BEFORE THE HEARING PANEL

AT HAMILTON

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of the Proposed Waikato Regional Plan Change 1 Waikato and Waipā River Catchments
AND	
IN THE MATTER	of Variation 1 to the Proposed Waikato Regional Plan Change 1 Waikato and Waipā River Catchments

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STATEMENT OF EVIDENCE IN CHIEF OF DR SIMON STEWART FOR THE DIRECTOR-GENERAL OF CONSERVATION

BLOCK 2

3 May 2019

Department of Conservation

Private Bag 3072
HAMILTON

Ph 07 838 5687

Email vtumai@doc.govt.nz

Counsel Acting: Victoria Tumai

Submission number: 71759

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INTRODUCTION

1. My full name is Simon Donald Stewart.

2. I hold the position of freshwater research scientist at the Cawthron Institute. I have held this position for one year.

3. I am presenting this evidence for the Director-General of Conservation (the **Director-General**) in relation to protecting and restoring the values of lake ecosystems through addressing water quality pressures in the Waikato and Waipā catchments. The evidence covers all lakes within the proposed Plan Change 1 (PC1) boundary.

QUALIFICATIONS AND EXPERIENCE

4. I hold a PhD in Limnology from the University of Waikato (2018), an MSc (Hons 1st class) in environmental science from the University of Canterbury (2011) and a BSc in biological science from the University of Canterbury (2008).

5. My PhD was entitled "Seasonal and spatial patterns in nitrogen cycling and food web interactions in a large monomictic lake, Lake Taupō, New Zealand". This project examined effects of nitrogen enrichment, and future reductions through Waikato Regional Plan 3.10 (Taupō nitrogen management), on food web dynamics in Lake Taupō including reciprocal effects of nutrient transformations on nutrient availability for phytoplankton growth.

6. My MSc was entitled "Using stable isotopes to trace the sources and fates of nitrate within mixed land-use catchments on the Banks Peninsula New Zealand". This project identified predominant land-use sources of nitrate and which invertebrate consumer groups were most impacted by elevated nitrogen.

7. Prior to beginning at the Cawthron Institute I worked as a post-doctoral research fellow at the University of Waikato on an Ministry for Business, Innovation and Enterprise 'Smart Ideas' funded project which applied stable isotope techniques to trace 'hotspots'

and 'hot-moments' of catchment nitrogen loss through to in-lake eutrophication impacts.

8. I worked for two years (2012 – 2013) at the GNS Science National Isotope Centre in Lower Hutt where I worked on developing stable isotope methods for examining nitrogen cycling processes and pollution sources in aquatic systems.

9. I was a member of the Lake Taupō nitrogen management plan change 10-year review science review board in 2018.

10. I have over ten years' experience researching nitrogen cycling, source-sink pathways and, food web impacts across a spectrum of freshwater ecosystems including headwater streams, lakes and estuaries.

11. My research has extensively focused on food web responses to ecosystem changes associated with nutrient enrichment. This has included understanding how the trout fishery in Lake Taupō will respond to expected mid-term nitrogen enrichment as well as macroinvertebrate community responses to increased nitrogen derived from gorse in headwater streams.

12. Through my research, I have authored peer-reviewed articles in international scientific journals and scientific reports. Among these are publications on novel method development, analysis and presentation of both field and experimental ecological data, model development and, high-level subject review.

13. I have been a member of the New Zealand Freshwater Science Society since 2009 (including two years as a co-opted executive committee member), a member of the International Society for Limnological (SIL), the Stable Isotope Network for New Zealand (SINNZ) and, the Associated Society for Limnology and Oceanography (ASLO).

CODE OF CONDUCT

14. While this is not an Environment Court hearing, I have read the Environment Court "Code of conduct for expert witnesses", and I agree to abide by it. I have prepared this Statement in accordance with that Code. I confirm that my evidence is within my area of expertise. I have not omitted to consider any material facts known to me that alter or detract from the opinions I express in this Statement. I have acknowledged the material used or relied on in forming my opinions and in the preparation of this Statement.

SUMMARY

15. This evidence covers freshwater lakes within the proposed Plan Change 1 (**PC1**) area, with specific focus on contaminant delivery to lakes.

16. In my opinion, water quality and ecosystem health declines in the Waikato lakes will not be halted or reversed by PC1 as it is currently proposed. This is because lakes are particularly sensitive environments and require more specific, tailored management approaches within these FMUs.

17. The single largest environmental stressor which all lakes covered by PC1 are experiencing is excessive nutrient loading. This includes both nitrogen and phosphorus forms that can enter the lake through surface water inflows, groundwater inputs, as well as recycling from lake bed sediments (i.e., internal loads).

18. Consequently, the single most important action that can be taken to prevent further degradation and enable enhancement of lake health is effective and immediate nutrient reductions. This requires reduced contaminant loads from all catchment sources (surface

and groundwater), with the aim of realising improving water quality trends in all lakes.

19. Improving water quality even in lakes with the highest water quality (i.e., those which still have extant macrophyte beds) is important as any water quality improvements will increase macrophyte health.

20. Healthy macrophyte communities are important to the ecological functioning of shallow lakes because they stabilise the lakebed, provide habitat for fish and invertebrates, substrate for ecologically important food resources, compete with phytoplankton for soluble nutrients, and maintain clear water.

21. The Plan Change 1 (**PC1**) presently only cites the requirement for maintaining present water quality, in lake catchments for which limited data exists on water quality. In my opinion this will not provide sufficient protection for the lake ecosystems because there is insufficient data available against which degradation/maintenance of water quality can be demonstrated.

22. In my opinion, setting a minimum standard of 'improvement', as opposed to 'maintain', is important for data deficient lakes as the lack of monitoring data makes it overly difficult to 'disprove' that water quality is being 'maintained'.

23. As PC1 is written, farm environment plans (FEPs) are the primary tool proposed for reducing nutrient loads and achieving the vision and strategy for the Waikato and Waipā Rivers. As such, FEPs require more concrete rules and regulations than currently proposed in order to achieve water quality targets for lakes.

24. FEPs within lake FMUs, whether in the form currently proposed in PC1 or good farm practice approach recommended in the S42-A Officers' Report, must specifically ensure that:

- Farm owners must demonstrate how they are reducing all contaminant loads
- All potential contaminant loss mitigation options should be evaluated
- All ephemeral watercourses are identified, and it is explicitly demonstrated that the most appropriate mitigation of contaminant loss risk is being implemented for all ephemeral watercourses.

25. I recommend that contaminant load reductions must be a mandatory requirement for all farms within lake FMUs as an immediate response to reduce nutrient loads in waterways. This would mitigate any potential representation issues that could arise from calculating the 75th percentile polluters based on the farms from the lower river FMU.

26. Within peat lake FMUs, already established best practice management should be compulsory within FEPs.

27. Stock exclusion rules should include sheep and goats around all lakes to reflect the demonstrated importance of riverine lakes as the primary spawning habitat for large bodied galaxiids within the Waikato River network (David et al., 2019) and the likely importance of other lakes to support significant spawning habitat.

28. Riparian setbacks of 20m should be set as a minimum across all lakes.

29. Setback buffer widths should be extended to 20 m around all riverine lakes to enable īnanga spawning in the face of naturally fluctuating water levels.

30. Setback buffer widths should be extended to 20 m around all peat lakes and their marginal wetlands in order to maintain a perennially

saturated lake margin enabling the peat to remain anoxic and attenuate nutrients before entering the lakes.

31. My recommendations can be summarised as the following:

- Water quality improvement be set as a minimum standard across all lakes
- All lakes have a minimum 10 m riparian setback from lake margin, inclusive of their marginal wetlands which is increased to 20 m for particularly sensitive habitats such as peat lakes and riverine lakes
- The initial target of high nitrogen emitters reducing their load to 75th percentile be adjusted within lake FMUs to a target of the 60th percentile
- Current best practice guidelines for farming in peat lake catchments be adopted as a rule framework
- All farm environment plans for land within lake FMUs to explicitly: rank all potential contaminant loss mitigation strategies; demonstrate contaminant load reductions; and, identify all ephemeral water courses and provide effective mitigation strategies.

SCOPE OF EVIDENCE

32. I have been asked to provide evidence specific to freshwater lakes in relation to the following matters:

- Farm environment plans
- Stock exclusion rules
- Best practice within peat lake catchments
- Nutrient reductions for the 75th percentile emitters
- Consideration of data-deficient lakes
- Riparian buffer setback widths
- Necessary measures to prevent loss of aquatic vegetation

MATERIAL CONSIDERED

33. In preparing this evidence I have considered the following information:

- Section 42A report including appendices
- For Peat's Sake – Good management practices for Waikato peat farmers
- Submission by the Director General for Conservation on Healthy Rivers Waikato Plan Change 1 Block 1
- Waikato region shallow lakes management plan: Volume 1 – Objectives and strategies for shallow lake management
- Livestock access 101: Technical guidance for DOC input to collaborative processes for regional freshwater plan development

STOCK EXCLUSION WITHIN RIVERINE LAKE FMUS

34. In the Section 42A report the officers recommend against including sheep and goats in the stock exclusion provision of PC1, in response to the Director-General's submission requesting consideration of īnanga which lay their eggs in riparian margins. Excluding sheep and goats was considered too broad for īnanga spawning habitat protection as the Officers noted "īnanga[1] typically spawn at spring tide in riparian areas that have a tidal influence" (paragraph 926). I disagree with this statement as galaxiids are known to spawn in a substantially greater range of locations than spring high-tide marks as I explain below. As such, I recommend

[1] It was unclear which definition of 'īnanga' was being applied here. Īnanga can refer to whitebait species from the family Galaxiidae as well as specifically Galaxis maculatus. I have assumed that īnanga is used here to refer to species generally from the family Galaxiidae.

that sheep and goats should be excluded from lake riparian margins for the following reasons.

35. A recent study by David et al. 2019 demonstrated that Giant Kokopu (currently listed at a declining species) and banded kokopu, are in fact primarily non-diadromous (i.e., do not have a marine life stage). The majority of adult giant kokopu (98%) and banded kokopu (97%) collected in the Waikato River catchment were spawned in the lower Waikato riverine lakes. Among other recommendations, the paper suggests that the riparian margins of riverine lakes and the lower reaches of their inflow catchments should be priority systems for restoration and habitat enhancement.

36. As noted in the Officers report, sheep and goats primarily ‘camp’ in riparian margins (paragraph 295). The impacts from camping are likely to be substantial if it is within īnanga and other galaxiid spawning habitat. Given 1) the cultural and ecological significance of īnanga and other galaxiid species; and, 2) the disproportionately high contribution of these lake systems to the overall catchment populations, stock exclusion should include sheep and goats around lakes.

37. Although David et al., (2019) looked only at a select few Waikato lakes, there is substantial potential that other lakes within the PC1 area (e.g., dune lakes and volcanic lakes in the upper catchment) are also important spawning habitat. Because of this I recommend that, while the riverine lakes are most important, stock exclusion rules should be extended to all lakes to protect galaxiid spawning. Evidence presented by Kathryn McArthur (paragraph 26), recommends GIS tools to identify likely galaxiid spawning habitat.

BEST PRACTICE MANAGEMENT FOR PEAT LAKES

38. Peat lakes are high in humic coloured dissolved organic matter (giving them their brown stained water) and have naturally low nutrient levels. Naturally, peat lakes have extensive marginal wetlands and maintain stable water levels as most of the catchment water enters the lakes via seepage flow (WRC 2006). Stable water

levels are important for maintaining macrophyte communities in these naturally low light environments. The seepage delivery through saturated anoxic peat soil acts as a 'natural denitrification bioreactor' (i.e., an area of exceptionally high denitrification rates) ensuring minimal nutrients, and particularly nitrogen, are delivered to the lakes. Internationally, humic-rich peat lakes are now recognised as naturally being nitrogen limited systems where N management should be prioritised (Daggett et al., 2015; Seekell et al., 2015; Bergström et al., 2018).

39. As a result of cultivation and drainage within peat lakes catchments, much of the water now enters the lakes via drainage surface inflows and is drained through artificial outflows resulting in two significant changes in lake ecosystem function. Firstly, water level fluctuations are substantially greater and more responsive to seasonal climate. This results in summer draw-downs when lake levels substantially lower. Secondly, nutrient delivery has greatly increased as much of the load bypasses the anoxic peat. High nutrient delivery is accentuated by dewatering of peat soils as the soils switch from anoxic denitrification 'hotspots' to oxic environments where nitrate accumulates. This can result in water with high nitrate concentrations being delivered to lakes during autumn and winter 'first flush' rains as was recorded in Lake Rotomanuka following a particularly dry summer in 2014/2015 (Lehmann et al. 2016).

40. Best practice land management guidelines have been created for the Waikato peat lake catchments (WRC 2006). The guidelines are designed to maintain water levels within peat lakes and reduce the delivery of contaminants from cultivated peat soils. These guidelines, however, have not been adopted in PC1. The guidelines' recommendations are:

- Ensure and maintain shallow depths of all drainage channels to avoid excessive peat dewatering.

- Maintain summer groundwater levels by blocking field drains in spring to reduce dewatering.

- Fence drains to reduce nutrient loss into drains.

- Minimise peat shrinkage due to tilling by banning rotary hoes and encouraging no-till cultivation methods such as direct sowing where possible.

- Restrict fertiliser application to spring and autumn to minimise losses into drains.

- Manage grazing to ensure that paddocks maintain 1200 kg dry-matter per hectare pasture cover.

41. Peat lakes are both globally unique and highly vulnerable ecosystems and, as such, I recommend that the established best practice guidelines be incorporated into PC1 as conditions of a FEP within peat lake catchments to protect and restore these lakes. For example, farming within the catchment of a peat lake could only occur if the operator can demonstrate to an auditor that:

- They have an effective system to stop drainage between spring and autumn

- All drains are fenced

- No fertilizer is applied at times where risk of loss to waterways is high

- Drain depth is maintained at minimum possible levels and shall never exceed the depth of peat

- No paddock ever has less than 1200 kg dry-matter per hectare pasture cover

42. I recommend adopting the established best practice guidelines within PC1 to minimise effects described, and to maintain water

levels within peat lakes and reduce the delivery of nutrient concentrations.

RIPARIAN BUFFER SETBACK WIDTHS

43. In the Director General's submission to Schedule C on PC1, it was recommended that 10 m stock exclusion riparian buffers are placed around all lakes apart from peat lakes, in relation to which 20 m width buffer strips from cultivation were sought. I am generally supportive of riparian buffers of a minimum width of at least 10 m but consider that a 20 m width buffer should be applied to Waikato lakes for the reasons described below. The justifications for this differ between the four lake types identified in PC 1 (peat, riverine, dune and volcanic), but in all cases, a larger buffer will act to prevent further degradation and enable recovery.

44. Minimum 10 m width buffers are recommended by an international study for maintaining supply of coarse woody debris into littoral habitat, a critical component of healthy ecosystem function in lakes (Francis and Schindler 2006).

45. Larger buffers will ensure improved littoral (near-shore) habitat through:

- increased shading and delivery of woody debris from riparian trees;
- reduced habitat damage and contaminant delivery by eliminating stock trampling (Kauffman et al., 1984);
- maintaining vegetation required for īnanga and other galaxiid spawning which is sensitive to stock grazing.

46. Protection and enhancement of lake shore margins in New Zealand is particularly important as food webs in New Zealand lakes are more reliant on littoral food resources than observed internationally (Rowe and Schallenberg 2004). Stock exclusion from riparian habitats is particularly important in the lower catchment riverine lakes as these are shown to be substantial galaxiid spawning

habitat (David et al., 2019). Large buffer widths (i.e., 20 m) are particularly important to protect īnanga and other galaxiid spawning habitat around these lakes as lake level can fluctuate drastically. Lake Waahi, for example, has fluctuated between 4 and 7 m maximum depth which, owing to its shallow lake basin with large surface area, can result in a > 30% change in surface area (Lehmann et al., 2016). A 20 m width riparian buffer should be considered minimum to enable successful īnanga and other galaxiid spawning to function in the face of natural variation in lake levels.

47. Riparian buffers of 20 m width[2] around peat lakes and their associated wetland complexes are important to help maintain perennially saturated marginal wetlands and riparian habitat by reducing water losses from evapotranspiration. This is critical for sustaining riparian nutrient attenuation capacity and reducing contaminant delivery to peat lakes.

48. Peat lakes and wetlands in the Waikato are commonly inter-connected with marginal delineation between the two. Because of this it is important to consider riparian setback buffer widths proposed here collectively with recommendations made by Dr Robertson. I support the recommendations made by Dr Robertson (paragraph 38) that all natural wetlands should be fenced and managed for reduced contaminant losses.

49. Although riverine and peat lakes remain the highest priority for having 20 m setback buffer widths for the reasons stated above, I recommend that all Waikato lakes have 20 m setbacks because:

- Waikato lakes and their specific habitat requirements to sustain biodiversity is largely unknown for many of the lakes, accordingly a precautionary approach is appropriate, and;
- it is likely that galaxiid spawning is occurring in lakes throughout the catchment particularly volcanic lakes and dune lakes which

[2] A 20 m buffer width was selected following recommendations from Davis-Colley et al., 2000 for limiting light, temperature and wind effects of edge habitat.

are not directly connected to the mainstem river and tend to have primarily land-locked fish populations; and,

- the acknowledged disproportionately important role of littoral habitat in maintaining resilient and productive food webs in lakes throughout New Zealand (Rowe and Schallenberg 2004).

50. 20 m buffer widths around all lakes is consistent with evidence presented by Kathryn McArthur (paragraph 39 of her evidence) which presents a case for 5 m and 10m setback widths for all intermittent and permanent rivers respectively and 20 m setback widths for more sensitive areas.

51. The envisaged implementation of setbacks for lakes and their catchments, and how this integrates with evidence from Kathryn McArthur and Dr Robertson is provided in Figure 1.

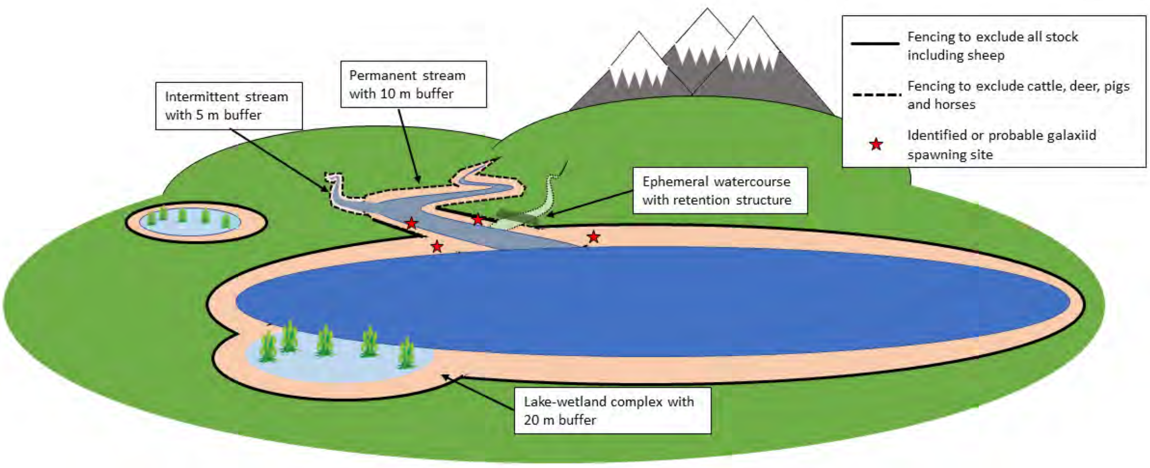

Figure 1: Conceptual representation of proposed riparian buffer setbacks and fencing requirements for lakes and their catchments.

FARM ENVIRONMENT PLANS WITHIN LAKE FMUS

52. Farm environment plans have been proposed in PC1 as the primary mechanism to reduce sub-catchment nutrient losses.

53. In principle I support the use of FEPs as this enables a tailored approach to the specific contaminant loss pathways for individual

farms; however, I believe that FEPs within lake FMUs require more prescriptive guidance recognising the unique attributes of lakes.

54. Lakes require more stringent control of contaminant loads than running waters where contaminants are continually being flushed. The ability for nutrients to elicit eutrophication impacts is far greater in lakes (Hamilton et al., 2016). Upon entry into lakes, catchment-derived nutrients accumulate and have the potential to be continually recycled within the lake, thereby degrading water quality far into the future after their time of delivery.

55. Catchment inflows to lakes essentially work as nutrient point sources delivering the vast majority of lake nutrient load (Hamilton et al., 2016). Most lake inflow streams in the Waikato region drain small catchments with minimal potential for nutrient attenuation within the stream channel.

56. Managing critical source areas and pathways of contaminant delivery prior to entering catchment streams is critical for controlling nutrients in lakes. Intercepting contaminants prior to entering first order streams is the most cost-effective strategy (McDowell et al. 2017; Krause et al., 2017).

57. Once contaminants enter the lake ecosystem and accumulate in the sediments of lakebed, mitigation measures to prevent their recycling become prohibitively expensive. This would necessitate the use of nutrient binding agents or sediment dredging. Although these management actions have occurred in a small number of high priority lakes in New Zealand (for example Lake Okaro in the Bay of Plenty) they have been extremely costly interventions (Gibbs and Hickey 2019).

58. I recommend that lake FMUs require more stringent FEPs that explicitly and demonstrably prevent or reduce all contaminant

losses to better reflect their integral role in implementing the vision and strategy for the Waikato River, and PC1.

59. I also recommend that FEPs are required to identify and rank or evaluate all potential contaminant mitigation measures to ensure that the best practicable options are implemented.

60. These recommendations are still in line with the with the S42-A Officers' Report recommendation that FEPs adopt the good farm practice approach and seek to set out specific environmental bottom lines.

61. Although sources and pathways can be specific to certain contaminants, ephemeral watercourses have been identified as priority pathways for mitigating contaminant delivery to lakes in the Waikato region.

62. The Officers recommended in the S42-A report that the definition of waterway from which stock are excluded be broadened to include all water bodies with an active bed (paragraph 900). While I support this recommendation, it still does not recognise ephemeral waterways and their importance in contaminant delivery.

63. Ephemeral watercourses are important contaminant delivery pathways and should be explicitly dealt with on-farm. A range of viable management options have been suggested including detainment bunds, silt traps and constructed wetlands. I support the current approach of the certified farm environment planner deciding on which intervention is best suited to specific farm landscapes and systems.

64. I recommend having a requirement that there be specific provision within FEPs within lake FMUs that landowners must identify all ephemeral watercourses on their property and demonstrate that they are implementing the most effective measure to reduce risk of contaminant losses from ephemeral watercourses.

65. In summary I recommend changes to the requirements for FEP's in schedule 1 so that FEPs within lake FMUs must:

- Explicitly demonstrate contaminant loss reductions
- Quantify and evaluate all potential contaminant loss mitigation measures
- Specifically identify all ephemeral watercourses and demonstrate that the most appropriate mitigation of contaminant loss risk is being implemented for all ephemeral watercourses.

MEASURES TO PROTECT AQUATIC PLANTS.

66. Macrophytes (submerged aquatic plants) are critical for the healthy functioning of lake ecosystems and food webs. Macrophytes:

- reduce shear-stress on sediments, lowering resuspension of sediment and nutrients;

- provide structure on which micro-algae can grow – the most important basal food resource supporting food webs in New Zealand lakes (James et al. 2000; Kelly and Hawes 2005);

- provide refugia for organisms from predation, and 4) compete with phytoplankton for soluble nutrients thereby maintaining lower algal biomass in the lake water column.

67. Macrophytes are progressively degraded by cumulative stressors associated with eutrophication to the point where they disappear. As nutrient loads to lakes increase, these stressors are:

- increased covering of epiphytic algae on plant fronds (Sand-Jensen and Søndergaard, 1981);
- reduced rooting depth as the anoxic sediment boundary rises closer to the sediment surface (Drew, 1997);
- reduced water clarity reduces light penetration to the lake bottom (Sand-Jensen and Søndergaard, 1981).

68. While macrophyte presence often follows an abrupt threshold relationship with increasing eutrophication, macrophyte health declines in a more linear fashion in the build-up to collapse.

69. Once macrophytes disappear, they are extremely difficult to re-establish. Re-establishment is difficult because:

- of lack of vegetative dispersal – i.e., fronds breaking off and establishing new plants (Kuiper et al., 2017);
- continual sedimentation results in the seedbank being deeper and less viable (de Winton et al., 2000);
- viable macrophyte seeds will rapidly germinate even when conditions are not conducive to establishment resulting in depletion of the seedbank (de Winton et al. 2004).

70. As highlighted in Block 1 evidence by Dr Phillips, it is estimated that only 22% of Waikato lakes currently have extant macrophyte communities.

71. Because of the reasons stated above, extant macrophyte beds in Waikato lakes are significant and should be a priority for protection in PC1. (refer Appendix 2).

72. Protection of extant macrophyte beds is best achieved through reducing external nutrients thus enabling macrophyte health to improve.

73. Consequently, I support the S42 A Officers' Report which recommends an amendment to Policy 1 so that instead it specifically seeks to '*<u>Reduce</u> catchment wide and sub-catchment diffuse discharges*' as also highlighted in paragraph 32 of evidence from Dr Robertson.

74. Immediate reductions of diffuse discharges of contaminants in lake FMUs are fundamental for preserving extant macrophyte beds as

well as creating conditions conducive to eventual re-establishment effort in other lakes.

CLASSIFICATION OF 75TH PERCENTILE NITROGEN EMITTERS WITHIN LAKE FMUS

75. In the S42-A report, the Officers state that due to the small number of farms within lake FMUs, the 75th percentile nitrogen emitters will be calculated based on the values from the larger lower river FMU.

76. While I understand the justification for this approach, I have concerns that it could result in a situation where lake catchments, which are vulnerable priority ecosystems, are underrepresented in the reductions.

77. Under-representation of high N-polluters within lake catchments would occur if lake FMUs have lower mean leaching rates. This situation would directly conflict with the S42-A Officers' recommendation that lake FMUs be given the highest priority to reflect their vulnerability and long recovery times.

78. This is largely a matter of timing as the long residence time of nutrients in lakes demands immediate action be taken in their catchments. In order to achieve 80 years targets, such as those outlined in Block 1 evidence by Dr Phillips (Appendix 1), urgent initial action is needed.

79. Furthermore, given the current assignment of a large number of small lakes with few individual farms in their catchments to only four FMUs, it is completely plausible that entire catchments for vulnerable lakes may end up not having any nutrient reductions for the first 10 year cycle of PC1.

80. However, it should be pointed out that adopting the revised lake FMUs proposed in the Block 1 evidence of Dr Phillips would go some way to alleviating this issue as individual lakes would be better accounted for.

81. Calculating thresholds for N reductions using the riverine FMU also does not account for the fact that lakes are far more effective at

converting nutrients into phytoplankton (chlorophyll a) than the mainstem Waikato River. In Table 1, I have compared nutrient: chlorophyll a ratios published by Verburg (2016) to natural lakes within the PC1 area from Waikato Regional Council monitoring data (obtained via local government official information request). This shows that the natural lakes on average produce more chlorophyll relative to both nitrogen and phosphorus than the mainstem Waikato River (Table 1). This is despite some of these lakes (e.g., Lake Waikare) having amongst the highest TN concentrations of any lake in the world (Abell 2018).

Table 1: Comparison of mean and median chlorophyll-a : nutrient ratios for total phosphorus (TP) and total nitrogen (TN) in natural lakes within PC1, mainstem Waikato River and Waikato River hydroelectric reservoir monitoring sites. PC1 lake data were obtained by local government official information request and hydro lake and mainstem data were reproduced from Verburg (2016).

Habitat type	Comparison type	Chl-a/TP	Chl-a/TN
Natural lakes	Mean	0.60	0.03
Mainstem river	Mean	0.22	0.02
Hydro-lakes	Mean	0.31	0.01
Natural lakes	Median	0.49	0.02
Mainstem river	Median	0.24	0.02
Hydro-lakes	Median	0.32	0.02

82. The stronger nutrient responses described above demonstrate the problem with assuming equivalency of nutrient between riverine and lake catchments.

83. Additional regulations, specifically within the first 10 years, are needed to ensure that these lakes receive the immediate contaminant load reductions which they require. Three possible solutions are:

i. Require 25% nutrient reductions across all farms within lake FMUs

- This is a simple option and similar than that used in the Taupō catchment N management (Waikato Regional Plan 3.10); however, it provides little flexibility without the N-trading scheme currently used in the Taupō catchment

- This approach also does not recognise and account for the disproportionate contribution that the highest polluters make to catchment nutrient budgets. By setting reductions equally across all emitters, it could be argued that low emitters are being unfairly penalised (Duhon et al., 2015).

ii. Adjust the 75th percentile for each lake relative to its median leaching rate.

- This option reflects the vision of the current approach but calculating median leaching rates for each lake catchment may be difficult.

- This approach also does not explicitly recognise inherent differences in nutrient impacts between rivers and lakes.

iii. Reduce the threshold for action and the target to 60th percentile for lake FMUs. The 60th percentile was chosen here as it best reflects differences in nitrogen use efficiency between rivers/reservoirs and lakes from the most recent peer-reviewed international synthesis study (Maranger et al., 2018)[3].

- This approach recognises and accounts for differences in nutrient impacts between rivers and lakes

- It also addresses the concerns raised in the S42-A Officers Report of limited data for Lake FMUs by still

[3] Nitrogen use efficiency (i.e., the ability for N to convert into algae biomass) was estimated from median seston C:N ratios for lakes and rivers and reservoirs which were taken from published data (Maranger et al., 2018). The difference between lake seston (C:N = 13.0) and river/reservoir seston (C:N = 9.25) indicated that lakes require a 29.8% greater reduction in N to achieve comparable environmental outcomes. Lowering the target point to the 60th percentile represents a 28.7% greater reduction when assuming that each consecutive percentile contributes an additional 2.5%.

fundamentally being based on leaching rates for the entire Lower Waikato FMU.

84. Ultimately, specific catchment nutrient reduction targets will have to be set for individual lake sub-catchment requirements to achieve 80-year lake goals – these will vary depending both on catchment loads but also lake characteristics not captured by the current four lake FMU classifications such as: hydraulic residence time, wind fetch and mean depth.

85. I recommend the third option stated above; that the nitrogen targets be set at the 60th percentile within all lake FMUs. This approach maintains PC1's current strategy of targeting the heaviest polluters first and addressed the noted concerns of insufficient data for calculations within lake FMUs while also providing appropriate measures to reduce nutrient loads within lakes.

ACCOUNTING FOR DATA-DEFICIENT LAKES WITHIN MANAGEMENT

86. The national objectives framework for lakes has been adopted for setting targets in PC1. Levels within the bands are set based on statistical measures, namely median and 95% confidence interval values. Being population measures, these two parameters are both sensitive to the sample size analysed. For example, comparing two populations with identical minimum, maximum, mean and median values but differing sample sizes, the population with the larger sample size will have a smaller 95% confidence interval. Correspondingly, as the sample size increases through time, the 95% confidence interval will inherently decrease. This 'sampling effect' is strongest when sample sizes are small relative to natural variation within the population.

87. Variance is not just a statistical artefact; it is also an important ecological phenomenon. Concentrations of chlorophyll, nitrogen and phosphorus all become increasingly variable within lakes as they become more eutrophic and potentially approach, or cross, tipping points (Wang et al., 2012; Rusak et al., 2018). The data

available indicates that many of the lakes within PC1 are eutrophic to super eutrophic and demonstrate significant variability and will require large datasets to validate water quality status and trends (Özdundakci and Allen 2018).

88. Given that approximately a quarter of lakes within PC1 currently have better water quality than their targets (NOF ‘C band’) and hence are proposed to be managed for ‘no decline’, sufficient data to enable trend analysis is critical for effective management.

89. Furthermore, with no baseline data to compare against (i.e., before vs. after comparison), trend analysis is the only meaningful way that ‘decline’ can be demonstrated.

90. In a statistical framework, managing for ‘no decline’ makes it overly difficult to prove that a decline is indeed occurring. Trend analysis typically requires 95% confidence to acknowledge a trend. This could result in a situation where contaminant concentrations increase but because they are variable through time and due to insufficient data, there will be insufficient statistical power to attribute a declining trend. The lake in this hypothetical situation would be listed as ‘no decline’

91. A simple solution is to set a target of ‘improvement’ across all lakes. This would result in more appropriate use of trend analysis. Targeting for ‘improvement’ is also more consistent with the vision and strategy – ‘safe to swim in and gather food from’ – in PC1.

92. As highlighted by Dr Philips’s Block 1 evidence, all lakes that fall within PC1 currently fall within B band or lower with most being below the D band. Hence, a blanket rule of water quality improvement across all lakes is pragmatic and would not result in situations where lakes with good water quality (A band) are required to improve and would not be able to. All of the lakes within the PC1 geographic area have significant ‘room for improvement’ in their water quality.

93. Specific improvements for individual lakes could be more effectively tailored through applying the revised lake FMUs and lake FMU targets outlined in the Block 1 evidence of Dr Phillips (Appendix 1),

after the initial 10 years. However, this would only be achievable if reasonable improvements were made in the initial 10 years.

94. In summary, I generally support the use of the national objectives framework for assessing lake water quality; however, to ensure the viability of the proposed framework, for the reasons stated above, I recommend that all lakes within PC1 be managed for improvement.

CONCLUSIONS

95. The lakes within the Waikato region covered within PC1 are ecologically and culturally significant. They are also extremely vulnerable to impacts from nutrient enrichment. To prevent further degradation and restore ecological health in these lakes I recommend that:

- Water quality improvement be set as a minimum standard across all lakes
- All lakes have a minimum 20 m riparian setback from lake margin, inclusive of their marginal wetlands
- The initial target of high nitrogen emitters reducing to their load to 75th percentile be adjusted within lake FMUs to a target of the 60th percentile
- Current best practice guidelines for farming in peat lake catchments be adopted as a rule framework
- All farm environment plans for land within lake FMUs to explicitly: rank all potential contaminant loss mitigation strategies; demonstrate contaminant load reductions; and, identify all ephemeral water courses and provide effective mitigation strategies.

96. In my opinion these options are the best available to achieve the vision and strategy of the Waikato and Waipā Rivers through PC1.

Dr Simon Donald Stewart

3rd May 2019

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Appendix 1 – Table of alternative lake freshwater management units and associated targets

This table was presented by Dr Ngaire Phillips to the Healthy Rivers PC1 commissioners on the 25th of March 2019.

FMU#	Annual median Chla (mg/m^3)				Annual Median TN (mg/m^3)				Annual Median TP (mg/m^3)			
	Short-term target*		Long term year target (80 years)		Short-term target *		Long term year target (80 years)		Short-term target *		Long term year target (80 years)	
1	33	D	12	C	674	C	500	B	124	D	50	C
4	22	D	12	C	1489	D	750	C	94	D	50	C
5	30	D	12	C	1186	D	750	C	79	D	50	C
6	12	C	5 - 12	B-C	1197	D	500-750	B-C	50	C	50	C
7	24	D	12	C	1218	D	750	C	97	D	50	C
9	2	A	2	A	394	B	300	A	11	B	10	A
10	46	D	12	C	1488	D	800	C	95	D	50	C

- Short-term target = 20% improvement on current state (medians for each FMU)
- Long term targets as per PC1 Table 3.11-1, except red text, which are targets proposed by Director-General that reflect what is considered achievable based on current state

Appendix 2. Lake SPI Index for Waikato Lakes.

Figure was presented by Prof. David Hamilton to the Healthy Rivers Collaborative Stakeholder Group Workshop 6. Data is adapted from NIWA report: HAM2013-034.