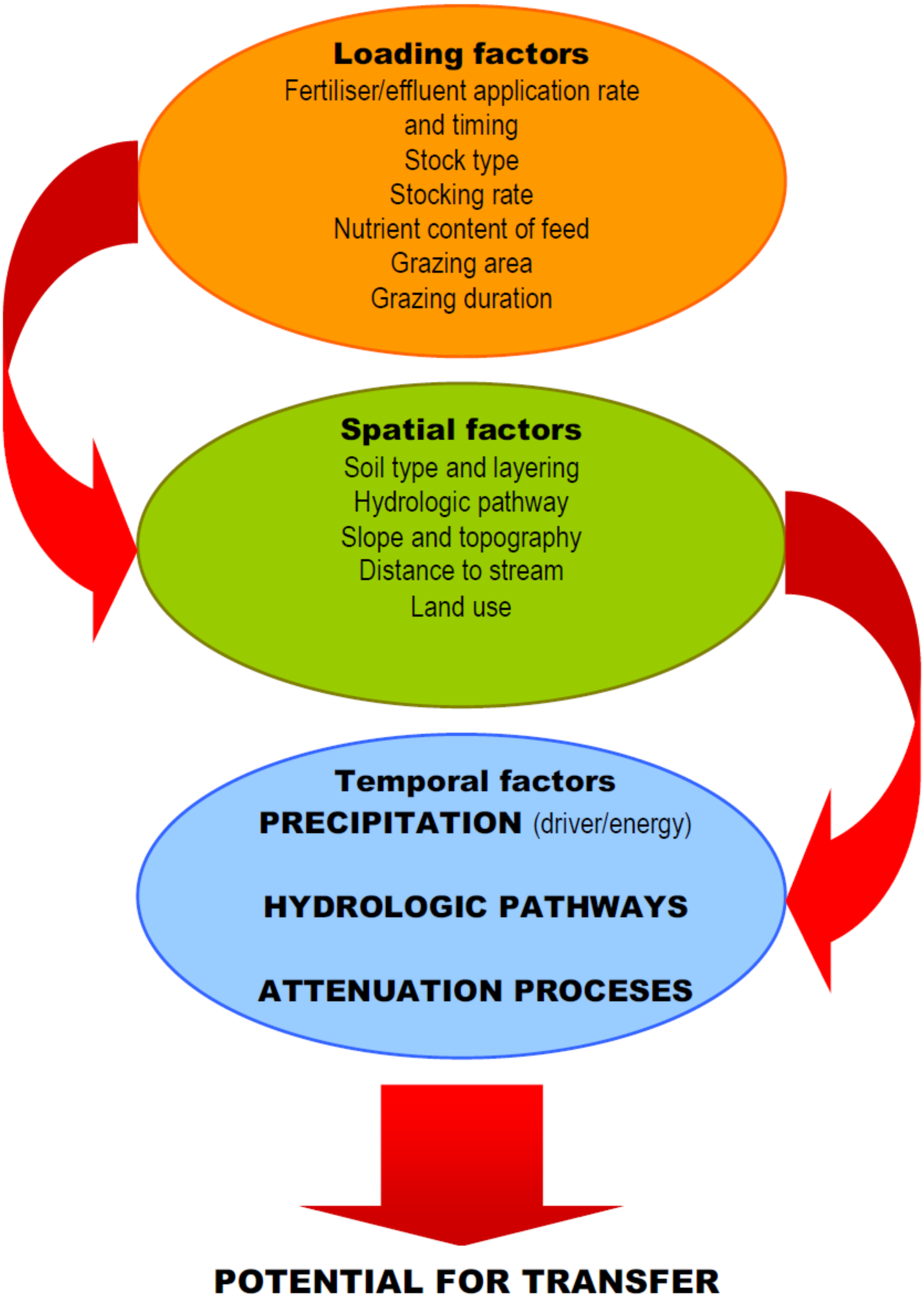

Fig. 4. Controls governing pollutant transfers from pasture (adapted from Oliver et al. 2005)

40. Information on the range of cost-effectiveness ($ per kg of nutrient or sediment retained per hectare) and percentage effectiveness were used by to rank farm mitigation strategies for each contaminant, and categorised into quartiles (low, medium, high and very high) (McDowell et al. 2013). Mitigation methods having effectiveness rankings of 'high' or 'very' high are shown in Appendix I of this evidence.

41. It is unlikely that further reductions in N loss below GMP (as defined in Variation 1 Plan Schedule 24) can occur without widespread adoption of mitigations with a high level of N reduction.

42. I am aware that an appraisal of relevant mitigation measures for Te Waihora and its catchment has recently been undertaken by NIWA, with the support of ECan. The study has focused on: the location and management of riparian land, use of constructed wetlands and the areas needed to achieve specified reductions in N and P, the feasibility of using floating wetlands, managing springheads in the catchment. There is clearly a need to implement wide-scale mitigation measures for intensive agriculture (viz. irrigated dairy farming) on lighter soils, where leaching rates in excess of 80 kg N/ha/y are likely. Without such wide-scale adoption of 'advanced' mitigation measures – in addition to GMP as defined in Variation 1 – coupled with sound soil conservation practices, it will be difficult to restrict and manage inputs of N, P and sediment to Te Waihora so that its water quality is ultimately improved.

Conclusions

43. Tight management of catchment exports of N, P and sediment will need to be coupled with in-lake measures that limit impaired lake water quality as a result of nutrient enrichment. Possible measures for achieving that are maintenance of higher summer lake levels and establishment of macrophytes in the lake margins. In addition, restoration of meandering channels near the lake margins, will need to be set aside as a riparian buffer that is intermittently flooded. Greater attention is needed to manage sediment and soil losses conveyed in farm drains.

REFERENCES

Bell, R. (2001). Impacts of climate change on coastal margins in Canterbury. NIWA Client Report CHC01/69, Prepared for Environment Canterbury. http://resources.ccc.govt.nz/files/2001CoastalImpactsCanterburyRobBellNIWA.pdf

Gibbs, M.; Norton, N. (2013). Te Waihora/Lake Ellesmere: Water quality remediation and ecosystem restoration opportunities. Report No. R13/111 Environment Canterbury.

Lilburne, L.; Webb, T.; Ford, R.; Bidwell, V. (2010). Estimating nitrate nitrogen leaching rates under rural land uses in Canterbury. Report No. R10/127 Environment Canterbury.

McDowell, R.W.; Wilcock, R.J. (2008). Water quality and the effects of different pastoral animals. *New Zealand Veterinary Journal 56*: 289-296.

McDowell, R.; Wilcock, B.; Hamilton, D. (2013). Assessment of Strategies to Mitigate the Impact or Loss of Contaminants from Agricultural Land to Fresh Waters. Report RE500/2013/066 prepared for Ministry for the Environment. http://www.mfe.govt.nz/issues/water/freshwater/supporting-papers/assessment-strategies-mitigate-impact-loss-contaminants-agricultural-land-freshwater.pdf

McKergow, L.A.; Tanner, C.C.; Monaghan, R.M.; Anderson, G. (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. NIWA Client report HAM2007-161. Prepared for Pastoral 21 Consortium. https://www.niwa.co.nz/sites/niwa.co.nz/files/import/attachments/stocktake-v10.pdf

Norton, N.; Allan, M.; Hamilton, D.; Horrell, G.; Sutherland, D.; Meredith, A. (2014). Predicting consequences of future scenarios: Te Waihora/lake Ellesmere. Technical report to support water quality and water quantity limit setting in Selwyn Waihora catchment. Report No. R14/14. Environment Canterbury.

Oliver, D.M.; Clegg, C.D.; Haygarth, P.M.; Heathwaite, A.L. (2005). Assessing the potential for pathogen transfer from grassland soils to surface water. Advances in Agronomy 85: 125-180.

Waikato Regional Council (2013). Menu of practices to improve water quality: dairy farms. www.waikatoregion.govt.nz/menus

Webb, T.; Hewitt, A.; Lilburne, L.; McLeod, M.; Close, M. (2010). Mapping of vulnerability of nitrate and phosphorus leaching, microbial bypass flow, and soil runoff potential for two areas of Canterbury. Report No. R10/125, Environment Canterbury.

Robert John Wilcock

29 August 2014

Appendix 1.

Table 1. Catchment mitigation methods with high or very high removals of N, P, N+P and suspended solids [SS] (McDowell et al. 2013)

Mitigation	Effectiveness	Relative cost	Factors limiting uptake	Co-benefits
Constructed wetlands	Very high [N]; Medium [P]; High [SS]	High [N]; Very high [P]; Medium [SS]	No suitable areas on farm (i.e. catchment lies outside of farm area).	Flood attenuation, wildlife habitat and biodiversity
Natural seepage wetlands	Very high [N]; Low [P]; High [SS]	Very high [N]; Very high [P]; Very high [SS]	Price of permanent fencing >> temporary fencing.	Flood attenuation, wildlife habitat and biodiversity
Stream fencing	High [P]; Low [SS]	Low [P]; Medium [SS];	Price of permanent fencing >> temporary fencing.	Stream shading decreasing water temperature and light for periphyton and macrophyte growth.
Vegetated buffer strips	High [P]; High [SS]	High [P]; High [SS]	Land adjacent to stream may not be available or suitable for a buffer strip.	Potential to stabilise stream banks.
Restricted grazing of winter forage crops	High [P]; Medium [SS]	Medium [P]; Low	Must be accompanied by a stand-off area that has no connection to a waterway (e.g. runoff/effluent is captured).	Decreased soil and pasture damage caused by animal treading will help increase pasture yields and decrease N2O emissions and denitrification rates.
Greater effluent pond storage and low rate effluent application to land	Medium [N]; High [P]	High [N]; Low [P]	Increased labour requirements compared to travelling irrigator.	Added water and carbon during summer. Land treatment of dairy effluent culturally favoured over

				direct pond discharge to streams.
Enhanced pond systems	Very high [N]; High [P]	Very high [N]; Very high [P]; Very high [SS]	Requires substantial land area (10 to 40 m^2/cow)	Energy recovery / production. Separation of effluent nutrient application from hydraulic application. Beneficial use of algae for biofuel and fertiliser or feed.
Restricted grazing and off pasture animal confinement systems	High [N]; Medium [P]; Low [SS]	Medium [N]; Medium [P]; Very high [SS]	High capital and operational costs and increased management complexity; immature design criteria and management systems that meet animal welfare and manure management requirements; and some risk of 'pollution swapping' by increasing NH3 or N2O emissions from the collected effluent and manures.	Decreased soil and pasture damage caused by animal treading will help increase pasture yields and decrease N2O emissions and denitrification rates.
Denitrification beds	Very high [N]	Very high [N]	Appropriate hydrology needed - tile/sub-surface drained land or small surface drains.	Might be integrated to support dissolved P removal
Sorbents in and near streams	High [P]	Very high [P]	Source may be far away and the cost of transport prohibitive. Installation in stream may require	None

			resource consent	
Tile drain amendments	Very high [P]	Medium [P]	Source may be far away and the cost of transport prohibitive	Potential to decrease (via filtration) the loss of sediment and faecal bacteria (both unquantified