Before the Environment Court **At Wellington** **I Mua I te Kōti Taiao** **Te Whanganui-a-Tara Rohe**	**ENV-2019-WLG-000106** **ENV-2019-WLG-000122** **ENV-2019-WLG-000125** **ENV-2019-WLG-000130**

Under	Clause 14, Schedule 1 of the Resource Management Act 1991
In the matter of	appeals on the Proposed Natural Resources Plan
Between	**Minister of Conservation** **Appellant**
And	**Wellington Fish and Game Council** **Appellant**
And	**Rangitāne Tū Mai Rā Trust and Rangitāne o Wairarapa Incorporated Society** **Appellant**
And	**Royal Forest and Bird Protection Society** **Appellant**
And	**Wellington Regional Council** **Respondent**
And	**Various** **Section 274 parties**

Statement of evidence of Antonius Hugh Snelder on behalf of Wellington Regional Council (Water quality trends)

Date: 14 June 2021

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INTRODUCTION

1 My full name is Antonuis (Ton) Hugh Snelder. I am a director of LWP Ltd and consultant/researcher in the field of water resources management.

2 I have prepared this statement of evidence on behalf of the Wellington Regional Council (**Council**) in respect of planning related matters arising from the appeals by the Minister of Conservation, The Royal Forest and Bird Protection Society, Rangitāne Tū Mai Rā Trust and Rangitane o Wairarapa Incorporated Society and the Wellington Fish and Game Council against the Council's decision on the Proposed Natural Resources Plan for the Wellington Region (**PNRP**).

3 Specifically, this statement of evidence relates to the matters raised in respect of water quality through Topics 29, 30 and 31.

QUALIFICATIONS AND EXPERIENCE

4 I hold a bachelor of agricultural engineering degree from the University of Canterbury, a post graduate diploma in hydrology from the University of New South Wales (Australia) and a PhD in environmental management from Lincoln University. I have 35 years of experience in the field of water resource management including 14 years as a water resources scientist at the National Institute of Water and Atmosphere (NIWA), and prior positions in regional councils and in consultancies as a water resources engineer. I am a specialist in the field of water quality.

5 In my current and previous positions, I have led many projects that have assessed water quality in freshwater environments and the association between water quality and land use at regional and national scales. I have written several guidelines for the management of water quality and quantity and developed several tools for water management purposes. I have authored or co-authored 50 scientific publications in the field of water resources management, including those that address water quality. I led or contributed to a sequence of studies (2002, 2003 and 2010,

2015, 2018) that analysed and reported on river and lake water quality state and trends at the national scale for the Ministry for the Environment and Statistics New Zealand. I regularly undertake analyses of water quality data for regional councils and have been involved in the development of methods of water quality analysis. I am also a specialist in water quality modelling. I recently led the development of national guidelines for the analysis of temporal trends in water quality data (Snelder *et al.*, 2021).

6 I am a member of the Freshwater Sciences Society of New Zealand and the Hydrological Society of New Zealand.

Code of conduct

7 I have read the Code of Conduct for Expert Witnesses set out in the Environment Court's Practice Note 2014. I have complied with the Code of Conduct in preparing my evidence and will continue to comply with it while giving oral evidence before the Environment Court. My qualifications as an expert are set out above. Except where I state I rely on the evidence of another person, I confirm that the issues addressed in this statement of evidence are within my area of expertise, and I have not omitted to consider material facts known to me that might alter or detract from my expressed opinions.

SUMMARY

8 I provided evidence concerning water quality trends in rivers of the Wellington Region based on two studies to the first stage Council's PNRP hearing process. Degrading river water quality trends may indicate that there is pressure on aquatic receiving environments through increased resource use (e.g., land use change or intensification).

9 The first study analysed trends for individual sites and 18 water quality indicators using data collected at Council's 61 long-term river monitoring sites. Trend directions for the 10-year period ending December 2016 were variable across sites and indicators. However, there was a dominance of improving trends for several indicators

including nutrients (i.e., total phosphorus, dissolved reactive phosphorus, total nitrogen and dissolved nitrogen) and water clarity and turbidity. The dominance of improving trends in these indicators is inconsistent with broad-scale intensification of resource use, in particular intensification of agriculture.

10 The second study characterised regional water quality trends (i.e., changes that are occurring in a consistent manner at many river sites across the Region). Regional trends were evaluated by aggregating the individual site trends derived by the first study using two methods. The first method indicated that over all water quality indicators, 66% of site trends were categorised as at least as 'likely as not' to be improving and for total phosphorus, total nitrogen, dissolved nitrogen and water clarity 70% or more of sites were at least 'likely' to have improving trends. The second method indicated that there were statistically significant improving regional trends in water clarity, total phosphorus, total nitrogen, dissolved nitrogen and chlorophyll and there were no statistically significant degrading regional trends.

11 As part of expert conferencing associated with the PNRP Council hearing my original studies (i.e., studies 1 and 2) were strongly critiqued. I undertook additional analyses to establish the robustness of the assessments undertaken in my second study. These additional analyses did not cause me to change my original conclusion that there had been a dominance of improving trends at the regional level and there was strong evidence of improving regional water quality trends over the 10-year period ending December 2016. The joint witness statement noted that the additional analyses increased the robustness of my original findings. As experts, we agreed that there was no evidence of region-wide degradation over the study time-period.

12 Water quality trends over periods of 5 to 15 years can be strongly influenced by inter-annual climate variability. Climate variation can compensate for, or amplify, the effects of anthropogenic drivers of trends and therefore lead to incorrect conclusions about whether there is evidence of resource use pressure on aquatic receiving environments. Subsequent to the PNRP hearing I undertook a third study to analyse, to

the extent that is possible with current scientific knowledge, the potential influence of climate variation on river water quality trends in the Region for the 10-year period ending December 2017.

13 The third study indicated that most water quality trends for the assessed physical and chemical indicators over the 10-year period were consistent with climate variation. Anthropogenic factors were associated with a minority of degrading trends (<10%). In addition, the results indicated that >20% had improving trends that were associated with anthropogenic factors. My interpretation of these results is they are evidence that changes in anthropogenic factors in the Region more likely contributed to regional water quality improvement than degradation over the study time-period.

14 My overall conclusion is that the three studies described above provide strong evidence of water quality improvement across the Wellington Region over the past decade (i.e., ending December 2017). Water quality has degraded at some sites and for some indicators, but this is isolated rather than occurring in a consistent and region-wide manner. Predominantly improving trends in nutrient concentrations (e.g., dissolved forms of nitrogen and phosphorus) are particularly relevant to the question of whether broad-scale changes in resource use are influencing water quality because intensification of agriculture can be expected to increase nutrient concentrations. Based on these findings, I conclude that there is no evidence that broad-scale changes in resource use across multiple catchments has degraded regional scale water quality in the Region over the past decade.

INVOLVEMENT WITH THE PROPOSED PLAN

15 I provided evidence to the first stage council PNRP hearing process concerning water quality trends in rivers of the Wellington Region. That evidence was based on two studies that I undertook, Snelder (2017) and Snelder (2018). In addition, I undertook further analyses of river water quality trends, which were carried out because of questions raised during expert conferencing.

16 I have been asked by the Council to provide expert evidence in relation to the appeal on the water quality issues topic. I understand the issues primarily relate to whether the PNRP provisions are a sufficient basis for managing water quality issues in the Region prior to completion of the whaitua-based objective and limit setting processes.

SCOPE OF EVIDENCE

17 My statement of evidence addresses recent changes (trends) in river water quality in rivers of the Wellington Region. Degrading river water quality trends may indicate that there is pressure on aquatic receiving environments (i.e., rivers, lakes and coastal environments) through increased resource use (e.g., land use intensification). Improving water quality trends may indicate that management interventions are being effective (e.g., improvements to point source discharges or mitigation measures to reduce non-point sources). Therefore, knowledge of recent changes in river water quality is important for judging the adequacy of the water quality management provisions of the PNRP.

WATER QUALITY TRENDS

18 Council has operated a network of 61 long-term state of environment (SoE) river monitoring sites at which observations of several water quality indicators have generally been made on a monthly basis since the mid-2000s. Water quality changes through time have been assessed by trend analyses of the monthly observations of each indicator at each individual site in three separate studies that are explained below. Trend assessment involves building a statistical model of the change in the observations over a time-period of interest. The observations are subject to random fluctuations and only comprise a sample of the indicator's behaviour over the time-period. Therefore, statistical modelling of trends involves estimating the direction and rate of change of the water quality indicators and the uncertainties associated with these two estimates.

19 Trends at individual monitoring sites may reflect impacts of resource use changes in that site's upstream catchment. For example, a trend in

nitrogen may occur due to intensification of land use on one or more farms in the catchment upstream of that site. Trends that are repeated at many monitoring sites may reflect broad-scale changes in resource use across multiple catchments. For example, increasing trends in nitrogen at many sites across a region may reflect widespread increases in land use intensity. Equally, decreasing trends in phosphorus at many sites across a region may reflect widespread uptake of management measures aimed at reducing phosphorus losses.

20 It is important to acknowledge that trend analysis detects changes in water quality indicators but is uninformative about the causes of those changes. While trends that are repeated at many monitoring sites may indicate that broad-scale changes in resource use are influencing water quality, it is not possible to be certain about this or to know which specific resource use changes are driving the trends. In addition, not all broad scale water quality changes are attributable to changes in resource use. For example, degrading water clarity trends at many monitoring sites may reflect widespread increases in erosion associated with a major storm event. Recently, it has become clearer that inter-annual climate variation can have a considerable impact on trends for a wide range of variables including nutrients (nitrogen and phosphorus), water clarity and turbidity, organic matter content and water temperature. The influence of climate on water quality trends is complex and is likely to confound associations between changes in resource use and water quality changes. The effects of climate variability on water quality trends may amplify or mask the effects of other drivers of water quality trends.

STUDIES OF RIVER WATER QUALITY TRENDS IN THE WELLINGTON REGION

Trend assessment studies

21 I have undertaken three recent studies concerning river water quality trends in the Wellington Region. Studies 1 and 2 were used in evidence at the PNRP Council hearing and Study 3 has been undertaken subsequently.

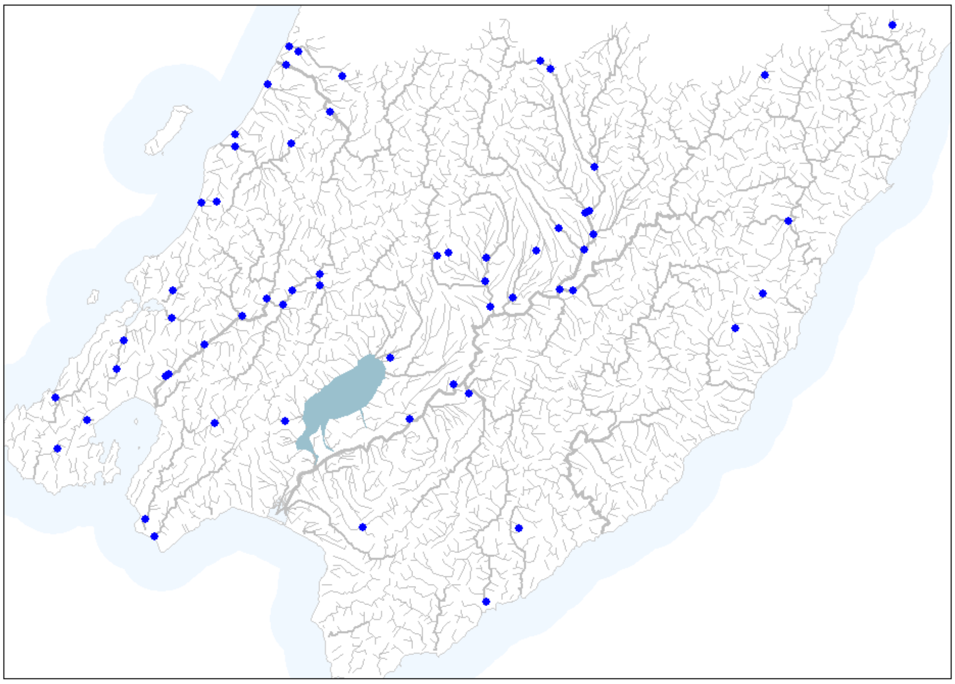
22 In all studies, trends have been quantified in terms of the direction and rate of change of the water quality observations through a fixed time-period. These assessments were consistent with the recently released national guidance for trend assessment for water quality data (Snelder *et al.*, 2021). The key outputs that are focussed on below are the assessment of trend direction and the associated estimate of confidence in that direction.

23 The first study focussed on assessing trends at individual sites and for each water quality indicator. In this study, trend direction for each site and indicator combination was categorised as either increasing or decreasing "established with confidence" if the statistical model indicated 95% or greater confidence in the assessed direction and was otherwise categorised as uncertain. It is noted that this follows a traditional and conservative requirement of a high level of confidence (i.e., 95%) before declaring a trend in an indicator at an individual site.

Assessment of water quality trends at individual sites

24 I undertook an assessment of water quality trends in data collected on a mostly monthly basis at 61 individual river water quality monitoring sites in the Wellington Region (Figure 1). Trends in up to nine physical, chemical and microbiological and water quality indicators were assessed at each site (Table 1). Trends in up to nine biological indicators (five measures of periphyton (riverbed algae) and four measures of the invertebrate community) were assessed (Table 1). Not all indicators were measured at every site and therefore the number of sites for which trends were assessed varied by indicator. Trends were assessed for sites that had sufficient data for three time-periods that all ended December 2016: 5-year period, 10-year period and 28-year period.

Figure 1. Water quality monitoring sites used by Snelder (2017) and showing the regional river network. Note that some river systems (i.e., catchments) have more than one site.



25 Snelder (2017) reported trends for all three time periods but only trends for the ten-year period are presented below. Although climate variation affects water quality trends of ten years duration and longer (see below), trends of five-years duration are very strongly confounded by the effects of climate variability. It is my opinion that 5-year trends are too influenced by climate variation to be used to consider whether there are broad-scale changes in water quality. The 28-year trends are not presented below because these could only be evaluated for a limited number of sites (five) for which monitoring had commenced in 1989. The 28-year trends are therefore not representative of the Region.

26 Snelder (2017) assessed trends based on both the 'raw' observations and the observations after a process called 'flow adjustment'. Flow adjustment is carried out as part of river water quality trend assessment because observed values of water quality indicators can be affected by river discharge (i.e., flow) at the time that observations are made. The influence of discharge on the observations is a source of 'noise' (i.e., random variation) that reduces the 'signal' (i.e., the trend) and therefore the confidence in the trend assessment. Flow adjustment removes the influence of river flow on the observations, which can thereby increase

confidence in assessments. However, flow adjustment can only be performed if water quality observations are made at, or close to, a river flow recording site. This was not always the case for Council's monitoring network with 12 sites not being associated with flow recorders. Snelder (2017) compared results of trend assessments made using raw and flow adjusted observations and found that although there could be appreciable differences for individual site and indicator combinations, there was generally a high level of correspondence between the two sets of trends. Snelder (2017) concluded that patterns of trends (i.e., over many sites) are not affected by whether assessments are based on raw or flow adjusted observations. Therefore, in this evidence I have reported only trends assessed using raw observations to maximize the number of sites representing the Region.

27 In general, the trend assessments for the 10-year period indicated trend direction and confidence in direction was variable across sites and indicators. Some water quality indicators exhibited more consistent directions across sites. For example, trends in water clarity and turbidity indicated improving water quality at most sites over the 10-year period. Other notable river water quality trends were a dominance of decreasing (i.e., improving water quality) ten-year trends in nutrient indicators (i.e., total phosphorus, dissolved reactive phosphorus, total nitrogen and dissolved nitrogen species). Decreasing trends in nutrient concentrations are particularly relevant to the question of whether broad-scale changes in resource use are influencing water quality because intensification of agriculture can be expected to increase nutrient concentrations. Most analyses of the eight biological indicators (including riverbed periphyton and the invertebrate community indicators) produced uncertain trends and where trend directions were established with confidence, there was a mix of both improving and degrading trends.

Table 1. River water quality indicators included in the Snelder (2017 and 2018) studies.

Variable type	Abbreviation	Description	Units
Physical and chemical	Clar	Black disc clarity (Field)	m
	Turb	Turbidity	NTU
	DRP	Dissolved reactive phosphorus	mg/L
	TP	Total phosphorus	mg/L
	NO_3-N	Nitrate-nitrogen	mg/L
	NNN	Nitrite nitrate-nitrogen (often referred to as dissolved inorganic nitrogen; DIN)	mg/L
	TN	Total nitrogen	mg/L
	TOC	Total organic carbon	mg/L
Microbiological	*E. coli**	*Escherichia coli*	n/100 mL or cfu/100 mL*
Invertebrates**	MCI	MCI score	unitless
	QMCI	Semi quantitative MCI score	unitless
	%EPT	Proportion of individuals belonging to EPT orders	%
	%EPT_Taxa	Proportion of taxa belonging to the EPT orders	%
Periphyton	Mats-Mean	Mean annual cover by mats	%
	Mats-Max	Maximum annual cover by mats	%
	Fils-Mean	Mean annual cover by filaments	%
	Fils-Max	Maximum annual cover by filaments	%
	Chla	Biomass as chlorophyll-a	mg/m^2

Regional trends

28 I undertook a second study to characterise regional water quality trends in water quality indicators (i.e., trends that are occurring in a consistent manner at a majority of sites across the region, Snelder, 2018). I evaluated 'regional trends' by aggregating the individual site trends assessed for the 18 water quality indicators at 62 sites described above (i.e., based on the results of Snelder, 2017). The study considered regional trends for both the 5-year and 10-year time-periods ending December 2016 but, for reasons discussed above, only the 10-year trends are discussed below.

29 Two methods of trend aggregation were used. The first method was based on assigning to all trends a categorical level of confidence that the

assessment indicated water quality improvement. This assignment is based on converting the estimate of confidence in the assessed direction into a confidence the trend direction indicates improvement (hereafter, ‘confidence the trend was improving’). For most variables shown in Table 1 a decreasing trend indicates water quality improvement. The exceptions to this are water clarity and the invertebrate indicators for which an increasing trend indicates improvement.

30 The first study used a binary “confident” or “uncertain” classification to trends for individual sites and indicator combinations based on the 95% confidence threshold. This level of certainty generally results in many uncertain trends when applied over many sites and indicators. In the first study, 77% of the raw ten-year trends were uncertain. This result is unhelpful when considering region-wide trends because most trends are consigned to being “uncertain”. However, this evaluation arises because the traditional 95% confidence requirement and binary classification for individual sites and indicator combinations is very restrictive. If only the trends that are ‘established with confidence’ (i.e., with 95% confidence) were used to assess region-wide trends a significant amount of information would be discarded. To understand this, consider a region where all trends were in the same direction but confidence in direction at all sites was only 90%. There are therefore no sites that for which trends that are ‘established with confidence’ but there is clearly a consistent pattern of water quality change across the region. The first method of trend aggregation, therefore, was to use all the available information by assigning each trend to one of nine potential confidence categories shown in Table 2. Note that trends that were ‘established with confidence’ in the first study were assigned to the categories ‘Virtually certain’ or ‘Extremely likely’. The cumulative proportion of sites in each of the trend categories shown in Table 2 were then tabulated. This tabulation (Table 3) provides a quantification of the degree to which there is a dominance of improving trends (or the complement; degrading trends) at the regional level.

Table 2. Categorical levels of confidence the trend was improving. The levels follow those used by the International Panel for Climate Change (Mastrandrea et al.*, 2010). Note that improving trends correspond to decreasing trend directions for all variables in Table 1 except visual clarity and the invertebrate variables.*

Categorical level of confidence	Confidence the trend was improving
Virtually certain	0.99-1.0
Extremely likely	0.95–0.99
Very likely	0.90–0.95
Likely	0.67–0.90
About as likely as not	0.33–0.67
Unlikely	0.10–0.33
Very unlikely	0.05–0.10
Extremely unlikely	0.01–0.05
Exceptionally unlikely	0–0.01

31 The results shown in Table 3 indicate that for the ten-year time-period and over-all water quality indicators, 66% of site trends were categorised as at least as 'likely as not' to be improving. For the physical and chemical indicators Clar, TP, NO3-N, NNN and TN, 70% or more of sites were at least 'likely' to have improving trends. Across all indicators, a minimum of 53% of sites were at least as 'likely as not' to have improving trends. Snelder (2018) concluded these results indicate that although water quality has not improved everywhere over the ten-year period, degradation was relatively isolated, and the dominant pattern (i.e., the regional trend) was one of improving water quality.

Table 3. Cumulative proportion of sites (%) with ten-year improving raw trends with at least the level of confidence indicated.

Variable	No. sites	Virtually certain	Extremely likely	Very likely	Likely	Likely as not
Clar	52	46	62	75	88	90
Turb	56	18	27	34	55	66
DRP	35	11	23	26	49	66
TP	45	33	49	53	71	87
NO_3-N	50	28	32	46	70	72
NNN	55	25	31	42	71	75
TN	40	42	60	68	82	92
TOC	51	6	16	22	45	75
E. coli	55	13	24	31	47	58
Fils-Max	47	4	11	17	55	68
Fils-Mean	45	4	11	18	40	76
Mats-Max	45	0	9	13	29	53
Mats-Mean	45	9	20	24	44	80
%EPT	45	2	13	18	31	73
%EPT_Taxa	54	2	6	9	41	57
MCI	54	0	7	22	50	63
QMCI	54	2	2	13	35	52

32 The second method of trend aggregation was based on assessing the proportion of improving trends. The binomial test was used to assess whether the evaluated proportion of improving trends was greater than would be expected by chance for each water quality indicator. If the proportion of improving trends was statistically significantly greater than could be expected by chance, it was concluded that there had been a significant improving 'regional trend'.

33 The results shown in Table 4 indicate that for the ten-year time-period and most water quality indicators, a higher proportion of sites had improving rather than degrading trends. The mean proportion of improving site trends over all indicators was 62%. There were significant improving regional-trends in Clar, TP, NO3-N, NNN, TN and Chla. Snelder (2018) concluded that these results indicate that there has been a dominance of improving trends at the regional level and are

strong evidence of an improving regional water quality trend over the time-period.

Table 4. Ten-year regional trends based on raw site trends.

Indicator	No. sites	No. decreasing	No. increasing	Proportion improving	Binomial p-value	Adjusted p-value	Regional trend
Clar	52	5	47	90	<0.001	<0.001	Improving
Turb	56	35	21	62	0.081	0.182	Not Significant
DRP	35	20	14	57	0.311	0.431	Not Significant
TP	45	36	10	80	<0.001	<0.001	Improving
NO3-N	50	35	14	70	0.003	0.011	Improving
NNN	55	40	14	73	<0.001	<0.001	Improving
TN	40	36	5	90	<0.001	<0.001	Improving
TOC	51	33	19	65	0.092	0.184	Not Significant
E. coli	55	29	26	53	0.788	0.834	Not Significant
Chla	47	32	15	68	0.019	0.057	Improving
Fils-Max	45	28	17	62	0.135	0.203	Not Significant
Fils-Mean	45	19	26	42	0.371	0.477	Not Significant
Mats-Max	45	27	17	60	0.135	0.203	Not Significant
Mats-Mean	45	24	21	53	0.766	0.834	Not Significant
%EPT	54	24	30	56	0.497	0.596	Not Significant
%EPT_Taxa	54	20	33	61	0.134	0.203	Not Significant
MCI	54	26	27	50	1	1.000	Not Significant
QMCI	54	33	20	37	0.076	0.182	Not Significant

Additional analyses resulting from PNRP hearing

34 The results of the above two studies were presented in evidence during the PNRP hearing process. Based on the above results, my position was (and is) that there is strong evidence of water quality improvement across the region over the past decade. It was my opinion that water quality has not improved everywhere, but degradation was isolated rather than occurring in a consistent and regional scale manner.

35 During the PNRP hearing process, five technical limitations of the above studies were identified by Dr Adam Canning representing Wellington Fish and Game Council and Ms Kate McArthur representing the

Minister of Conservation and Rangitāne. Because of these limitations, Dr Canning and Ms McArthur had reservations about my conclusion that there was strong evidence of water quality improvement across the region over the past decade.

36 Four of the technical limitations identified were addressed by me in subsequent analyses, all of which were presented to the PNRP hearing process. These four issues were: (1) performing multiple binomial tests may have led to overestimating the number of significant regional trends, (2) the assessment of the proportion of improving trends included all results including those for which confidence in direction was low and may have biased the results (3) pseudo replication may have biased the region-wide results, and (4) the monitoring site network may not well represent the rivers of the Region. The fifth issue identified by Dr Canning and Ms McArthur was that water quality trends can be influenced by natural variability and climate effects. This issue was not addressed by further analysis but as part of expert conferencing[1]. As part of expert conferencing, it was agreed that the trends in water quality for the Wellington Region cannot be attributed to particular causes, such as resource management or climate. The additional study on the four listed technical issues is briefly described below.

37 The first issue concerns the results from Snelder (2018) that were based on performing multiple binomial tests in the analysis of regional trends (each test associated with a different water quality indicator). When multiple hypothesis tests are performed, the possibility of a type one error (i.e., falsely rejecting the null hypothesis) is larger than indicated by the nominated alpha value (in this case 0.05) because the tests are performed repeatedly. Dr Canning and Ms McArthur's criticism was that because multiple hypothesis tests had been performed, I may have over-stated the number of significant regional improving trends.

[1] http://pnrp.gw.govt.nz/assets/Uploads/HS4-Expert-Conference-Joint-Witness-Statement-WQ-trends-19-February-2020.pdf (note that although the link refers to 2020, this document is dated 2018)

38 In response to this criticism, I presented an additional analysis and evidence to the PNRP hearing. The significance levels for the individual binomial tests made by Snelder (2018) were adjusted to account for multiple tests using the false discovery rate (FDR) adjustment method (Benjamini and Hochberg, 1995). After this adjustment, there remained significant improving regional-trends in Clar, TP, NO3-N, NNN, and TN (Table 1). After adjustment, the individually significant improving trend in Chla did not reach significance at 0.05 level but there was a significant regional trend for this indicator if the nominated alpha value was relaxed to 0.1. There were no significant degrading regional-trends.

39 The second issue concerned including all trend assessments in the second trend aggregation method. The criticism was the proportion of improving trends was evaluated by counting the trends assessed as increasing and decreasing, irrespective of the estimate of confidence in the trend direction. In evidence presented at the PNRP Council hearing, Dr Canning said that the inclusion of 'uncertain' site trends in the evaluation meant that there could only be low confidence in the conclusion that there has been a dominance of improving trends at the regional level over the ten-year period.

40 In response to this criticism by Dr Canning, I presented an additional analysis and evidence to the PNRP Council hearing. The additional analysis was based on a Monte Carlo simulation, which is a commonly used method for estimating accuracy of models and statistical assessments. The Monte Carlo simulation is described in detail in my Right of Reply evidence[2] to the PNRP Council hearing and the results for the ten-year trends are shown in Table 5 below.

41 The Monte Carlo simulation indicated that the accuracy of the evaluation of the proportion of improving trends, was between 3% and 6% depending on the water quality indicator in Table 5. This is a relatively high accuracy given that the mean proportion of improving

[2] http://pnrp.gw.govt.nz/assets/Uploads/HS4-ROR-evidence-Water-Quality-Ton-Snelder-11-May-2018.pdf

site trends over all variables is 62%. The analysis indicates that the 95% confidence intervals are small relative to the estimated proportion of sites with improving trends. For example, 89% of sites were estimated to have improving Clarity with a 95% confidence interval of 83% to 95% and 70% of sites were estimated to have improving nitrate (NO_3-N) trends with a 95% confidence of 62% to 78% (Table 5). It is notable that all variables have upper confidence intervals for the proportion of sites with improving trends that are greater than 50%. For eight indicators, the lower confidence interval was ≥50%, which indicates there is very high confidence (i.e., ≥97.5% confidence) that a majority (>50%) of sites were improving.

Table 5. Results of Monte Carlo analysis of the estimated proportion of sites with improving trends and the 95% confidence interval of this estimate. The indicators are ordered from top to bottom by the proportion of improving sites.

Water quality indicator	Number of sites	Proportion of improving trends (%)	95% confidence interval (%)
Clar	52	89	83 - 95
TN	40	84	76 - 92
TP	45	77	69 - 85
NNN	55	71	63 - 79
NO3-N	50	70	62 - 78
Turb	56	64	54 - 74
Chla	47	64	52 - 76
Mats-Max	45	62	50 - 74
TOC	51	59	49 - 69
%EPT_Taxa	54	59	49 - 69
Fils-Max	45	58	46 - 70
DRP	35	55	45 - 65
Mats-Mean	45	55	43 - 67
E. coli	55	52	44 - 60
%EPT	54	52	42 - 62
Fils-Mean	45	48	36 - 60
MCI	54	48	38 - 58
QMCI	54	44	34 - 54

42 The third issue concerned 'pseudo-replication' of the sites used in the analyses of the aggregate trends. Pseudo-replication occurs when samples in an analysis are not statistically independent. The criticism was that some of the sites in Council's monitoring network were in the same catchment (see Figure 1). It may not be appropriate to assume that sites that are in the same catchment are independent because they are influenced by the same conditions and a component of the water at downstream sites is measured at the upstream sites. The inclusion of sites that are pseudo-replicates raises the possibility that the analyses of the regional trends were biased.

43 As part of expert conferencing, I conducted a sensitivity analysis to assess the degree to which my original results may have been influenced by pseudo-replication. The sensitivity analysis indicated that controlling for pseudo-replication did not change my original conclusions (i.e., those of Snelder, 2018). The sensitivity analysis was detailed in the joint witness statement.

44 The fourth issue concerned the representativeness of Council's network. The criticism was that water quality monitoring programmes have multiple objectives and therefore sites are not randomly selected. A non-random geographic distribution of sites introduces the potential for the regional trend analyses to produce a misleading representation of region-wide trends. In our joint witness statement, we agreed that the sites in Council's monitoring network may not be adequately representative of the Wellington Region. No further analysis of this issue was made as part of expert conferencing, but Dr Canning raised this issue when he presented his primary evidence.

45 Subsequently, in my right of reply, I presented results of additional analysis of the representativeness of Council's river water quality monitoring network. The approach I took was to describe the character of rivers in the Wellington Region using six environmental variables that are strongly associated with variation in water quality (Table 6). These environmental variables are available for each segment of a commonly used spatial database that represents all of New Zealand's rivers. The rivers of the Wellington region are represented is in this

database by 18,000 segments (Snelder 2017). Each site in the monitoring network was associated with the same six environmental variables corresponding to the segment on which the site was located. The representativeness of the network was evaluated by comparing how closely the distribution of environmental variables describing the sites in the monitoring network was matched by the distribution of the same variables across all segments in the region. Closely matching distributions indicate that the site network is representative of the regional variation for the environmental variable under consideration (i.e., that the site network is not biased to rivers with particular environmental characteristics).

Table 6. Environmental variables used to describe the character of rivers of the Wellington region. Each monitoring site was associated with the same variables based on values pertaining to the river network segment on which it was located.

Environmental variable name	**Characteristic**	**Relevance**
segAveElev	Elevation (m ASL)	High elevation sites generally have higher water quality than lower sites.
usArea	Log (base 10) transformed catchment area (km2)	Depending on catchment land cover, water quality varies according to size of upstream catchment.
usCatElev	Mean elevation of upstream catchment (m ASL)	High elevation catchments generally have better water quality than low elevation catchments.
usUrban	Proportion of upstream catchment occupied by urban land cover types (proportion)	Catchments with a high proportion of urban land generally have poor water quality.
usPastoral	Proportion of upstream catchment occupied by pastoral land cover types (proportion)	Catchments with a high proportion of agricultural land generally have poor water quality.
usIFS	Proportion of upstream catchment occupied by indigenous forest and scrub land cover types (proportion)	Catchments with a high proportion of indigenous forest and scrub generally have good water quality.

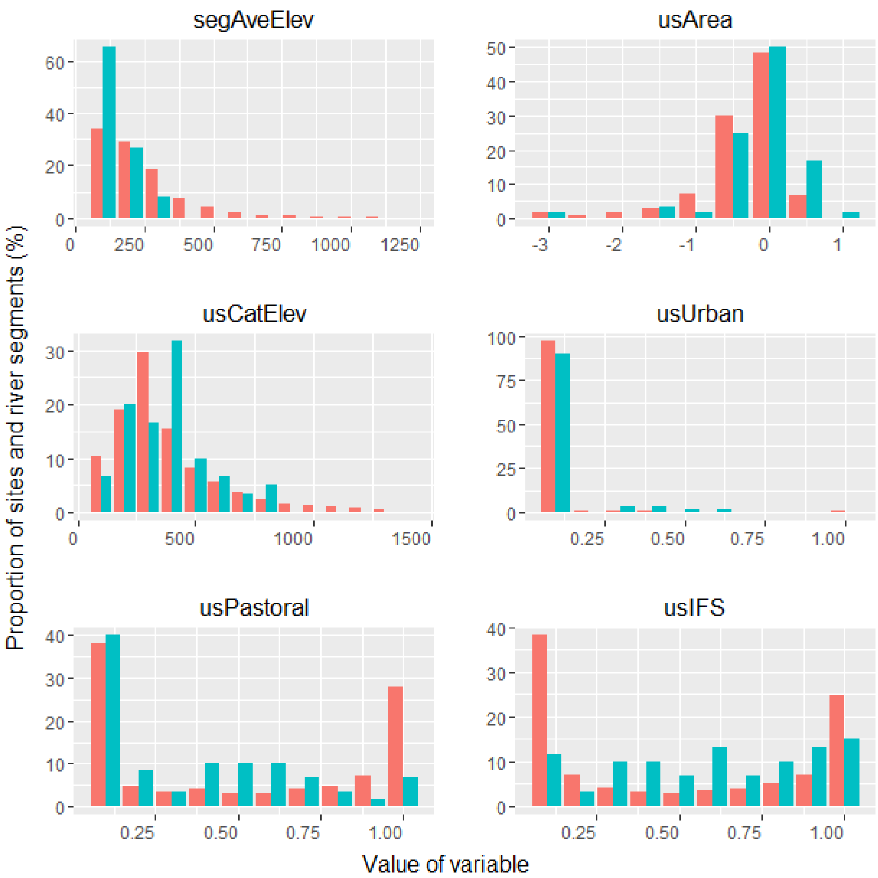
46 The comparison of the distribution of the six environmental variables for sites in the water quality monitoring network and across all the Region's rivers are shown in Figure 2. Each panel represents an environmental variable. On each panel, the blue bars represent the monitoring sites and the red bars indicate the entire river network. Adjacent blue and red bars with similar values (indicated on the vertical axis) indicate that the

monitoring network has sites in close to the same proportion as the entire network for the indicated values of that environmental variable.

47 Most paired bars (red and blue) shown in Figure 2 have reasonably closely matched values on the y-axes. This indicates a reasonably close match between the distribution of monitoring sites over the range of each of the environmental variables and the distribution of the variables over the entire river network. There are some exceptions to this, which indicate a degree of bias in the monitoring sites' representation of regional variation for some environmental variables. For example, Figure 2 indicates that there is a lower proportion of monitoring sites that are associated with very high values of pastoral land cover (usPastoral) (blue bars) compared to proportion of river segments with very high values of pastoral land cover (red bars). Conversely, there are a lower proportion of monitoring sites that are associated with very low values of indigenous forest and scrub land cover (usIFS) (blue bars) than river segments (red bars). There is also over-representation (i.e., bias) of monitoring sites with low elevation locations (segAveElev) and with low to mid-elevation catchments (usCatElev). The monitoring sites also over-represent catchments with very high urban land cover (usUrban). It is noted that low elevation and high urban land cover sites are more likely to have water quality impacts than high elevation (headwater) sites and therefore the network is somewhat biased to impacted sites.

48 It is not possible to define a monitoring network that is perfectly representative of a region's rivers for several reasons including the practicalities of sample collection and the need for monitoring to provide for a variety of types of information. In my opinion, and based on the above analysis, I consider the existing network is reasonably representative of the range of river environments in the Wellington Region. Therefore, my analyses provide a reasonably representative picture of the water quality changes that have occurred in the Wellington Region over the past decade.

Figure 2. Comparison of the distribution of the six environmental variables for the monitoring site network (blue bars) and across all the Region's rivers (red bars).



Accounting for climate variability

49 Studies have shown that water quality trends over periods of 5 to 15 years can be strongly associated with inter-annual climate variability (Scarsbrook *et al.*, 2003; Snelder and Fraser, 2019). These studies indicated associations between water quality trends and the cyclic climatic process known as El Niño–Southern Oscillation (ENSO). Variation in ENSO strength is quasi-cyclic, with El Niño and La Niña events occurring on average every two to seven years. ENSO strength is associated with regionally variable effects on climate conditions in New Zealand (Mullan, 1996; Salinger and Mullan, 1999). For example, during El Niño events, New Zealand experiences stronger and more frequent westerly winds in summer, leading to dry conditions in eastern regions and increased rainfall in western regions. In winter, El Niño events are associated with more frequent southerly winds and colder than average temperatures.

50 Subsequent to the study of regional-scale trends (i.e., Snelder, 2018) and the PNRP hearing, I developed methods that help to interpret whether water quality trend direction (increases or decreases) is consistent or inconsistent with the variation in ENSO during the time-period of analysis. Using these methods, I undertook the third study of regional-scale trends in water quality that included an assessment the influence of ENSO variation on those trends (Snelder, 2020). This third study was based on trend assessments of seven physical and chemical water quality indicators (CLAR, TURB, DRP, NH4N, NO3N, TN, TP; see Table 1) and the microbiological variable ECOLI at between 35 and 43 individual river water quality monitoring sites for the 10-year assessment period ending December 2017. It is noted that techniques for assessing the influence of ENSO variation on invertebrates and periphyton have not been developed and therefore these indicators were not included in the third study.

51 Water quality trend directions over the time-period used for the third study (2008-2017) indicated predominantly improving water quality. This result was consistent with the previous studies, despite the different analysis time-period.

52 Each study site was assigned to a 'water quality trend – influence' category for each water quality indicator based on the combination of water quality trend direction ('Increasing' or 'Decreasing') and whether the trend was consistent with the site's expected water quality response to the ENSO variation through the time-period. The site's expected water quality response to ENSO variation was derived independently for each site and water quality indicator based an analysis of the correlation between the individual water quality indicator's monthly observations and the Southern Oscillation Index (SOI). The SOI is an indicator of ENSO strength, which is calculated as the normalized anomalies of the monthly mean sea level pressure difference between Tahiti and Darwin, Australia (Salinger and Mullan, 1999). The variation in ENSO was characterised by the trend in the SOI through the time-period. For the study-period (2008-2017) there was a strong negative trend in the SOI.

53 Sites with negative correlations between observations and the SOI and increasing water quality trends were categorised as having an increasing trend that was consistent with the SOI trend and were labelled 'Increasing-Climate'. Sites with positive correlations and decreasing water quality trends were categorised as having a decreasing trend that was consistent with the SOI trend and were labelled 'Decreasing-Climate'. Conversely, sites with negative correlations and decreasing water quality trends were categorised as having a decreasing trend that was inconsistent with the SOI trend and were labelled 'Decreasing-Anthropogenic'. Sites with positive correlations and increasing trends were categorised as having an increasing trend that was inconsistent with the SOI trend and were labelled 'Increasing-Anthropogenic'. There were therefore four water quality trend – influence categories: Increasing-Climate, Decreasing-Climate, Increasing-Anthropogenic and Decreasing-Anthropogenic.

54 It is noted that the analysis does not definitively attribute the increases or decreases to climatic or anthropogenic factors. Rather, compared to trends labelled 'Increasing-Climate' and 'Decreasing-Climate', the labels 'Decreasing-Anthropogenic' and 'Increasing-Anthropogenic' indicate a greater likelihood of being related to anthropogenic factors.

55 The results of the analyses were that sites were predominantly assigned to the Increasing-Climate and Decreasing-Climate categories. This indicates that trends at most sites were consistent with climate variation through the study period and this was interpreted as evidence that climate was the dominant influence on these trends. Sites assigned to the Increasing-Anthropogenic and Decreasing-Anthropogenic categories indicated a minority of sites in the Region (<10%) exhibited water quality degradation that appeared to be dominated by anthropogenic factors. In addition, the results indicated that >20% of sites had improving trends that appeared to be dominated by anthropogenic factors. This was interpreted as evidence that changes in anthropogenic factors in the Region more likely contributed to regional water quality improvement than degradation over the study time-period.

56 The analyses undertaken in the third study were simple and the results allow only broad conclusions about the likely influence of climate and anthropogenic factors on water quality trends in the Wellington region over the 2008-2017 time-period. The evidence is that most water quality trends over the period were consistent with climate variation and anthropogenic factors were clearly implicated in a minority of degrading trends. In addition, the evidence indicates that anthropogenic factors were more clearly implicated in regional water quality improvement than degradation.

CONCLUSIONS

57 As set out above, I have undertaken extensive analysis of river water quality trends for the Wellington Region. These studies were conducted on data that terminated at the end of 2017 (Studies 1 and 2) and 2018 (Study 3). It would be possible to update these studies to (for example) the ten-year period to the end of 2020. In my opinion, updating the studies is very unlikely to change the conclusions because the bulk of the data would be for a common period (i.e., 2010 -2017/18).

58 My original studies (i.e., Studies 1 and 2) were strongly critiqued during the PNRP hearing. I responded to the criticisms by undertaking additional analyses. These additional analyses all supported the original conclusions and supported refuting the criticisms. The joint witness statement noted that the additional analyses increased the robustness of my original findings. As experts, we agreed that there is no evidence of region-wide degradation over the study time-period.

59 Subsequent to the PNRP hearing I have further considered water quality trends and analysed, to the extent that is possible with current scientific knowledge, the potential influence of climate variation. This third study indicates that most water quality trends over the period were consistent with climate variation. Anthropogenic factors are clearly implicated in a minority of degrading trends and anthropogenic factors are more clearly implicated in regional water quality improvement over the decade than degradation.

60 My overall conclusion is that the analyses described above provide strong evidence of water quality improvement across the Wellington Region over the past decade (i.e., ending December 2017). Water quality has degraded at some sites and for some indicators. However, the analyses indicate degradation is isolated rather than occurring in a consistent and regional scale manner. Decreasing trends in nutrient concentrations (e.g., dissolved forms of nitrogen and phosphorus) are particularly relevant to the question of whether broad-scale changes in resource use are influencing water quality because intensification of agriculture can be expected to increase nutrient concentrations. Based on these findings, I conclude that there is no evidence that broad-scale changes in resource use across multiple catchments has degraded regional scale water quality in the Region over the past decade.

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Antonius Hugh Snelder

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