**BEFORE COMMISSIONERS APPOINTED**
**BY THE WAIKATO REGIONAL COUNCIL**

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| **IN THE MATTER** | of the Resource Management Act 1991 |
| **AND** | |
| **IN THE MATTER** | of the First Schedule to the Act |
| **AND** | |
| **IN THE MATTER** | of Waikato Regional Plan Change 1 – Waikato and Waipā River Catchments and Variation 1 to Plan Change 1 |
| **AND** | |
| **IN THE MATTER** | of submissions under clause 6 First Schedule |
| **BY** | **BEEF + LAMB NEW ZEALAND LIMITED**<br>**Submitter** |

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# BRIEF OF EVIDENCE OF HANNAH MUELLER

**15 February 2019**

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## QUALIFICATIONS AND EXPERIENCE

1. My full name is Hannah Mueller.

2. I am a Senior Ecologist with Tonkin & Taylor Ltd (T+T), Environmental and Engineering Consultants of Hamilton.

3. I hold the qualifications of Bachelor of Arts with Honours (Liberal Arts – Humanities and Life Sciences) from the University of Maastricht, a Master of Social Science with Honours (Environmental Policy), and a PhD (Biology – Freshwater Ecology) from the University of Waikato.

4. My doctoral research in freshwater ecology focused on catchment management, land use change, and ecosystem services in relation to lake restoration and downstream water quality improvements by reducing diffuse pollution from the catchment.

5. I am a member of the New Zealand Freshwater Sciences Society, the New Zealand Ecological Society, and the Environment Institute of Australia and New Zealand.

6. I practice as Senior Ecologist and have seven years' experience in environmental consulting. With a background and experience in both terrestrial and freshwater ecology, I specialise in environmental impact assessments, ecological management, catchment and land use management, and mitigation and restoration plans.

7. I have authored and co-authored a range of publications, including papers in peer-reviewed journals on aspects including: an assessment of catchment land use change and mitigation to achieve downstream water quality improvements in the Lake Rotorua catchment[1]; and an analysis of catchment management and the disconnect between land use intensification and its role in driving water quality change[2].

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[1] Mueller, H., Hamilton, D., Doole, G., Abell, J. and McBride, C., 2019. Economic and ecosystem costs and benefits of alternative land use and management scenarios in the Lake Rotorua, New Zealand, catchment. Global Environmental Change, 54, pp.102-112.

[2] Mueller, H., Hamilton, D.P. and Doole, G.J., 2015. Response lags and environmental dynamics of restoration efforts for Lake Rotorua, New Zealand. Environmental Research Letters, 10(7), p.074003.

8. I was involved in the development of an Integrated Catchment Management Plan in a Waihou-Piako sub-catchment on behalf of Waikato Regional Council. The management plan addressed a range of catchment and land use aspects, including nutrient management, hydrology, alternative land use options, biodiversity and socio-economic implications[3].

9. I was involved in the development of an Integrated Catchment Management Plan for Lake Rotokauri, in Hamilton City[4]. The management plan covered aquatic and terrestrial values, mitigation options, and restoration opportunities. Integrated management included aspects including stormwater, wetlands, water quality, and fish passage.

10. I am familiar with the Waikato and Waipā catchments and have been involved in various projects relating to land use activities, biodiversity, the restoration of riparian margins of streams and lakes, and peat lake water quality.

11. In preparing this evidence, I have read and relied on the references listed in footnotes. Regulatory documents, reports and statements of evidence of other experts relevant to my area of expertise I have relied on included the following documents:

    a. The Proposed Regional Plan Change 1 and Variation 1;

    b. The officers section 42A (s42A) report;

    c. The Regional rivers water quality monitoring programme data report 2016[5];

    d. The Waikato River Vision and Strategy[6];

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[3] Bartels B, Mueller H, Kessels G 2014. Draft Pouarua Sub-catchment Management Plan. Consultancy report prepared by Kessels and Associates Ltd. DM#3208518. Hamilton, Kessels and Associates Ltd. DM#3208518.

[4] Price, J., van der Zwan, W., Bartels, B. & Mueller, H. 2016. Rotokauri ICMP – Ecological Assessment and Inputs. Consultancy report prepared by Kessels and Associated Ltd. for Hamilton City Council.

[5] WRC 2018. Regional rivers water quality monitoring programme data report 2016. Waikato Regional Council Technical Report 2017/33

[6] Waikato River Authority 2011. Restoring and protecting the health and wellbeing of the Waikato River. Vision and Strategy for the Waikato River.

e. The National Policy Statement for Freshwater Management 2014 (NPS-FM, amended 2017[7]);

f. Various Horizons Regional Council One Plan documents[8];

g. The technical document: Freshwater biophysical ecosystem health framework (Cawthron)[9];

h. Description of mitigation options defined within the economic model for Healthy Rivers Wai Ora Project[10];

i. The United Nations Sustainable Development Goal framework, in particular Goal 6 (Clean Water and Sanitation)[11];

j. The evidence in chief of Dr Chris Dada, on behalf of Beef & Lamb New Zealand (BLNZ);

k. The evidence in chief of Dr Jane Chrystal, on behalf of BLNZ;

l. The evidence in chief of Gerry Kessels, on behalf of BLNZ;

m. The submissions and further submissions on behalf of the Minister of Conservation; and

n. BLNZ submission on PC1 and Variation 1.

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[7] Ministry for the Environment, 2017. National Policy Statement for Freshwater Management 2014. Updated August 2017 to incorporate amendments from the National Policy Statement for Freshwater Management Amendment Order 2017. http://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/nps-freshwater-ameneded-2017_0.pdf

[8] Horizons Regional Council 2014. Regional Policy Statement and Regional Plan: One Plan. http://www.horizons.govt.nz/data/one-plan.

[9] Clapcott, J., Young, R., Sinner, J., Wilcox, M., Storey, R., Quinn, J., Daughney, C. & Canning, A. 2018. Freshwater biophysical ecosystem health indicators. Report prepared by the Freshwater Science and Technical Advisory Group. Cawthron Institute Report No. 3194.

[10] Doole, G. 2015. Description of mitigation options defined within the economic model for Healthy Rivers Wai Ora Project. Description of options and sensitivity analysis. Prepared for the Technical Leaders Group of the Healthy Rivers/Wai Ora Project. Report No. HR/TLG/2015-2016/4.6

[11] United Nations 2017. Sustainable Development Goals Report 2017. SDG 6 Clean Water and Sanitation: https://unstats.un.org/sdgs/report/2017/goal-06/

12. I have read the Code of Conduct for Expert Witnesses in the Environment Court's 2014 Practice Note and agree to comply with it. I confirm that the opinions I have expressed represent my true and complete professional opinions. The matters addressed by my evidence are within my field of professional expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

**SCOPE OF EVIDENCE**

13. I have been asked by BLNZ to prepare evidence in relation to freshwater ecological health and water quality outcomes (including freshwater objectives and targets as defined by the NPS-FM)outlined in the Proposed Waikato Regional Council Plan Change 1 – Waikato and Waipā River catchments (hereafter PC1) and Variation 1 to PC1. My evidence includes:

    a. Summary of current water quality in the Waikato and Waipā catchments;

    b. Review of current water quality parameters of PC1 (Table 13.11-1) and related freshwater objectives;

    c. Description of the role of nutrients in healthy freshwater systems, and management approaches to reduce nutrient loads to waterways;

    d. Discussion of additional freshwater objectives and parameters; and

    e. Discussion of additional management strategies focusing on cumulative environmental outcomes.

**EXECUTIVE SUMMARY**

14. The National Policy Statement for Freshwater Management (NPS-FM) states that the life supporting capacity of freshwater systems must be safeguarded. A main objective of the NPS-FM is to protect ecosystem health, which is a compulsory national value and described as: "The freshwater management unit supports a healthy ecosystem appropriate to that freshwater body type (river, lake, wetland, or aquifer). In a healthy

freshwater ecosystem ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change"[12].

15. PC1 includes two primary mechanisms for achievement of the desired water quality outcomes that are set out in Table 3.11-1: a Nitrogen Reference Point (NRP) aimed at the reduction of nitrogen losses from individual properties, and the requirement of a Farm Environment Plan (FEP) for each property to manage contaminant losses from various land uses.

16. Water quality in the Waikato River changes from the headwaters to river mouth, with total nitrogen, total phosphorus, turbidity and *E. coli* levels increasing. These increases are predominantly linked to anthropogenic factors, including diffuse pollution from land uses (in particular impacting nitrogen and sediment levels).

17. The same trend can be observed for the Waipā River, where turbidity is comparatively (to the Waikato River) high in the headwaters, and downstream levels increase. Total nitrogen, total phosphorus, turbidity and *E. coli* levels increase from the headwaters to the downstream end of the river.

18. Water quality objectives set out in Table 3.11-1 can be complemented by including additional attributes. The water quality parameters currently proposed to be applied as part of PC1 (as represented in Table 3.11.-1) are chlorophyll *a*, Total Nitrogen (TN), Total Phosphorus (TP), nitrate (often linked to land use), ammonia (which at high concentrations is toxic to aquatic life), *E.coli* and clarity. These parameters are useful indicators of water quality, as well as swimmability related to human health (*E. coli*). However, the chosen parameters fall short of encompassing attributes of overall ecological health such as oxygen levels or biota that can indicate that an ecosystem can sustain diverse life. Some of the attributes included

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[12] Ministry for the Environment, 2017. National Policy Statement for Freshwater Management 2014. Updated August 2017 to incorporate amendments from the National Policy Statement for Freshwater Management Amendment Order 2017, Appendix 1. http://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/nps-freshwater-ameneded-2017_0.pdf

as part of the NPS-FM National Objectives Framework (NOF) guidelines (e.g. dissolved oxygen (DO)) are not covered in the PC1 parameters.

19. Excess levels of nutrients (both nitrogen (N) and phosphorus (P)) in waterways can lead to nuisance biological growth and compromise the way a freshwater ecosystem functions and the quality of habitat it provides for its biota (including invertebrates and fish). Limitation of N only may not prevent nuisance biological growth in river systems. River system conditions are changeable and complex, and community compositions of algae and macrophytes may change depending on availability and ratios of nutrients. On a spatial scale, nutrient levels vary at different locations within the same catchment, so both N and P should be limited. Spatial and seasonal variations will need to be accounted for.

20. A Nitrogen Reference Point (NRP) is proposed in PC1 to determine limits of nitrogen losses from individual properties based on a percentage reduction. This approach may not be sufficient to achieve water quality targets for a range of factors. These factors include the nitrogen load already accumulated in the ground water system. This load means that due to historic land use activities, a currently undetermined amount of nitrogen will enter surface waters through groundwater regardless of load reductions on land [13,14]. A further factor is that the approach does not distinguish between land use types or capability of land resources, and does not account for attenuation, topography, or soil types.

21. The s42A report acknowledges uncertainties in the effect of nutrient loss reductions on land on water quality outcomes: the relationship between nutrient concentrations and chlorophyll, and uncertainties in relation to

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[13] Petch, T. 2015. Summary of phase 1 ground water investigations commissioned to support the Healthy Rivers - Plan for Change: Waiora He Rautaki Whakapaipai project. Summary of phase 1 ground water investigations commissioned to support the Healthy Rivers - Plan for Change: Waiora He Rautaki Whakapaipai project.

[14] Journeaux, P, Schischka, T. & Philips, Y. 2011. Economic analysis of reducing nitrogen input into the Upper Waikato River catchment. MAF Technical Paper No: 2011/98. Report prepared by Ministry of Agriculture and Forestry

attenuation and nitrogen travel time[15], which could mean that the targets set out may not be aligned with the management approaches suggested in the plan.

22. Additional management strategies which could be implemented to improve ecological health in the region's waterways should focus on an integrated management approach that targets the multidimensional drivers of water quality decline through monitoring and management of sub-catchment groups. Management approaches could include a spatial framework based on sub-catchment groups; integrated contaminant management focusing on nutrients, sediment and microbial contaminants; a focus on critical source areas at a property scale; and the consideration of a wide range of edge-of-field management options. This could also involve optimisation of the natural capital of the land, and the inclusion of ecosystem services to monitor and incentivise land management practices for effective improvements in water quality outcomes [16,17,18].

## WATER QUALITY IN THE WAIKATO AND WAIPĀ CATCHMENTS

23. Water quality decline is a multidimensional issue, and deterioration of various parameters measuring water quality from the headwaters to the river mouth of the Waikato are closely linked to land use, and in particular intensification of land use. TP, TN, nitrate and ammonia concentrations in waterways have been found to increase with intensification of land use

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[15] McCallum Clark, M, Fenemor, A, Dawson, A, Crawford, N & Mako, A. Section 42A Report Proposed Waikato Regional Plan Change 1 – Waikato and Waipā River Catchments. Waikato Regional Policy Series 2019/04. Report prepared for Waikato Regional Council.

[16] Dominati, E., Maysek, F. J. F., Mackay, A. D., & Rendel, J. M. 2019. Farming in a changing environment: Increasing biodiversity on farm for the supply of multiple ecosystem services. Science of the Total Environment (in press).

[17] Maseyk, F.J., Mackay, A.D., Possingham, H.P., Dominati, E.J. and Buckley, Y.M., 2017. Managing natural capital stocks for the provision of ecosystem services. Conservation Letters, 10(2), pp.211-220.

[18] Mueller, H., Hamilton, D., Doole, G., Abell, J. and McBride, C., 2019. Economic and ecosystem costs and benefits of alternative land use and management scenarios in the Lake Rotorua, New Zealand, catchment. Global Environmental Change, 54, pp.102-112.

within a catchment[19]. For context, Figure 1 shows a spatial representation of changes in overall ecological health (life supporting capacity) based on seven key water quality variables such as dissolved oxygen, temperature and turbidity, from upstream to downstream along the mainstem of the Waikato and Waipā Rivers.

24. Based on WRC monitoring data, I have assessed data on nutrient concentrations[20] from three sites along the Waikato River (upper, middle and lower) to spatially represent water quality across the catchment. Data from an upper and lower site along the Waipā River is also presented. The state and trend results for the five sites allows a comparison across sites using the median monthly value to show the trending changes over a 10-year period. TP, TN and ammonia (NH4) have been assessed and represented in graphs. Only a small number of monitoring sites have been assigned TN and TP targets under the PC1 objectives (Table 3.11-1), so I have included NH4 as a variable to show current levels, trends over time and the context of the PC1 and the NPS-FM NOF objectives.

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[19] Quinn, J.M. and Stroud, M.J., 2002. Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. New Zealand journal of marine and freshwater research, 36(2), pp.409-429.

[20] *E.coli* levels and implications are discussed in the evidence of Dr Dada.


Figure 1*:* Life supporting capacity: The blue band shows how often water quality is at least satisfactory for supporting aquatic life. The wider the band, the better the waterway's capacity to support aquatic life, as reflected by a range of water quality indicators such as dissolved oxygen, temperature and turbidity. Graphic and data source: WRC 2018. Regional rivers water quality monitoring programme data report 2016. Waikato Regional Council Technical Report 2017/33.

25. The PC1 target for annual median ammonia (NH4) concentrations, represented in the monitoring data through ammonia, at some of the sites is set as low as 0.003 mg/L. The detection level of standard laboratory testing of ammonia concentration is <0.01 mg/L. This is also noted in the s42A report (paragraph 584). I would recommend the value of ≤0.01 mg/L as a discussion point for an amended numerical outcome for any sites that are currently set lower than the detection level. The NPS-FM numerical limit for this attribute set the A band at ≤0.03 mg/L (annual median for lakes and rivers).

26. At the upstream end, at the Waikato River at Ohaaki Bridge, ammonia is within NOF category 'Excellent' (band A) (Figure 2). While TN appears to be slightly degrading (concentrations are increasing) (Figure 3), ammonia and total phosphorus (Figure 4) are improving (concentrations are decreasing).

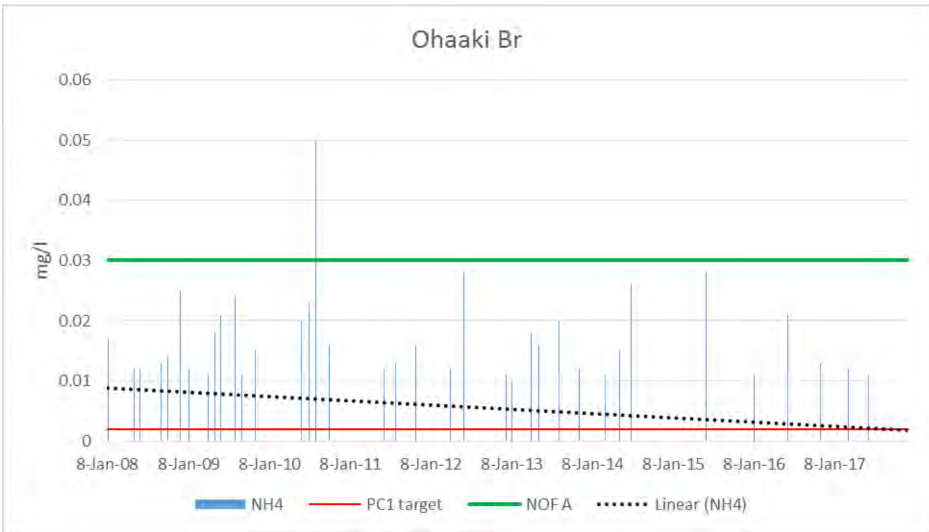


Figure 2: Ammonia concentrations 2008-2017 at Ohaaki Bridge, PC1 target (short term and 80 year target are of the same value). NOF A band. 10-year linear trend. Data supplied by WRC.

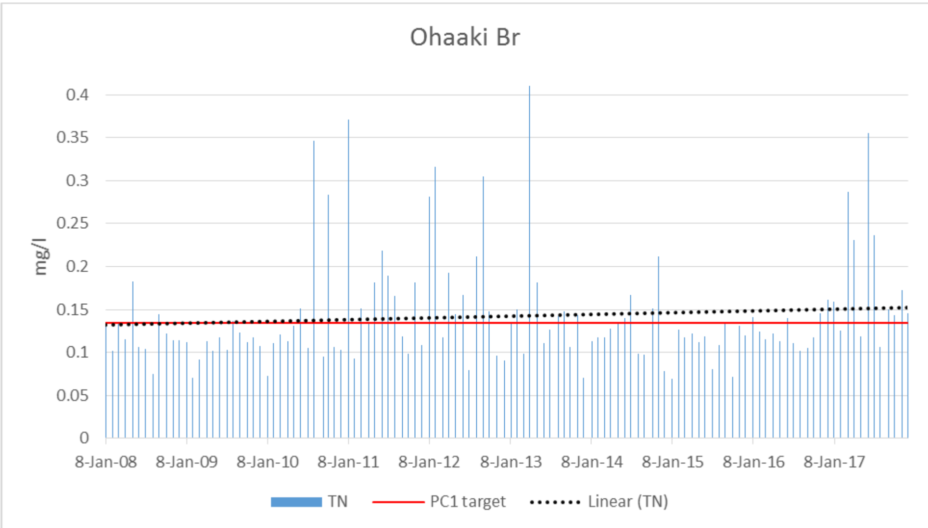


Figure 3: Total nitrogen (TN) concentrations 2008-2017 at Ohaaki Bridge, PC1 target (short term and 80 year target are of the same value). 10-year linear trend. Data supplied by WRC.

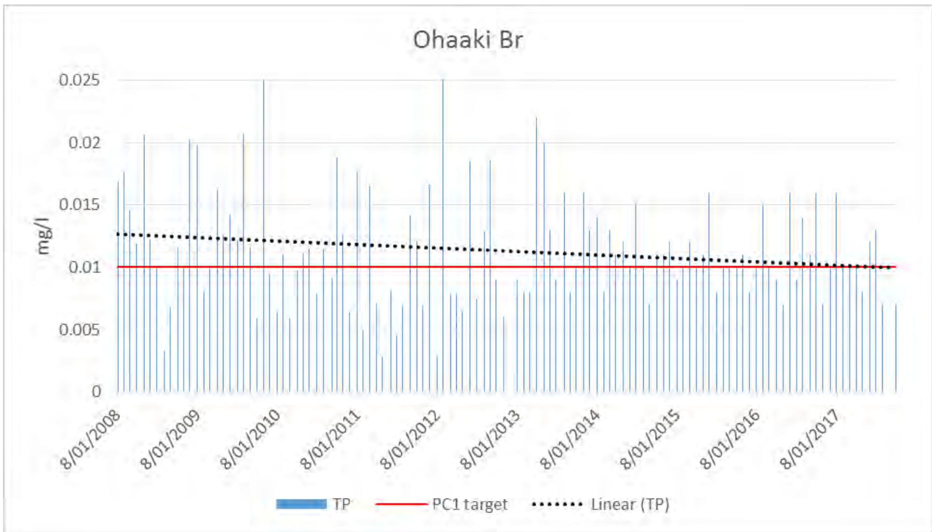


Figure 4: Total phosphorus (TP) concentrations 2008-2017 at Ohaaki Bridge, PC1 target (short term and 80 target are of the same value). 10-year linear trend. Data supplied by WRC.

27. Mid-reach, the Waikato River at Horotiu Bridge ammonia is within NOF category 'Excellent' (band A) (Figure 5). TN is degrading (concentrations are increasing) (Figure 6), while ammonia and TP are improving (Figure 7).

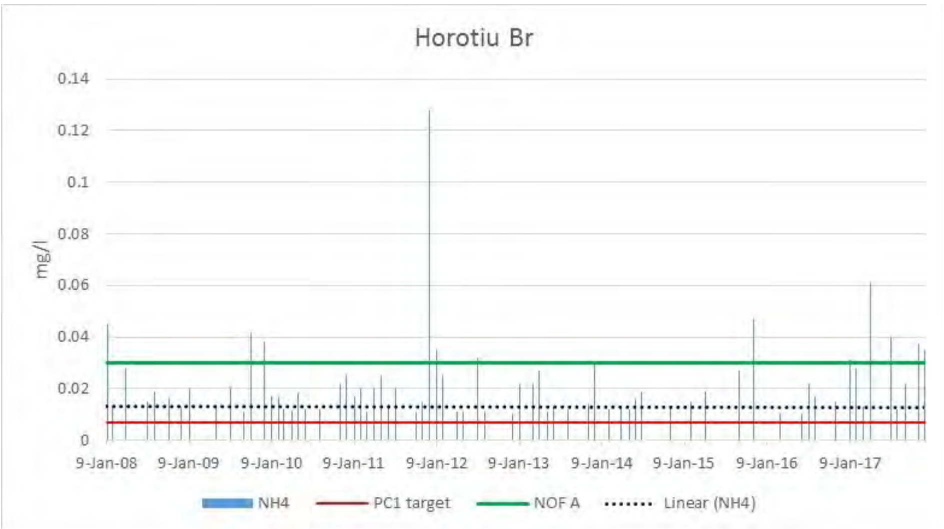


Figure 5: Ammonia concentrations 2008-2017 at Horotiu Bridge, PC1 target (short term and 80 target are of the same value). NOF A band. 10-year linear trend. Data supplied by WRC.

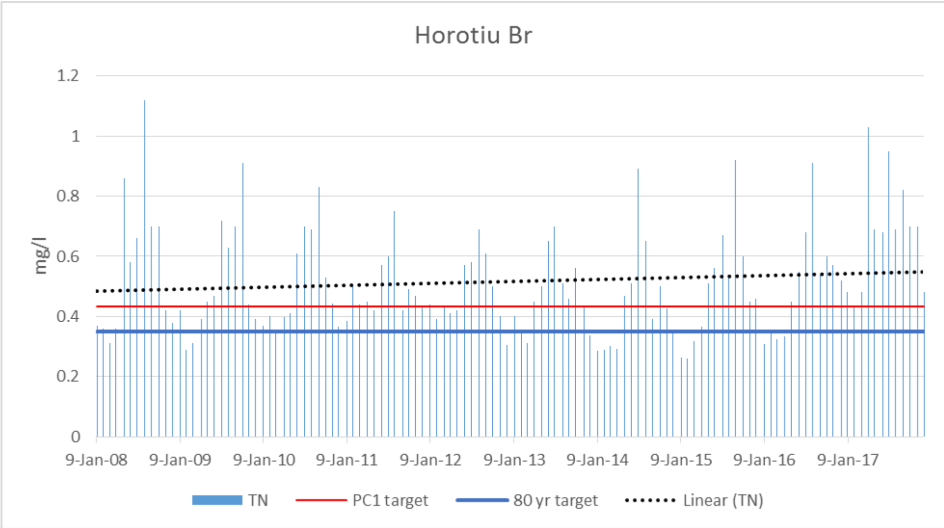


Figure 6: Total nitrogen (TN) concentrations 2008-2017 at Horotiu Bridge, PC1 target (short term and 80 target). 10-year linear trend. Data supplied by WRC.

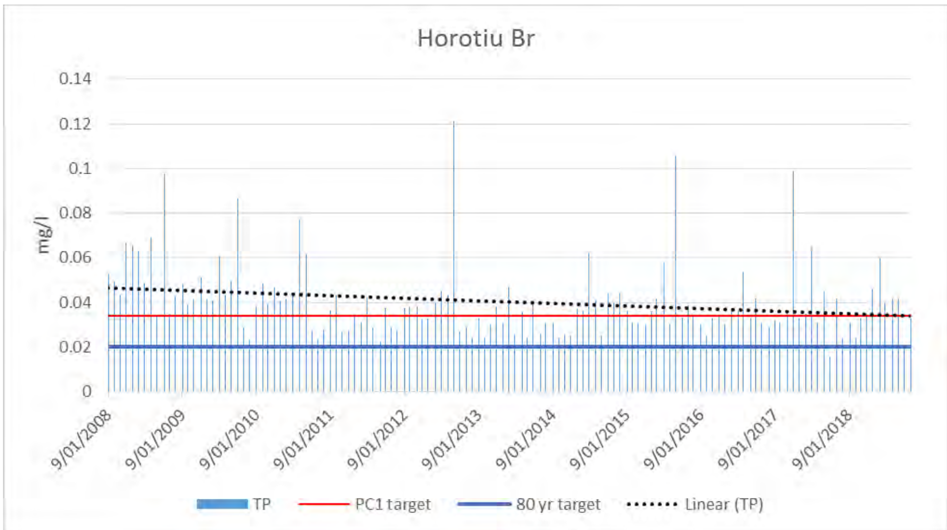


Figure 7: Total phosphorus (TP) concentrations 2008-2017 at Horotiu Bridge, PC1 target (short term and 80 target). 10-year linear trend. Data supplied by WRC.

28. At the downstream end, the Waikato River at Mercer shows ammonia results within NOF category 'Excellent' (band A) (Figure 8). Total nitrogen values are slightly improving (Figure 9), and phosphorous values (TP) are improving (Figure 10).

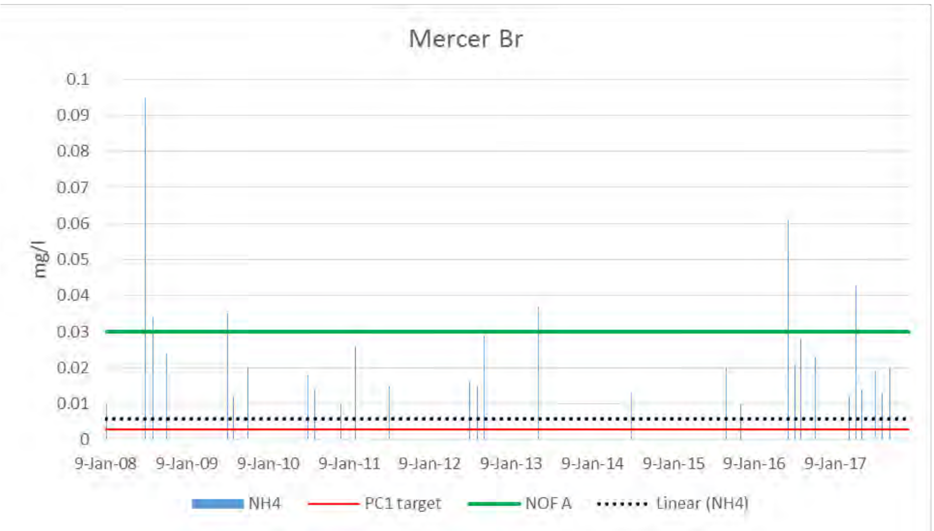


Figure 8: Ammonia concentrations 2008-2017 at Mercer Bridge, PC1 target (short term and 80 target are of the same value). NOF A band. 10-year linear trend. Data supplied by WRC.

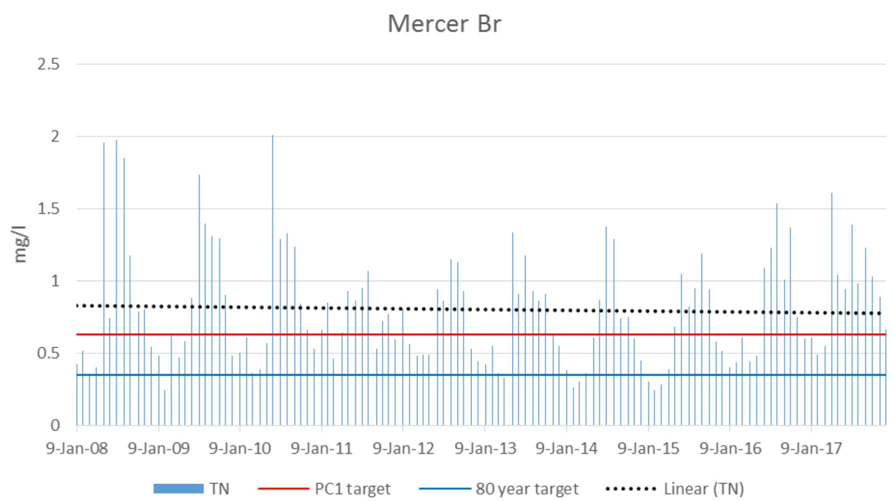


Figure 9: Total nitrogen (TN) concentrations 2008-2017 at Mercer Bridge, PC1 target (short term and 80 target). 10-year linear trend. Data supplied by WRC.

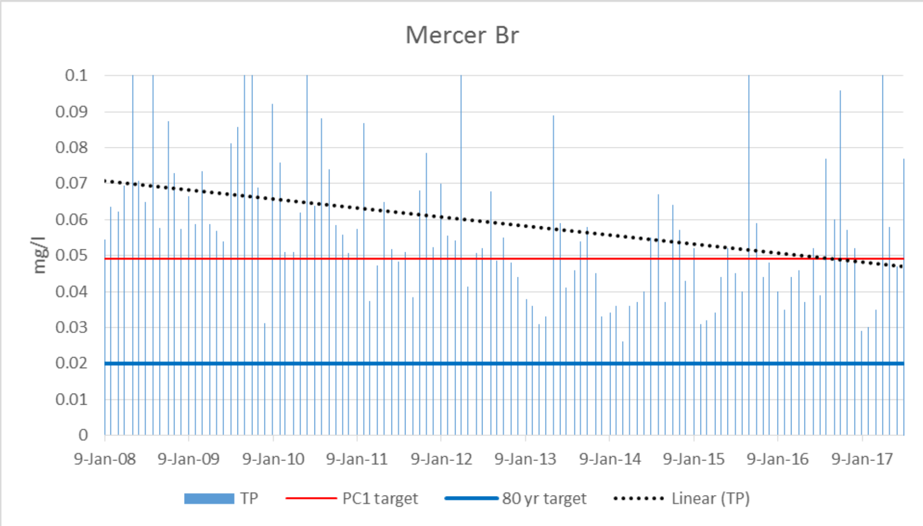


Figure 10: Total phosphorus (TP) concentrations 2008-2017 at Mercer Bridge, PC1 target (short term and 80 target). 10-year linear trend. Data supplied by WRC.

29. In the upper catchment of the Waipā River at Otewa, ammonia is within NOF category ‘Excellent’ (band A) (Figure 11). The 10-year monitoring trend shows a slight increase (degradation) in NH4 concentrations. TN and TP at this site are slightly degrading[21].

[21] Monitoring through National River Water Quality Network (NRWQN), NIWA. https://www.lawa.org.nz/explore-data/waikato-region/river-quality/waikato-river/waipa-at-otewa/

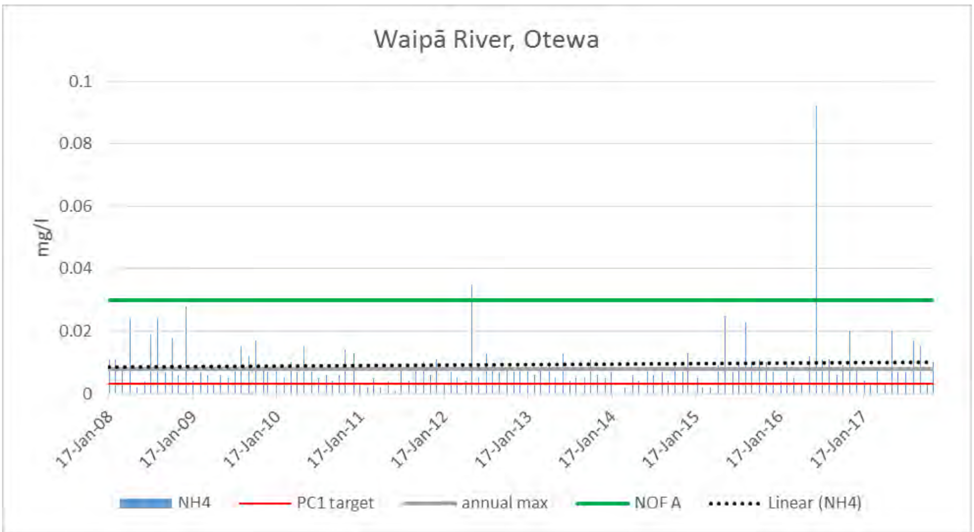


Figure 11: Ammonia concentrations 2008-2017 at Otewa, PC1 target (short term and 80 target are of the same value), annual maximum short term target. NOF A band. 10-year linear trend. Data supplied by WRC.

30. Downstream at the Whatawhata monitoring site, ammonia concentrations in the Waipā River over the last 10 years are slightly decreasing. Overall, Waipā River water quality at Whatawhata has ranges within the worst 25-50% of like sites due to turbidity and *E.coli* levels. Ammonia level is within NOF category 'Excellent' (band A), and has been very slightly improving (Figure 12). TN and TP at this site are showing no increasing or decreasing trends[22].

[22] Monitoring through National River Water Quality Network (NRWQN), NIWA. https://www.lawa.org.nz/explore-data/waikato-region/river-quality/waikato-river/waipa-at-whatawhata/

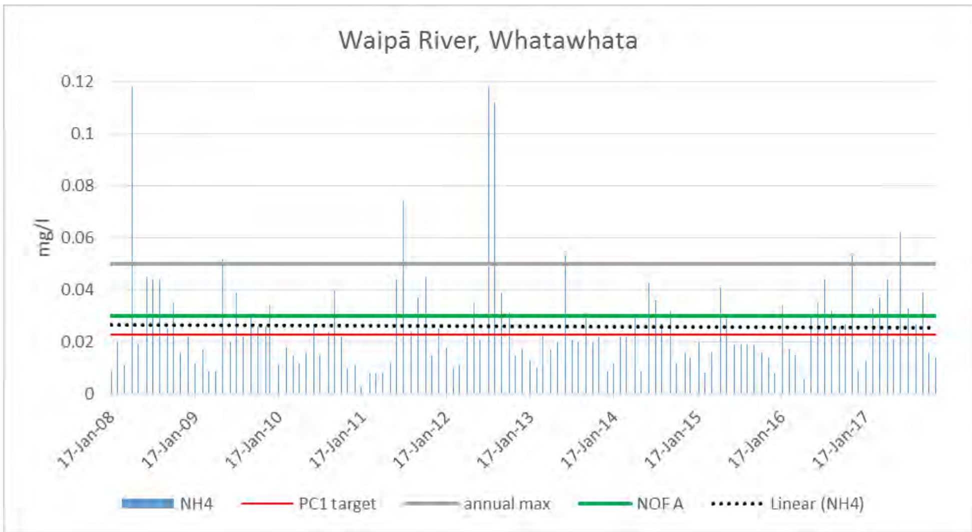


Figure 12 Ammonia concentrations 2008-2017 at Whatawhata, PC1 target for NH4 set (short term and 80 target), annual maximum short term target. NOF A band. 10-year linear trend. Data supplied by WRC.

31. Water quality within both the Waikato and Waipā catchments decreases from the headwaters to downstream sites. Ammonia levels increase from upstream to downstream sites, but stay within the NOF A band at all the sites represented across both catchments. Alongside increases in nutrient concentrations, turbidity levels also increase from upstream to downstream. Within the Waikato River, turbidity changes from relatively low levels at Ohaaki (0.8 NTU, WRC data based on an annual median), to 3.4 NTU at Horotiu, and higher levels at Mercer, located downstream of the confluence of the two rivers (9.0 NTU). The headwaters of the Waipā River are comparatively higher due to geological characteristics (3.6 NTU at Otewa), and increase to 20.3 NTU at Whatawhata.

## SAFEGUARDING ECOLOGICAL HEALTH AND PROCESSES

32. Objective A1 of the NPS-FM is to safeguard the life-supporting capacity of freshwater, and the health of people and communities when in contact with freshwater. Other NPS-FM objectives are to protect natural character, mahinga kai, fishing, water supply, industrial and commercial, and other use

values. The provision of Te Mana O Te Wai also requires that the integrated and holistic well-being of freshwater systems is provided for.[23].

33. For the Waikato region, the Waikato River Vision and Strategy[24] requires the implementation of targets that 'improve the health and wellbeing of the Waikato River by utilising mātauranga Māori and latest available scientific methods'.

34. PC1 is founded on a range of values (Mana Atua – Intrinsic Values, Section 3.11.1.1) for freshwater management. These include, amongst several others, ecosystem health (resilient freshwater ecosystems and healthy freshwater populations of indigenous plants and animals) and mahinga kai (the ability to access the Waikato and Waipā and their tributaries to gather sufficient quantities of kai (food) that is safe to eat and meets the social and spiritual needs of their stakeholders). The mechanisms currently proposed by PC1 do not seem sufficient to either monitor or manage ecosystem health across both catchments.

**PC1 WATER QUALITY PARAMETERS**

35. PC1 seeks to reduce the amount of contaminants entering the Waikato River from the Waikato and Waipā catchments and has been developed to achieve the Vision and Strategy for the Waikato River/Te Ture Whaimana o Te Awa o Waikato (the Vision and Strategy), as well as giving effect to the NPS-FM.

36. The water quality parameters applied to set outcomes prescribed by PC1 (Table 3.11-1) are chlorophyll, TN, TP, nitrate, ammonia, *E.coli* and clarity.

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[23] Ministry for the Environment, 2017. National Policy Statement for Freshwater Management 2014. Updated August 2017 to incorporate amendments from the National Policy Statement for Freshwater Management Amendment Order 2017. http://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/nps-freshwater-ameneded-2017_0.pdf

[24] Waikato River Authority 2011. Restoring and protecting the health and wellbeing of the Waikato river. Vision and Strategy for the Waikato river. https://waikatoriver.org.nz/wp-content/uploads/2011/07/Vision-and-Strategy.pdf

These parameters are useful indicators of water quality, as well as swimmability related to human health (*E. coli*).

37. The choice of monitored water quality parameters and freshwater targets set out in PC1 does not thoroughly account for ecological health, the life supporting capacity of freshwater systems, or incorporate mātauranga Māori concepts to measure ecosystem health.

38. To adequately assess, monitor and manage for ecological health, PC1 should consider additional water quality parameters (DO, temperature, conductivity, suspended sediment which all can impact biota such as invertebrates). It should also include biodiversity indicators such as the Macroinvertebrate Community Index (MCI) and/or other measurements of biota (e.g. fish, birds), as well as consider mātauranga Māori indicators such as the cultural health index (CHI).

39. The management of nutrients alongside these other parameters is essential to manage ecological health of a freshwater system. Ecological health relates to the combination of 'vigour, organisation and resilience' of an ecosystem[25]. In the context of a freshwater system, vigour can be related back to the life-supporting capacity of the ecosystem (e.g. sufficient oxygen concentrations and absence of enriched nutrient concentrations). Organisation refers to the presence of critical ecosystem components, e.g. the presence of a complex food web and associated indigenous species. Resilience in the freshwater context refers to the ability of a system to withstand pressure (e.g. anthropogenic pressures such as increased nutrient loads and climate change).

40. DO is an important ecological indicator, as most of the organisms within a freshwater system consume DO; which also means that it must be continuously replenished (e.g. through flow, wind and plant growth). Organisms can become stressed or die if insufficient oxygen is present. Pressures on freshwater systems such as nutrient enrichment, microbial breakdown of organic matter and weed invasion can lead to depleted DO

[25] Rapport DJ, Costanza R, McMichael AJ (1998) Assessing ecosystem health .Trends in Ecology and Evolution 13: 397–402.

concentrations. Due to its importance to most organisms, and the intricate link to other water quality parameters, DO is a critical parameter to assess the ecological condition of freshwater systems[26,27].

41. DO is also included in the monitoring framework suggested in the United Nations Sustainable Development Goals[28], as part of a set of indicators intended to assess the intactness of ecosystem function and human health indicators.

42. The New Zealand National Rivers Water Quality Network (NRWQN)[29] includes, amongst others, DO, temperature, and conductivity as part of its routinely measured parameters.

43. The National Environmental Monitoring and Reporting (NEMaR) programme[30] includes DO and temperature (which can act as a stressor to invertebrates if elevated[31].) as a secondary variable, and an assessment of habitat and biota as primary variables for ecosystem health monitoring.

44. The ecosystem health framework proposed by the Freshwater Science and Technical Advisory Group[32] suggests parameters to be included for the assessment of freshwater ecological integrity should include aspects of

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[26] Butler, B & Burrows DW 2007. Dissolved oxygen guidelines for freshwater habitats in of Northern Australia. ACTFR Report No 07/32. Prepared for Department of Environment and Heritage, Canberra by the Australian Centre for Tropical Freshwater Research.

[27] DO fluctuates diurnally and continuous logging is required to understand the DO concentrations in a waterway. DO also changes with other parameters such as temperature.

[28] United Nations 2017. Sustainable Development Goals Report 2017. SDG 6 Clean Water and Sanitation: https://unstats.un.org/sdgs/report/2017/goal-06/

[29] Davies-Colley, Robert J., David G. Smith, Robert C. Ward, Graham G. Bryers, Graham B. McBride, John M. Quinn, and Mike R. Scarsbrook, 2011. Twenty Years of New Zealand's National Rivers Water Quality Network: Benefits of Careful Design and Consistent Operation. Journal of the American Water Resources Association (JAWRA) 47(Niyogi, D.K., Koren, M., Arbuckle, C.J. and Townsend, C.R., 2007. Longitudinal changes in biota along four New Zealand streams: declines and improvements in stream health related to land use. New Zealand Journal of Marine and Freshwater Research, 41(1), pp.63-75.4):750-771

[30] Hudson, N, Ballantine, D, Gibbs, M, de Winton, M, Storey, R, Verburg, P, Hamill, K 2011. Investigation of single indicators for water quality assessment and reporting. NIWA Client Report HAM 2011-066 prepared for the Ministry for the Environment.

[31] Vander Laan, J.J., Hawkins, C.P., Olson, J.R. and Hill, R.A., 2013. Linking land use, in-stream stressors, and biological condition to infer causes of regional ecological impairment in streams. Freshwater Science, 32(3), pp.801-820.

[32]Clapcott, J., Young, R., Sinner, J., Wilcox, M., Storey, R., Quinn, J., Daughney, C. & Canning, A. 2018. Freshwater biophysical ecosystem health indicators. Report prepared by the Freshwater Science and Technical Advisory Group. Cawthron Institute Report No. 3194.

aquatic life (e.g. invertebrates, plants, fish, water birds) and habitat aspects (e.g. connectivity and riparian habitat) alongside water quality parameters (including conductivity and suspended sediment).

45. The Macroinvertebrate Community Index (MCI) provides a measure of the different types of invertebrates present in a stream, as represented by their relative abundance (the 'community'). The index has been used widely in New Zealand, and macroinvertebrates are recognised nationally and internationally as a key indicator for water quality and ecological health in streams[33]. MCI is also included as part of the monitoring data for river ecosystem health presented in the LAWA database, so it is a parameter already widely monitored at wadeable stream sites for this purpose.

46. An extended range of parameters, including DO, temperature and biota, means that ecosystems can be monitored (and therefore managed) in a way that encompasses the most important aspects that represent the suitability of a freshwater system to sustain life.

47. Table 1 outlines suggested ranges of instream parameters within good to high quality ecosystem limits that provide a better method of assessing water quality based on available literature. These ranges are based on discussion papers that have developed proposed thresholds. I also propose to revise the attribute values Table 3.11-1 to reflect aspects such as detection levels of ammonia concentrations. Expert conferencing could be used to agree on these parameters alongside a discussion of the attributes currently included in Table 3.11-1.

48. In conclusion, based on the knowledge presented by the assessment frameworks discussed above both in New Zealand and internationally, the parameters chosen as part of the PC1 proposal (Table 3.11-1) fall short of encompassing attributes of overall ecological health such as oxygen levels, temperature and biota, and therefore may not be sufficient to give effect to the ecological health objectives set out in the NPS-FM.

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[33] Collier KJ, Clapcott J, Neale M 2014. A macroinvertebrate attribute to assess ecosystem health for New Zealand waterways for the national objectives framework – Issues and options. Environmental Research Institute report 36, University of Waikato, Hamilton.

Table 1: Suggested additional parameters and target ranges to provide for ecological health. Values for discussion based on thresholds proposed by the documents referenced.

| **Suggested parameter** | **Suggested target range** | **Notes** |
|---|---|---|
| **Dissolved oxygen (DO)** | 7-day mean: ≥8.0 – 9.0 mg/L<br>7-day mean minimum: ≥7.0 – 8.0 mg/L<br>1-day minimum: ≥5.0 – 7.5 mg/L | Continuous logging required for adequate monitoring that accounts for daily oxygen fluctuations.<br>Suggested A and B NOF Band[34]:<br>A - No stress caused by low dissolved oxygen on any aquatic organisms that are present at matched reference (near-pristine) sites.<br>B - Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance of sensitive fish and macroinvertebrate species. |
| **Temperature** | ≤18 degrees C | Suggested A and B NOF Band for 'Maritime Regions of NZ'[35]:<br>A - No thermal stress on any aquatic organisms that are present at matched reference (near-pristine) sites.<br>B - Minor thermal stress on occasion (clear days in summer) on particularly sensitive organisms such as certain insects and fish. |

[34] Davies-Colley, R, Franklin, P, Wilcock, B, Clearwater, S. & Hickey, C. 2013. National Objectives Framework – Temperature, Dissolved Oxygen & pH. Proposed thresholds for discussion. Report prepared for the Ministry for the Environment, NIWA Client report HAM2013-056, prepared by National Institute of Water & Atmospheric Research Ltd.

[35] Davies-Colley, R, Franklin, P, Wilcock, B, Clearwater, S. & Hickey, C. 2013. National Objectives Framework – Temperature, Dissolved Oxygen & pH. Proposed thresholds for discussion. Report prepared for the Ministry for the Environment, NIWA Client report HAM2013-056, prepared by National Institute of Water & Atmospheric Research Ltd.

| Suggested parameter | Suggested target range | Notes |
|---|---|---|
| **Macroinvertebrate Community Index (MCI)** | Upper Waikato: >120 (A)<br>Lower Waikato: > 100 (B)<br>Waipā: >100 (B) | 3-year mean for wadeable streams only. Suggested A and B NOF Band[36]. MCI scores >120 indicate excellent water quality, scores 100-119 indicate good water quality with mild levels of pollution[37]<br>A – High quality environment where species composition is close to the natural state most of the time.<br>B – Good quality environment where human activities and/or natural disturbances cause some loss of sensitive species. |

## THE ROLE OF NUTRIENTS IN HEALTHY FRESHWATER SYSTEMS, AND MANAGEMENT APPROACHES

49. Excess levels of nutrients in waterways can lead to nuisance biological growth and compromise the way a freshwater ecosystem functions and the quality of habitat it provides for its biota (including invertebrates and fish). Globally, increased nutrient levels are a major stressor to flora and fauna within waterways[38]. When managing nutrients for water quality outcomes and ecological health, there is lack of scientific evidence that focusing on a single nutrient can achieve water quality improvements. In particular, limitation of N only may not prevent nuisance biological growth in river

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[36] Collier KJ, Clapcott J, Neale M 2014. A macroinvertebrate attribute to assess ecosystem health for New Zealand waterways for the national objectives framework – Issues and options. Environmental Research Institute report 36, University of Waikato, Hamilton.
[37] Stark, J. D. & Maxted, J. R. 2007. A user guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. Cawthron Report No. 1166. 58p.
[38] Allan, J.D., 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu. Rev. Ecol. Evol. Syst., 35, pp.257-284.

systems. The importance of managing P is emphasised in the s42A report (paragraph 131).

50. Excess biological growth can reduce habitat quality and negatively impact biodiversity (including macroinvertebrates) in lakes, rivers and streams. It also has an impact on human values such as recreation and aesthetics[39]. For monitoring purposes, chlorophyll *a* (chl *a*) concentrations are used to estimate biomass of phytoplankton, which in turn can indicate eutrophication (accumulation of nutrients) within a water body[40,41].

51. In order to reduce nuisance biological growth, including periphyton, nutrient loads to freshwater need to be managed; however, there is uncertainty around the level of nutrient concentrations related to achieving this target[42,43]. To preserve ecological health of waterways, management also needs to address aspects beyond nutrient concentrations[44].

52. Nitrogen is generally leached into sub-soil flow paths (mainly into groundwater) from agricultural systems via excess fertiliser application and urine from livestock[45]. Further details regarding the risk factors on nitrogen

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[39] Suplee MW, Watson V, Teply M, McKee H. 2009. How green Is too green? Public opinion of what constitutes undesirable algae levels in streams. JAWRA Journal of the American Water Resources Association 45(1):123–140.
[40] Gregor, J. and Maršálek, B., 2004. Freshwater phytoplankton quantification by chlorophyll a: a comparative study of in vitro, in vivo and in situ methods. Water Research, 38(3), pp.517-522.
[41] Suren AM, Biggs BJF, Duncan MJ, Bergey L, Lambert P. 2003. Benthic community dynamics during summer low-flows in two rivers of contrasting enrichment 2. Invertebrates. New Zealand Journal of Marine and Freshwater Research. 37:71–83.
[42] Snelder, T. 2018. Nutrient concentration targets to achieve periphyton biomass objectives incorporating uncertainties. Lower Hutt (NZ): GNS Science. 41p. (GNS Science report; 2018/38). doi:10.21420/ajsh-nw16.
[43] Snelder TH, Booker DJ, Quinn JM, Kilroy C. 2014. Predicting periphyton cover frequency distributions across New Zealand's rivers. JAWRA Journal of the American Water Resources Association 50(1):111–127.
[44] Death, R., Canning, A., Magierowski, R., Tonkin, J. 2018. Why aren't we managing water quality to protect ecological health? Farm environmental planning – Science, policy and practice. (Eds. L. D. Currie and C. L. Christensen). Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13 pages.
[45] Collins, S. B., Singh, R., Rivas, A., Palmer, A., Horne, D., Roygard, J. & Matthews, A., 2016. Assessment of nitrogen flow pathways and its potential attenuation in shallow groundwaters in the lower Rangitikei catchment. In: Integrated nutrient and water management for sustainable farming. (Eds L. D. Currie and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 14 pages.

losses from land use types are discussed in the evidence in chief presented by Dr Chrystal. In contrast, phosphorus mostly travels in surface water including ephemeral streams during high rainfall, and into streams and rivers, generally attached to sediment[46].

53. The reduction of losses of just phosphorus or nitrogen alone from land use may not be sufficient to prevent nuisance biological growth in river systems as outlined in paragraphs 54. – 57. Many scientific studies reach conclusions that for effective control of nuisance biological growth in river systems, both P and N should be managed, within ecologically relevant ranges I agree with the suggestion of the s42A report (page 26, paragraphs 132 – 134) that inflexible management of N as proposed in PC1 could be improved through balancing this with an explicit requirement for Good Farming Management (GFC) practices, aimed to reduce impacts of P and sediment on waterways to complement N management. The s42A report also concludes that management of N may be less pressing in some areas, for example the Waipā catchment, where management of P, sediment and *E. coli* is more critical for ecosystem health (paragraph 136).

54. River system conditions are changeable and complex, and community compositions of algae and macrophytes may change depending on availability and ratios of nutrients. Increased concentrations of nutrients can lead to excessive biological growth, which can impact biological communities and lead to the decline in ecological health[47,48,49]. At a spatial scale, nutrient levels vary at different locations within the same catchment,

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[46] van Beek CL, van der Salm C, Plette ACC, van de Weerd H (2009) Nutrient loss pathways from grazed grasslands and the effects of decreasing inputs: experimental results for three soil types. Nut Cycl Agroecosyst 83:99-110.
[47] Smith, V.H., Joye, S.B. and Howarth, R.W., 2006. Eutrophication of freshwater and marine ecosystems. Limnology and Oceanography, 51(1part2), pp.351-355.
[48] Smith, V.H., 2003. Eutrophication of freshwater and coastal marine ecosystems a global problem. Environmental Science and Pollution Research, 10(2), pp.126-139.
[49] Death R.G., Death F. & Ausseil O.M.N. (2007) Nutrient limitation of periphyton growth in tributaries and the mainstem of a central North Island river. New Zealand Journal of Marine and Freshwater Research, 41, 273-281.

so both N and P should be managed to control biological growth[50]. Spatial and seasonal variations will need to be accounted for.

55. Nitrogen is a key element for freshwater ecosystems[51]. However, control of N or P alone is widely recognised as insufficient to control biological growth, with both N and P needed for plant growth meaning both nutrients are key nutrients to limit for reducing eutrophication (nutrient enrichment)[52,53]. Experiments have shown that combined N and P enrichment leads to substantial growth responses, whereas additions of single nutrients of either N or P led to less substantial and less frequent growth[54].

56. Ratios of nitrogen to phosphorus concentrations are often analysed to predict the limitation of biological growth by either nutrient in different freshwater systems[55,56]. However, there is evidence that N:P ratios are not always useful indicators of nutrient limitation, and scientific literature on this topic reports a high level of uncertainty in the ability of these ratios to predict biological growth effects [57,58].

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[50] Wilcock, B.; Biggs, B.; Death, R.; Hickey, C.; Larned, S.; Quinn, J. 2007: Limiting nutrients for controlling undesirable periphyton growth. Prepared for Horizons Regional Council. NIWA Client Report HAM2006-006.

[51] Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H. and Tilman, D.G., 1997. Human alteration of the global nitrogen cycle: sources and consequences. Ecological applications, 7(3), pp.737-750.

[52] Conley, D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F., Seitzinger, S.P., Havens, K.E., Lancelot, C. and Likens, G.E., 2009. Controlling eutrophication: nitrogen and phosphorus. Science, 323(5917), pp.1014-1015.

[53] Smith, V.H., 2003. Eutrophication of freshwater and coastal marine ecosystems a global problem. Environmental Science and Pollution Research, 10(2), pp.126-139.

[54] Elser, J.J., Marzolf, E.R. and Goldman, C.R., 1990. Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: a review and critique of experimental enrichments. Canadian Journal of fisheries and aquatic sciences, 47(7), pp.1468-1477.

[55] Hecky, R.E. and Kilham, P., 1988. Nutrient limitation of phytoplankton in freshwater and marine environments: a review of recent evidence on the effects of enrichment 1. Limnology and Oceanography, 33, pp.796-822.

[56] Rhee, G.Y., 1978. Effects of N: P atomic ratios and nitrate limitation on algal growth, cell composition, and nitrate uptake 1. Limnology and oceanography, 23(1), pp.10-25.

[57] Keck, F. and Lepori, F., 2012. Can we predict nutrient limitation in streams and rivers? Freshwater Biology, 57(7), pp.1410-1421.

[58] Downing, J.A., Watson, S.B. and McCauley, E., 2001. Predicting cyanobacteria dominance in lakes. Canadian journal of fisheries and aquatic sciences, 58(10), pp.1905-1908.

57. In addition to the relevance of both nutrients for biological growth, and the uncertainty related to N:P ratios in predicting growth limitation within a system by either nutrient, some algae species, for example blue-green algae, are able to transform atmospheric nitrogen to support their growth[59,60]. This means that if N is limited, but P is high, nuisance growth of these species is favoured.

58. In other New Zealand policy cases aimed at improving water quality, such as the development of the Horizons Regional Council Regional Policy Statement and Regional Plan (One Plan)[61], the management of both nitrogen and phosphorus has been assessed as effective to achieve improvements in limiting biological growth.

59. In addition to the recommendations for amendment of Table 3.11-1 made in paragraph 47, expert conferencing would be useful to revise the TN and nitrate targets set for some of the sites, in particular for upland areas to reflect some of the flexibility that might be required to achieve overall ecological health outcomes as discussed in paragraph 53. As a starting point, numerical outcomes for instream concentrations for these attributes could be aligned with recommendations made on nitrate concentrations[62], and ANZECC values for TN[63].

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59 Smith, V.H., 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science, 221(4611), pp.669-671.

60 Vitousek, P.M., Cassman, K.E.N., Cleveland, C., Crews, T., Field, C.B., Grimm, N.B., Howarth, R.W., Marino, R., Martinelli, L., Rastetter, E.B. and Sprent, J.I., 2002. Towards an ecological understanding of biological nitrogen fixation. In The Nitrogen Cycle at Regional to Global Scales (pp. 1-45). Springer, Dordrecht.

61 Horizons Regional Council 2014. Regional Policy Statement and Regional Plan: One Plan. http://www.horizons.govt.nz/data/one-plan

62 Suggested concentrations of <0.11 mg/L (A band<), >0.58 mg/L (B band) and <1.66 mg/l (C band) for nitrate as discussed in Death, R. G., Canning, A., Magierowski, R. and Tonkin, J., 2018. Why aren't we managing water quality to protect ecological health?. In: Farm environmental planning – Science, policy and practice. (Eds L. D. Currie and C. L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13 pages.

63 TN trigger values for chemical stressors: 0.295 mg/L for upland rivers, 0.614 mg/L for lowland rivers. Presented in: ANZECC (Australian and New Zealand Environment and Conservation Council) 1992. Australian water quality guidelines for fresh and marine waters. ANZECC, Canberra, Australia.

60. The nutrient directly addressed as part of PC1 is nitrogen, through a Nitrogen Reference Point (NRP). Monitoring and managing nitrogen is useful as it indicates diffuse pollution impacts from land use such as fertiliser or livestock waste, whereas phosphorus can be naturally increased depending on soil and slope conditions. The NRP is proposed to limit nitrogen losses from individual properties based on a percentage reduction relative to the estimated nitrogen leach rate calculated using Overseer® at a set point in time (2014/2015 and 2015/2016 for all land uses except commercial vegetable production), and seeking reductions from the highest emitters currently above the 75$^{th}$ percentile in terms of nitrogen losses within each Freshwater Management Unit (FMU).

61. A discussion of the approach taken to calculate nitrogen losses to link back to the water quality targets, including limitations of Overseer® (e.g. aspects of N pathways and attenuation) is covered in the evidence in chief presented by Dr. Chrystal. Farm optimisation modelling has shown that a certain amount of flexibility in nitrogen targets can allow for overall improved environmental outcomes across a farm system, including water quality (e.g. through lowering stocking rates for N management, and retiring land sensitive to erosion for P management) and biodiversity outcomes[64].

62. The emphasis on N management does not necessarily lead to water quality and ecosystem health everywhere across the catchments. For example, reduction of N losses may be the most critical factor to be implemented in low lying areas with high stocking rates, whereas, for example, P and sediment loss reduction may lead to better water quality outcomes for sub-catchments and properties with steep slopes that are prone to significantly accelerated erosion, making the management of P more critical. As discussed in the evidence in chief of Dr. Tim Cox, there are also variations across the catchment with regards to factors such as attenuation which have an impact on nitrogen concentrations in receiving water bodies that

[64] Dominati, E., Maysek, F. J. F., Mackay, A. D., & Rendel, J. M. 2019. Farming in a changing environment: Increasing biodiversity on farm for the supply of multiple ecosystem services. Science of the Total Environment (*in press*).

have not been accounted for in the management approach suggested by PC1.

63. Specifically, the approach does not distinguish between land use types or capability, or account for other downstream impacts on water quality such as phosphorus and sediment. N leaching generally is lowest from forestry land uses, followed by dry stock farming, mixed cropping, dairy farming, and vegetable cropping[65]. Constructed wetlands, 'best management practices' (BMPs) or Good Farming Management (GFC), optimised stocking rates and denitrification beds are some of the options to manage N loss. Edge-of-field mitigation options are discussed in Mr. Kessels' evidence in chief.

64. By working within land use capability, soil types, farming systems and climatic conditions, nitrogen loss rates (as well as losses of phosphorus, sediment and pathogens, thereby reducing the overall environmental footprint) can be managed. Dr. Chrystal in her evidence in chief has said this also leads to the profitability of the business being optimised through changes in aspects such as stocking rates, fertiliser use and feed choices[66].

65. There is lack of scientific evidence that the limitation of a single nutrient (in this case nitrogen) can successfully achieve water quality outcomes that ensure ecological health. The limitation of a single nutrient is unlikely to limit nuisance biological growth in all freshwater systems of the target catchments. Instead, I support an approach that manages both N and P to improve or maintain ecological health.

66. The proposed approach of PC1 may not be sufficient to achieve the desired water quality outcomes in the long term. It does not have regard to land use and soil types, and does not recognise land uses that currently have lower levels of N losses and that match the capability of land and soil to attenuate these losses. As discussed in Mr. Parkes, Dr. Chrystal and Mr. Kessels'

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[65] Abell, J.M., Hamilton, D.P. and Paterson, J., 2011. Reducing the external environmental costs of pastoral farming in New Zealand: experiences from the Te Arawa lakes, Rotorua. Australasian Journal of Environmental Management, 18(3), pp.139-154.
[66] Dewes, A. (2014). Economic resilience and environmental performance of dairy farms in the upper Waikato region (Thesis, Master of Science (MSc)). University of Waikato, Hamilton, New Zealand. Retrieved from https://hdl.handle.net/10289/9220

evidence, an approach to achieving reductions in contaminant losses, and overall environmental footprints of various land use types, may involve a focus on critical source areas (see below), mitigation options such as edge-of-field mitigation, and the optimisation of farming operations to create win-win scenarios of environmental and economic outcomes.

## ALTERNATIVE MANAGEMENT STRATEGIES

67. Alternative management strategies beyond a single nutrient reference point and including the chosen water quality parameters (Table 3-11.1) could involve an integrated management approach that targets the multidimensional drivers of water quality decline through monitoring and management of sub-catchment groups.

68. In contrast to larger management zones, the management focused on sub-catchment groups is better able to account for variabilities in land use capability, topography, climatic conditions and soil types. At a sub-catchment level, the reduction of contaminant losses can be coordinated more effectively, outcomes can be better monitored at a subcatchment and/or property scale, and landowners therefore can be more directly accountable for water quality outcomes[67].

69. An integrated approach to managing a range of nutrients and other contaminants will be more successful at achieving water quality objectives. Through the solutions summarised in Paragraph 73, multiple contaminants can be addressed.

70. Critical source areas (CSAs) are areas on a property where the majority of contaminant loss occurs, in particular during high rain fall events[68]. Losses mainly relate to sediment, phosphorus and pathogens, but also nitrogen (especially where stock has access to waterways, and during high rainfall

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[67] Sinner, J & Newton, M. 2018. Water management groups: preliminary guidance. Consultancy report No. 3199, prepared by Cawthron Institute for the Ministry for the Environment.
[68] Srinivasan, M.S. and McDowell, R.W., 2009. Identifying critical source areas for water quality: 1. Mapping and validating transport areas in three headwater catchments in Otago, New Zealand. Journal of hydrology, 379(1-2), pp.54-67.

events)[69,70]. In CSAs, about 80% of contaminant losses can occur over about 20% of the catchment or sub-catchment area[71]. These areas include landscape features such as gullies and swales, and farm areas such as water troughs and stock crossings. By targeting management of these CSAs, a large proportion of contaminant loss can be reduced over a relatively small area, and reductions can therefore be made most effectively by taking this approach. Nitrogen can be managed through mitigation measures such as lower stocking rates, optimised fertiliser application, cropping regimes, fencing and stand-off pads, optimisation in drainage and effluent systems, and feed choices[72,73,74].

71. To incentivise changes in land use types and practices, ecosystem services (services provided by an ecosystem to be benefit of humans), and the concept of natural capital are a useful tool to evaluate means to mitigate land use impacts, improve water quality, and provide monetary incentives for land use change, and optimisation of land use[75,76,77]. The consideration of ecosystem services in an economic context means that changes in land

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[69] McDowell, R.W. and Srinivasan, M.S., 2009. Identifying critical source areas for water quality: 2. Validating the approach for phosphorus and sediment losses in grazed headwater catchments. Journal of Hydrology, 379(1-2), pp.68-80.
[70] Heathwaite, L., Sharpley, A. and Gburek, W., 2000. A conceptual approach for integrating phosphorus and nitrogen management at watershed scales. Journal of Environmental Quality, 29(1), pp.158-166.
[71] Djodjic, F. and Villa, A., 2015. Distributed, high-resolution modelling of critical source areas for erosion and phosphorus losses. Ambio, 44(2), pp.241-251.
[72] Monaghan, R.M., De Klein, C.A. and Muirhead, R.W., 2008. Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways: A case study of New Zealand dairy farming. Journal of environmental management, 87(4), pp.609-622.
[73] Monaghan, R.M., Hedley, M.J., Di, H.J., McDowell, R.W., Cameron, K.C. and Ledgard, S.F., 2007. Nutrient management in New Zealand pastures—recent developments and future issues. New Zealand journal of agricultural research, 50(2), pp.181-201.
[74] Dijkstra, J., Oenema, O. and Bannink, A., 2011. Dietary strategies to reducing N excretion from cattle: implications for methane emissions. Current Opinion in Environmental Sustainability, 3(5), pp.414-422.
[75] Dominati, E., Maysek, F. J. F., Mackay, A. D., & Rendel, J. M. 2019. Farming in a changing environment: Increasing biodiversity on farm for the supply of multiple ecosystem services. Science of the Total Environment (in press).
[76] Maseyk, F.J., Mackay, A.D., Possingham, H.P., Dominati, E.J. and Buckley, Y.M., 2017. Managing natural capital stocks for the provision of ecosystem services. Conservation Letters, 10(2), pp.211-220.
[77] Mueller, H., Hamilton, D., Doole, G., Abell, J. and McBride, C., 2019. Economic and ecosystem costs and benefits of alternative land use and management scenarios in the Lake Rotorua, New Zealand, catchment. Global Environmental Change, 54, pp.102-112.

use practices and land use change can lead to win-win scenarios of improved economic outcomes alongside better environmental results[78]. The monitoring and management of ecosystem services provision across the region is a requirement of the Waikato Regional Policy Statement 2016[79]. Payment for ecosystem services provisions is one mechanisms to incorporate this concept into catchment land use management[80].

72. To achieve the desired water quality outcomes and ecological health set out in the NPS-FM and the Waikato River Vision & Strategy, land use practices and differences in land use capability (including soil, topography and climatic conditions) need to be considered alongside losses of nutrients and other contaminants.

73. This can be achieved by using a spatial framework based on sub-catchments; integrated contaminant management focusing on nutrients, sediment and microbial contaminants[81]; a focus on critical source areas at a property scale; mitigation options targeting stocking rates, fertiliser application and feed choices; the consideration of a wide range of edge-of-field management options (as discussed in Mr. Kessels' evidence in chief); and the inclusion of ecosystem services to monitor and incentivise land management practices for effective improvements in water quality outcomes. Such an approach will also achieve better biodiversity outcomes throughout the catchment by encouraging valuable measures such as plantings, retirement of unproductive land and the creation of biodiversity corridors (details are discussed in Mr. Kessels' evidence in chief).

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[78] Mueller, H., Hamilton, D., Doole, G., Abell, J. and McBride, C., 2019. Economic and ecosystem costs and benefits of alternative land use and management scenarios in the Lake Rotorua, New Zealand, catchment. Global Environmental Change, 54, pp.102-112.

[79] Waikato Regional Policy Statement – Te Tauākī Kaupapa here ā-Rohe. Operative since 20 May 2016. https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/RPS-Regional-Policy-Statement/WRPolicyStatement2016.pdf

[80] Fripp, E. 2014. Payments for Ecosystem Services (PES): A practical guide to assessing the feasibility of PES projects. Bogor, Indonesia: CIFOR

[81] Monitoring for these parameters could be implemented through monitoring by subcatchment groups, and conducted by landowners. While costs are associated with this, it has been shown that involving land owners in monitoring of water quality on farm can increase understanding of land use impacts on waterways, and provide an incentive to implement good management practice.

## CONCLUSION

74. Water quality in the Waikato River changes from the headwaters to river mouth, with total nitrogen and total phosphorus levels increasing alongside turbidity and *E. coli* levels. The same spatial trend can be observed for the Waipā River. These increases are partially linked to anthropogenic factors, including diffuse pollution from land use (in particular impacting nitrogen and sediment levels).

75. The National Policy Statement for Freshwater Management (NPS-FM) states that as a bottom line, the 'life supporting capacity; of freshwater systems must be safeguarded. Degradation of waterways in the Waikato and Waipā catchments is a multidimensional issue driven by pressures beyond the impacts of nutrients, and should be managed accordingly.

76. PC1 includes two primary mechanisms for achievement of the desired water quality outcomes that are set out in Table 3.11-1: a Nitrogen Reference Point (NRP) aimed at the reduction of nitrogen losses from individual properties, and the requirement of a Farm Environment Plan (FEP) for each property to limit nutrient losses from various land uses.

77. The water quality parameters chosen as part of the PC1 proposal (Table 3.11-1) fall short of encompassing attributes of overall ecological health such as oxygen levels or biota, and therefore may not be sufficient to give effect to the objectives set out in the NPS-FM.

78. PC1 should also include biodiversity indicators such as the Macroinvertebrate Community Index (MCI) and/or other measurements of biota (e.g. fish, birds), as well as consider mātauranga Māori indicators such as the cultural health index (CHI) to give effect to NPS FM and the Vision & Strategy of the Waikato River.

79. To achieve the desired water quality outcomes and ecological health, land use practices and differences in land use capability (including soil, topography and climatic conditions) need to be considered alongside losses of nutrients and other contaminants. This can be achieved by using a spatial framework based on sub-catchments; integrated contaminant management focusing on nutrients, sediment and microbial contaminants; a focus on

critical source areas at a property scale; the consideration of a wide range of edge-of-field management options; and the consideration of payments for ecosystem services provisions to incentivise land management practices for effective improvements in water quality outcomes.

**DATED** this 15th day of February 2019

Dr Hannah Mueller