BEFORE THE PROPOSED NATURAL RESOURCES PLAN HEARINGS PANEL

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of Water quality
AND	
IN THE MATTER	of the submissions and further submissions set out in the S42A Officer Report

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STATEMENT OF PRIMARY EVIDENCE OF ANTONIUS HUGH SNELDER ON BEHALF OF WELLINGTON REGIONAL COUNCIL

TECHNICAL – REGIONAL WATER QUALITY TRENDS

12 January 2018

TABLE OF CONTENTS

1. SUMMARY

1.1 My name is Antonius (Ton) Hugh Snelder. I am a director of LWP Ltd and consultant/researcher in the field of water resources managment. I have 31 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. In my current and previous positions I have lead many projects that have assessed the water quality trends and state in freshwater environments. I have written a number of guidelines for the management of water quality and quantity and developed several tools for water management purposes. I have authored or co-authored 44 scientific publications in the field of water resouces management, including those that address water quality. A full copy of my qualifications and experience is available in **Attachment A** of my evidence.

1.2 I do not refer here to evidence of other experts.

1.3 I have been asked to provide evidence to aid in the response to submissions received coded to the topic of water quality.

1.4 The scope of my evidence includes an assessment of regional scale water quality changes (trends) in the Wellington Region over the last decade.

1.5 To develop my evidence I have used various statistical analyses of river water quality monitoring data collect over the past decade on a mostly monthly basis at 61 sites.

2. INTRODUCTION

2.1 My name is Antonius (Ton) Hugh Snelder. I am a director of LWP Ltd and consultant/researcher in the field of water resources managment. I have 31 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. In my current and previous positions I have lead many projects that have assessed the water quality trends and state in freshwater environments. I have written a number of guidelines for the management of water quality and quantity and developed several tools for water management purposes. I have authored or co-authored 44 scientific publications in the field of water resouces management, including those that address water quality. A full copy of my qualifications and experience is available in **Attachment A** of my evidence.

2.2 I do not refer here to evidence of other experts.

2.3 I have been engaged by Wellington Regional Council to provide evidence relating to water quality trends.

3. CODE OF CONDUCT

3.1 I confirm that I have read the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note and that I agree to comply with the code. My evidence in this statement is within my area of expertise. I have not omitted to consider material facts known to me that might alter to detract from the opinions which I express.

4. SCOPE

4.1 I have been asked to provide evidence to aid in the response to submissions received on the proposed Natural Resource Plan for the Wellington Region (proposed Plan), which is currently under consideration by the proposed Plan Hearing Panel. A requirement of the proposed Plan is to maintain or improve water quality. The proposed Plan contains region-wide objectives, policies and other provisions that address water quality issues. In addition, GWRC is currently running more localised catchment based processes that will develop objectives, policies and other provisions to manage specific water quality issues in each of six Whaitua.

4.2 Recent changes in water quality may indicate that there is pressure on water quality through increased resource use (e.g., land use intensification) or 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 water quality is important for judging the adequacy of GWRC's management responses under the proposed Plan.

4.3 Water quality changes through time are assessed by trend analyses of data collected at individual long-term state of environment (SoE) monitoring sites. The individual trends at SoE sites may reflect a localised impact in that site's upstream catchment. For example, a trend in nitrogen may be induced at a SoE site due to intensification of land use on a single farm or a trend in visual clarity may be induced by a single recent erosion event upstream. Regional-scale trends are changes in specific water quality variables that are occurring in a consistent manner at many sites across a catchment or region. Because the proposed Plan addresses broad-scale management of water quality (i.e., applying over large areas and not to specific locations), judgements about the provisions of these policy documents should be primarily informed by regional-scale trends.

4.4 I have carried out a study that has assessed recent regional-scale trends in water quality to support the development of objectives, policies and other provisions in the proposed Plan. The study provides an understanding of the general regional water quality changes that have occurred over the past decade and any general regional patterns in these changes that may be relevant to judging the adequacy of GWRC's management responses under the proposed Plan.

4.5 It is noted that the study did not consider the state of water quality. Water quality may be improving at a site but the state may nevertheless be unacceptable. My evidence therefore addresses recent regional water quality changes but does not make any judgements about the acceptability of the current state

5. METHODOLOGY

5.1 This evidence is based on a regional scale assessment of trends made by Snelder (2017a). Snelder (2017a) aggregated the results of a separate study of trends performed by Snelder (2017b) on river water quality monitoring data collected at 61 state of environment (SoE) sites in the Wellington region over the last decade. The regional scale assessment (Snelder 2017a) included trends in up to 18 water quality variables (Table 1) at each site, and for two time-periods of five and ten years; both ending at the end of 2016.

5.2 Flow adjustment is a statistical treatment of the water quality measurements that removes the effect of flow. Flow adjustment is carried out as part of trend analysese because it can increase statistical power (i.e., increases the likelihood of detecting a trend with certainty). Because flow records were available for only 49 of the 61 sites, Snelder (2017b) analysed both ‘flow adjusted’ and ‘raw’ trends (i.e., trends performed on the water quality variables without flow adjustment).

Table 1: River water quality variables included in this study. Field in parentheses in the description indicates that the variable was measured in the field.

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	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

E. coli is measured at GWRC sites as number per volume (n/100mL) and at NRWQN sites as colony forming units (cfu/100mL).

** The invertebrate measure MCI score for soft bottomed streams (MCI-sb) was excluded from this study as it is only relevent to a small number of locations in the region.

5.3 When statistical analyses of trends are made for individual sites a high level of certainty is generally required before a trend is declared to be ‘significant’ or ‘certain’. Levels of significance or certainty of 5% or 95% respectively are traditionally required before a trend is confidently inferred. However, the evaluated trend has information that should not be discarded because it does not meet an arbitrary significance or certainty threshold.

5.4 The aggregation of trend data from many sites across the region was used to characterise regional-scale changes in water quality variables (i.e., changes that are occurring in a consistent manner at many sites across the region) in two ways.

5.5 The first, characterisation of regional-scale changes in water quality changes used categorical levels of confidence (Table 2) to express the likelihood that water quality was improving for each site and variable. This evaluation of the trend direction facilitates a more nuanced inference rather than the ‘yes/no’ output for the chosen acceptable misclassification error rate of 5%. The categories express the probability that a trend was improving (Table 2).

5.6 The second characterisation of regional-scale changes in water quality inferred a regional-trend in a certain direction if the number of sites that exhibited that trend was greater than could be expected if increasing and decreasing trends were equally likely. A binomial test was used to test for regional-trends as follows. First, the number of increasing trends over all sites was counted for each water quality variable. Because this analysis aggregated all trends over all sites across the region, the misclassification error risk for individual sites was disregarded (i.e., all RSS values were included). The logic for this is that over many sites, incorrect classifications of direction will cancel each other (i.e., as many sites will be misclassified as increasing as sites misclassified as decreasing). Second, a ‘two-tailed’ binomial test was performed based on the expectation that sites have a 50% probability of having an increasing trend. If the binomial test *p*-value was less than 0.05, the null hypothesis was rejected, i.e., it was concluded that there were more trends in the region than could be expected by chance and that there was an ‘regional-trend’. The regional-trend direction was determined as positive if the proportion of positive trends was greater than 50%, and negative if the reverse were true. The magnitude of the regional trend was quantified by the median of all site trends.

Table 2: Level of confidence categories used to convey the likelihood that water quality was improving. The levels follow Stocker et al. (2014). Note that improving trends correspond to decreasing trend directions for all variables in Table 1 except Clar, and the invertebrate variables.

Categorical level of confidence	Probability (%)
Virtually certain	99–100
Extremely likely	95–99
Very likely	90–95
Likely	67–90
About as likely as not	33–67
Unlikely	10–33
Very unlikely	5–10

Categorical level of confidence	Probability (%)
Extremely unlikely	1–5
Exceptionally unlikely	0–1

6. RESULTS

6.1 For both the ten and five-year time-periods and over all water quality variables, between 66% and 68% of site trends were categorised as at least as likely as not to be improving (Table 3 and 4). Results were similar when the analysis was performed on a smaller subset of sites for which flow adjusted trends were available (Snelder 2017a). The results indicate that although water quality has not improved everywhere over the last decade, degradation has been relatively isolated, and the general pattern is 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

Table 4: Cumulative proportion of sites (%) with five-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	51	33	61	71	94	100
Turb	55	13	35	42	69	80
DRP	37	8	19	22	35	70
TP	44	9	23	30	52	70
NO_3-N	50	6	12	20	40	66
NNN	54	4	13	20	41	69
TN	42	2	7	24	50	71
TOC	52	29	54	67	92	98
E. coli	55	4	13	20	58	71
Chla	45	0	0	7	31	56
Fils-Max	43	0	7	9	30	49
Fils-Mean	43	2	5	12	23	51
Mats-Max	41	2	7	10	17	76
Mats-Mean	41	5	7	12	15	56
%EPT	41	0	0	5	24	51
%EPT_Taxa	42	0	2	5	31	50
MCI	42	0	2	5	19	40
QMCI	42	0	0	2	17	38

6.2 The analyses of regional-trends indicate significant regional improvement in several water quality variables over both time periods (Table 5 and 6). There were improving regional-trends in visual clarity, and nutrients (including total phosphorus and nitrogen species) over both time-periods. There was an improving regional-trend in a measure of periphyton biomass (Chlorphyll-a) over the ten-year period and an improving regional trend in *E. coli* over the five-year period. There were no degrading regional trends in either time period.

6.3 Three exceptions to the general pattern of improving water quality are noteworthy. First, one periphyton measure (Fils-Max) and two invertebrate measures (MCI and QMCI) have degraded at more sites than they have improved over the five-year time-period although there are no significant regional trends for these variables. Second, there are some sites for which several water quality variables have degrading trends. These sites are inconsistent with the general regional pattern of water quality improvement and may be indicative of specific activities in the upstream catchments of the sites. Third, there was weak and somewhat contradictory evidence for regional degradation with respect to the dissolved nitrogen variables NO_3-N and NNN over the five-year time-period.

Table 5: Ten-year regional trends based on raw site trends.

Variable	No. sites	No. decreasing	No. increasing	Binomial p-value	Regional trend	Regional trend magnitude (%)
Clar	52	5	47	0	Improving	3.86
Turb	56	35	21	0.081	Not Significant	-1.5
DRP	35	20	14	0.311	Not Significant	-0.2
TP	45	36	10	0	Improving	-2.09
NO_3-N	50	35	14	0.003	Improving	-1.57
NNN	55	40	14	0	Improving	-1.45
TN	40	36	5	0	Improving	-2.12
TOC	51	33	19	0.092	Not Significant	-0.38
E. coli	55	29	26	0.788	Not Significant	0
Chla	47	32	15	0.019	Improving	-7.18
Fils-Max	45	28	17	0.135	Not Significant	0
Fils-Mean	45	19	26	0.371	Not Significant	0
Mats-Max	45	27	17	0.135	Not Significant	0
Mats-Mean	45	24	21	0.766	Not Significant	0
%EPT	54	24	30	0.497	Not Significant	0.17
%EPT_Taxa	54	20	33	0.134	Not Significant	0.58
MCI	54	26	27	1	Not Significant	0.03
QMCI	54	33	20	0.076	Not Significant	-0.16

Table 6: Five-year regional trends based on raw site trends.

Variable	No. sites	No. decreasing	No. increasing	Binomial *p*-value	Regional trend	Regional trend magnitude (%)
Clar	51	0	51	0	Improving	9.05
Turb	55	44	11	0	Improving	-5.08
DRP	37	20	17	0.743	Not Significant	0
TP	44	28	17	0.174	Not Significant	-1.51
NO_3-N	50	31	19	0.119	Not Significant	-0.33
NNN	54	36	19	0.04	Improving	-0.73
TN	42	28	14	0.044	Improving	-1.44
TOC	52	50	1	0	Improving	-7
E. coli	55	38	18	0.014	Improving	-5.32
Chla	45	25	20	0.551	Not Significant	-7.96
Fils-Max	43	18	26	0.222	Not Significant	0.99
Fils-Mean	43	19	25	0.36	Not Significant	0
Mats-Max	41	23	18	0.533	Not Significant	0
Mats-Mean	41	16	26	0.117	Not Significant	0
%EPT	41	20	20	1	Not Significant	0
%EPT_Taxa	42	21	20	0.878	Not Significant	-0.21
MCI	42	25	17	0.28	Not Significant	-1.05
QMCI	42	26	16	0.164	Not Significant	-0.57

7. CONCLUSIONS

7.1 Snelder (2017a) aggregated site trends and relaxed the required level of certainty in order to reveal regional-scale water quality changes in two ways. First, categorical levels of confidence, representing various levels of relaxation of the required level of certainty, were used to express the likelihood that water quality was improving for each site and variable. Second, a regional-trend in a certain direction was inferred if the number of sites that exhibited that trend was greater than could be expected if increasing and decreasing trends were equally likely.

7.2 The summaries of sites and variables categorised by different levels of confidence that trends are improving indicate a dominance of improving river water quality across the region. Across all sites and variables, f or both the ten and five-year time-periods, between 66% and 68% of raw trends were at least as likely as not to be improving. Results were similar when the analyses were performed on a smaller subset of sites for which flow adjusted trends were available. The results indicate that although water quality has not improved everywhere over the last decade, degradation has been relatively isolated.

7.3 The analyses of regional trends indicate significant regional improvement in several water quality variables over both time periods. There were improving regional-trends in Clarity, and nutrients (including TP, and nitrogen species) over both periods. There was an improving regional-trend in the periphyton measure Chla over the ten-year period and an improving regional trend in *E. coli* over the five-year period.

7.4 Three exceptions to the general pattern of improving water quality are noteworthy. First, one periphyton measure (Fils-Max) and two invertebrate measures (MCI and QMCI) have degraded at more sites than they have improved over the five-year time-period, although there are not significant regional trends for these variables. Second, there are some sites for which several water quality variables have degrading trends. These sites are inconsistent with the general regional pattern of water quality improvement and may reflect the effects of specific activities in the upstream catchments of the sites. The make-up of sites with degrading trends for several variables differs between time periods but some sites are common to both time periods. For example, sites with more than five trends that were at least likely to be degrading in both time periods included Mangaone Stream at Sims Road Bridge, Otaki River at Pukehinau, Pakuratahi River 50m Below Farm Creek and Taueru River at Castlehill. Third, five-year flow adjusted trends suggest that the dissolved nitrogen variables NO_3-N and NNN were at least as likely as not to be degrading at 61% and 54% of sites. However, the raw trends for these variables were at least as likely as not to be improving at 66% and 69% of sites. In addition, the regional-scale trends for NO_3-N and NNN based on the five-year flow adjusted trends were not significant. There is therefore some evidence for regional degradation of water quality with respect to dissolved nitrogen, however this is less compelling than the evidence for regional improvement in the majority of variables.

7.5 Overall the study by Snelder (2017a) provides strong evidence of water quality improvement across the region over the past decade. Water quality has degraded at some sites and for some variables. However, the study indicates degradation is isolated rather than occurring in a consistent and regional scale manner. The recent degrading trend (i.e., five-year trends) in invertebrate and periphyton measures is an exception to the general pattern of water quality improvement. Periphyton and invertebrates are sensitive to water quality and are used as long term integrative measures of water quality and other impacts. Given that physical and chemical measures of water quality are generally improving, the reasons for declines in these measures are unclear.

8. REFERENCES

Snelder, T., 2017a. Analysis of regional-scale river water quality trends in the Wellington region; Period 2007 to 2016. LWP Client Report: 2017-07, Christchurch.

Snelder, T., 2017b. Analysis of Water Quality Trends for Rivers and Lakes of the Wellington Region. LWP Client Report: 2017-01, Christchurch.

Stocker, T., D.Q. Qin, and G.-K. Plattner (Editors)., 2014. Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. http://www.climatechange2013.org/images/report/WG1AR5_Frontmatter_FINAL.pdf.

Attachment A
Qualifications and experience

Qualifications

PhD, Environmental Management, Lincoln University. New Zealand	2004
PG Dip, Hydrology, University of New South Wales, Australia	1987
BE, Natural Resources Engineering, University of Canterbury, New Zealand	1984

Experience:

Director, LWP Ltd	2014 –
Senior Principal: Water Resource Management, Aqualinc Research Ltd	2012 – 2014
Principal Scientist and Research Programme Leader, NIWA	2010 – 2012
Principal Scientist and Group Manager, NIWA	2009 – 2010
Marie Curie Research Fellow, CEMAGREF (Lyon, France)	2006 – 2009
Principal Scientist and Group Manager, NIWA	2004 – 2006
Water Resources Engineer/Scientist, NIWA	1995 – 2004
Stormwater Quality Program Manager, Auckland Regional Council	1992 – 1995
Senior Engineer, Connell Wagner Consultants	1988 – 1992
Water Resource Engineer, Auckland Regional Water Board	1986 – 1988

Attachment B

Analysis of regional-scale river water quality trends in the Wellington region; Period 2007 to 2016

Analysis of regional-scale river water quality trends in the Wellington region

Period 2007 to 2016

January 2018

Prepared By:

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LWP Project:	2017-07

Quality Assurance Statement

Version	Reviewed By	
1	Caroline Fraser	

Table of Contents

Figures

Tables

Executive Summary

This study aggregated the results of trend analyses performed on river water quality monitoring data collected at 61 state of environment (SoE) sites in the Wellington region over the last decade. The analysis included trends in up to 18 water quality variables at each site, and for two time-periods of five and ten years; both ending at the end of 2016.

The aggregation of trend data from many sites across the region was used to characterise regional-scale changes in water quality variables (i.e., changes that are occurring in a consistent manner at many sites across the region) in two ways. First, categorical levels of confidence were used to express the likelihood that water quality was improving for each site and variable. Second, a regional-trend in a certain direction was inferred if the number of sites that exhibited that trend was greater than could be expected if increasing and decreasing trends were equally likely.

For both the ten and five-year time-periods, between 66% and 68% of trends were at least as likely as not to be improving. Results were similar when the analysis was performed on a smaller subset of sites for which flow adjusted trends were available. The results indicate that although water quality has not improved everywhere over the last decade, degradation has been relatively isolated, and the general pattern is one of improving water quality.

The analyses of regional-trends indicate significant regional improvement in several water quality variables over both time periods. There were improving regional-trends in visual clarity, and nutrients (including total phosphorus and nitrogen species) over both time-periods. There was an improving regional-trend in a measure of periphyton biomass (Chlorphyll-a) over the ten-year period and an improving regional trend in *E. coli* over the five-year period.

Three exceptions to the general pattern of improving water quality were noteworthy. First, one periphyton measure (Fils-Max) and two invertebrate measures (MCI and QMCI) have degraded at more sites than they have improved over the five-year time-period although there are not significant regional trends for these variables. Second, there are some sites for which several water quality variables have degrading trends. These sites are inconsistent with the general regional pattern of water quality improvement and may be indicative of specific activities in the upstream catchments of the sites. Third, there was weak and somewhat contradictory evidence for regional degradation with respect to the dissolved nitrogen variables NO_3-N and NNN over the five-year time-period.

Overall the study provides strong statistical evidence of general water quality improvement across the region over the past decade. Water quality has degraded at some sites, however, this degradation is isolated rather than occurring in a consistent and regional scale manner. The degrading trends in periphyton and invertebrate measures over the five-year period is an exception to the general pattern of water quality improvement. Periphyton and invertebrates are sensitive to water quality and are used as long term integrative measures of water quality and other impacts. Given that physical and chemical measures of water quality are generally improving, the reasons for declines in these measures are unclear.

1 Introduction

Submissions on the proposed Natural Resource Plan for the Wellington Region (proposed Plan) is currently under consideration by the proposed Plan Hearing Panel. A requirement of the proposed Plan is to maintain or improve water quality. The proposed Plan contains region-wide objectives, policies and other provisions that address water quality issues. In addition, GWRC is currently running more localised catchment based processes that will develop objectives, policies and other provisions to manage specific water quality issues in each of six Whaitua.

Recent changes in water quality may indicate that there is pressure on water quality through increased resource use (e.g., land use intensification) or 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 water quality is important for judging the adequacy of GWRC’s management responses under both the proposed Plan and Whaitua processes.

Water quality changes through time are assessed by trend analyses of data collected at individual long-term state of environment (SoE) monitoring sites. The individual trends at SoE sites may reflect a localised impact in that site’s upstream catchment. For example, a trend in nitrogen may be induced at a SoE site due to intensification of land use on a single farm or a trend in visual clarity may be induced by a single recent erosion event upstream. Regional-scale trends are changes in specific water quality variables that are occurring in a consistent manner at many sites across a catchment or region. Because the proposed Plan addresses broad-scale management of water quality (i.e., applying over large areas and not to specific locations), judgements about the provisions of these policy documents should be primarily informed by regional-scale trends.

This study has assessed recent regional-scale trends in water quality to support the development of objectives, policies and other provisions in the proposed Plan. Regional-scale trends have been assessed by aggregating the results of a recent study of trends at up to 61 individual SoE sites across the region (Snelder, 2017). The present study aims to provide an understanding of the general regional water quality changes that have occurred over the past decade and any general regional patterns in these changes that may be relevant to judging the adequacy of GWRC’s management responses under the proposed Plan.

It is noted that this study did not consider water quality state. Water quality may be improving at a site, but the state may nevertheless be unacceptable. This study therefore addresses recent regional water quality changes but does not make any judgements about the acceptability of the current state.

2 Data

The data used in this study comprised results of analyses of trends in a variety of water quality measures at 61 river state of environment (SoE) monitoring sites in the Wellington region. The trend analyses and the significance of each water quality measure are described by Snelder (2017). The water quality measures included physical-chemical, microbiological and biological variables for which trends had been assessed for at least 50% of the sites to ensure a reasonable regional coverage (Table 1). The variables DO, DO% and pH were included in the study by Snelder (2017) but were excluded from this study because grab sample measurements are sensitive to the time of sampling. In addition, conductivity (Cond) was included in the study by Snelder (2017) but was excluded from this study because trends in this variable cannot be expressed as degrading or improving water quality. The trend analyses of the physical, chemical and microbiological variables were based on monthly observations. The trend analyses of the periphyton and invertebrate variables were based on annual values (Table 1).

The trend analyses conducted by Snelder (2017) determined the rates of change of each water quality variable through the specified time-periods (5 and 10 years) at individual sites. The present study retrieved two outputs from Snelder (2017) for each site and variable combination: the estimated trend magnitude known as the relative Sen slope (RSS)[1] and the confidence in the determination of the trend direction. Trends were only used in this study if they complied with the inclusion rules used by Snelder (2017). The inclusion rules restricted site and variable combinations for a given time-period to those for which 90% of the years had had observations for at least 90% of the sampling occasions. Sites and variable combinations that met the inclusion rules can be regarded as having robust trend evaluations in the assessments described below.

Flow rate at the time that a river water quality measurement is made can affect the observed values because many water quality variables are subject to either dilution (decreasing concentration with increasing flow) or wash-off (increasing concentration with increasing flow) (Smith *et al.*, 1996). Flow adjustment is a statistical treatment of the water quality measurements that remove the effect of flow. Flow adjustment is carried out because it can increase statistical power (i.e., increases the likelihood of detecting a trend with certainty; Helsel and Hirsch, 1992). Only the physical, chemical and microbiological variables in Table 1 were flow adjusted because the instantaneous values of these variables can be expected to be affected by flow; whereas measures of periphyton and invertebrates are not influenced by instantaneous flow. Because flow records were available for only 49 of the 61 sites, Snelder (2017) analysed both ‘flow adjusted’ and ‘raw’ trends (i.e., trends performed on the water quality variables without flow adjustment).

Analyses were performed on four sets of results for each site and variable; ‘raw’ trends for the five-year and ten-year time-periods ending at the end of 2016 and ‘flow adjusted’ trends for the same time-periods. Because flow adjusted trends were not available for all SoE sites, this study has concentrated on analyses performed on the raw trends. A parallel set of analyses on the available flow adjusted trends is provided in appendices. The main body of the report provides a commentary on the extent to which conclusions differ, depending on whether raw or flow adjusted trends are used in the regional analysis.

[1] Trends in the physical, chemical and microbiological variables and for the monthly periphyton cover variables Mats and Fils were evaluated using the Seasonal Kendall Sen slope estimator. The other variables were annual values (including the remaining periphyton and all invertebrate variables) and were evaluated using the Kendall Sen slope estimator. Irrespective of method used, the trends were converted to relative Sen slopes (RSS) by dividing by the median of the measured values and expressing as a percentage change per year.

Table 1. River water quality variables included in this study. Field in parentheses in the description indicates that the variable was measured in the field.

Variable type	Abbreviation	Description	Units
Physical and chemical	Clar	Black disc clarity (Field)	m
	Turb	Turbidity	NTU
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	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

* *E. coli* is measured at GWRC sites as number per volume (n/100mL) and at NRWQN sites as colony forming units (cfu/100mL).

** The invertebrate measure MCI score for soft bottomed streams (MCI-sb) was excluded from this study as it is only relevent to a small number of locations in the region.

3 Methods

3.1 Summary of site trends based on confidence in direction

Traditionally, trend analyses have described trends as 'significant' or 'non-significant'. This study used the confidence in trend direction approach explained in more detail in (Larned *et al.*, 2016). The significance tests and confidence in trend direction approach are both methods of expressing confidence in a trend determination. This is necessary because all water quality data is "noisy" (i.e., variable). A trend is the "signal" that is extracted from the data by regressing the measured values against time. The slope of this line is the RSS value, which can only be regarded as an estimate of the "true" trend at a SoE site because it is evaluated from a small number of samples (i.e., the measured monthly or annual values). When there are few and/or noisy data, the slope of the line is uncertain and, therefore, so is the RSS.

The confidence in trend direction approach is based on the confidence interval for the slope of the regression line. If the confidence interval around the trend (i.e., the RSS value) does not contain zero, then the trend direction (classified as either positive of negative depending on the RSS value) is 'established with confidence'. If it does contain zero, it is concluded that there are insufficient data to be confident about the trend direction and the assessment is that the trend is “uncertain”. The width of the confidence interval can be varied to reflect the tolerance for misclassifying the trend direction. Traditionally, in statistics a value of ‘alpha’ of 0.05 is used in single hypothesis test. In the confidence in trend direction approach, the traditional alpha value of 0.05 is equivalent to a misclassification error rate of 5%.

The alpha value of 0.05 applied to traditional trend tests, or the misclassification error rate of 5% applied in the newer confidence in trend direction approach, is often appropriate when a trend in a specific variable at a single site is being considered and a high level of certainty about that trend is required before a decision can be made. However, this level of certainty generally results in many insignificant or uncertain trends when applied over many sites and variables. In the study of Snelder (2017), a large proportion of trends were classified uncertain; for example, approximately 77% of the raw ten-year trends and 72% of the flow adjusted 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 alpha value and ‘yes/no’ output is very restrictive.

The evaluation of the trend direction by the confidence interval approach facilitates a more nuanced inference rather than the ‘yes/no’ output for the chosen acceptable misclassification error rate of 5%. The approach can be used to express the probability that a trend has a given direction. The traditional misclassification error rate of 5% is equivalent to establishing the direction with 95% certainty. However, if there is insufficient data to infer the direction of a trend at a minimum of 95% confidence, the direction can be determined with lower levels of confidence and a categorisation can be used to convey that information. This study has used the approach to presenting levels of confidence of the Intergovernmental Panel on Climate Change (IPCC; Stocker *et al.*, 2014) to convey the certainty of trend directions (Table 2). The categorical levels of confidence were used to express the likelihood that water quality was improving for each site and variable.

The categorical levels of confidence in Table 2 of extremely likely and virtually certain have probabilities of greater than 95% and therefore correspond to ‘certain’ improving trends. Correspondingly, categorical levels of confidence in Table 2 of extremely unlikely and exceptionally unlikely have probabilities of less than 5% and therefore correspond to ‘certain’ degrading trends.

Table 2. Level of confidence categories used to convey the likelihood that water quality was improving. The levels follow Stocker et al. (2014). Note that improving trends correspond to decreasing trend directions for all variables in Table 1 except Clar, and the invertebrate variables.

Categorical level of confidence	Probability (%)
Virtually certain	99–100
Extremely likely	95–99
Very likely	90–95
Likely	67–90
About as likely as not	33–67
Unlikely	10–33
Very unlikely	5–10
Extremely unlikely	1–5
Exceptionally unlikely	0–1

This study summarises trends at all sites and across all variables on a single graphical plot by combining the confidence in the determination of the trend direction (expressed as likelihood that water quality was improving) with the categories shown in Table 2. Each site and variable is represented on the plot by a point that is coloured by a green to red colour scale representing the categories shown in Table 2. When probabilities indicate a high likelihood of improving water quality the colours are greener and as probabilities decrease the colours transition through yellow (representing as likely as not) to orange and red. Redder colours can be regarded as expressing a high likelihood that water quality is degrading.

This summary plot summarises the regional-scale trends without losing information pertaining to the individual sites. The proportion of green coloured points indicates the regional tendency toward improvement and the proportion of red coloured point indicates the regional tendency toward degradation. The proportion of green coloured points in each column of the plot indicates the tendency of trends in an individual variable to be toward improving water quality. The consistency of coloured points in rows represents the tendency of trends at an individual site to be toward improving or degrading water quality.

3.2 Test of regional trend

A test of whether there is an “regional-trend” for the region was also performed using all trend results for each variable. It was deemed that there was a regional-trend in a certain direction if the number of sites that exhibited that trend were greater than could be expected if increasing and decreasing trends were equally likely. The significance of the regional-trend was evaluated using a binomial test.

A binomial test was performed by first counting the number of positive RSS values (increasing trends) over all sites for each water quality variable. Because this analysis aggregated all trends over all sites across the region, the misclassification error risk for individual sites was disregarded (i.e., all RSS values were included). The logic for this is that over many sites, incorrect classifications of direction will cancel each other (i.e., as many sites will be misclassified as increasing as sites misclassified as decreasing). It is noted that despite having uncertain trends (when applying, for example, a misclassification error rate of 5%), these RSS values were robust because they met the inclusion rules described above.

A ‘two-tailed’ binomial test was then performed based on the expectation that sites have a 50% probability of having an increasing trend. If the binomial test *p*-value was less than 0.05, the null hypothesis was rejected, i.e., it was concluded that there were more trends in the region than could be expected by chance and that there was an ‘regional-trend’. The regional-trend direction was determined as positive if the proportion of positive trends was greater than 50%, and negative if the reverse were true. The magnitude of the regional trend is quantified by the median of all RSS values.

4 Results

4.1 Ten-year trends

4.1.1 Summary of site trends

Overall 68% of raw ten-year trends analysed were at least as likely as not to be improving (Table 3, Figure 1). All physical and chemical variables had greater than 58% of sites that were at least as likely as not to be improving. For 17 of the 18 variables at least 50% of sites were at least as likely as not to be improving (Table 3). The invertebrate variable QMCI had fewer than 50% of sites that were at least as likely as not to be improving (Table 3).

The predominance of improving raw ten-year trends was evident on the summary plot (Figure 1). There were no sites that had consistently degrading trends across all or most water quality variables. However, some notable sites had degrading trends for at least eight variables. The Horokiri Stream at Snodgrass had trends that were at least likely to be degrading (note the inverse of the improving categorisation shown on Figure 1) for ten variables; NO_3-N, NNN, TN, TOC, E. coli, Mats-Max, Mats-Mean, Chla, %EPT and QMCI. The Taueru River at Castlehill had trends that were at least likely to be degrading for ten variables; Clar, Turb, DRP, NO_3-N, NNN, E. coli, %EPT, %EPT_Taxa, MCI and QMCI. The Waikanae River at Mangaone Walkway had trends that were at least likely to be degrading for ten variables; Turb, DRP, NO_3-N, NNN, TN, TOC, Fils-Mean, %EPT, %EPT_Taxa and MCI. The Whareroa Stream at Waterfall Rd had trends that were at least likely to be degrading for eight variables; Clar, Turb, NO_3-N, NNN, TOC, E. coli, %EPT and QMCI.

When the summary of site trends was made using flow adjusted trends the conclusions were similar to that made with raw trends. Overall 68% of flow adjusted trends were at least as likely as not to be improving (see Appendix A, Table 7, Figure 3). All water quality variables except TOC had greater than 55% of sites that were at least as likely as not to be improving. However, consistent with the raw trends, several sites had trends for several variables that were at least likely to be degrading (Appendix A, Figure 3).

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

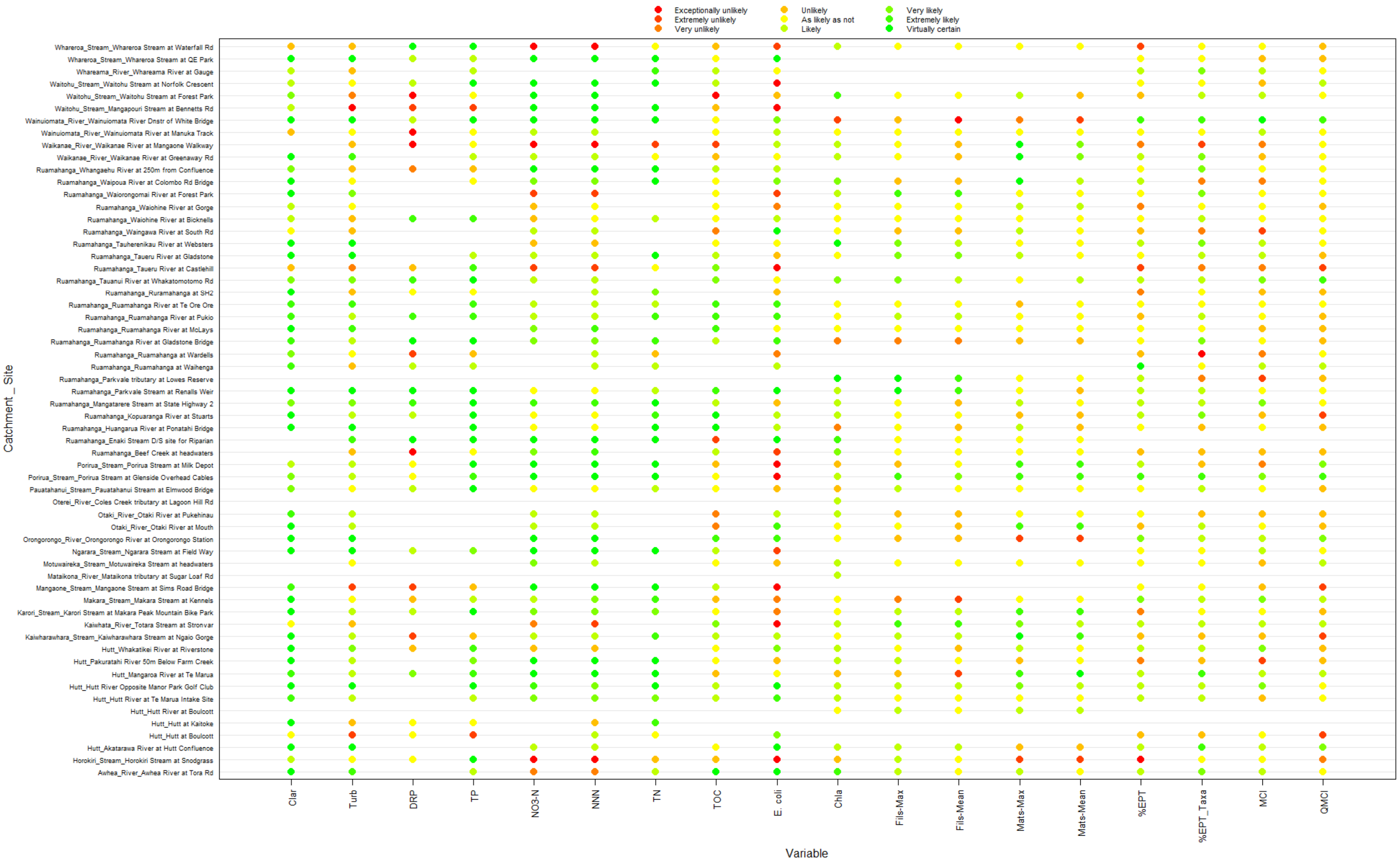

Figure 1. Summary plot of 10-year raw trend analysis results. The plot shows the level of confidence that water quality was improving for each site and variable. Missing dots indicate the variable was either not monitored, the water quality trend description was 'not analysed' or the data did not comply with the filtering rules. See Table 2 for details of the confidence categories. Sites are grouped by the sea draining catchment to which they belong and then alphabetical order of the site names (separated by an underscore).

4.1.2 Regional-trends

There were significant improving regional-trends in Clar, TP, NO_3-N, NNN, TN and Chla (Table 4). All other regional-trends were not significant.

When the regional-trend analyses were based on flow adjusted trends, a similar pattern of regional-trends was produced. There were significant improving regional-trends in Clar, TP, NNN, TKN and TN (Table 8).

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

Variable	No. sites	No. decreasing	No. increasing	Binomial p-value	Regional trend	Regional trend magnitude (%)
Clar	52	5	47	0	Improving	3.86
Turb	56	35	21	0.081	Not Significant	-1.5
DRP	35	20	14	0.311	Not Significant	-0.2
TP	45	36	10	0	Improving	-2.09
NO_3-N	50	35	14	0.003	Improving	-1.57
NNN	55	40	14	0	Improving	-1.45
TN	40	36	5	0	Improving	-2.12
TOC	51	33	19	0.092	Not Significant	-0.38
E. coli	55	29	26	0.788	Not Significant	0
Chla	47	32	15	0.019	Improving	-7.18
Fils-Max	45	28	17	0.135	Not Significant	0
Fils-Mean	45	19	26	0.371	Not Significant	0
Mats-Max	45	27	17	0.135	Not Significant	0
Mats-Mean	45	24	21	0.766	Not Significant	0
%EPT	54	24	30	0.497	Not Significant	0.17
%EPT_Taxa	54	20	33	0.134	Not Significant	0.58
MCI	54	26	27	1	Not Significant	0.03
QMCI	54	33	20	0.076	Not Significant	-0.16

4.2 Five-year trends

4.2.1 Summary of site trends

Overall 66% of raw 5-year trends were at least as likely as not to be improving (Table 5, Figure 2). All physical and chemical variables had greater than 66% of sites that were at least as likely as not to be improving. For 15 of the 18 variables at least 50% of sites were at least as likely as not to be improving including (Table 5). However, Fils-Max, MCI and QMCI had 49%, 40% and 38% of sites respectively that were at least as likely as not to be improving (Table 3).

The predominance of improving raw five-year trends was evident on the summary plot (Figure 2). There were no sites that had consistently degrading trends across all or most water quality variables. However, two sites had degrading trends for at least eight variables. The Otaki River at Pukehinau had trends that were at least likely to be degrading (note the inverse of the improving categorisation shown on Figure 1) for eight variables; Turb, NO_3-N, NNN, Mats-Mean, Fils-Max, Fils-Mean, %EPT_Taxa and MC. The Pakuratahi River 50m Below Farm Creek had trends that were at least likely to be degrading for eight variables; NO_3-N, NNN, TN, Fils-Max, Fils-Mean, Mats-Max, %EPT_Taxa and MCI.

When the summary of site trends was made using flow adjusted trends the conclusions were similar to that made with raw trends. Overall 68% of flow adjusted trends for physical and chemical variables were at least as likely as not to be improving (see Appendix A, Table 9, Figure 4). The variables Clar, Turb, DRP, TP, TN, TOC, and *E. coli* were at least as likely as not to be improving for at least 54% of sites (Appendix A, Table 9). However, flow adjusted five-year trends for the variables NO_3-N and NNN were at least as likely as not to be degrading at more than 54% of sites. Thus, the flow adjusted five-year trends suggest that dissolved nitrogen species (NO_3-N and NNN) degraded at a majority of sites.

There were no sites that had consistently degrading five-year raw trends across all or most water quality variables. However, some sites had degrading trends for several variables (Figure 2).

Table 5. Cumulative proportion of sites (%) with five-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	51	33	61	71	94	100
Turb	55	13	35	42	69	80
DRP	37	8	19	22	35	70
TP	44	9	23	30	52	70
NO_3-N	50	6	12	20	40	66
NNN	54	4	13	20	41	69
TN	42	2	7	24	50	71
TOC	52	29	54	67	92	98
E. coli	55	4	13	20	58	71
Chla	45	0	0	7	31	56
Fils-Max	43	0	7	9	30	49
Fils-Mean	43	2	5	12	23	51
Mats-Max	41	2	7	10	17	76
Mats-Mean	41	5	7	12	15	56
%EPT	41	0	0	5	24	51
%EPT_Taxa	42	0	2	5	31	50
MCI	42	0	2	5	19	40
QMCI	42	0	0	2	17	38

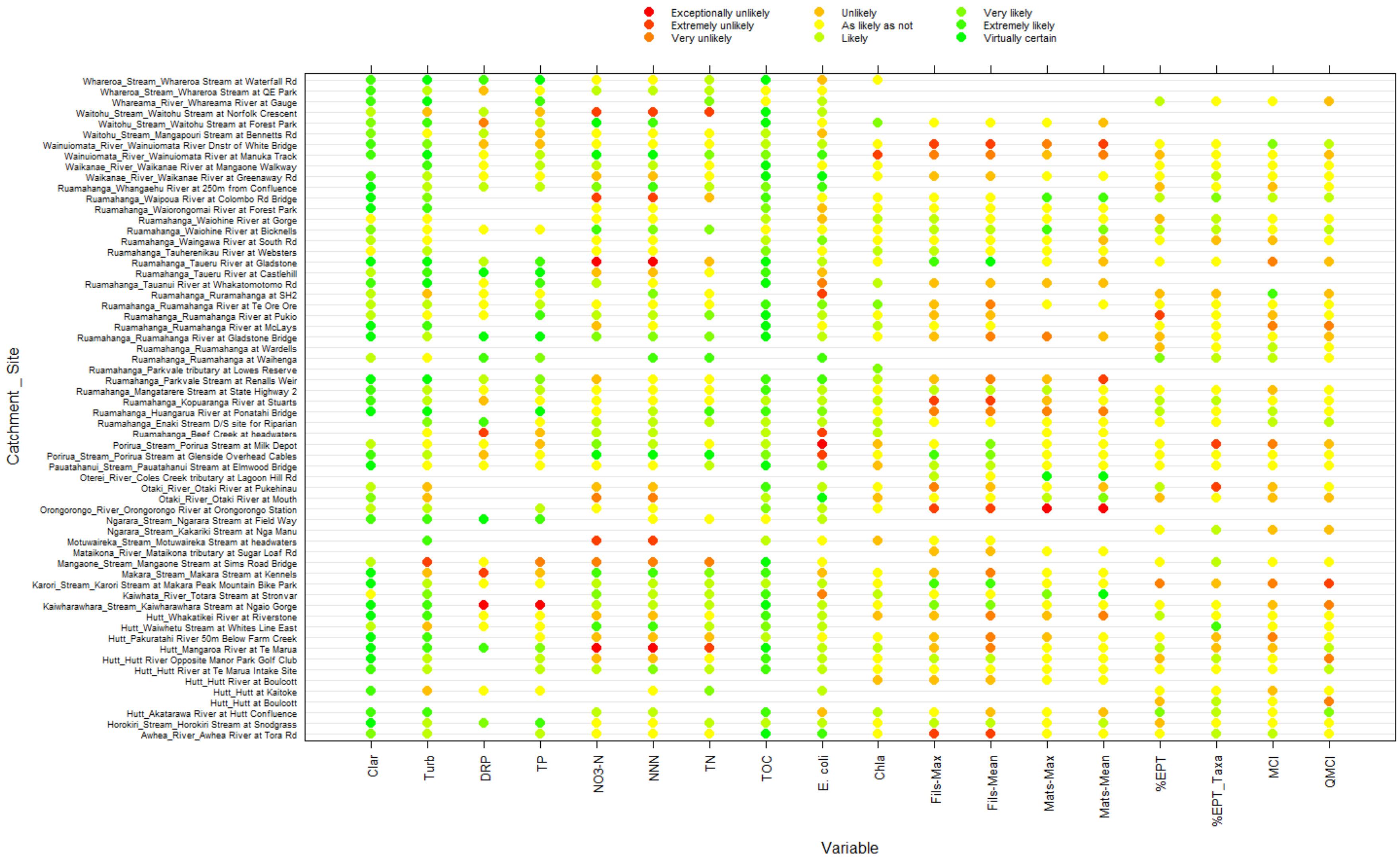

Figure 2. Summary plot of five-year raw trend analysis results. The plot shows the level of confidence that water quality was improving for each site and variable. Missing dots indicate the variable was either not monitored, the water quality trend description was 'not analysed' or the data did not comply with the filtering rules. See Table 2 for details of the confidence categories. Sites are grouped by the sea draining catchment to which they belong and then alphabetical order of the site names (separated by an underscore).

4.2.2 Regional-trends

There were significant improving regional-trends in Clar, Turb, NNN, TN, TOC and *E. coli* (Table 6). There were no significant degrading regional-trends (Table 6).

When the regional-trend analyses were based on flow adjusted trends, similar patterns of regional-trends for the physical and chemical variables were produced. There were significant improving regional-trends in Clar, Turb, TOC, and *E. coli* (Appendix A, Table 10).

Table 6. Five-year regional trends based on raw site trends.

Variable	No. sites	No. decreasing	No. increasing	Binomial *p*-value	Regional trend	Regional trend magnitude (%)
Clar	51	0	51	0	Improving	9.05
Turb	55	44	11	0	Improving	-5.08
DRP	37	20	17	0.743	Not Significant	0
TP	44	28	17	0.174	Not Significant	-1.51
NO_3-N	50	31	19	0.119	Not Significant	-0.33
NNN	54	36	19	0.04	Improving	-0.73
TN	42	28	14	0.044	Improving	-1.44
TOC	52	50	1	0	Improving	-7
E. coli	55	38	18	0.014	Improving	-5.32
Chla	45	25	20	0.551	Not Significant	-7.96
Fils-Max	43	18	26	0.222	Not Significant	0.99
Fils-Mean	43	19	25	0.36	Not Significant	0
Mats-Max	41	23	18	0.533	Not Significant	0
Mats-Mean	41	16	26	0.117	Not Significant	0
%EPT	41	20	20	1	Not Significant	0
%EPT_Taxa	42	21	20	0.878	Not Significant	-0.21
MCI	42	25	17	0.28	Not Significant	-1.05
QMCI	42	26	16	0.164	Not Significant	-0.57

5 Summary and conclusions

Water quality changes through time are traditionally assessed by trend analysis of data collected at individual SoE monitoring sites. The individual trends at SoE sites reflect specific effects of changes in that site's upstream catchment. The information that trend analyses provide about an individual site and variable is relevant to localised management of that site but is of limited value for informing regional scale management because these decisions address different spatial scales. This study has provided regional-scale analyses of changes in river water quality by aggregating trends over many sites. These regional-scale analyses reveal changes in water quality variables that are occurring in a consistent manner at many sites across a catchment or region. The regional-scale analyses are appropriate for informing regional scale management decisions such as judging the adequacy of GWRC's management responses under the proposed Plan.

The regional-scale analyses provided by this study were based on aggregating the results of trend analyses of individual sites made by Snelder (2017). These trends pertained to up to

61 river SoE sites across the Wellington region and two time-periods of five and ten years ending at the end of 2016. Trends for up to 18 of the 19 river water measures that were assessed by Snelder (2017) were included in this study.

When statistical analyses of trends are made for individual sites a high level of certainty is generally required before a trend is declared to be ‘significant’ or ‘certain’. Levels of significance or certainty of 5% or 95% respectively are traditionally required before a trend is confidently inferred. However, when trends at many sites are considered together with the question being what proportion of the sites are (for example) improving, the misclassification error risk for individual sites should be relaxed or disregarded. The logic for this is that over many sites, incorrect classifications of direction will cancel each other (i.e., as many sites will be misclassified as increasing as sites misclassified as decreasing). In addition, trend analyses often do not reach the required level of significance or certainty needed to confidently infer a trend for an individual site and variable. However, the evaluated trend has information that should not be discarded because it does not meet an arbitrary significance or certainty threshold.

This study has aggregated site trends and relaxed the required level of certainty in order to reveal regional-scale water quality changes in two ways. First, categorical levels of confidence, representing various levels of relaxation of the required level of certainty, were used to express the likelihood that water quality was improving for each site and variable. Second, a regional-trend in a certain direction was inferred if the number of sites that exhibited that trend was greater than could be expected if increasing and decreasing trends were equally likely.

The summaries of sites and variables categorised by different levels of confidence that trends are improving indicate a dominance of improving river water quality across the region. For both the ten and five-year time-periods, between 66% and 68% of raw trends were at least as likely as not to be improving. Results were similar when the analyses were performed on a smaller subset of sites for which flow adjusted trends were available. The results indicate that although water quality has not improved everywhere over the last decade, degradation has been relatively isolated.

The analyses of regional trends indicate significant regional improvement in several water quality variables over both time periods. There were improving regional-trends in Clarity, and nutrients (including TP, and nitrogen species) over both periods. There was an improving regional-trend in the periphyton measure Chla over the ten-year period and an improving regional trend in *E. coli* over the five-year period.

Three exceptions to the general pattern of improving water quality are noteworthy. First, one periphyton measure (Fils-Max) and two invertebrate measures (MCI and QMCI) have degraded at more sites than they have improved over the five-year time-period although there are not significant regional trends for these variables. Second, there are some sites for which several water quality variables have degrading trends. These sites are inconsistent with the general regional pattern of water quality improvement and may reflect the effects of specific activities in the upstream catchments of the sites. The make-up of sites with degrading trends for several variables differs between time periods but some sites are common to both time periods. For example, sites with more than five trends that were at least likely to be degrading in both time periods included Mangaone Stream at Sims Road Bridge, Otaki River at Pukehinau, Pakuratahi River 50m Below Farm Creek and Taueru River at Castlehill. Third, five-year flow adjusted trends suggest that the dissolved nitrogen variables NO_3-N and NNN were at least as likely as not to be degrading at 61% and 54% of sites. However, the raw trends for these variables were at least as likely as not to be improving at 66% and 69% of sites. In addition, the regional-scale trends for NO_3-N and NNN based on the five-year flow adjusted trends were not significant. There is therefore some evidence for regional degradation of water quality with respect to dissolved nitrogen, however this is less compelling than the evidence for regional improvement in the majority of variables.

Overall the study provides strong evidence of water quality improvement across the region over the past decade. Water quality has degraded at some sites and for some variables. However, this study indicates degradation is isolated rather than occurring in a consistent and regional scale manner. The recent degrading trend (i.e., five-year trends) in invertebrate and periphyton measures is an exception to the general pattern of water quality improvement. Periphyton and invertebrates are sensitive to water quality and are used as long term integrative measures of water quality and other impacts. Given that physical and chemical measures of water quality are generally improving, the reasons for declines in these measures are unclear.

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Appendix A Regional analyses based on flow adjusted data

A1 Ten-year trends

Overall 68% of flow adjusted water quality trends analysed were at least as likely as not to be improving (Table 7, Figure 3). With the exception of Turb and TOC, water quality variables were at least as likely as not to be improving for at least 59% of sites (Table 7, Figure 3).

The predominance of improving trends was evident on a summary plot showing the confidence that trends are improving across all sites (Figure 3). There were no sites that had consistently degrading trends across the majority of water quality variables. However, some sites had degrading trends for several variables.

Table 7. Cummulative proportion of sites with ten-year improving flow adjusted trends with at least the indicated level of confidence (%).

Variable	No. sites	Virtually certain	Extremely likely	Very likely	Likely	Likely as not
Clar	45	49	64	69	89	91
Turb	47	13	26	32	40	55
DRP	26	15	19	27	65	73
TP	38	37	53	61	68	79
NO_3-N	41	17	29	34	56	63
NNN	45	16	29	33	53	67
TN	34	32	50	53	74	79
TOC	41	5	12	20	41	46
E. coli	43	19	26	28	51	63

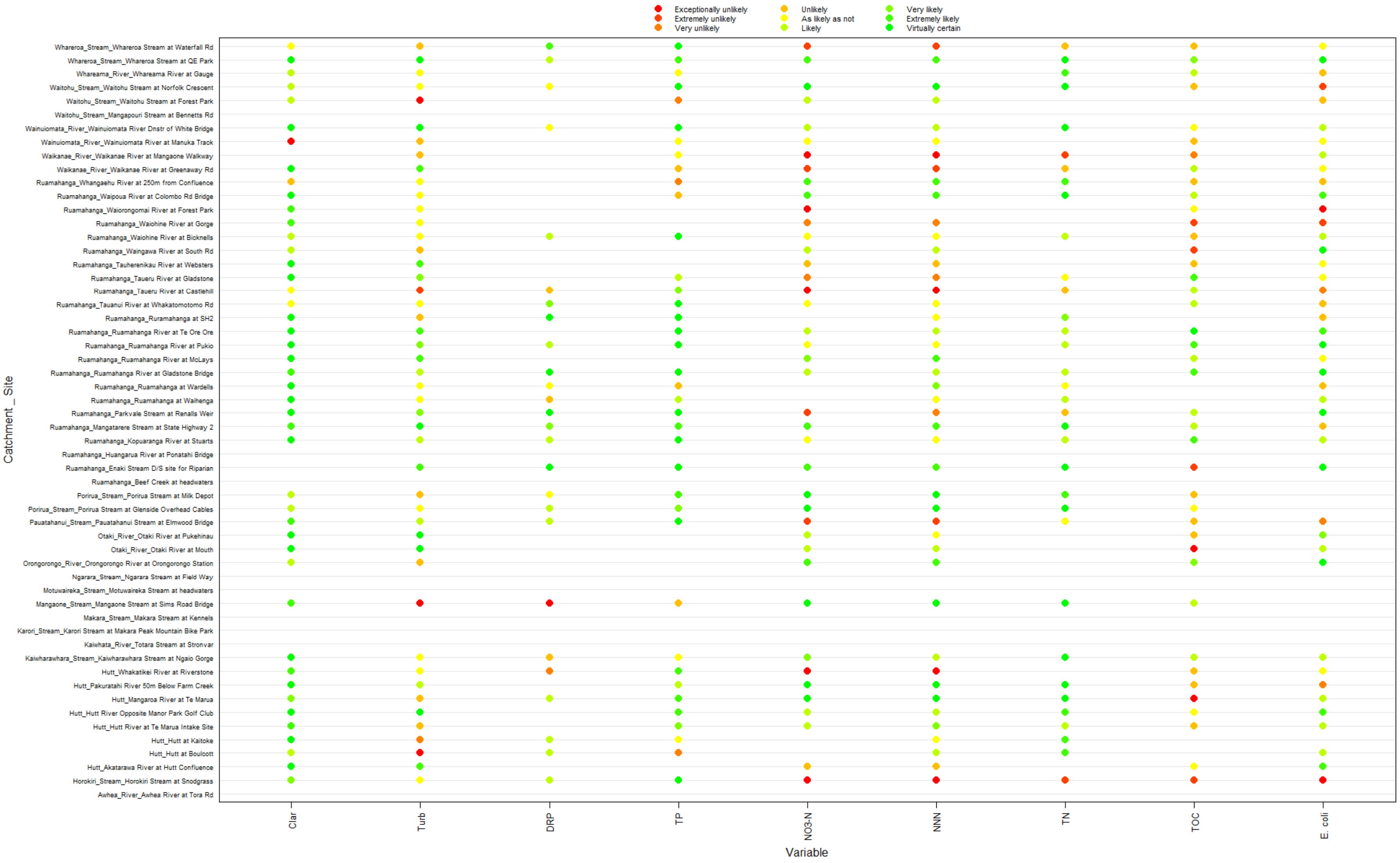

Figure 3. Summary plot of ten-year flow adjusted trend analysis results. The plot shows the level of confidence that water quality was improving for each site and variable. Missing dots indicate the variable was either not monitored, the water quality trend description was 'not analysed' or the data did not comply with the filtering rules. See Table 2 for details of the confidence categories. Sites are grouped by the sea draining catchment to which they belong and then alphabetical order of the site names (separated by an underscore).

There were significant improving regional-trends in Clar, TP, NNN and TN (Table 8).

Table 8. Regional flow adjusted ten-year trends.

Variable	No. sites	No. decreasing	No. increasing	Binomial *p*-value	Regional trend	Regional trend magnitude (%)
Clar	46	4	42	0	Improving	2.68
Turb	48	26	22	0.665	Not Significant	-0.14
DRP	30	19	11	0.2	Not Significant	-0.55
TP	39	30	8	0	Improving	-1.92
NO_3-N	42	27	15	0.088	Not Significant	-1.12
NNN	47	31	16	0.04	Improving	-0.96
TN	35	28	7	0.001	Improving	-1.23
TOC	43	19	24	0.542	Not Significant	0.24
E. coli	47	28	19	0.243	Not Significant	-1.48

A2 Five-year trends

Overall 67% of flow adjusted five-year water quality trends analysed were at least as likely as not to be improving (Table 9, Figure 4). The variables Clar, Turb, TN, TOC, and *E. coli* were at least as likely as not to be improving for at least 50% of sites (Table 9). The dissolved nitrogen variables NO_3-N and NNN were at least as likely as not to be degrading at 66% and 61% of sites (note this is the inverse of the figures shown in Table 9).

The predominance of improving trends was evident on a summary plot showing the confidence that trends are improving across all sites (Figure 4). There were no sites that had consistently degrading trends across the majority of water quality variables. However, some notable sites had degrading trends for several variables.

Table 9. Cumulative proportion of sites with five-year improving flow adjusted trends with at least the indicated level of confidence (%).

Variable	No. sites	Virtually certain	Extremely likely	Very likely	Likely	Likely as not
Clar	41	44	59	68	90	98
Turb	43	9	16	21	56	70
DRP	26	4	8	19	46	54
TP	31	3	6	23	52	65
NO_3-N	38	3	8	13	26	39
NNN	41	2	5	12	29	46
TN	33	3	9	12	36	55
TOC	40	22	38	42	82	95
E. coli	43	7	14	28	63	74

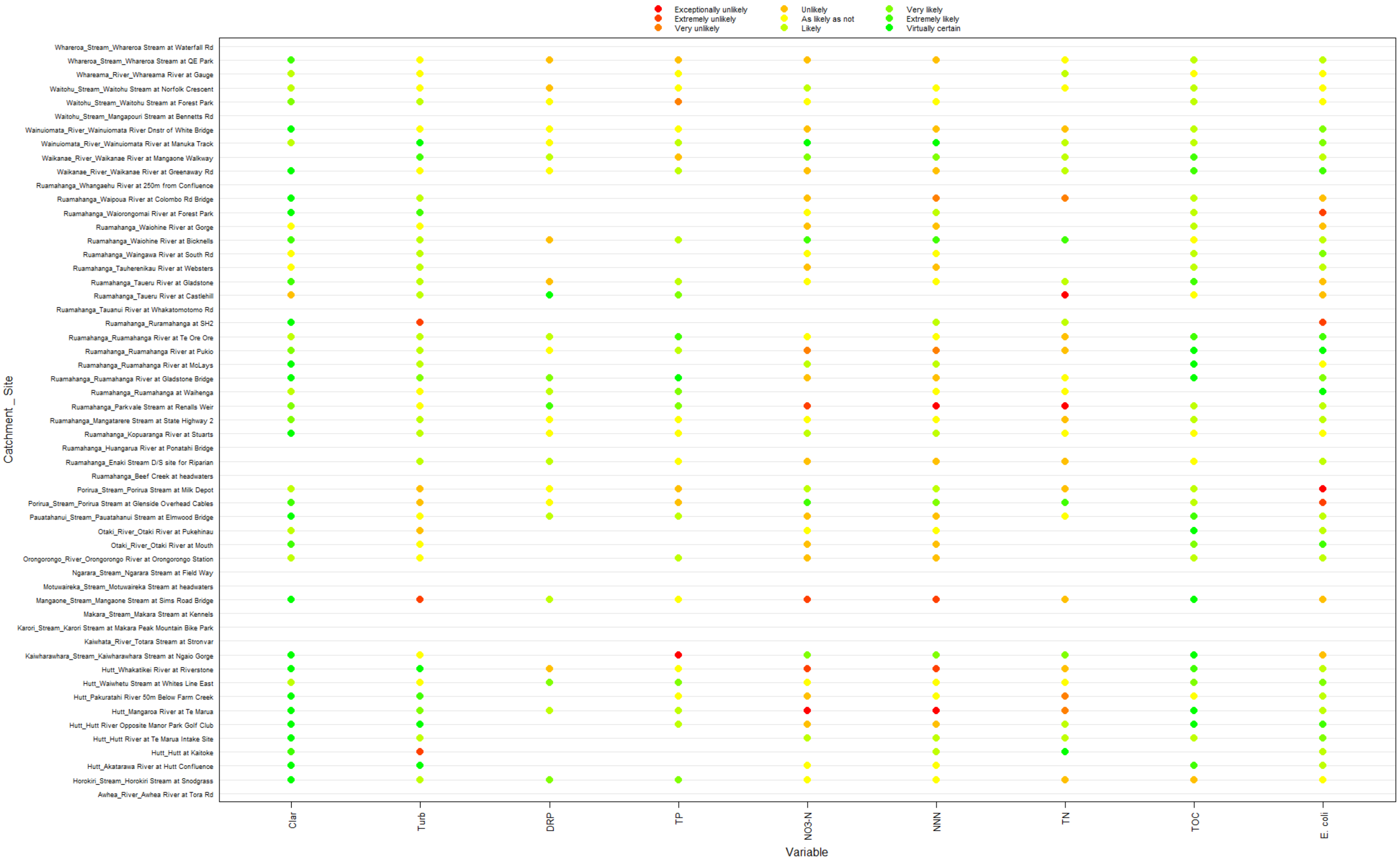

Figure 4. Summary plot of five-year flow adjusted trend analysis results. The plot shows the level of confidence that water quality was improving for each site and variable. Missing dots indicate the variable was either not monitored, the water quality trend description was 'not analysed' or the data did not comply with the filtering rules. See Table 2 for details of the confidence categories. Sites are grouped by the sea draining catchment to which they belong and then alphabetical order of the site names (separated by an underscore).

There were significant improving regional-trends in Clar, Turb, TOC and *E. coli* (Table 10).

Table 10. Regional flow adjusted five-year trends

Variable	**No. sites**	**No. decreasing**	**No. increasing**	**Binomial *p*-value**	**Regional trend**	**Regional trend magnitude (%)**
Clar	41	1	40	0	Improving	6.07
Turb	43	30	13	0.014	Improving	-2.5
DRP	27	14	13	1	Not Significant	-0.47
TP	31	20	11	0.15	Not Significant	-0.99
NO_3-N	39	15	24	0.2	Not Significant	0.97
NNN	42	19	23	0.644	Not Significant	0.62
TN	33	18	15	0.728	Not Significant	-0.79
TOC	40	38	2	0	Improving	-5.1
E. coli	43	32	11	0.002	Improving	-5.65