State and Trends of River Water Quality in the Manawatū-Whanganui Region

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Client Report 2018-08

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For all records up to 30 June 2017

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Executive Summary

This study analysed the available water quality data in the Manawatū-Whanganui Region. We report on the state of water quality in the region, on a site by site basis, relative to targets set in the One Plan (Horizons Regional Council, 2014), as well as those specified in the National Objectives Framework (NOF) of the National Policy Statement – Freshwater Management (NPS-FM) (Ministry for Environment, 2017a). In addition, the study assessed water quality trends site by site, and across the region as a whole.

We analysed water quality data representing 35 physico-chemical and microbiological variables and biological indicators for 265 monitoring sites in the region; these included river (238), coastal (4), estuary (8) and lake (15) sites. River sites were also further categorised as State of the Environment - SoE (representative sites), impact (sites immediately downstream of known discharges) and discharge (effluent) sites. All variables were evaluated for state and trends at all sites (when sufficient data was available), but this report describes only river state and trends for the variables that specifically relate to environmental targets: clarity, field dissolved oxygen saturation, dissolved reactive phosphorus, ammoniacal-N, nitrate, field pH, volatile matter, soluble inorganic nitrogen, field temperature, *E. coli*, chlorophyll-*a* (cover), cyanobacteria cover, filamentous periphyton cover, mat periphyton cover and macroinvertebrate community index (MCI). The state and trend outputs for all sites and variables are provided in supplementary files (a full list of these files is provided in Appendix A). Sites were graded as 'pass' or 'fail' (for One Plan criteria), or a NOF Band (A, B, C, D, and for *E. coli*) (for NOF Criteria) for each variable based on a comparison of the assessed state with the relevant criteria.

A trend assessment was carried out for 10-year and 20-year periods ending in July 2017 for all site and water quality variable combinations that met a minimum requirement for numbers of observations. The methods used for statistical trend analyses are Kendall's test of rank correlation and the Sen slope estimator (SSE), which have both been used for trend analysis of water quality for several decades (Hirsch et al., 1982).

This study considered flow adjusting the river water quality data as part of trend assessment. Adjusting data to account for flow (or any covariate) decreases variation and increases statistical power (i.e., increases the likelihood of detecting a trend with a given level of confidence, (Helsel and Hirsch, 1992)). In addition, flow adjustment can improve trend detection if there has been a bias in the flow on sample occasion (i.e., increasing or decreasing flow on sample occasion with time). However, for the dataset used in this study, flow data was only available on 42% of sample occasions, which means that requiring flow adjustment would significantly reduce the number of site trends evaluated for the region. Based on the examination of a subset of sites with adequate flow data and comparing trends evaluated with and without flow adjustment, it was concluded that the regional-scale findings of this study do not differ between analyses based on raw or flow adjusted trends. Therefore, the trends presented in this report are not flow adjusted but flow adjusted results for sites with flow data are provided as supplementary data.

Individual site trend estimates were aggregated, to provide an overall picture of trends for the region. This was done graphically using stacked bar charts showing proportions of sites for each variable that fall into different trend direction confidence categories. In addition, we used a statistical procedure that aggregates individual site trends and their individual uncertainties to quantify the proportion of improving trends (PIT) for each variable.

The most obvious pattern associated with the assessment of water quality state was that for many variables, sites almost uniformly passed or failed targets (Figure 9 and Figure 12). Site grades based on the Horizons One Plan criteria were dominated by failing sites for DRP, *E. coli* and clarity. Conversely, almost all sites passed the One Plan criteria for ammoniacal-N, cyanobacteria, periphyton (mats) and volatile matter, and NOF criteria for nitrate toxicity (mean and 95th percentile) and ammoniacal-N (median). Similarly, most sites across the region passed the NOF criteria for ammoniacal-N toxicity (maximum) and periphyton. There were similar numbers of passing and failing sites for the One Plan criteria for dissolved oxygen, chlorophyll-*a*, macroinvertebrate community index, periphyton (filaments) and soluble inorganic nitrogen, and NOF *E. coli* criteria.

There are no immediately obvious spatial patterns associated with the variation in grades, however this does not mean that there are not associations with, for example, river size or catchment land cover. Generally, the patterns in grades were similar for the impact sites. These relationships will be explored in more detail in a second state and trends spatial modelling study. At the discharge sites, there was a dominance of sites failing the criteria for change in pH, and percent reduction in clarity. Conversely, the change in temperature criteria was met at most sites across the region. There were very few sites with quantitative macroinvertebrate community index (QMCI) available data to evaluate reduction in QMCI.

For the 10-year time period, a majority of SoE site trends had “insufficient data” to determine trend direction at the 95% confidence level (Figure 21). Relaxation of the 5% misclassification error risk provided greater insight into the general trend direction at the regional scale, indicating that, for many variables, there are approximately equal numbers of increasing and decreasing trends (Figure 23). However, some variables were dominated by degrading trends (e.g. MCI, chlorophyll-a) or conversely, by improving trends (e.g. particulate organic matter, soluble inorganic nitrogen and ammoniacal-N).

The proportion of improving trends (PIT) statistics for SoE sites for the 10-year trends varied between 10% to 100%, depending on the variable (Table 10). Five variables had a majority of degrading site trends (i.e., the lower 95% confidence level for PIT was less than 50% (chlorophyll-*a*, MCI, DRP, clarity and DO)). Five of the variables had a majority of improving trends at the 95% confidence level (G540, DO-sat, NH_4-N, SIN, POM). The remaining four variables had 95% confidence intervals for the PIT that included 50%. The relativities in PIT between variables for the impact sites was similar to those for the SoE sites, but there was generally a greater proportion of improving sites for the impact sites.

We found that there were significant relationships between decreasing *E. coli* trends at discharge sites and decreasing *E. coli* trends at associated downstream impact sites (Figure 28). This is strong evidence of regional improvement in *E. coli* associated with improvements to point source discharge quality over the past decade. However, the relationships were much weaker (or non-existent) for other variables.

Trend magnitude was highly variable between sites (Figure 27). In general, we found that the largest degrading trends were associated with those sites that also had the poorest state grades based on the One Plan and/or NOF criteria (Figure 37 and Figure 38). It is these sites that are likely to warrant the greatest effort to reverse degrading water quality. Contrary to the pattern for most variables, the largest magnitude improving trends for *E. coli* were at sites that currently have *E. coli* in the NOF E band. This may reflect targeted efforts to improve practices in catchments upstream of these sites; this will be explored as part of the state and trends spatial modelling report.

1 Introduction

Horizons Regional Council operates an extensive network of water quality and flow monitoring sites throughout the Manawatū-Whanganui Region for monitoring the state and trends in water quality and reporting on policy effectiveness. Prior to mid-2007, there were fewer monitoring sites in the Region (Roygard *et al.*, 2011). Following a review, a more extensive and detailed monitoring programme commenced in mid-2007 and was rolled out over three years. Since that date, a suite of variables, including physico-chemical and microbiological variables and biological indicators have been measured at 265 sites in the region. These data represent State of Environment (SoE), point source discharges, impact, lake, estuary and beach monitoring sites. SoE sites were chosen to be collectively representative of the water quality conditions in the catchment.

This study analysed the available water quality data for rivers in the Manawatū-Whanganui Region. We report on the state of water quality in the region, on a site by site basis, relative to targets set in the One Plan (Horizons Regional Council, 2014), as well as those specified in the National Objectives Framework (NOF) of the National Policy Statement – Freshwater Management (NPS-FM) (Ministry for Environment, 2017a). In addition, the study assessed water quality trends site by site, and across the region as a whole.

2 Data

We obtained water quality data representing physico-chemical and microbiological variables and biological indicators (Table 1) for 258 monitoring sites in the region from the Horizons database. Of the 258 sites, 182 had data from the most recent 5 years, and were included in this analysis. These included river (155), coastal (4), estuary (7) and lake (16) sites (Figure 1).

Most of the river sites are sampled for physico-chemical and microbiological variables on a monthly basis. All variables listed in Table 1 were evaluated for state and trends at all sites (where available), but in this report we only provide river state and trends for the variables that specifically relate to river environmental targets; these variables are highlighted in the table. The state and trend outputs for all sites and variables are provided in supplementary files (a full list of these files is provided in Appendix A).

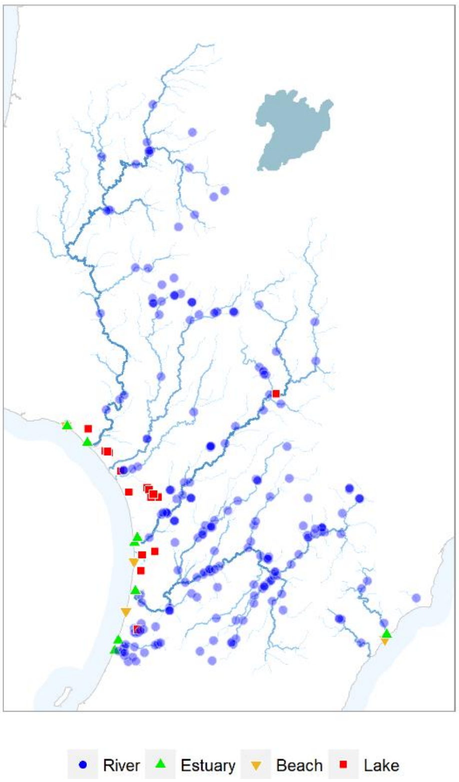

Figure 1: Water quality monitoring network in the Manawatū-Whanganui region (with data from the most recent 5 years)

Table 1: Water quality variables included in this study. This report only presents results for river monitoring sites and the variables highlighted in blue. The results for the other types of monitoring sites and variables are included in the supplementary files.

Variable type	Variable name	Description	Units
Physico-Chemical	CLAR	Black Disc Visibility	m
	Cond	Field Conductivity	µS cm^{-1}
	DO_Conc	Field Dissolved Oxygen Concentration	g m^{-3}
	DO_Sat	Field Dissolved Oxygen Saturation	%
	DRP	Dissolved Reactive Phosphorous	g m^{-3}
	NH_4-N	Ammoniacal Nitrogen	g m^{-3}
	NO_2-N	Nitrite	g m^{-3}
	NO_3-N	Nitrate	g m^{-3}
	pH	Field pH	pH
	POM	Volatile Matter	g m^{-3}
	SHMAK	SHMAK Tube	m
	SIN[b]	Soluble Inorganic Nitrogen	g m^{-3}
	SSC	Suspended Sediment Concentration	g m^{-3}
	TDP	Total Dissolved Phosphorus	g m^{-3}
	Temp	Field Temperature	ºC
	TN	Total Nitrogen	g m^{-3}
	TO_x-N	Total Oxidised Nitrogen	g m^{-3}
	TP	Total Phosphorous	g m^{-3}
	TSS	Total Suspended Solids	g m^{-3}
	TurbEPA	Turbidity EPA	NTU
	TurbISO	Turbidity ISO	NTU
	TurbISO-NTU	Turbidity ISO-NTU	NTU
Microbiological	Ecoli	*E. coli* by MPN	MPN $100mL^{-1}$
	Entci[a]	Enterococci	MPN $100mL^{-1}$
Biological	Chl_a[a]	Chlorophyll-*a*	mg Chl-a m^{-3}
	Chla	Chlorophyll-*a* (cover)	mg Chl-a m^{-2}
	Cyano	Cyanobacteria cover	%
	Fils	Filamentous Periphyton cover	%
	Mats	Mat Periphyton Cover	%
	MCI	Macroinvertebrate Community Index	MCI
	NoInd	Count: No of Individuals	no.
	NoTaxa	Count: No of Taxa	no.
	pEPT_A	Count: % EPT Abundance	no.
	pEPT_R	Count: % EPT Richness	no.
	QMCI	Quantitative Macroinvertebrate Community Index	QMCI

Notes: a. these variables are not measured at River sites.

b. SIN was not provided in the dataset, but was derived form available observations, as described in section 2.2

Visual water clarity is monitored because it is associated with the attenuation of light due to contaminants that are suspended in the water column, and because it indicates suspended solids that have the potential to settle and smother the beds of rivers and downstream water bodies. Visual clarity is generally measured as the sighting range of a black disc (Ministry for Environment, 1994), but has recently also been also measured by Horizons using a SHMAK tube (Kilroy and Biggs, 2002). Low visual clarity has ecosystem effects, including changes in animal behaviour. Water clarity also has implications for contact recreation as it is an indicator of the ability for humans to see through water to identify hazards.

Temperature affects most aquatic organisms directly, because it controls their growth rate (Davies-Colley *et al.*, 2013). The temperature tolerance of many aquatic species in New Zealand has been studied (see review by Davies-Colley *et al.*, 2013), leading to the establishment of environmental targets for maximum water temperature as part of the Horizons One Plan (2014). Water temperature also affects aquatic ecosystem health through its influence on equilibrium points (for instance, the solubility of dissolved oxygen) and the rates of physico-chemical reactions (for instance, the rate of consumption of dissolved oxygen by bacterial respiration). Spot measurements of temperature cannot be reliably used as SoE variables because temperature varies throughout the day. However, in this study, we evaluated the change in temperature between sample locations that were upstream and downstream of 26 point source discharges, and compared these changes with targets (see Section 3.2.2).

Dissolved oxygen and pH are water quality variables that are strongly influenced by the growth of plants in water bodies. These variables fluctuate over the course of a day due to the metabolic cycles of plants (Davies-Colley *et al.*, 2013). This means that spot (i.e. once per month) samples of dissolved oxygen and pH cannot be reliably used as SoE variables because they must be interpreted with reference to the time of day that the sample was taken; sites classified as meeting the pH and dissolved oxygen criteria could potentially be failing at other times of the day. In this study, we evaluated the change in dissolved oxygen and pH between sample locations that were upstream and downstream of 26 point source discharges, and compared these changes with targets (see Section 3.2.2).

The two nutrient species (soluble inorganic nitrogen [SIN], and dissolved reactive phosphorus [DRP]) were included because they contribute to the growth of plants, including periphyton (slime), which grows on the beds of streams and rivers. Nutrient enrichment of freshwater results from point and non-point source discharges and is strongly associated with intensive land use. High nutrients can promote excessive ('nuisance') growth of plants that, in turn, can smother habitat, produce adverse fluctuations in dissolved oxygen and pH, and impede flows and block water intakes. Excess plants in water bodies can also have detrimental effects on aesthetics and human uses by causing changes to water colour, odour and the general physical nature of the environment.

At sufficiently high concentrations, nitrate and ammoniacal-N are toxicants that can adversely affect aquatic animals. There are, therefore, environmental targets for these contaminants related to these toxic effects. NOF criteria for nitrate and ammoniacal-N are based on toxic effect levels, as these concentrations are generally significantly higher than levels that are problematic from the point of view of nuisance growth of plants.

The microbiological variable *E. coli* indicates the presence of human or animal faeces in water. The concentration of *E. coli* is associated with the risk of infectious disease from waterborne pathogens via both contact recreation and drinking water.

The abundance of periphyton is an indicator of trophic state for gravel bed rivers, which comprise a large proportion of the Manawatū-Whanganui region. Frequent high abundance of periphyton (‘blooms’) affect ecosystem health by causing adverse fluctuations in dissolved oxygen and pH, smothering habitat, and altering invertebrate communities (Ministry for Environment, 2000). Periphyton blooms are also associated with changes to water colour, odour, and alteration of the general appearance of the river bed, which have detrimental effects on human use values.

The Horizons water quality monitoring programme routinely measures periphyton abundance in two different ways: measurement of chlorophyll-*a* concentrations and by visual observation of percentage cover of different ‘types’ of periphyton. Chlorophyll-*a* is considered to be the most commonly recognised standard method (internationally and within New Zealand) for estimating stream periphyton biomass (e.g., as used within Ministry for Environment, 2000) because all types of algae contain chlorophyll-*a*, and this metric reflects the total amount of live algae in a sample. Visual assessments of cover have the advantage that they indicate the ‘type’ of periphyton at a river site as well as a readily understood estimate of the coverage (i.e. what people see when they are at a site) therefore linking to recreational and aesthetic values. The Horizons periphyton monitoring programme has the dual purpose of informing the development of a regional periphyton model as well as providing state and trend information (Roygard *et al.*, 2011).

The most common and problematic mat-forming cyanobacteria genus in the Manawatū-Whanganui region is *Phormidium.* It is very distinctive and can form expansive black/brown leathery mats that may cover the entire substrate. *Phormidium* can produce powerful neuromuscular blocking toxins, which pose a threat to humans and animals when consumed or when there is contact with contaminated water. During the recent past there has been an apparent increase in blooms of *Phormidium* in New Zealand rivers. Since 2011, percentage coverage of *Phormidium* has been routinely measured as part of the Horizons water quality monitoring programme by visual assessment using the methods outlined in the *New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters* (Wood *et al.*, 2009). The presence of detaching mats is also noted. Its presence is considered high risk as these occurrences commonly result in accumulations along shorelines or in vegetation and may become more persistent and accessible to humans and animals.

Volatile matter (or particulate organic matter) in rivers contributes to the total sediment load, absorbs and scatters light, and provides a pool of nutrients (C, N and P) that can be mineralised through microbial processes with the consumption of dissolved oxygen (Davies-Colley *et al.*, 2013). In extreme cases this can lead to anoxic conditions in the water.

Macroinvertebrates are invertebrate animals that live on the bed of rivers. The composition of the invertebrate community is used to measure the ecological health of waters and expresses the long-term effect of water and habitat quality at a site, compared to chemical water quality sampling which indicates only the quality at the instant the sample was taken. Macroinvertebrates are relatively long-lived and, consequently, the community composition reflects the historic flux of contaminants and habitat quality at a site. Therefore, invertebrates do not need to be sampled as frequently, and are sampled annually during summer. The invertebrate data were expressed as macroinvertebrate community (MCI) and quantitative macroinvertebrate community (QMCI) scores, which are widely used for environmental monitoring in New Zealand (Stark and Maxted, 2007). The MCI score is a metric that is based on the presence of different invertebrate taxa, which was designed to reflect water quality, where site scores potentially range from >150 (high water quality) to as low as 20 (very poor water quality) (Stark and Maxted, 2007). The QMCI is a metric that also incorporates quantitative or percentage data for different invertebrate taxa, where site scores potentially range from > 6 (high water quality to as low as 4 (very poor water quality)[1].

2.1 Flow data

Many of the water quality monitoring sites were associated with flow records, which we also obtained from the Horizons database. The flow on each sample occasion was used for two purposes. First, some of the environmental targets apply only when flows are in a certain range (see Section 3.2.1). Second, water quality can be strongly associated with flow, and the effect of flow on water quality can be accounted for in analysis of trends (see Section 3.3.3). For SoE and impact sites, for those variables included in the trends analyses in this report, approximately 42% of all sample occasions had an associated flow.

Three sources of river flow were utilised to provide flow data for the time of sampling (or the closest record on the day of sampling). They were:

- Gauged flow (measured during the sampling event)
- Flow from a hydrometric site located at the same place as the water quality monitoring station
- Modelled flow from Horizons Regional Council flow models.

Where measured (gauged and hydrometric station) flow and modelled flow existed for a site priority was given to the measured flow to match the water quality sample.

To allow an assessment against the environmental targets that apply only when flows are in a certain range the 20th flow exceedance percentile (80th percentile flow) and the median flow were calculated from the continuous record for a site using the hydrometric station or modelled flow record[2]. Where a site is gauged and there is no modelled flow the specified statistics were calculated based on the gaugings alone; this provides a less reliable estimate of the flow percentiles, and hence these sites are identified differently in the outputs.

2.2 Dataset pre-processing

Some processing was required to prepare the data for the subsequent state and trend analysis. Data were first processed to remove any duplicate observations. For days with sub-daily sampling the daily medians were then evaluated and used as replacements for all values on that day. Medians were calculated based on the face values of the censored values. If more than half of the observations were censored, then the median value is recorded as censored. These data cleaning steps reduced the total number of observations by ~0.1%.

Soluble inorganic nitrogen (SIN) was not provided as part of the dataset but is a variable that has a specified criterion in the One Plan (Horizons Regional Council, 2014) and is measured via calculation of its components. In the One Plan, SIN is described as either the sum of NO_3-N, NO_2-N and NH_4-N or the sum of the total oxidised nitrogen (TO_x-N) and NH_4-N. TO_x-N, NO_3-N, NO_2-N and NH_4-N were all provided in the dataset, however, in some cases TO_x-N was provided at sites where NO_3-N and NO_2-N were not, and a non-censored TO_x-N was sometimes provided when one of either NO_3-N or NO_2-N were individually censored on that sampling occasion. Preference was first given to calculating SIN based on TO_x-N+NH_4-N.

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[1] https://www.lawa.org.nz/learn/factsheets/benthic-macroinvertebrates/

[2] This was done by carrying out a distribution analysis across the whole record for the site. Note this was not naturalized. Periods of record and source of the flow statistic was provided to LWP by Horizons to accompany the dataset.

When one of the observations was censored, half of the censored value was added to the non-censored value. When both observations were censored, the face value of the censored values was summed, and the observation was noted as being censored. A similar process was performed when TO_x-N values were not available, with SIN noted as censored when NO_3-N, NO_2-N and NH_4-N were all censored.

Ammonia is toxic to aquatic animals and is directly bioavailable. When in solution, ammonia occurs in two forms: the ammonium cation (NH_4^+) and unionised ammonia (NH_3); the relative proportions of the forms are strongly dependent on pH (and temperature). Unionised ammonia is significantly more toxic to fish than ammonium, hence the total ammonia toxicity increases with increasing pH (and/or temperature) (ANZECC, 2000). Standards related to ammoniacal-N concentrations in freshwater typically require a correction to account for pH and temperature. We applied a pH correction to NH_4-N to adjust values to equivalent pH 8 values, following the methodology outlined in Hickey (2014). For pH values outside the range of the correction relationship (pH 6-9), the maximum (pH<6) and minimum (pH>9) correction ratios were applied.

Data collected for clarity using black disc measurement frequently have missing observations, as the measurement technique becomes unsafe at higher river flows (typically associated with lower water clarity). An alternate method of estimating clarity is to use a SHMAK tube (Kilroy and Biggs, 2002), a method that relies on a sample being taken from the river for evaluation, and hence a safe alternative under high flow conditions. To provide a more complete coverage of clarity observations for this analysis, we have infilled missing clarity observations with SHMAK tube observations, where appropriate. In the dataset provided by HRC, there were 199 simultaneous observations at 80 different sites of SHMAK tube and black disc clarity, these data are plotted in Figure 2. These data suggest that below approximately 0.5m, as measured by SHMAK tube, there is good agreement between clarity measurements for the two methods, but above this value the two measurements diverge; this is consistent with comparisons made between SHMAK tube and black disc observations in Kilroy and Biggs (2002). We have therefore only infilled black disc water clarity with SHMAK tube observations on occasions when there was no black disc clarity observation and the SHMAK tube observation was less than 0.5m. For sites with SHMAK observations, this infilling increased the number of clarity observations by 16%, on average. In total this increased the number of clarity observations in the dataset by 4%.

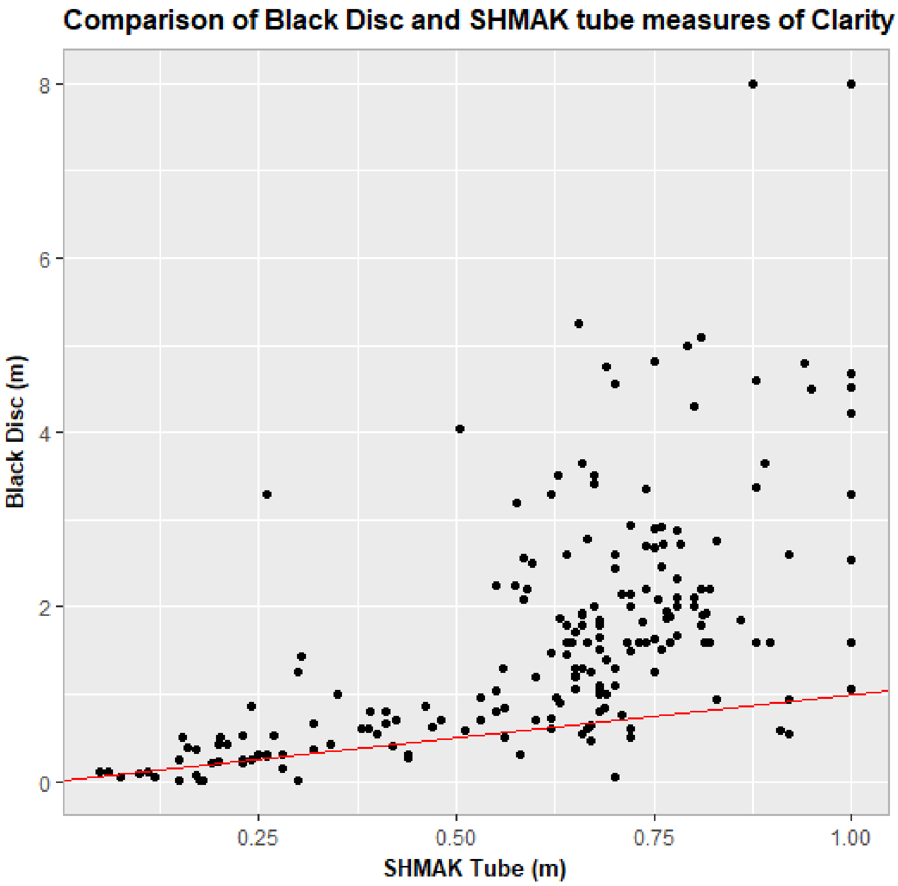

Figure 2: Comparison of Black Disc and SHMAK tube measures of clarity

2.3 Dataset summary data

Figure 3 summarises the available water quality data for all river monitoring sites for those variables included within this report. The same summary data are also plotted, by variable, in Appendix D. The duration of sampling across all SoE sites and variables in this study varied between 1 and 29 years (Figure 3). Sampling start years were variable between sites, with a notable increase in monitoring sites occurring around 2008. The total number of samples varied between SoE sites, partly reflecting variation in the number of years that the variables had been measured and partly in association with differences in sampling frequency. Most SoE sites had a low proportion of observations having censored values (Appendix D), however, just a few variables (ammoniacal-N and volatile matter) accounted for most of high proportions of censored values (Appendix D).

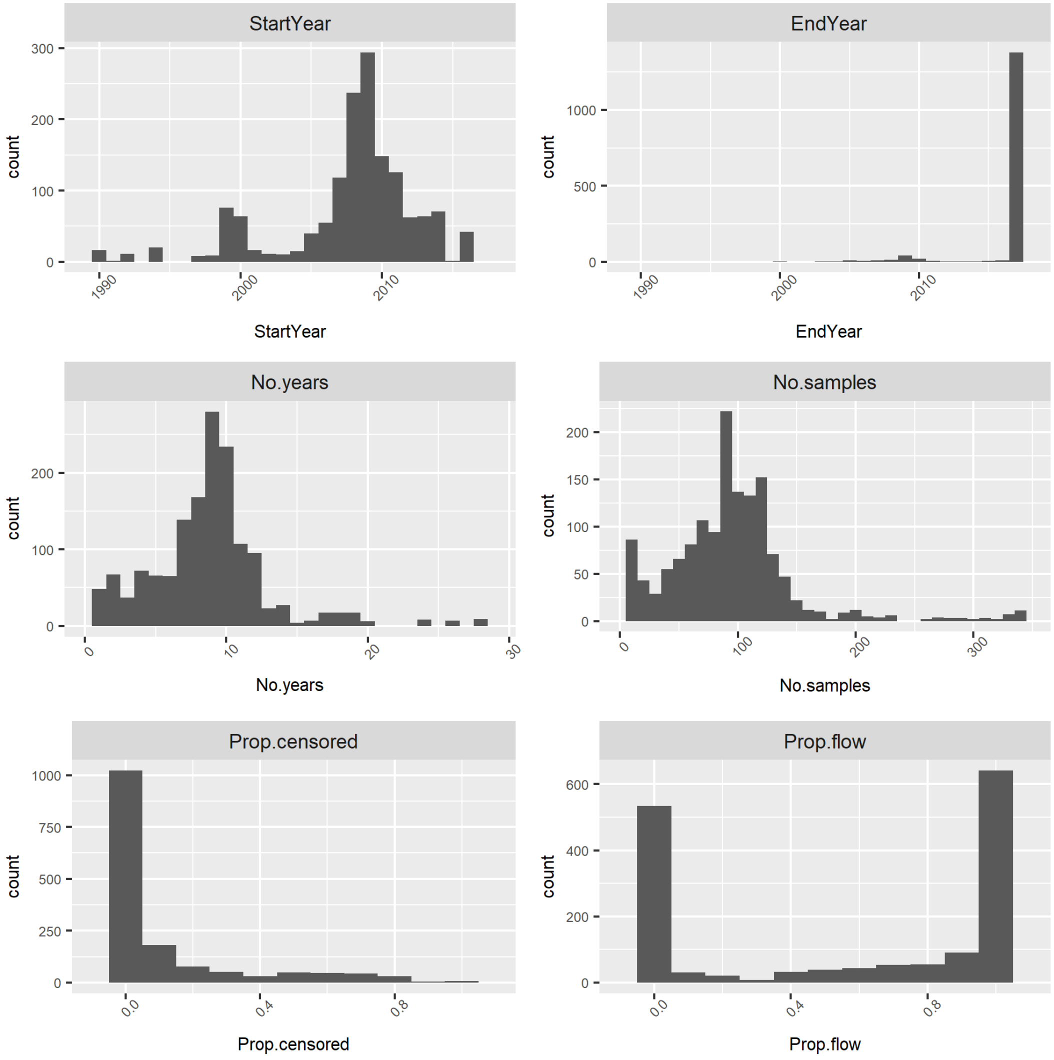

Figure 3. Histograms summarising the available data for the SoE river water quality monitoring sites, where each site:variable combination contributes one count. The histograms describe the variation in the start and end years of sampling, the duration of the sampling period, the number of sample occasions, and the proportion of samples that are censored and the proportion of samples with associated measurement of flow.

3 Methods

3.1 Categorisation of sites

Sites were categorised into three types: discharge, impact and state of environment (SoE) (Figure 4). Discharge and impact sites represent specific point source discharges or locations downstream (at the end of the consented mixing zone) of significant and specific point sources, respectively. It has been assumed SoE sites are not significantly affected by point source discharges and that they reflect both state and trends arising from the combination of diffuse and point sources of contaminants occurring in their catchments. SoE sites were assumed to be representative of general regional water quality conditions.

The three categories of sites were analysed separately in the study. State and trends were evaluated at SoE sites and were used to make inferences about water quality and biological conditions across the entire region. Trends were evaluated at discharge and impact sites to provide information about the association between river water quality trends and interventions that have occurred in the region over the last decade (see Section 4.7). Discharge sites presented in this report all have an associated downstream impact site and an upstream SoE site, allowing for assessment of the change in state associated with the point source discharge to be evaluated. Appendix B provides a list of the point source discharges and their associated upstream (SoE) and downstream (impact) monitoring sites.

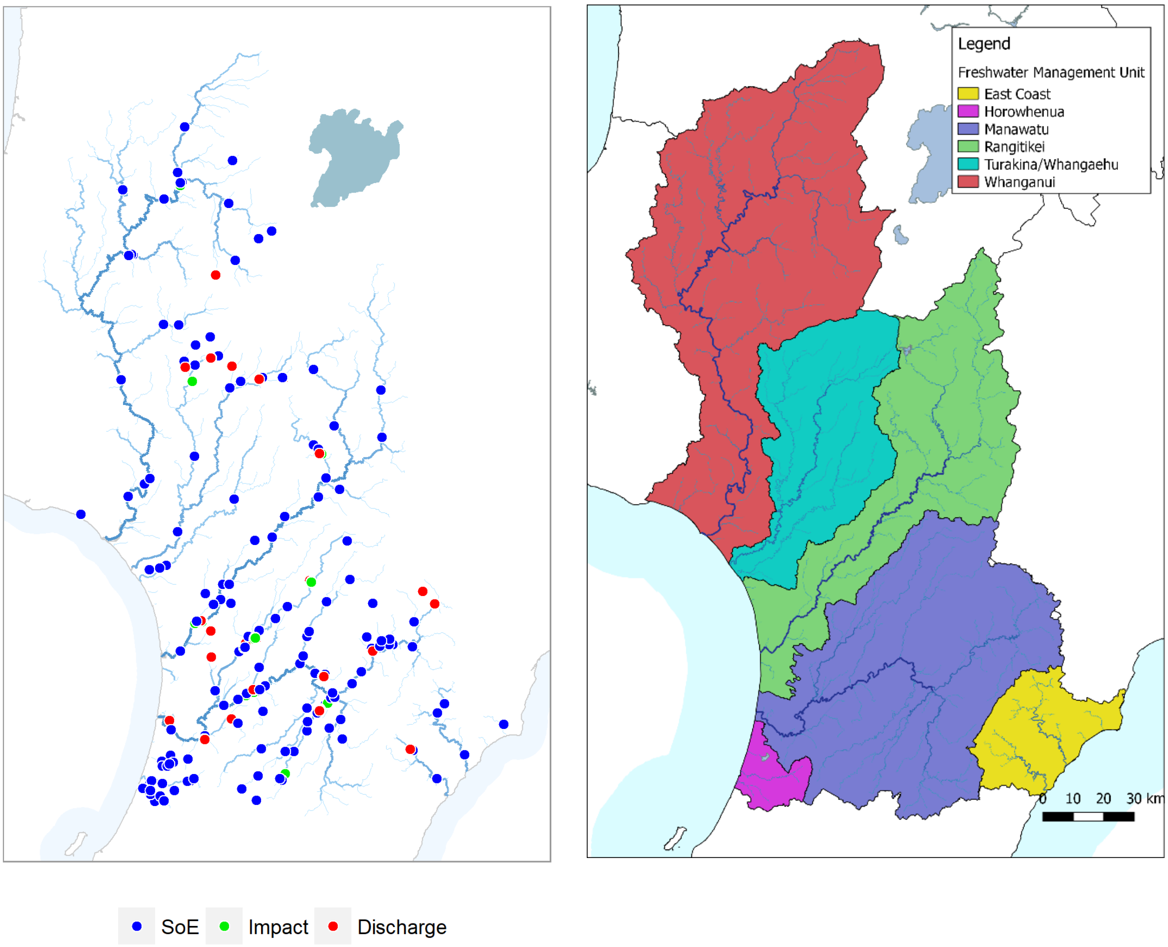

Figure 4: Monitoring locations in the Manawatū-Whanganui Region (with data in the most recent 5 years), by category (left) and Freshwater Management Units in the Manawatū-Whanganui Region as defined by the One Plan (right).

3.2 Assessment of water quality state

3.2.1 Grading of SoE and impact sites

State of the Environment sites are graded based on performance against Horizons One Plan targets (Table 2; Horizons Regional Council, 2014) as well as against national water quality criteria, as defined by the National Objectives Framework (NOF) of the National Policy Statement – Freshwater Management (NPS-FM) (Ministry for Environment, 2017a) (shown in Table 3 and Table 4). In some cases, there are criteria/targets for the same measures in both the Horizons One Plan, and the NOF (e.g. the maximum ammoniacal-N concentration) – however, because these criteria/targets have different numeric values, we report each site's grade based on both sets of criteria/targets.

For each criteria/target, a "compliance statistic" is calculated and compared to the criteria/target e.g., for a site, the 95th percentile of nitrate is calculated from the water quality record (the compliance statistic) and evaluated as passing or failing, depending on whether the compliance statistic is less than or greater than the NOF national bottom line of 9.8 mg/l (the criteria), respectively. We note that, depending on the variable, the observations needed to be either lower than the threshold (e.g. all chemical concentration targets, periphyton abundance targets) or greater than the threshold (e.g. clarity and MCI targets). In the cases where the compliance statistic is a quantile (i.e., the median or 95th percentile), the Hazen method was used to calculate the appropriate quantile, following the recommendation in the New Zealand Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (Ministry for Environment and Ministry of Health, 2003).

The numeric values for Horizons One Plan targets for many variables vary by site based on varying expectations for environmental outcomes (details are provided in Appendix C). Several of the Horizons One Plan targets consider only sampling occasions associated with specified dates or flows (Table 2). This reflects considerations associated with the effects of the contaminant. For example, nutrients and microbial contaminants are of less concern during high flows. The bathing water microbial concentration target (Ecoli.Bath; Table 2) only applies to the summer season when swimming is likely. These additional details for how the threshold values are compared to observations are provided for each variable in Table 2.

Censored values were replaced by imputation for the purposes of calculating the state statistics. Left censored values (values below the detection limit(s)) were replaced with imputed values generated using ROS (Regression on Order Statistics; Helsel, 2012), following the procedure described in Larned *et al.* (2015). The ROS procedure produces estimated values for the censored data that are consistent with the distribution of the uncensored values and can accommodate multiple censoring limits. Censored values above the detection limit were replaced with values estimated using a procedure based on "survival analysis" (Helsel, 2012). A parametric distribution is fitted to the uncensored observations and then values for the censored observations are estimated by randomly sampling values larger than the censored values from the distribution. The survival analysis requires a minimum number of observations for the distribution to be fitted; hence in the case that there were fewer than 24 total observations, censored values above the detection limit were replaced with 1.1* the detection limit.

The grading assessments were made for a 5-year period to end of June 2017. The end date for this period was determined by the availability of quality assured information that was loaded in the Horizons database. The statistical robustness of the determinations of water quality state depends on the variability in the measurements between sampling occasions and the number of observations. This is particularly important for sites that are close to the objective or target because the confidence that the assessment of state is 'correct' (i.e., that the site has been correctly classified as either passing or failing) increases as the number of observations increase. As a general rule, increases in confidence for estimates of population statistics slow for sample sizes greater than 30 (i.e., there are diminishing returns on increasing sample size with respect to confidence above this sample number; McBride, 2005). A period of five years represented a reasonable trade-off for most of the targets because it yielded a sample size that was 30 or more for many sites and variable combinations (i.e., five years of monthly observations, where observations that are counted for some variables are for flows below the 50th percentile). We evaluated state for site by variable combinations that did not meet the required minimum sample size and indicated in the results that the confidence in these assessments is less than those that met the nominated minimum sample size. For annually sampled macroinvertebrate variables, which are generally more stable in time than most physical or chemical water quality variables, the nominated minimum sample size requirement was reduced to 5 (Table 2).

Assessments of benthic cyanobacteria were undertaken using a target that was based on thresholds suggested in the *New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters* (Wood *et al.*, 2009). The Guidelines suggest a benthic cyanobacteria threshold of less than 20% coverage of the river bed substrate by potentially toxigenic cyanobacteria. Greater than 20% would be categorised as “Alert” and greater than 50% coverage is considered a threshold for “action”. We did not consider the observations of detaching mats in our analysis. Wood *et al.,* (2013) demonstrated that detaching mats were common even when percentage coverage was low, and inclusion of the detached component in the assessment of state is therefore inappropriate. The Guidelines suggest that a single observation that exceeds the threshold should trigger a series of management actions. However, this is not an appropriate method for determining a grade that represents the longer-term human health risk posed by benthic cyanobacteria at a specific site. In this report, we followed the recommendations of Wood *et al.* (2014), as implemented in Snelder *et al.* (2014) and used the 90th percentile of monthly observations to assign a grade for planktonic cyanobacteria for secondary contact recreation.

Table 2: Details of the Horizons One Plan targets for each water quality variable used to grade the state of the SoE sites.

Target name	**Method**[1]	**Flow percentile**[2]	**Sample size required**	**Target description**
DO	All	100	30	The Dissolved oxygen (DO) must exceed […][3]% of saturation.
POM	Mean	50	30	The average concentration of particulate organic matter when the river flow is at or below 50th flow exceedance percentile must not exceed […] grams per cubic meter.
Chla	All	100	30	The algal biomass on the river bed must not exceed […] milligrams of chlorophyll-*a* per square metre.
DRP	Mean	80	30	The annual average concentration of dissolved reactive phosphorus (DRP) when the river flow is at or below the 20th flow exceedance percentile must not exceed […] grams per cubic metre, unless natural levels already exceed this.
SIN	Mean	80	30	The annual average concentration of soluble inorganic nitrogen (SIN) when the river flow is at or below the 20th flow exceedance percentile must not exceed […] grams per cubic metre, unless natural levels already exceed this.
NH4	Mean	100	30	The average concentration of ammoniacal-N must not exceed […] grams per cubic metre.
NH4.Max	All	100	30	The maximum concentration of ammoniacal-N must not exceed […] grams per cubic metre.

Target name	Method[1]	Flow percentile [2]	Sample size required	Target description
Clar	All	50	30	The visual clarity of the water^ measured as the horizontal sighting range of a black disc must equal or exceed […] metres when the river^ is at or below the 50th flow exceedance percentile..
Ecoli.Bath	All	50	30	The concentration of *Escherichia coli* must not exceed […] per 100 millilitres between 1 November - 30 April (inclusive) when the river^ flow is at or below the 50th flow exceedance percentile*.
Ecoli.Year	All	80	30	The concentration of *Escherichia coli* must not exceed […] per 100 millilitres year-round when the river^ flow is at or below the 20th flow exceedance percentile*.
MCI	Mean	100	5	The average value of the annual MCI scores must not be less than […][4].
Peri.Fils	All	100	30	The maximum cover of the visible river bed by periphyton as filamentous algae more than 2 centimetres long must not exceed […]%.
Peri.Mats	All	100	30	The maximum cover of visible river bed by periphyton as diatoms or cyanobacteria more than 0.3 centimetres thick must not exceed […]%.
Cyan.Alert	All	100	30	The maximum cover of coverage of potentially toxigenic cyanobacteria to substrate must not exceed […]%.
Cyan.Action	All	100	30	The maximum cover of coverage of potentially toxigenic cyanobacteria to substrate must not exceed […]%.

1. Where all observations must comply with the target, the method is “All”. Where a statistic of the observation’s distribution must comply, the statistic is shown as “Mean” or “Median” percentile (i.e. 80, 90 or 95).
2. The maximum flow percentile for an observation to be included in the analysis.
3. The symbol […] indicates that the thresholds used were variable and site specific. The thresholds for all sites are provided in Appendix A.
4. Unless natural physical conditions are beyond the scope of application of the MCI. In cases where the river^ habitat is suitable for the application of the soft-bottomed variant of the MCI (sb-MCI) the Water Quality Target* (or standard where specified under conditions/standards/terms in a rule) also apply.

For each ‘attribute’ proposed in the NOF (Table 3), there are four (or five) ‘attribute states’, which are designated A to D (or A to E, in the case of the *E. coli* criteria) (Table 4). The D attribute state represents a condition that is below the bottom line (i.e. unacceptable) in any water-body nationally, and attribute states C, B and A represent progressively higher levels of protection that could be adopted by regions or communities, depending on aspirations for water quality. Sites were assigned grades based on the performance against the NOF criteria outlined in Table 4.

The NPS-FM human health for recreation attribute table was modified by the 2017 amendments to the NPS-FM. The new attribute defines the swimming grade at a site based on four statistics derived from *E. coli* measurements: median, percentage of exceedances over 540 *E. coli* 100mL^{-1}, percentage of exceedances over 260 *E. coli* 100mL^{-1}, and the 95th percentile. Thresholds for each statistic are associated with a category from A (Excellent) to

E (Poor) (Table 4). These thresholds are associated with the level of risk of Campylobacter infection. The swimming grade (referred to as *NOF.Ecoli.Combined* in this report) for a site is the lowest (i.e., worst) grade indicated by the individual statistics. Each grade indicates the site's average level of risk; Table 4, (Ministry for Environment, 2017c).

The 95th percentile is estimated with lower precision than the other three statistics. This imprecision cannot be reduced because it is determined by the available data and varies between sites in association with the level of variability in the individual *E. coli* observations. The imprecision affects the robustness of swimming grade assessments (Stats NZ, 2017). A precisely measured 95th percentile value is consistent with the average level of risk indicated by the other three statistics, but an imprecise measurement may result in an erroneous allocation of a site to a swimming grade. As such, following the approach of Snelder (2018) the 95th percentile statistic was not used to assess swimming grades (*NOF.Ecoli.Combined)*, but is still provided as a standalone statistic.

Table 3: Details of the NOF criteria for each water quality variable used to grade the state of the SoE and impact sites.

Target name	**Method**	**Sample size required**	**Criteria description**
NOF.NH4.Med	median	30	The median concentration of Ammoniacal-N must not exceed […] mg l^{-1}
NOF.NH4.Max	All	30	The maximum concentration of Ammoniacal-N must not exceed […] mg l^{-1}
NOF.NO3N.Median	median	30	The median concentration of Nitrate must not exceed […] mg l^{-1}
NOF.NO3N.p95	95	30	The 95th percentile concentration of Nitrate […] mg l^{-1}l
NOF.Peri.p92	92	5	The 92nd percentile of periphyton chlorophyll-*a* (mg chl-a m^{-2}) for default river class[2], must not exceed […]
NOF.Peri.p83	83	5	The 83rd percentile of periphyton chlorophyll-*a* (mg chl-a m^{-2}) for productive river class[1], must not exceed 200
NOF.Ecoli.G260	G260	30	% exceedances over 260 cfu 100 mL^{-1} must be less than […]%
NOF.Ecoli.G540	G540	30	% exceedances over 540 cfu 100 mL^{-1} must be less than […]%
NOF.Ecoli.Med	median	30	The median concentration of *E. coli* (cfu 100 ml^{-1}) must be less than […]
NOF.Ecoli.p95	95	30	The 95th percentile concentration of *E. coli* (cfu 100 ml^{-1}) must be less than […]

1. Classes are streams and rivers defined according to types in the River Environment Classification (REC) (Snelder and Biggs, 2002). The Productive periphyton class is defined by the combination of REC "Dry" Climate categories (i.e. Warm-Dry (WD) and Cool-Dry (CD)) and REC Geology categories that have naturally high levels of nutrient enrichment due to their catchment geology (i.e. Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)).

Table 4: Details of the NOF attribute state thresholds for rivers. Values for each variable are in units defined in Table 4[3]*.*

Target name	**A**	**B**	**C**	**D**	**E**
NOF.NH4.Med	≤0.03	≤0.24	≤1.3	>1.3	-
NOF.NH4.Max	≤0.05	≤0.4	≤2.2	>2.2	-
NOF.NO3N.Median	≤1	≤2.4	≤6.9	>6.9	-
NOF.NO3N.p95	≤1.5	≤3.5	≤9.8	>9.8	-
NOF.Peri.p92	≤50	≤120	≤200	>200	-
NOF.Peri.p83	≤50	≤120	≤200	>200	-
NOF.Ecoli.G260	≤20	≤30	≤34	≤50	>50
NOF.Ecoli.G540	≤5	≤10	≤20	≤30	>30
NOF.Ecoli.Med	≤130	≤130	≤130	≤260	>260
NOF.Ecoli.p95	≤540	≤1000	≤1200	≤1200	>1200

3.2.2 Grading of point source discharge sites

The grading of water quality state at point source discharge sites involved two types of comparison. First, the observations at the sites downstream of the discharges were compared to the targets set out in Table 2 and Table 4. Second the difference between the paired upstream and downstream sites (Appendix B) were determined and compared against specific thresholds for change set by the Horizons One Plan (Table 5). If the observations were within the threshold for change, the site was classified as pass, otherwise it was classified fail. The details of the grading procedure for each water quality variable is summarised in Table 5. For all variables, all observations (i.e. differences between upstream SoE sites and downstream 'impact' sites) needed to comply with the targets at all flows, otherwise the site was classified as failing. The actual threshold values vary by site, and these details are provided in Appendix C.

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[3] From : http://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/nps-freshwater-ameneded-2017_0.pdf

Table 5: Details of the Horizons One Plan targets for each water quality variable used to grade the point source monitoring sites.

Target name	Method	Flow percentile[1]	Sample size required	Target description[2]
pH.Change	All	100	30	The pH of the water must not be changed by more than […].
Temp.Change	All	100	30	The temperature of the water must not be changed by more than […] degrees Celsius.
Clarity.Change	All	100	30	The visual clarity of the water measured as the horizontal sighting range of a black disc must not be reduced by more than […] %.
QMCI.Change	All	100	5	There must be no more than a 20% reduction in Quantitative Macroinvertebrate Community Index (QMCI) score between appropriately matched habitats upstream and downstream of discharges to water.

1. The maximum flow percentile for an observation to be included in the analysis.
2. The symbol […] indicates that the thresholds used were variable and site specific. The thresholds for all sites are provided in Appendix A.

3.3 Trend analysis methods

3.3.1 Sampling dates and time periods for analyses

Trend assessments are specific for a given period of analysis. In this study, trends were characterised for the 10 and 20 years up to the end of June 2017 (note additional time periods are also included in the supplementary data).

The dataset had variable starting and ending dates, variable sampling frequencies, and variable numbers of missing values. Filtering rules were therefore used to achieve a reasonable degree of data-representativeness of all site:variable combinations, and a trade-off analysis performed to determine the trade-off between length of time period, sample size and numbers of sites. We used the filtering rules suggested by Helsel and Hirsch (1992), which restricted site and variable combinations for trends in a given time period such that there were measurements for at least 80% of the years and at least 80% of seasons.

We assessed trends for the water quality variables using seasons defined by months preferentially, and quarters when there were insufficient monthly observations, provided the filtering rules were met. Because the biological variables (excluding periphyton) are generally sampled annually, analysis of these trends does not involve seasons. For some sites and variables there was more than one sample within some seasons or years (for annual observations). In these cases, we used the median of the values for the season (or year for the annual observations) to ensure consistent statistical power across all sites. We note that when there is more than one sample in a season, all samples can be used in a trend analysis resulting in increased statistical power and potentially different results. However, because our analyses are used to make regional comparisons and contribute to spatial models, we elected to ensure analyses had consistent statistical power. All site by variable combinations that did not comply with these filtering rules were excluded from the analysis.

3.3.2 Statistical analyses

The statistical analyses of trends involved the evaluation of (1) the probability that the true trend was decreasing and (2) the magnitude of the trend (including uncertainty).

In traditional water quality trend analysis, a statistical test of significance developed by Hirsch *et al.* (1982) is used. The statistical test is Kendall's test of rank correlation, which is a nonparametric correlation coefficient measuring the monotonic association between y and x. In water quality trend analysis, y is a sample of water quality measurements and x is the corresponding sample dates.

McBride (in press) suggested a more graduated expression of confidence in the trend direction is available from a calculation of the probability that the trend was decreasing. McBride (in press) showed how the probability that the trend was decreasing can be calculated as part of the Sen slope calculation. However, because the Sen slope calculations cannot account for censored values, these statistics become increasingly less robust as the proportion of censored values increase. Therefore, the LWP-Trends library provides a more robust method for inferring trend direction using the Kendall p-value and S-statistics rather than the Sen slope calculations. Confidence in the trend direction is provided by interpreting the Kendall p-value as a probability that the trend is decreasing by:

$$P(S < 0) = 1 - 0.5 \ \times pvalue$$

$$P(S > 0) = 0.5 \ \times pvalue$$

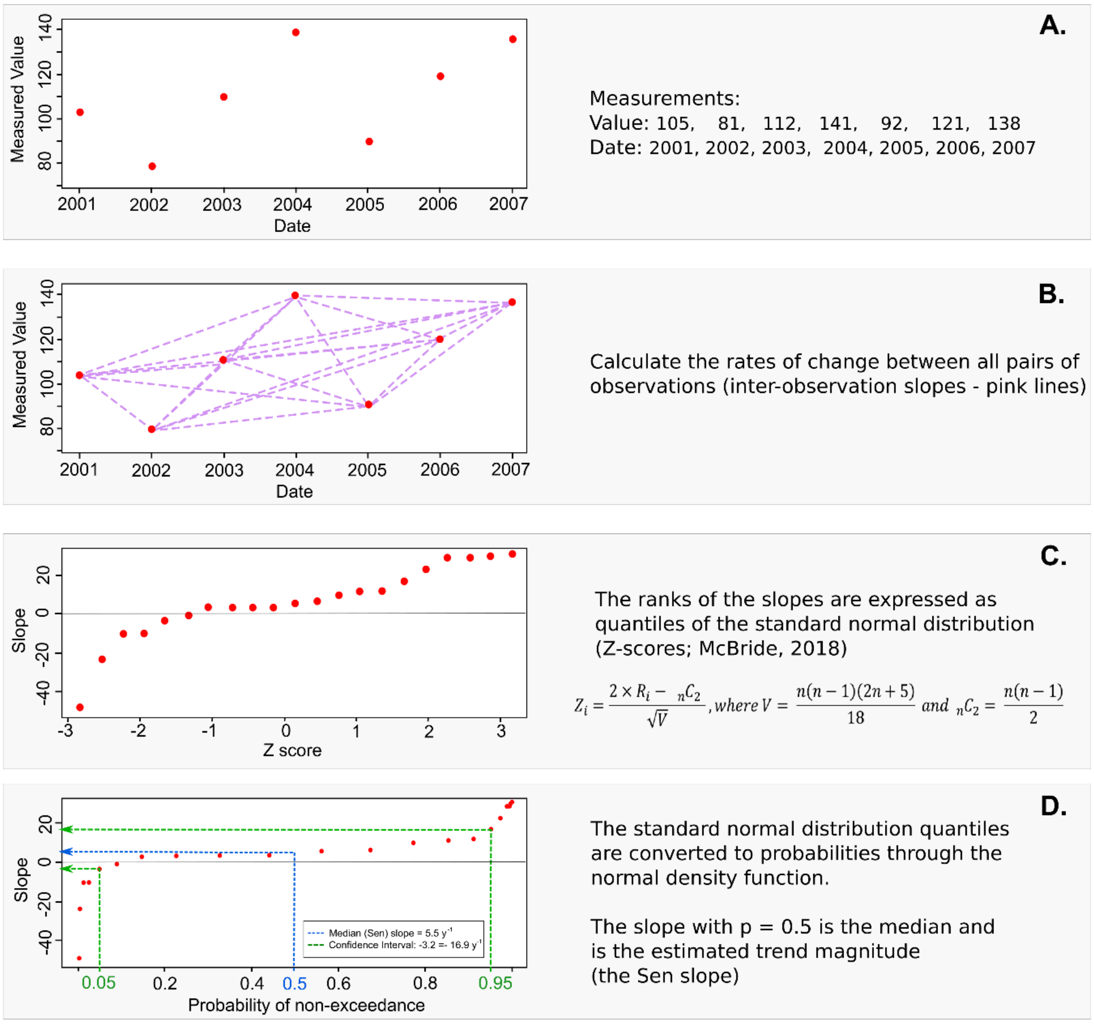
where, $pvalue$ is the p-value returned by Kendall test (either seasonal or non-seasonal)), *S* is the S statistic returned by Kendall test (either seasonal or non-seasonal) and *P* is the probability that the trend was decreasing.

The trend direction is interpreted as decreasing when P > 0.5 and increasing when P < 0.5. The benefit of this approach is the Kendall p-value, and therefore the probability that the trend is decreasing, robustly accounts for censored values.

The trend magnitude is determined by the Sen slope estimator (SSE), which is the median of all possible inter-observation slopes i.e., the difference in the measured observations (including censored values at their face value) divided by the time between sample dates. A diagrammatic explanation of the method used to determine trend magnitude and uncertainties is shown in Figure 5. Consider 5 years of monthly observations (i.e., n=60). There are (60 x 59)/2 = 1770 possible inter-observation slopes. These inter-observation slopes are ranked from the smallest to largest and the Sen slope is the average of two inter-observation slopes with ranks 885 and 886 (i.e., the median of all 1770 inter-observation slopes). The seasonal version of the SSE is used in situations where there are significant differences in water quality measurements between 'seasons'. Seasons are defined primarily by the sampling frequency. In New Zealand, it is common to sample either monthly or quarterly, and in these cases, seasons are defined by months or quarters. The seasonal Sen slope estimator (SSSE) is the median of all inter-observation slopes within each season. Consider monthly data for 5 years of record. All possible inter-observation slopes between data pertaining to January are calculated (10 in number). This is then repeated for all other months giving 120 inter-observation slopes. The SSSE is the average of the two inter-observation slopes with ranks 60 and 61 (i.e., the median of all 120 slopes). The SSE and SSSE values express trends in units of change in the variable per year.

Confidence intervals for the Sen slope are determined by first expressing the ranks of the slopes as quantiles of the standard normal distribution (Z-scores). The probabilities of observing those Z-scores are then calculated using the normal density function (Figure 5). The slopes and associated non-exceedance probabilities can be used to: (1) evaluate the Sen slope, by interpolating the slope at which the non-exceedance percentile = 0.5; and (2) determine the confidence interval for the Sen slope, by interpolating the slopes at which the non-exceedance percentiles are α and 1- α. In this study we have a nominated an alpha value of 0.05, to be consistent with Larned *et al.* (2015).

When the precision of the measured observations is low, there will be many observations with the same value leading to many ties (i.e., inter-observation slopes of exactly zero). This results in a high chance of obtaining a Sen slope of exactly zero. However, an overarching assumption of the new approach is that there always are differences between observations (leading to the assumption that the trend can never by zero; McBride, 2018). It follows that a Sen slope evaluated as zero, is in fact either an increase or decrease but with a magnitude that cannot be established due to the low precision of the variable being measured. To avoid equivocal assessments of trend direction evaluated from the Sen Slope, we use the probability that the trend is decreasing, derived from the Kendall test (as described earlier) to evaluate confidence in the trend direction. If this probability is <0.05 and >0.95 then we can conclude, with confidence, that the trend is increasing or decreasing respectively, but at a rate that cannot be resolved with the dataset precision. Very rarely, the Kendall probability estimate will be evaluated to be 0.5 (which is generally associated with very low precision datasets), in these cases, the trend direction is labelled as “indeterminate”.



Measurements:
Value: 105, 81, 112, 141, 92, 121, 138
Date: 2001, 2002, 2003, 2004, 2005, 2006, 2007

Calculate the rates of change between all pairs of observations (inter-observation slopes - pink lines)

The ranks of the slopes are expressed as quantiles of the standard normal distribution (Z-scores; McBride, 2018)

$$Z_i = \frac{2 \times R_i - \ {}_nC_2}{\sqrt{V}}, where\ V = \frac{n(n-1)(2n+5)}{18}\ and\ {}_nC_2 = \frac{n(n-1)}{2}$$

The standard normal distribution quantiles are converted to probabilities through the normal density function.

The slope with p = 0.5 is the median and is the estimated trend magnitude (the Sen slope)

Figure 5: Pictogram of the steps taken in the trend analysis to calculate the Sen slope and the its uncertainty bounds.

3.3.2.1 Censored values

Censored values are those above or below a detection limit (e.g., >2.5 or <0.001). Values above the detection limit are described as right censored and values below the detection level are described as left censored. Trends are most robust when there are few censored values in the time period of analysis. It has been common to substitute the censored values with 0.5×detection limit and 1.1×reporting limit. Although common, replacement of censored values with constant multiples of the detection and reporting limits can result in misleading results when statistical tests are subsequently applied to those data (Helsel, 2012).

The previous method of trend analysis (i.e., Larned *et al.*, 2015) substituted censored values with values that were imputed from the data. In that study, the effect of censored values and missing data on the evaluated trend magnitude was minimal because sites and variable combinations were restricted to those for which the number of censored values was <15% of the total number of observations. Imputation of censored values is an accepted method for obtaining sample statistics (e.g., mean values and standard deviations). The use of imputed values in trend analysis by Larned *et al.* (2015) was not strictly correct because the imputation process cannot account for the time order of samples. However, the restriction rules avoided making incorrect determinations of trend magnitude because this quantity is unaffected by censoring when fewer than 15% of the data are censored values.

The methods used in this study treat censored values in the manner described by Nondetects and Data Analysis for Environmental Data (Helsel, 2005) and Statistics for censored environmental data using MINITAB and R (Helsel, 2012). Calculations that are affected by censored values are the calculation of Kendall's S and its variance (varS), and the estimation of the Sen slope (including the seasonal Sen slope) and its confidence intervals. To calculate S and varS, and the confidence intervals for Sen slopes, the functions used in this study utilise code obtained from the cenken() function in the R package NADA, which implements the analyses discussed in the above two references. Briefly, for left-censored data, increases and decreases in a water quality variable are measured whenever possible. Thus, a change from <1 to 10 is an increase. A change from a <1 to a detected 0.5 is considered a tie, as is a <1 to a <5, because neither can definitively be called an increase or decrease. Similar logic applies to right censored values. The variance of the S statistic is adjusted for ties (it is reduced) and this influences the computation of confidence intervals.

When Sen slopes are calculated, the face values of the observations (either raw or flow adjusted, irrespective of censoring) are used. However, the slope between any combination of observations in which either one or both are censored cannot be definitively calculated. The slopes associated with censored values are therefore uncertain. Because the Sen slope is the median of all the inter-observation slopes, when a small proportion of observations are censored the Sen slope is unaffected by censoring and is a reliable estimate of the trend magnitude and direction, and its confidence intervals can be used to determine the confidence in trend direction (by evaluating whether the confidence intervals contain zero). As the proportion of censored values increase the probability that the Sen slope is affected by censoring increases. Helsel (1990) estimated that these effects would be negligible for as many as 15% censored values. However, this is a rule of thumb and is not always true. Depending on the arrangement of the data, 15% censored values could affect the computation of a Sen slope (Helsel 2012). When there is no censoring, the direction and confidence implied by the Sen slope analysis is consistent with the Mann-Kendall or seasonal Kendall test (whichever is appropriate). However, as the number of censored values increase, the Sen slope becomes a less reliable estimate of the trend magnitude and trend direction confidence. We recommend that Sen slopes estimated from data with greater than 15% censored values are treated very cautiously (see Appendix D for summaries of the percentage censoring for the sites/variables used in this study). In addition, we recommend that when there are censored values, greater confidence is placed in the statistics returned by the Kendall tests (including the trend direction and the probability the trend was decreasing). Where there are fewer than five total and three unique, non-censored observations (but when the other filtering criteria are otherwise met), the method will not analyse the data and these cases are reported as "not analysed".

For many of the variables there are changes in censoring limit in time due to changes in analytical method. There is a potential for these changes to influence the evaluation of the SSE. Appendix F presents an exploration of the potential impacts on the evaluated SSE and associated confidence interval of varying censoring limits. This analysis was based on comparing trend analysis outputs based on the complete dataset with outputs based on a dataset where all values below the highest censored value were treated as censored.

3.3.2.2 Seasonality

When there is seasonal variation in the observations, the seasonal Sen slope estimator (SSSE) should be used (Hirsch *et al.*, 1982). Larned *et al.* (2015) evaluated all trends using the SSSE, however, the seasonal estimator has lower statistical power than the non-seasonal estimator (due to smaller sample sizes). It is therefore advantageous to establish whether the water quality observations are seasonally varying and if this is not the case, to use the more powerful SSE to evaluate the trend. The new method of trend analysis commences by testing for the effect of season (i.e., month or quarter) on each site and variable combination using a Kruskal Wallis test. When there is a statistically significant effect ($p \leq 0.05$) of season on the value of a variable, the SSSE is evaluated, otherwise the non-seasonal SSE is evaluated. In seasonal tests, the filtering criteria (described above) must be met within each season. When seasonal filtering criteria are not met for monthly seasons, the analysis is attempted for quarterly seasons.

3.3.3 Covariate adjustment

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). Different mechanisms may dominate at different sites so that the same water quality variable (e.g., *E. coli*) can exhibit positive or negative relationships with flow (Snelder *et al.*, 2016).

Adjusting the observations to account for the effect of flow (flow adjustment, or any other covariate) decreases variation and increases statistical power (i.e., increases the likelihood of detecting a trend with certainty; Helsel and Hirsch, 1992). In addition, a trend in a water quality variable may arise because there is a relationship between time and flow on sample occasion (i.e., a trend in the flow on sample occasion such as increasing or decreasing flow with time). Flow adjustment may change this trend's direction and/or magnitude. Previous studies have often provided trend analyses based on both flow adjusted and raw data (e.g., Ballantine *et al.*, 2010; Larned *et al.*, 2015). The appropriate interpretation of the two sets of results by previous studies has been unclear (e.g., Ballantine, 2012).

Flow adjustment requires that water quality observations are associated with the flow at the time of sampling. Of a total of 200 SoE and impact sites for which we had some water quality data, 77 had no flow information provided. Where flow measurements were available, we used these. Where flow measurements were not available, we used flows based on HRC's flow models.

In this study we followed the conclusions and recommendations of Snelder (2018) concerning flow adjustment of water quality variables. In particular, we did not rely on the automated flow adjustment procedure used by Larned *et al.* (2015) because unsupervised fitting of regression models to flow versus concentration relationships can result in the selection of unreliable models. We used both generalised additive models (GAM), locally weighted least squares regression (LOESS) and log-log models to fit flow-water quality variable models. We inspected the models and used expert judgement to choose the most suitable model based on the homoscedasticity (constant variance) of the regression residuals and plausibility of the shape of the fitted model. Where there was little difference among models, we selected a log - log model. When the flow concentration relationship was poor (as evaluated by expert judgement), no flow adjustment was performed.

Flow at the time of sampling can be significantly correlated with periphyton abundance (Biggs and Close, 1989). However, the hydrological metrics more directly related to periphyton standing crop are the magnitudes of high flows (which remove periphyton) and the length of the flood-free periods prior to each survey (which allow periphyton to accumulate; i.e., the accrual period).

We evaluated both accrual period and the size of the flow required to remove (i.e., re-set) periphyton biomass at each monitoring site in a two-step process (analysis conducted by NIWA):

1. At each site we identified the flow magnitude (expressed as multiples of median flow) most likely to represent the periphyton removal threshold at that site. This flow is called the effective flow. At each site with a flow record and sufficient data (49 sites), we extracted the time in days since a high flow greater than N_m x median flow (where N_m = 1.5, 2, 3, 4, 5, …. in steps of 1, up to 15), for the two flow records (daily mean flow and daily maximum flow). Linear regressions were run on log-transformed chlorophyll-*a* or square-root-transformed cover by mats or filaments versus log-transformed time in days since an event of each magnitude. The linear regression results (particularly the adjusted R^2, hereafter R^2) and plots of the relationships at each site were reviewed. The event magnitude that explained the highest proportion of variance in periphyton chlorophyll-*a* or percentage cover by mats or filaments was interpreted as being the effective flow for the site and variable (note the effective flow at a site can differ between the three periphyton abundance measures). If a range of flow magnitudes had similar R^2, we used the smallest flow magnitude.

2. The second step in the process was to analyse the site flow record to assess the accrual time pertaining to the effective flow for each observation of chlorophyll-*a*, mats or filaments. This accrual time was then used as a covariate to adjust the record of chlorophyll-*a*, percentage cover by mats or percentage cover by filaments at each site. The number of days since an effective flow event is potentially the accrual time available for periphyton development, assuming that any smaller flow perturbations during that time have no or only a minor effect on biomass.

The method described in step 1 above isolates the effective flow because if N_m is too low, high chlorophyll-*a* could occur after short accrual times because some high flows would fail to remove biomass, leading to low explanatory power. If the selected flow size is too high, then low chlorophyll-*a* could occur after long accrual periods after being removed by smaller flows, again leading to low explanatory power. Only at flow sizes close to the threshold for removal would we expect a strong correlation between chlorophyll-*a* and days since the high flow, with the slope of the relationship approximating the rate of accrual. A caveat to this method is that care needs to be taken in interpreting relationships when accrual times are very long, because spontaneous sloughing can lead to unexpectedly low biomass (Biggs and Close, 1989). It is also acknowledged that the condition of the periphyton can influence the effect of a particular high-flow event (Katz *et al.*, 2017).

Daily maximum flow would be expected to provide the best relationships because periphyton removal has been shown to depend on peak velocity, with most loosely attached periphyton removed in the first few minutes (Francoeur and Biggs, 2006). However, more tightly attached mats may be scoured off more gradually (Biggs and Thomsen, 1995). In that case the daily mean flow (which partly reflects the duration of a high flow) may work better. We used both metrics and selected the strongest relationship at each site. The same flow adjustment procedures used for the other water quality variables were used to adjust all periphyton variables by days of accrual, where the relationships were strong enough to justify this adjustment.

Tests of whether conclusions would have differed substantially if trends had been evaluated using flow adjusted data were carried out by examining differences between raw and flow adjusted trends for a subset of sites and variables for which flow data was available for at least 80% of sample occasions. These tests and further considerations of flow adjustment are detailed in Appendix E. The tests for the subset data indicated that differences in trend directions and magnitudes derived from raw and flow adjusted data were not large. It was concluded that the overall findings of this study (regional aggregates) would not be appreciably different were the analysis to be performed using flow adjusted data. However, individual sites can have moderate to large differences in both the direction and magnitude of the calculated trends following flow adjustment, particularly for variables that have strong flow-concentration relationships (e.g., clarity, turbidity) and if there is a trend in the sample occasion flows.

3.4 Interpretation of trends

The analyses returned site trend outputs for each site and variable combination and these were classified into four direction categories: improving, degrading, insufficient data and not analysed. An increasing or decreasing trend category was assigned when the when probability ≥95% or ≤5% (i.e., the trend direction is established with confidence; Larned *et al.*, 2016). An “insufficient data” trend category was assigned when the when probability ≤95% and ≥5%; (the trend direction was not defined with confidence; Larned *et al.*, 2016). Trends were classified as “not analysed” for two reasons:

1) When a large proportion of the values were censored (data has <5 non-censored values and/or <3 unique non-censored values). This arises because trend analysis is based on examining differences in the value of the variable under consideration between all pairs of sample occasions. When a value is censored, it cannot be compared with any other value and the comparison is treated as a “tie” (i.e., there is no change in the variable between the two sample occasions). When there are many ties there is little information content in the data and a meaningful statistic cannot be calculated.

2) When there is no, or very little variation in the data (<3 unique non-censored values), because this also results in ties. This can occur because laboratory analysis of some variables has low precision (i.e., values have few or no significant figures). In this case, many samples have the same value resulting in ties.

Trends can be compared between time periods and also between pairs of associated sites. For the between time period comparisons, scatter plots were used to compare differences in calculated trend magnitudes (and associated uncertainty bounds). The distribution of the points relative to the 1:1 was examined to evaluate whether any systematic reductions or increases in trend magnitudes had occurred. The importance of any particular difference was evaluated qualitatively by taking into consideration the size of the confidence intervals in relation to the difference in magnitudes. Trend magnitudes for discharge sites were compared against trend magnitudes for associated downstream impact sites using scatter plots of the discharge versus impact site magnitudes, and by calculating the correlation coefficient between the discharge and impact sites for each water quality variable.

3.5 Aggregation of trend analyses from many sites

Long term water quality data that are collected at regular intervals (e.g., monthly) at monitoring sites are regularly analysed to assess the direction and magnitude of trends (e.g., Larned *et al.*, 2004, 2016). Trend analyses performed on many sites are regularly aggregated by water quality variable and presented in tabular or graphical form as part of environmental reporting (e.g., Ministry for the Environment, 2015, 2017). The aggregated water quality trends are intended to provide an overview of recent water quality changes over a spatial domain of interest (e.g., the entire country, a region, an environment class). Aggregated trends, for example expressed as proportions of site trends in different trend-direction categories, are intended to represent the recent progress toward or away from environmental objectives for the spatial domain.

3.5.1 Traditional approach

Environmental reports tend to tabulate the numbers or proportions of site trends in three categories: increasing, decreasing, and insufficient data to confidently determine direction (“insufficient data”). When tabulating site trends by category, it has been usual to adopt a default alpha value (generally 0.05) to define trends for which direction is established with confidence. This generally means that the insufficient data category can make up a substantial proportion of the sites. This type of tabulation has two important problems. First, the insufficient data category can be misinterpreted as “no change” or “stable”. This is an incorrect inference; the insufficient data outcome simply indicates a lack of confidence in the analysis at the level defined by alpha. The second problem is that trends categorised as insufficient data contain information about the general direction of change that is effectively ignored. For example, a trend’s direction may not be established with confidence at the 95% level but may be established with an 80% level of confidence. An extreme but plausible outcome of these tabulations is a situation in which, over many sites, no trend is established with confidence at the default value of alpha, but all trends are in the same direction at a lower level of confidence. The tabulation would show that all trends are in the insufficient data category, implying that nothing is known about the aggregate trend direction. However, it is likely there is a general trend (i.e., the group of sites as a whole exhibit a trend).

When aggregating trends across many sites, some studies have chosen to accept the trend direction at the face value of the evaluated trend slope (i.e., accept the direction indicated by the estimated Sen slope irrespective of the statistical significance or confidence in the evaluation e.g., Ballantine *et al.*, 2010; Scarsbrook *et al.*, 2003). This approach is justifiable because over many sites, incorrect classifications of direction will cancel each other out (i.e., as many sites will be misclassified as increasing as sites misclassified as decreasing). Thus, ‘count-based’ assessments of the number of trends in a given direction for a domain of interest are made by simply counting the number of individual trends for which the sign of the evaluated trend is in the direction of interest, disregarding the level of confidence in the trend directions. However, because the evaluated trend at any given site is always an uncertain estimate of the true trend, count based assessments are subject to unquantified uncertainty. For example, if the proportion of improving trends is the statistic being derived, the estimated proportion is uncertain.

3.5.2 Graphical presentation of aggregated trends

This new trend assessment procedure enables the uncertainty associated with individual site trends to be incorporated in any analysis that aggregates trends over many sites. The basis for this is the evaluation of the probability that the true trend (i.e., the trend in the population from which the samples were drawn) was decreasing (hereafter 'probability the trend was decreasing', see details of how this is assessed in S4.2). Note that trend direction is arbitrary and the probability that the true trend was increasing is one minus the probability that it was decreasing. It follows that for any individual site trend, the direction is a Bernoulli distributed variable where the probability of "success" (a decreasing trend) is defined by the evaluated probability. Thus, a trend with an evaluated probability >0.5 indicates success (a decreasing trend) and conversely the probability of "failure" (an increasing trend) is <0.5.

The probability that the true trend was decreasing facilitates a more nuanced inference rather than the 'yes/no' output corresponding to the chosen acceptable misclassification error rate (McBride, 2018). Confidence categories can be used to express probability that the trend direction is improving (or its complement; degrading). Note that the conversion of the probability that a trend is decreasing to the probability it is improving (and its complement, degrading) depends on whether decreasing values represent improvement or degradation and differs between variables.

The approach to presenting levels of confidence of the Intergovernmental Panel on Climate Change (IPCC; Stocker *et al.*, 2014) is one way of categorising confidence that trends are improving (Table 6). Note that descriptions of the probabilities of degrading trends are the complement of the categorical levels of confidence in Table 6, i.e. an "exceptionally unlikely" degrading trend is the same as a "virtually certain" improving trend.

Table 6. Level of confidence categories used to convey the probability that water quality was improving. The confidence categories are used by the Intergovernmental Panel on Climate Change (IPCC; Stocker, 2014)).

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

The aggregate proportion of sites in each category shown in Table 6 can be calculated for sites grouped by some spatial domain of interest, and for each variable. The values can then be plotted as colour coded bar charts. These charts provide a graphical representation of the proportions of improving and degrading trends at the levels of confidence indicated by the categories.

The categorical levels of confidence presented in Table 6 were used to express the likelihood that water quality was improving for each site and variable. Each site trend was assigned a categorical level of confidence that the trend was improving according to its evaluated probability and the categories shown in Table 6. For the chemical and microbiological water quality measures (Table 1), improvement is indicated by decreasing trends (i.e. decreasing concentrations). For all macroinvertebrate variables, clarity and DO improvement is indicated by increasing values.

The aggregate proportion of sites in each category were then calculated for each variable and these values were shown as colour coded bar charts. These charts were produced using all available sites (i.e., national scale aggregation). It is noted that this type of chart can be produced for sites aggregated according to any grouping. Graphical presentations were not produced for other site groupings in this study because we considered that the probabilistic assessments of the proportions of improving trends were a simpler way to represent grouped aggregate trends.

3.5.3 Evaluation of the proportion of improving trends

The trends, evaluated at several monitoring sites for a given variable over some domain of interest, can be assumed to represent independent samples of the population of trends, at all sites within that domain. Let the sampled sites within this domain be indexed by s, so that $s \in \{1,\ldots,S\}$ and let I be a random Bernoulli distributed variable which takes the value 1 with probability p and the value 0 with probability $q = 1 - p$. Therefore, $I_s = 1$ denotes an improving trend at site $s \in \{1,\ldots,S\}$ when the estimated $p_s \geq 0.5$ and a degrading trend as 0 when $p_s < 0.5$. Then, the estimated proportion of sites with improving trends in the domain is:

$$PIT = \sum_{s=1}^{s=S} I_s / S$$

Because the variance of a random Bernoulli distributed variable is $Var(I) = p(1-p)$, and assuming the site trends are independent, the estimated variance of PIT is:

$$Var(PIT) = \frac{1}{S^2} \sum_{s=1}^{s=S} Var(I_s) = \frac{1}{S^2} \sum_{s=1}^{s=S} p_s(1-p_s)$$

PIT and its variance represent an estimate of the population proportion of improving trends and the uncertainty of that estimate. It is noted that the proportion of degrading trends is the complement of the result (i.e., 1 - PIT). The estimated variance of PIT can be used to construct 95% confidence intervals[4] around the PIT statistics as follows:

$$CI_{95} = PIT \pm 1.96 \times \sqrt{Var(PIT)}$$

3.6 Implementation

All trend analyses presented in this report were undertaken with purpose written functions ("LWP-Trends") that implement the new trend assessment method using the R statistical computing environment (http://www.r-project.org) that are available here; http://landwaterpeople.co.nz/pdf-reports/.

The assignment and plotting of categorical levels of confidence and calculation of the PIT statistics were undertaken using purpose written functions developed using the R statistical computing environment that are available here; http://landwaterpeople.co.nz/pdf-reports/.

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[4] Note that +/- 1.96 are approximately the 2.5th and 97.5th percentile of a standard normal distribution.

4 Results for state assessments

4.1 Water quality data

Box and whisker plots summarise all observations of some illustrative water quality variables and biological indicators for the SoE sites (Figure 6 and Figure 7) and impact sites (Figure 8) for the 5-year period ending July 2017. Sites are ordered from upstream to downstream by FMU, based on site order numbers provided by HRC. The plots indicate that water quality (i.e. concentrations of contaminants, water clarity, periphyton abundance and MCI scores) are highly variable both within and between sites.

Box and whisker graphs for all variables, sites and time are available in the supplementary file: DataBoxandWhiskerSummaryPlots_Aug18.pdf

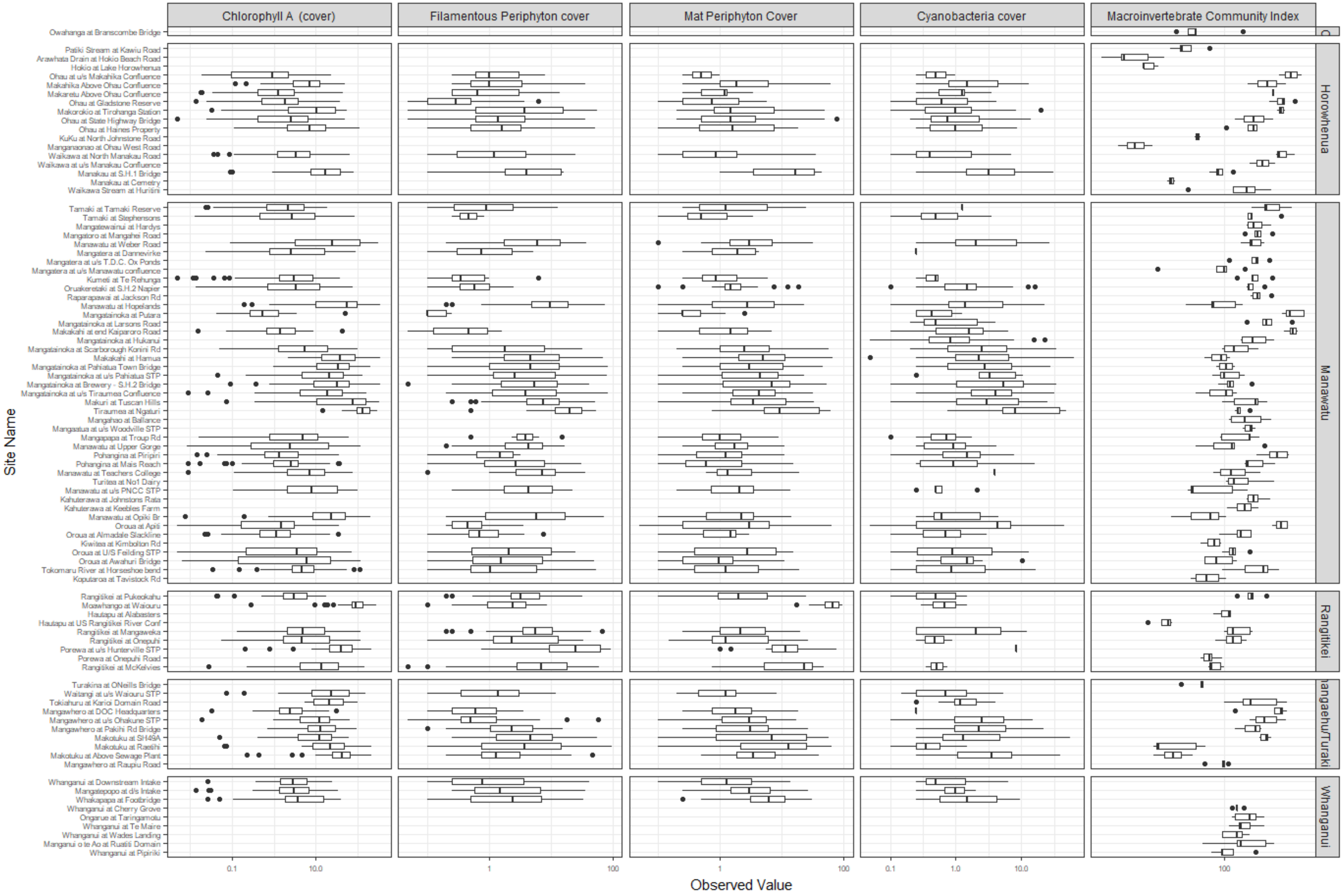


Figure 6: Box and whisker plots representing all observations of selected water quality variables at the SoE sites for the 5-year period ending July 2017. The box indicates the inter-quartile range and the vertical bar within the box indicates the median. The whiskers indicate the lowest datum still within 1.5 IQR of the lower quartile, and the highest datum still within 1.5 IQR of the upper quartile. Outliers are indicated by black dots. The Freshwater Management Units that each site belongs to are indicated by the boxes on the right. Units as per Table 1.

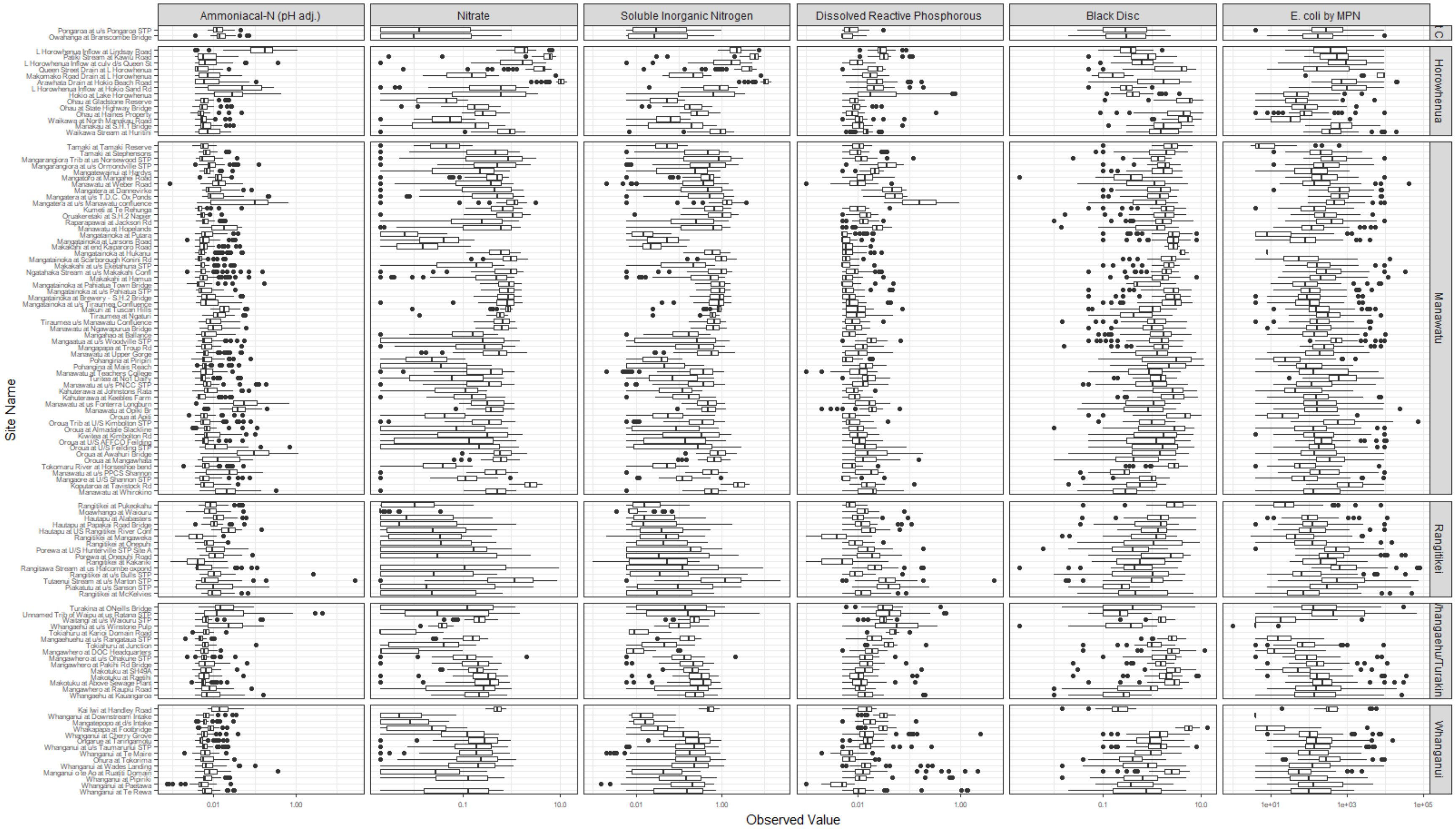


Figure 7: Box and whisker plots representing all observations of selected water quality variables at the SoE sites for the 5-year period ending July 2017. Notes as per Figure 6.

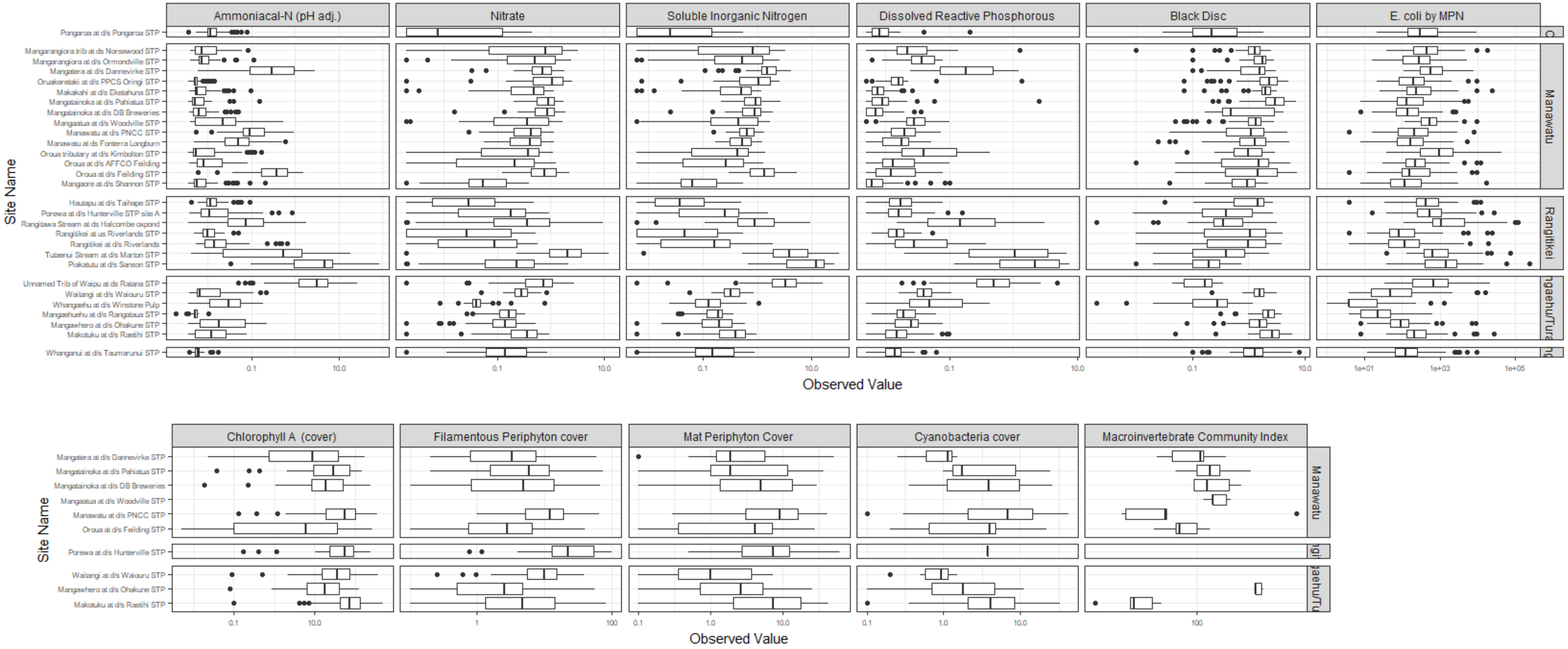


Figure 8: Box and whisker plots representing all observations of selected water quality variables at the impact sites for the 5-year period ending July 2017. Notes as per Figure 6.

4.2 Grading of SoE sites

The results of grading the SoE sites according to the Horizons One Plan water quality variable targets are mapped on Figure 9 and summarised in Table 7, Figure 10 and Figure 11. The grey cells shown in Figure 10 and Figure 11 indicate that there were insufficient observations to make statistically robust assessments of state (see Section 3.2.1). This occurred more often for variables whose targets included specified flow states, for example clarity, *E. coli*, DRP, and SIN (Table 3) or for those that were monitored annually (e.g. MCI).

Most sites failed the Horizons One Plan criteria for DRP, *E. coli* and Clarity. Conversely, almost all sites passed the criteria for NH_4-N, cyanobacteria, periphyton (mats) and volatile matter. Grades varied across the region for dissolved oxygen, chlorophyll-*a*, MCI, periphyton (filaments) and SIN.

Table 7: Percentage and number of sites that meet the inclusion criteria passing Horizons One Plan criteria, by FMU

Standard Name	**East Coast**	**Horowhenua**	**Manawatū**	**Rangitikei**	**Whangaehu /Turakina**	**Whanganui**
Ammoniacal-N (Max)	100% (2)	86% (12)	100% (56)	87% (13)	87% (13)	93% (13)
Ammoniacal-N (Mean)	100% (2)	86% (12)	100% (56)	93% (14)	93% (14)	93% (13)
Chlorophyl a (cover)	*NA*	100% (9)	62% (18)	50% (3)	12% (1)	100% (3)
Clarity	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Cyanobacteria cover (Action)	*NA*	100% (10)	94% (29)	100% (6)	88% (7)	100% (3)
Cyanobacteria cover (Alert)	*NA*	100% (10)	94% (29)	100% (6)	88% (7)	100% (3)
DRP	50% (1)	7% (1)	25% (14)	27% (4)	0% (0)	21% (3)
E. coli (Bathing)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
E. coli (year round)	0% (0)	14% (2)	0% (0)	0% (0)	0% (0)	0% (0)
Field DO (Sat.)	50% (1)	36% (5)	86% (48)	47% (7)	60% (9)	71% (10)
MCI	0% (0)	24% (4)	40% (17)	0% (0)	33% (3)	83% (5)
Periphyton (filaments)	*NA*	56% (5)	48% (14)	17% (1)	43% (3)	0% (0)
Periphyton (mats)	*NA*	78% (7)	90% (26)	67% (4)	86% (6)	100% (3)
Soluble Inorganic Nitrogen	50% (1)	14% (2)	27% (15)	53% (8)	7% (1)	14% (2)
Volatile Matter	0% (0)	*NA*	35% (7)	33% (2)	33% (2)	0% (0)

The results of grading the SoE sites according to the NOF criteria are shown in Figure 13 and Figure 14 and are mapped on Figure 12. Most sites were in the A band for both nitrate criteria and the ammoniacal-N (median) criteria. Similarly, most sites were generally in the A band for ammoniacal-N (max) and periphyton criteria, however there was a small number of sites that were below the bottom line (D band). NOF bands were variable across the region for the *E. coli* criteria.

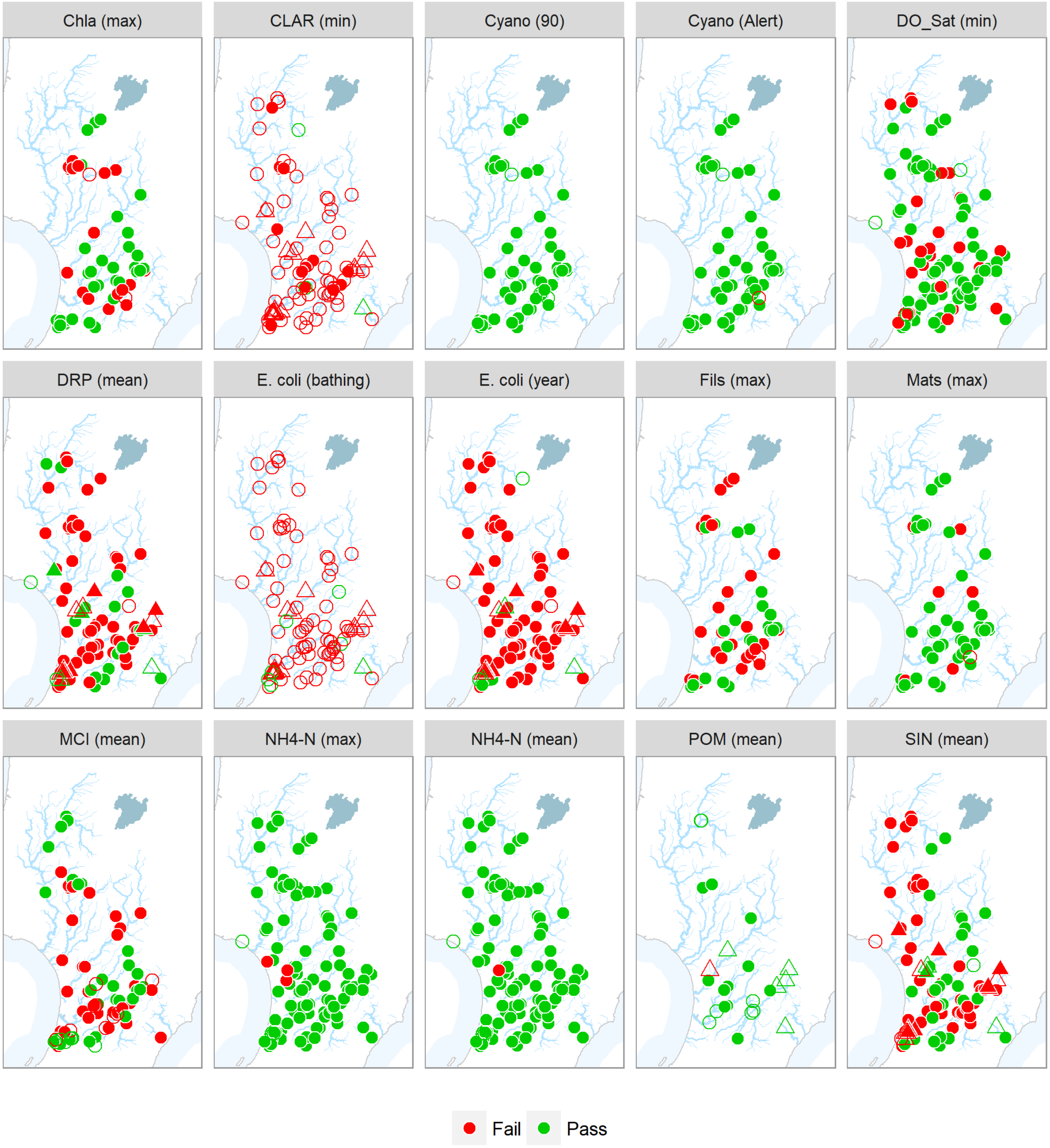


Figure 9: Maps showing SoE site state grades based on the Horizons One Plan criteria. Sites that required flow data for evaluating the state statistic, but for which flow percentiles were estimated only from gaugings are shown as triangles. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown with open shapes.

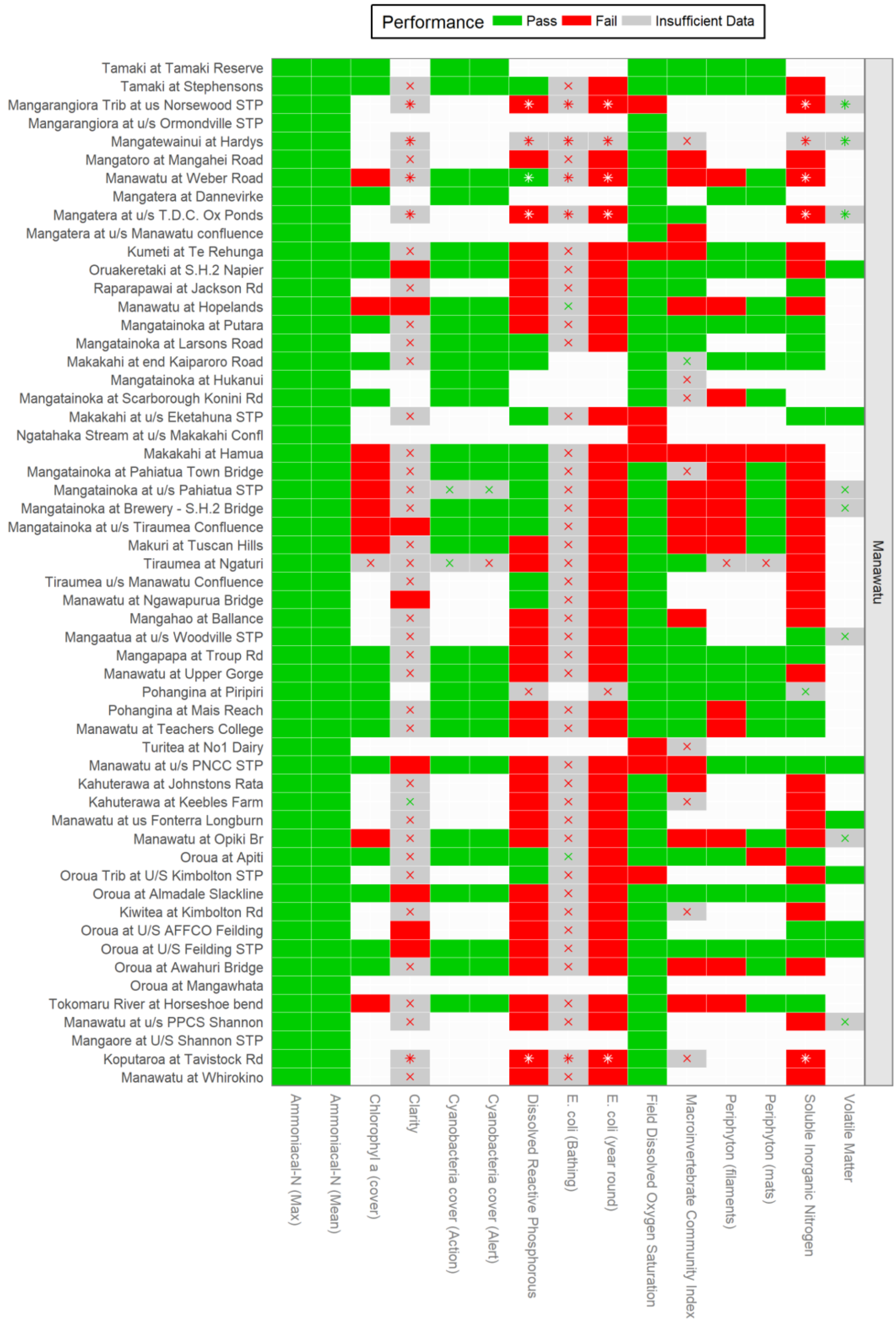


Figure 10: Grading of the SoE sites of the Manawatū FMU based on the Horizons One Plan Criteria. Green and red cells indicate sites that pass and fail the targets respectively. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. Sites where flow percentiles were estimated based on gaugings are indicated by stars. The white cells indicate sites for which the variable (or flow if required) was not monitored. The Freshwater Management Units that each site belongs to are indicated by the boxes on the right.

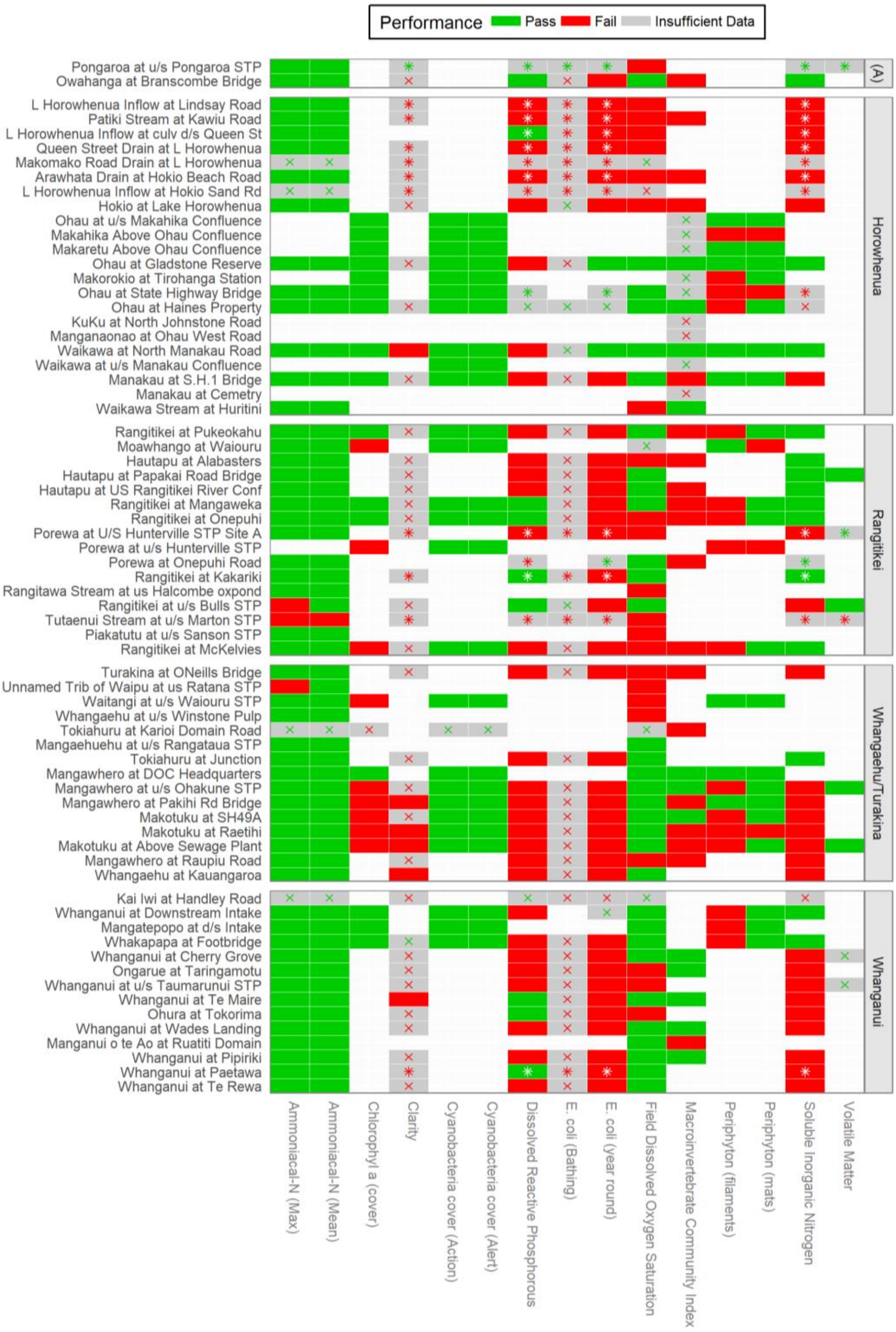


Figure 11: Grading of the SoE sites other than those in the Manawatū FMU based on the Horizons One Plan Criteria. Green and red cells indicate sites that pass and fail the targets respectively. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. Sites where flow percentiles were estimated based on gaugings are indicated by stars. The white cells indicate sites for which the variable (or flow if required) was not monitored. The Freshwater Management Units that each site belongs to are indicated by the boxes on the right. FMU labelled (A) is "East Coast".

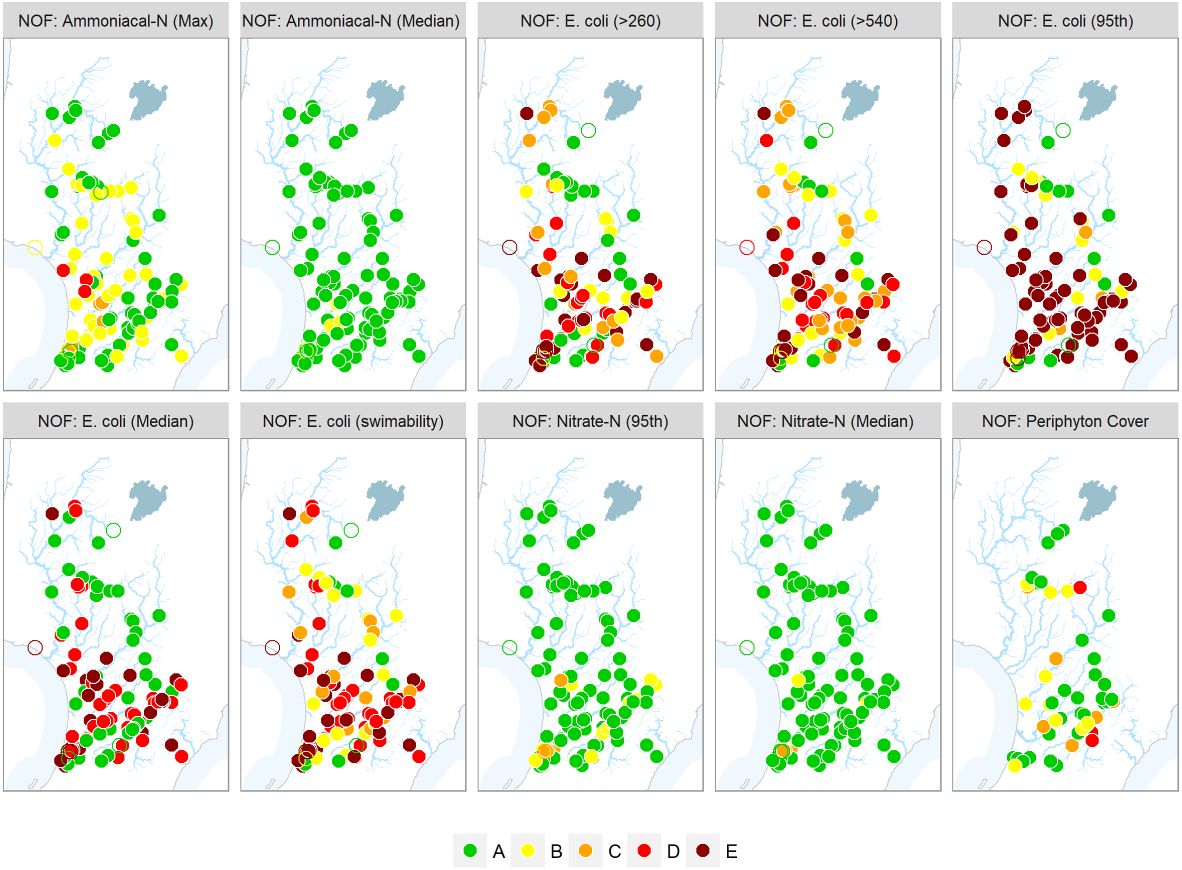
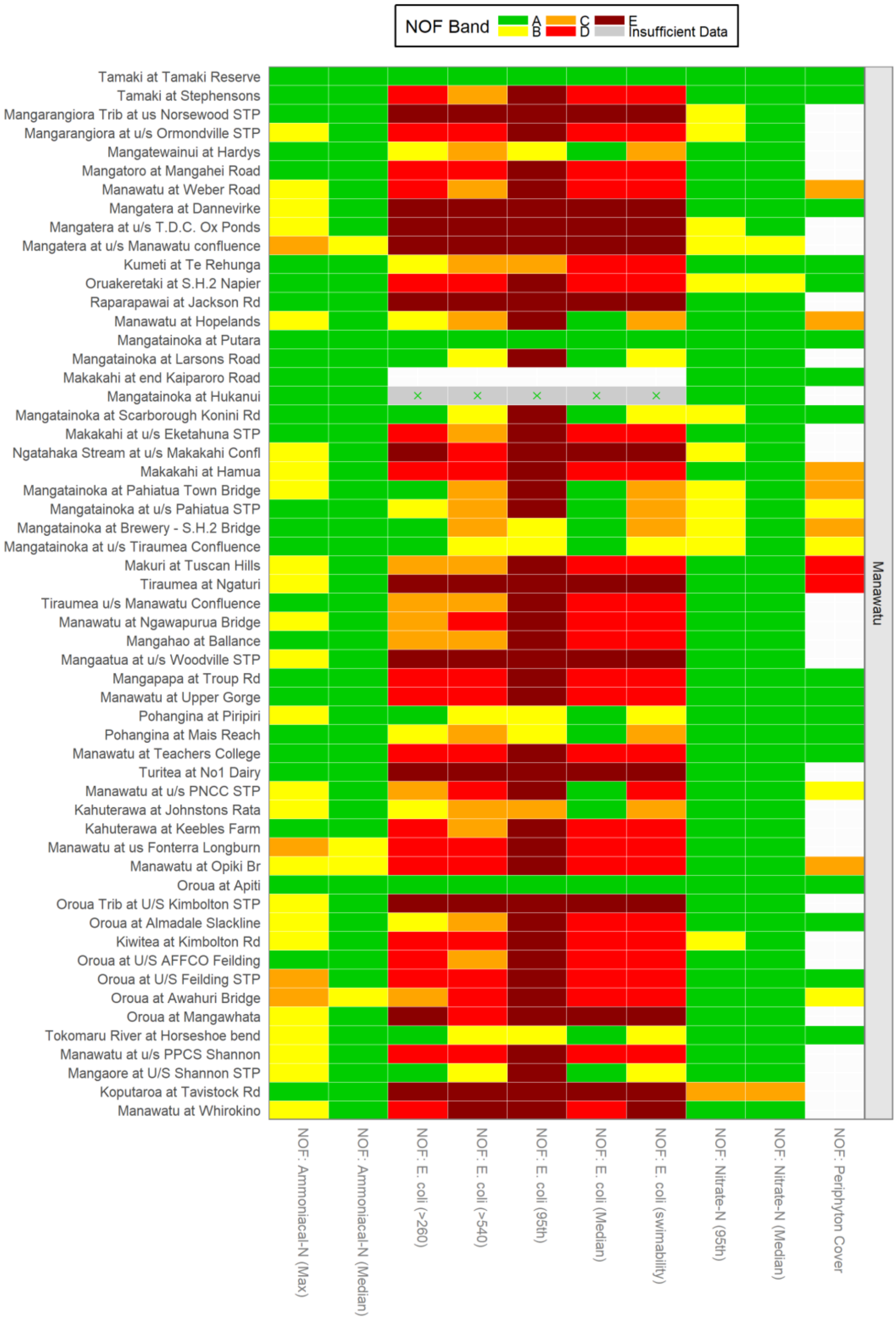


Figure 12: Maps showing SoE site state bands categorised by the NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 2 are shown with open circles. Periphyton Cover in this context is assessed using chlorophyll a measurements.



	NOF: Ammoniacal-N (Max)	NOF: Ammoniacal-N (Median)	NOF: E. coli (>260)	NOF: E. coli (>540)	NOF: E. coli (95th)	NOF: E. coli (Median)	NOF: E. coli (swimability)	NOF: Nitrate-N (95th)	NOF: Nitrate-N (Median)	NOF: Periphyton Cover
Tamaki at Tamaki Reserve	A	A	A	A	A	A	A	A	A	A
Tamaki at Stephensons	A	A	D	C	E	D	D	A	A	A
Mangarangiora Trib at us Norsewood STP	A	A	E	E	E	E	E	B	A	
Mangarangiora at u/s Ormondville STP	B	A	D	D	E	D	D	B	A	
Mangatewainui at Hardys	A	A	B	C	B	A	C	A	A	
Mangatoro at Mangahei Road	A	A	D	D	E	D	D	A	A	
Manawatu at Weber Road	B	A	D	C	E	D	D	A	A	C
Mangatera at Dannevirke	B	A	E	E	E	E	E	A	A	A
Mangatera at u/s T.D.C. Ox Ponds	B	A	E	E	E	E	E	B	A	
Mangatera at u/s Manawatu confluence	C	B	E	E	E	E	E	B	B	
Kumeti at Te Rehunga	A	A	B	C	C	D	D	A	A	A
Oruakeretaki at S.H.2 Napier	A	A	D	D	E	D	D	B	B	A
Raparapawai at Jackson Rd	A	A	E	E	E	E	E	A	A	
Manawatu at Hopelands	B	A	B	C	E	A	C	A	A	C
Mangatainoka at Putara	A	A	A	A	A	A	A	A	A	A
Mangatainoka at Larsons Road	A	A	A	B	E	A	B	A	A	
Makakahi at end Kaiparoro Road	A	A						A	A	A
Mangatainoka at Hukanui	A	A	×	×	×	×	×	A	A	
Mangatainoka at Scarborough Konini Rd	A	A	A	B	E	A	B	B	A	A
Makakahi at u/s Eketahuna STP	A	A	D	C	E	D	D	A	A	
Ngatahaka Stream at u/s Makakahi Confl	B	A	E	D	E	E	E	B	A	
Makakahi at Hamua	B	A	D	D	E	D	D	A	A	C
Mangatainoka at Pahiatua Town Bridge	B	A	A	C	E	A	C	B	A	C
Mangatainoka at u/s Pahiatua STP	A	A	B	C	E	A	C	B	A	B
Mangatainoka at Brewery - S.H.2 Bridge	A	A	A	C	B	A	C	B	A	C
Mangatainoka at u/s Tiraumea Confluence	A	A	A	B	B	A	B	B	A	B
Makuri at Tuscan Hills	B	A	C	C	E	D	D	A	A	D
Tiraumea at Ngaturi	B	A	E	E	E	E	E	A	A	D
Tiraumea u/s Manawatu Confluence	A	A	C	C	E	D	D	A	A	
Manawatu at Ngawapurua Bridge	B	A	C	D	E	D	D	A	A	
Mangahao at Ballance	A	A	C	C	E	D	D	A	A	
Mangaatua at u/s Woodville STP	B	A	E	E	E	E	E	A	A	
Mangapapa at Troup Rd	A	A	D	D	E	D	D	A	A	A
Manawatu at Upper Gorge	A	A	D	D	E	D	D	A	A	A
Pohangina at Piripiri	B	A	A	B	B	A	B	A	A	A
Pohangina at Mais Reach	A	A	B	C	B	A	C	A	A	A
Manawatu at Teachers College	A	A	D	D	E	D	D	A	A	A
Turitea at No1 Dairy	A	A	E	E	E	E	E	A	A	
Manawatu at u/s PNCC STP	B	A	C	D	E	A	D	A	A	B
Kahuterawa at Johnstons Rata	B	A	B	C	C	A	C	A	A	
Kahuterawa at Keebles Farm	A	A	D	C	E	D	D	A	A	
Manawatu at us Fonterra Longburn	C	B	D	D	E	D	D	A	A	
Manawatu at Opiki Br	B	B	D	D	E	D	D	A	A	C
Oroua at Apiti	A	A	A	A	A	A	A	A	A	A
Oroua Trib at U/S Kimbolton STP	B	A	E	E	E	E	E	A	A	
Oroua at Almadale Slackline	B	A	B	C	E	D	D	A	A	A
Kiwitea at Kimbolton Rd	B	A	D	D	E	D	D	B	A	
Oroua at U/S AFFCO Feilding	A	A	D	C	E	D	D	A	A	
Oroua at U/S Feilding STP	C	A	D	D	E	D	D	A	A	A
Oroua at Awahuri Bridge	C	B	C	D	E	D	D	A	A	B
Oroua at Mangawhata	B	A	E	D	E	E	E	A	A	
Tokomaru River at Horseshoe bend	B	A	A	B	B	A	B	A	A	A
Manawatu at u/s PPCS Shannon	B	A	D	D	E	D	D	A	A	
Mangaore at U/S Shannon STP	B	A	A	B	E	A	B	A	A	
Koputaroa at Tavistock Rd	A	A	E	E	E	E	E	C	C	
Manawatu at Whirokino	B	A	D	E	E	D	E	A	A	

Figure 13: Grading of the SoE sites of the Manawatū FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. The white cells indicate sites for which the variable was not monitored. Periphyton Cover in this context is assessed using chlorophyll a measurements.

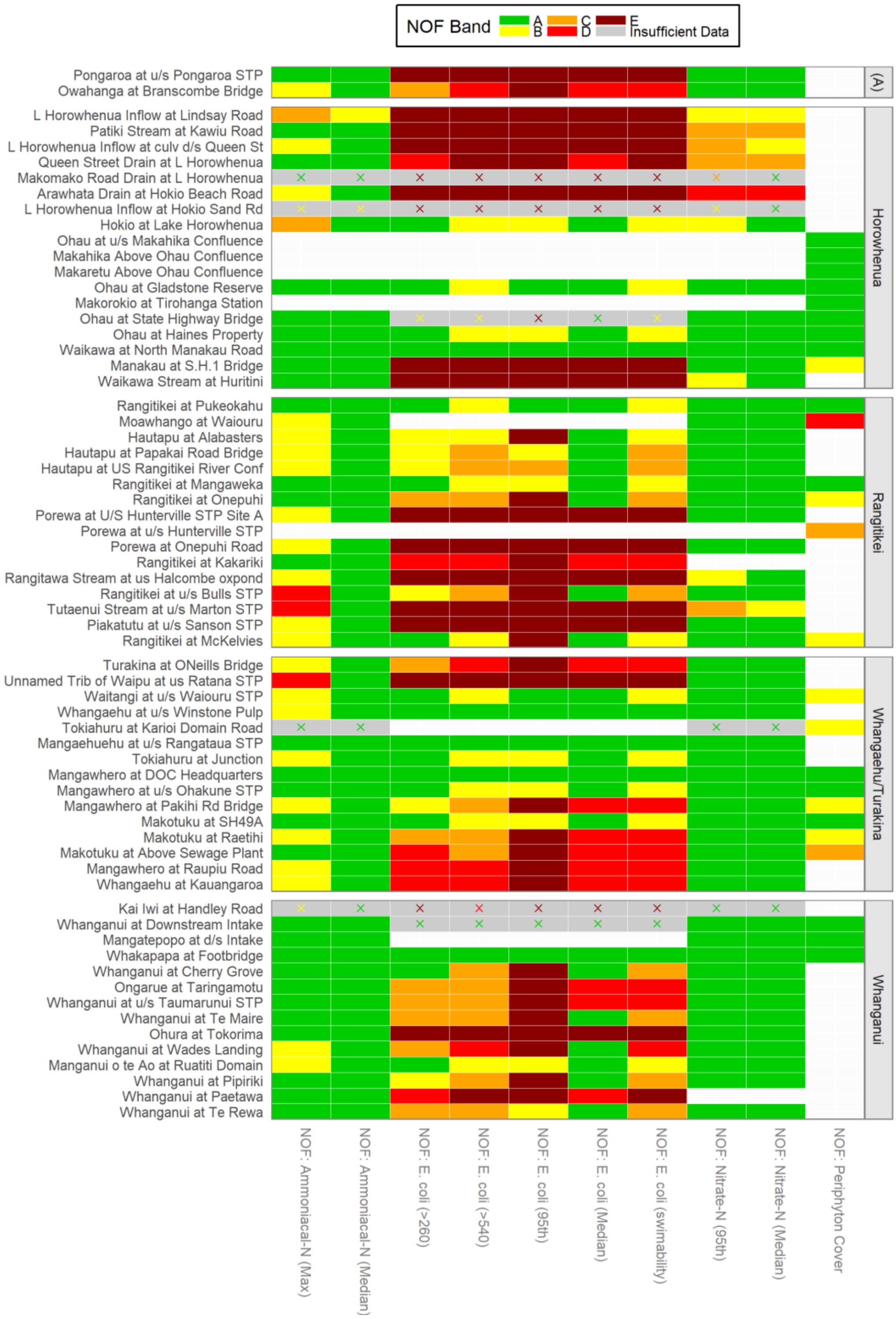


Figure 14: Grading of the SoE sites outside of the Manawatū FMU based on the NOF Criteria. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. The white cells indicate sites for which the variable was not monitored. The Freshwater Management Units that each site belongs to are indicated by the boxes on the right. Periphyton Cover in this context is assessed using chlorophyll a measurements.

4.3 Grading of impact sites

The results of grading the impact sites according to the Horizons One Plan water quality variable targets are mapped in Figure 15 and summarised in Table 8 and Figure 16.

Most sites failed the Horizons One Plan criteria for DRP and *E. coli*, clarity, chlorophyll-*a*, MCI, periphyton (filaments) and SIN. Conversely, almost all sites passed the criteria for cyanobacteria, periphyton (mats) and volatile matter. Grades varied across the region for NH_4-N and dissolved oxygen. These patterns are similar to those of the SoE sites, although with a tendency for greater proportions of failing sites.

Table 8: Percentage and number of impact sites passing Horizons One Plan criteria, by FMU

Standard Name	**East Coast**	**Manawatū**	**Rangitikei**	**Whangaehu /Turakina**	**Whanganui**
Ammoniacal-N (Max)	100% (1)	93% (13)	71% (5)	83% (5)	100% (1)
Ammoniacal-N (Mean)	100% (1)	86% (12)	71% (5)	83% (5)	100% (1)
Chlorophyl a (cover)	NA	0% (0)	0% (0)	0% (0)	NA
Clarity	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Cyanobacteria cover (Action)	NA	80% (4)	100% (1)	100% (3)	NA
Cyanobacteria cover (Alert)	NA	80% (4)	100% (1)	100% (3)	NA
DRP	0% (0)	14% (2)	0% (0)	0% (0)	0% (0)
E. coli (Bathing)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
E. coli (year round)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Field DO (Sat.)	0% (0)	86% (12)	43% (3)	33% (2)	100% (1)
MCI	NA	17% (1)	NA	0% (0)	NA
Periphyton (filaments)	NA	0% (0)	0% (0)	0% (0)	NA
Periphyton (mats)	NA	100% (5)	0% (0)	100% (3)	NA
Soluble Inorganic Nitrogen	0% (0)	7% (1)	29% (2)	0% (0)	0% (0)
Volatile Matter	0% (0)	43% (6)	43% (3)	33% (2)	0% (0)

The results of grading the impact sites according to the NOF criteria are mapped in Figure 17 and summarised in Figure 18. Most sites were in the A band for both nitrate criteria. Similarly, most sites were in the A band for the ammoniacal-N (median) criteria, however there were small number of sites that were below the bottom line (D band). Grades were much more variable over the region for the periphyton, ammoniacal-N (max) and *E. coli* criteria.

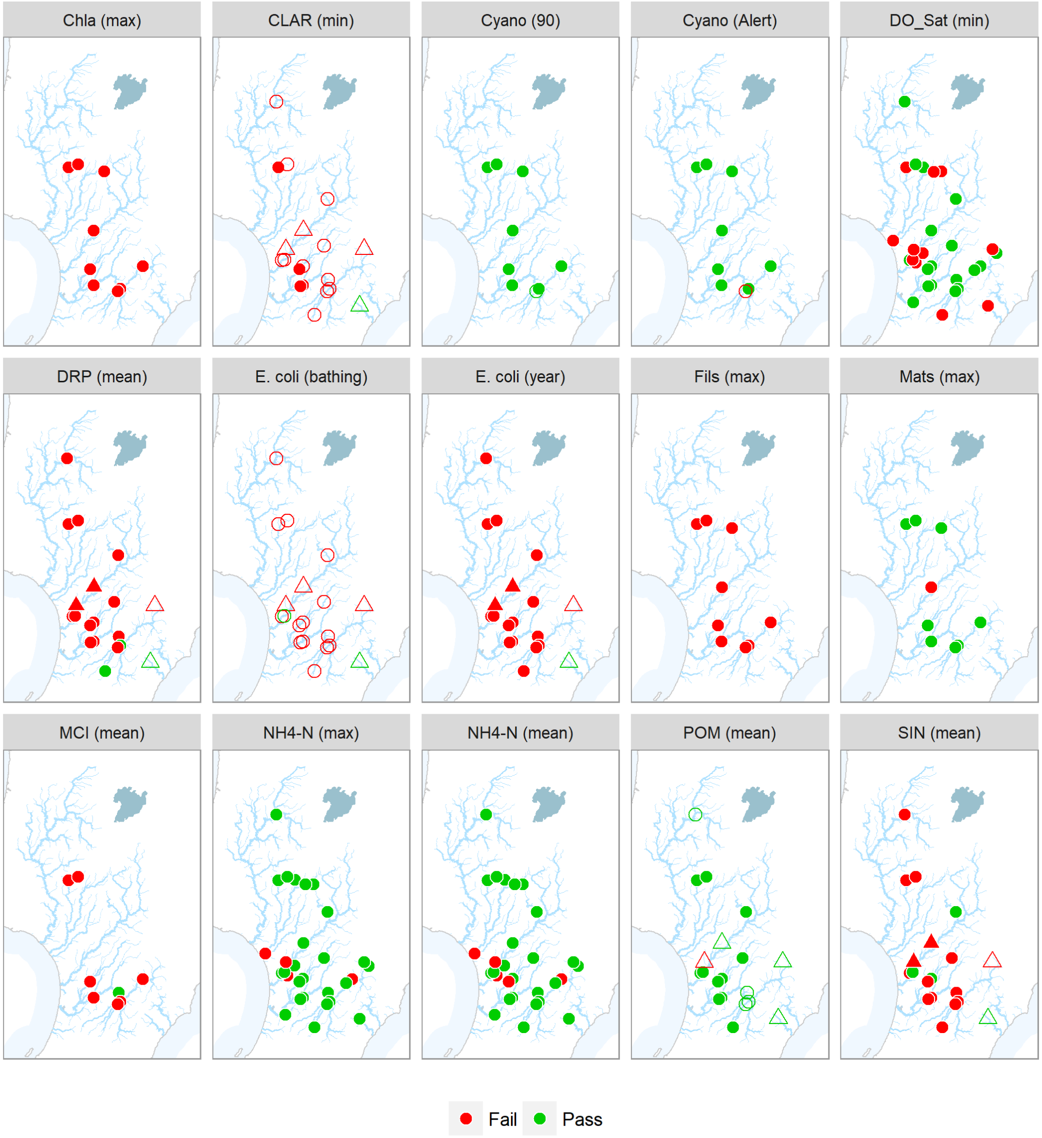


Figure 15: Maps showing impact site state grades based on the Horizons One Plan criteria. Sites that required flow data for evaluating the state statistic, but for which flow percentiles were estimated only from gaugings are shown as triangles. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown with open shapes.

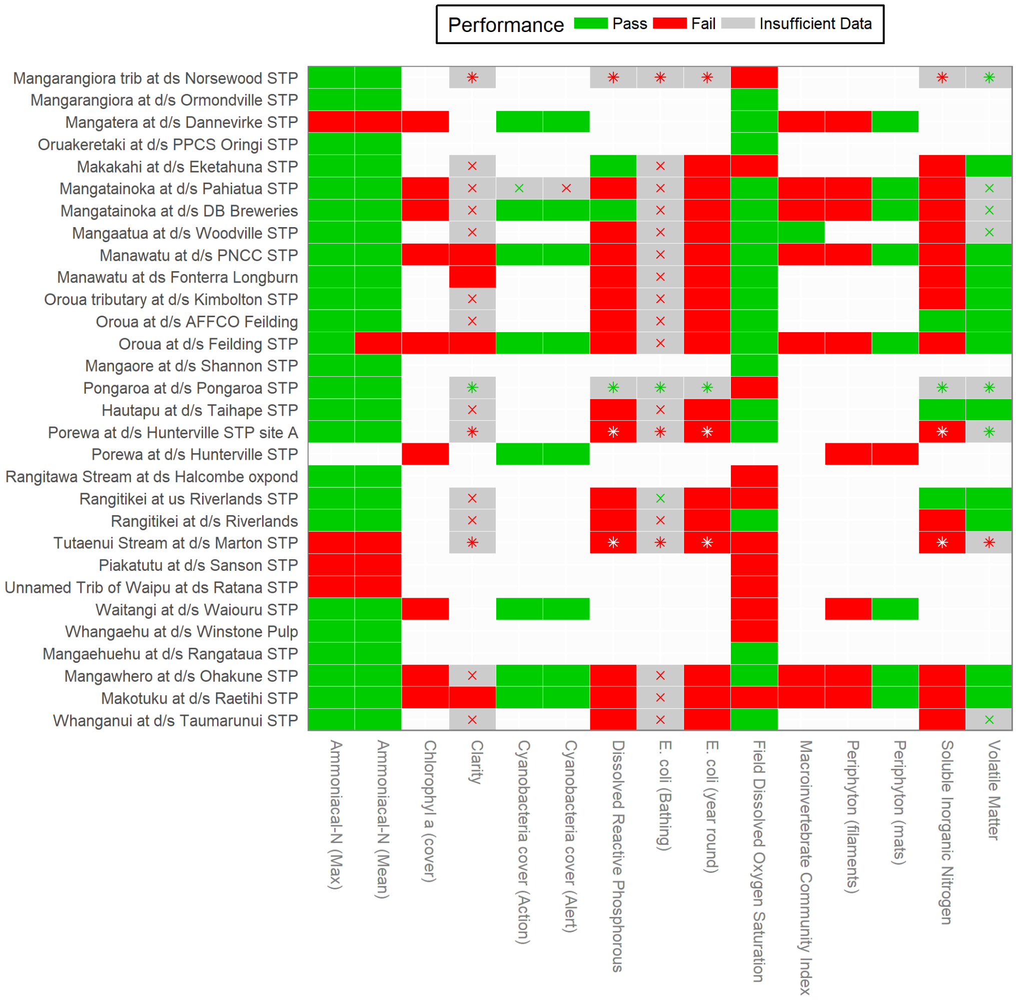


Figure 16: Grading of the impact sites based on the Horizons One Plan criteria. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. Sites where flow percentiles were estimated based on gaugings are indicated by stars. The white cells indicate sites for which the variable (or flow if required) was not monitored.

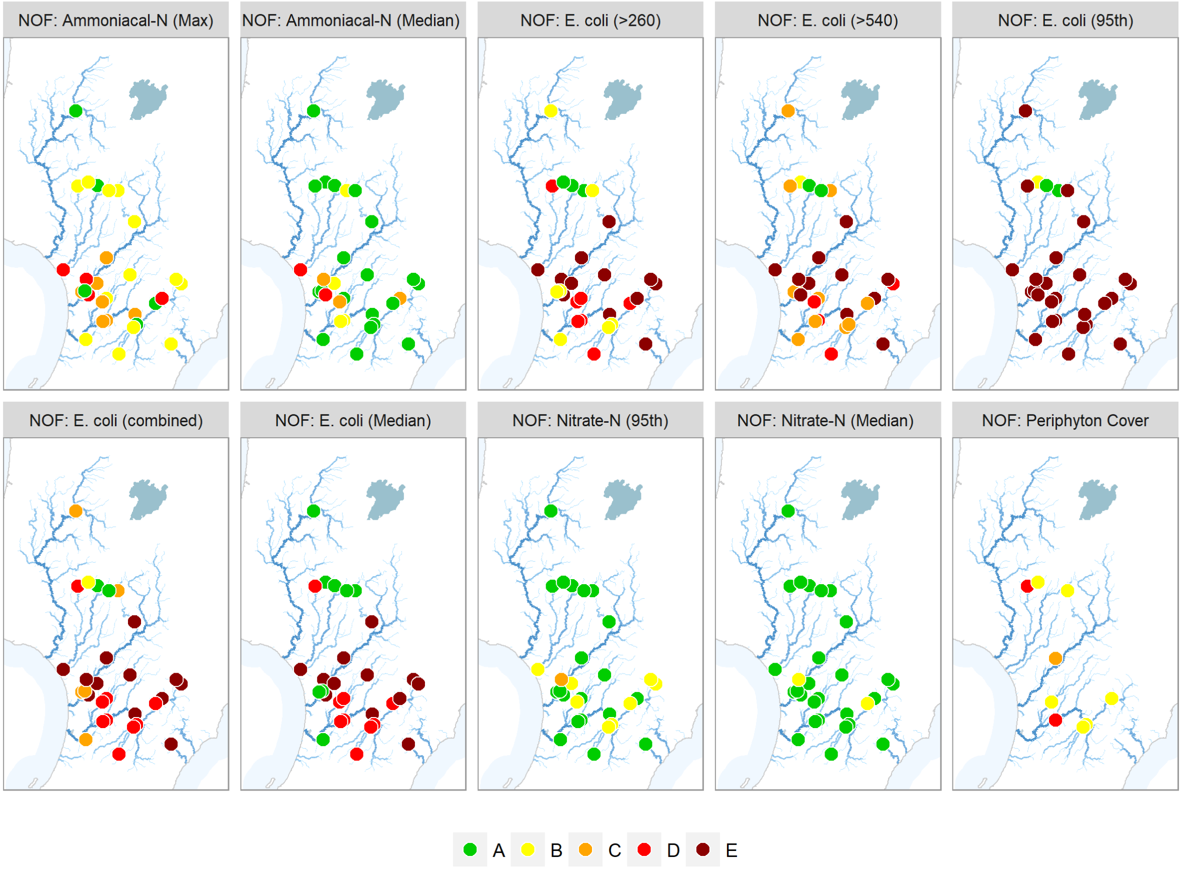


Figure 17: Maps showing impact site state bands categorised by the NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 2 are shown with open circles. Periphyton Cover in this context is assessed using chlorophyll a measurements.

Figure 18: Grading of the impact sites based on the NOF criteria. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. The white cells indicate sites for which the variable was not monitored. The Freshwater Management Units that each site belongs to are indicated by the boxes on the right.

4.4 Grading of point source discharge sites

The results of grading the impact sites according to the Horizons One Plan water quality variable change targets are mapped in Figure 19 and shown in Figure 20. Most sites passed the criteria for pH, QMCI, and clarity, although it is also noted that there were very few sites with QMCI data to allow evaluation of the criteria. Grades varied across the region for the temperature criteria and were slightly dominated by sites passing the criteria.

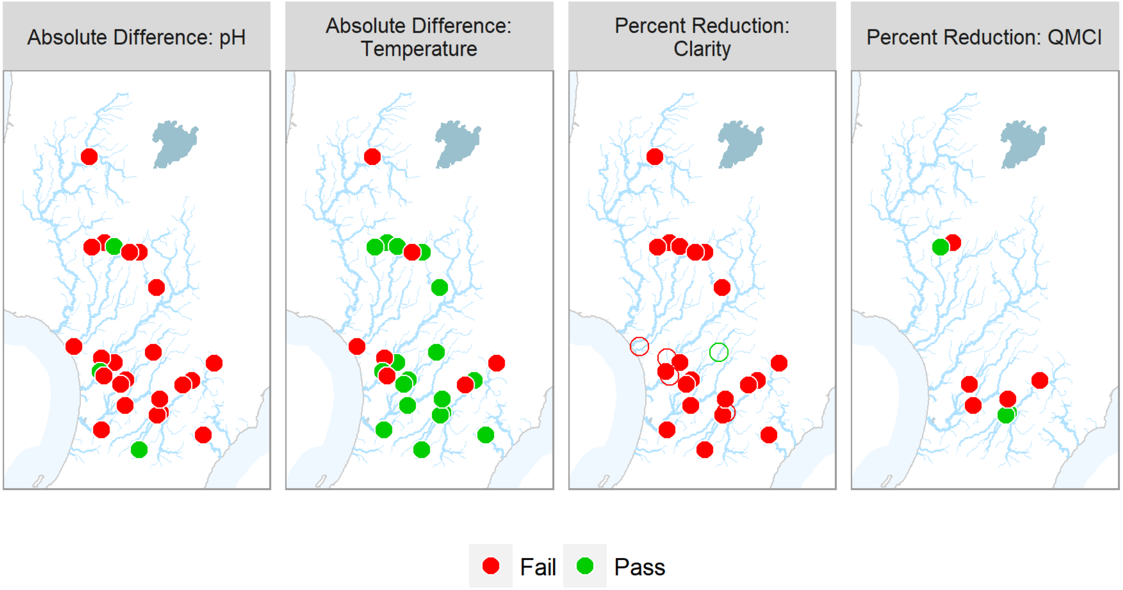


Figure 19: Maps showing discharge site state grades based on the Horizons One Plan change criteria. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown with open circles.

Figure 20: Grading of the discharge sites based on the Horizons One Plan change criteria. Grades for sites that did not meet the sample number requirements specified in Table 2 are shown as grey cells with coloured crosses. The white cells indicate sites for which the variable (or flow if required) was not monitored.

5 Results for trends

5.1 Trends at SoE sites

5.1.1 Trends classifications

Figure 21 and Figure 22 show site trend classifications for the 10 and 20-year time periods, respectively. Trend classificaitons for both time periods are also summarised in Table 9. For the 10-year time period a large proportion of the trends (78%) analysed were classified as having “insufficient data” to determine a confident trend. For the 10-year trends defined with confidence, there were a mix of both improving (16%) and degrading (14%) trends. However, this distribution varied between variables, with some variables dominated by degrading trends (e.g., chlorophyll-*a*, MCI) or by improving trends (NH_4-N[5] and POM).

There was not a strong geographical pattern associated with the distribution of increasing or decreasing trends for any variables, although there may be some patterns associated with river size or catchment characteristics that are not immediately evident from the maps. There appeared to be a cluster of the improving DRP trends within the Manawatū River Catchment for the 10-year trends and most of the improving trends for the 20-year period (across all variables) were within the Manawatū catchment. For the 20-year time period, across all variables, 46% of site trends were classified as having “insufficient data”, 35% as improving and 19% degrading.

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[5] Note: NH_4-N reported in the trend analysis is based on non-pH adjusted values

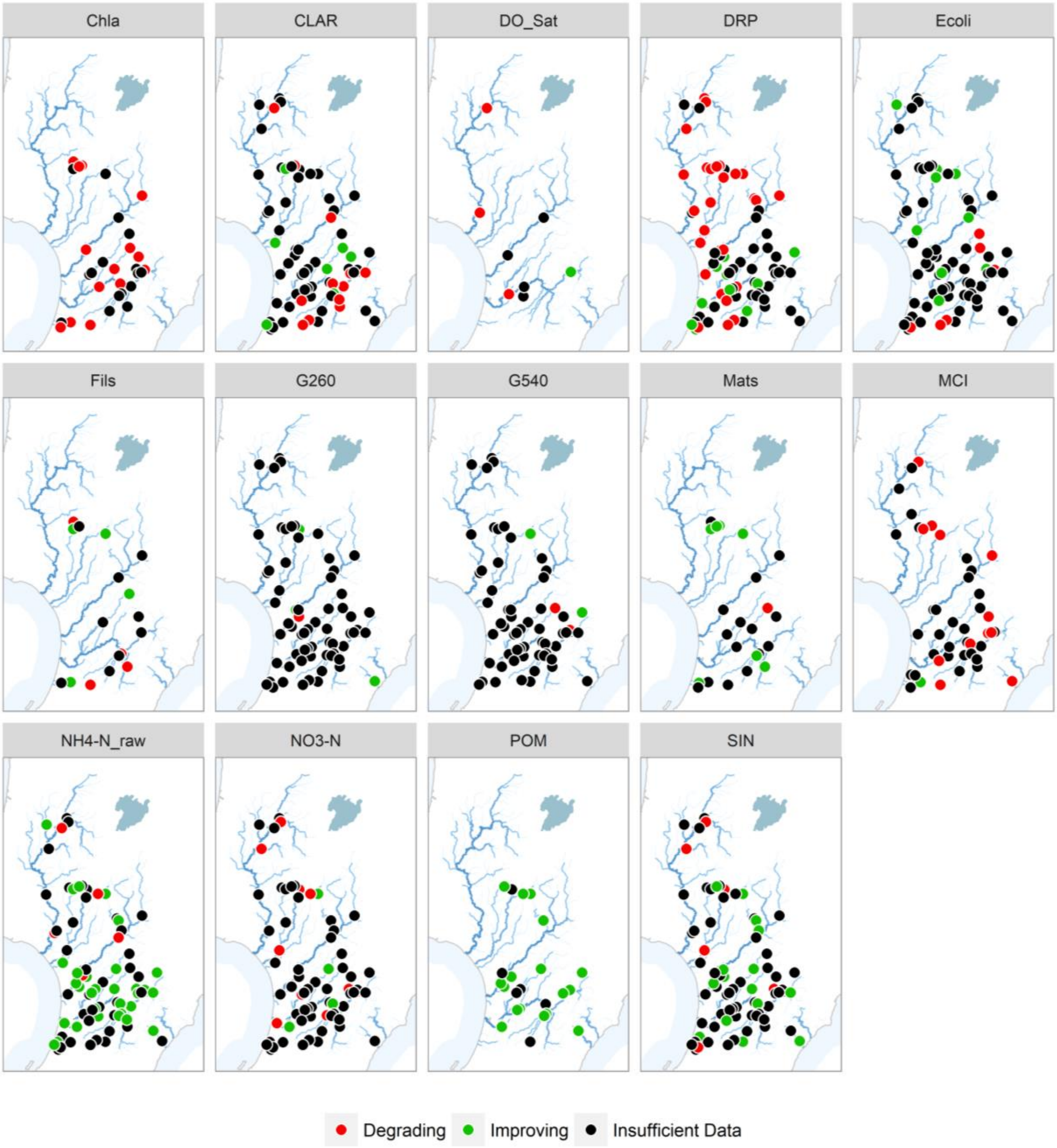

Figure 21. Map of sites classified by their 10-year raw water quality variable trend descriptions. Site and variable combinations for which there were many missing or censored values are not shown in the plots. Note that trend descriptions indicate degrading and improving (rather than trend direction of the water quality variable). Trends are all based on analyses performed using raw (i.e., not flow adjusted) data.

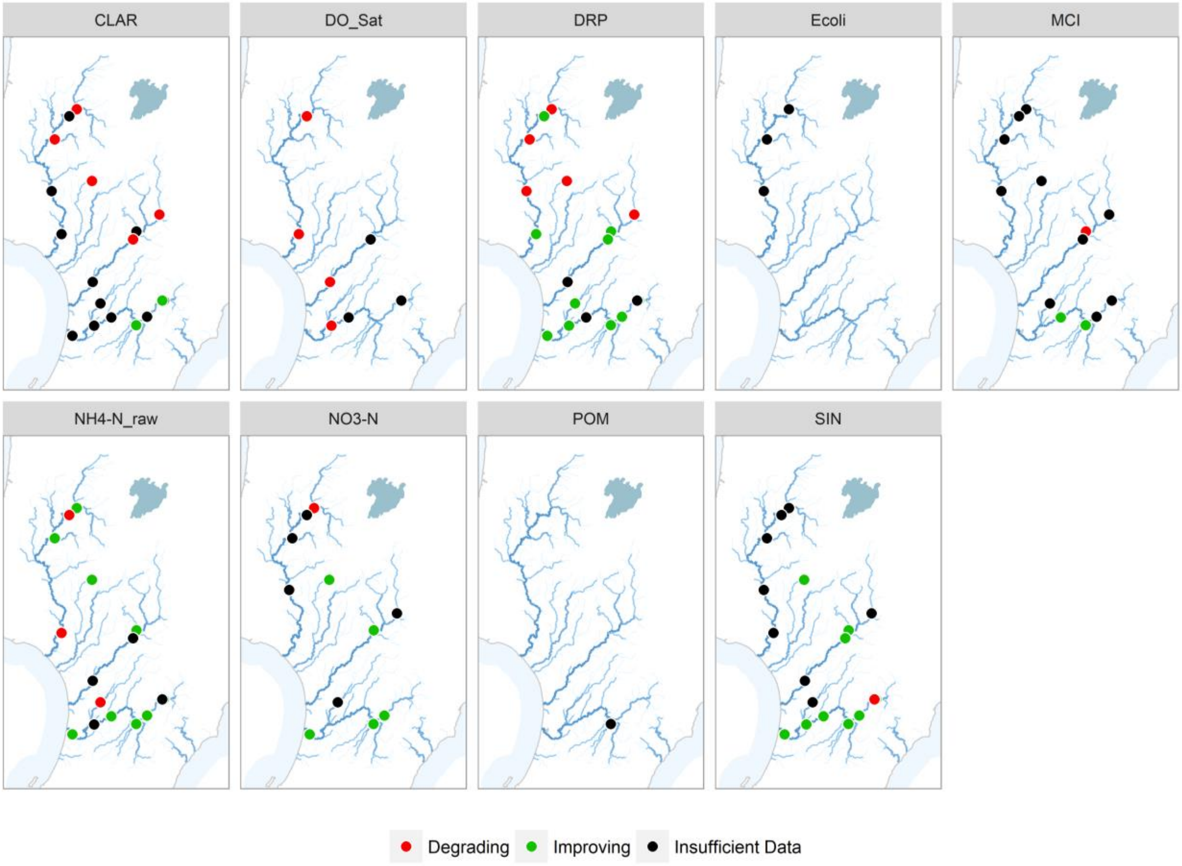

Figure 22. Map of SoE sites classified by their 20-year raw water quality variable trend descriptions. Site and variable combinations for which there were many missing or censored values are not shown in the plots. Note that trend descriptions indicate degrading and improving (rather than trend direction of the water quality variable). Trends are all based on analyses performed using raw (i.e., not flow adjusted) data.

Table 9. Summary of the number of sites classified by the raw trend descriptions for SoE sites included in the 10-year and 20-year period datasets. Values in parentheses are the proportion of sites (%).

	10 Years			**20 Years**		
Variable	Degrading	Improving	Insufficient Data	Degrading	Improving	Insufficient Data
Chla	14 (47)	0 (0)	16 (53)	NA	NA	NA
CLAR	12 (17)	7 (10)	53 (74)	5 (28)	2 (11)	11 (61)
DO_Sat	3 (38)	1 (12)	4 (50)	4 (57)	0 (0)	3 (43)
DRP	26 (32)	12 (15)	42 (52)	5 (28)	10 (56)	3 (17)
E. coli	7 (9)	10 (12)	63 (79)	0 (0)	0 (0)	3 (100)
Fils	4 (24)	4 (24)	9 (53)	NA	NA	NA
G260	1 (1)	3 (4)	67 (94)	NA	NA	NA
G540	2 (3)	2 (3)	61 (94)	NA	NA	NA
Mats	1 (4)	7 (30)	15 (65)	NA	NA	NA
MCI	12 (27)	1 (2)	32 (71)	1 (8)	2 (15)	10 (77)
NH_4-N	5 (6)	35 (44)	40 (50)	3 (19)	9 (56)	4 (25)
NO_3-N	10 (14)	4 (6)	58 (81)	1 (9)	5 (45)	5 (45)
POM	0 (0)	18 (75)	6 (25)	0 (0)	0 (0)	1 (100)
SIN	6 (8)	16 (20)	58 (72)	1 (6)	9 (50)	8 (44)

5.1.2 Probability of improvement

A more nuanced approach to reporting the site-trend directions is to map the probability that trends were improving. In this case, those sites that are classed as “improving” in the previous plots are shown in green and those as “degrading” (i.e., exceptionally unlikely to be improving) in red, but the “insufficient data” sites are placed on a continuous colour spectrum between green and red, based on their evaluated probability of trend improvement (Figure 23 and Figure 24). Because probability of improvement is the complement of the probability of degradation, “unlikely” improvement, could also be categorised as “likely” degradation. The maps indicate that for many variables there are approximately equal numbers of increasing and decreasing trend directions of those sites categorised as having insufficient data. However, in some cases, the sites with “insufficient data” are dominated by degrading trends (e.g., DRP, chlorophyll-a) or conversely, by improving trends (e.g., periphyton mats, clarity, G540, NH_4-N).

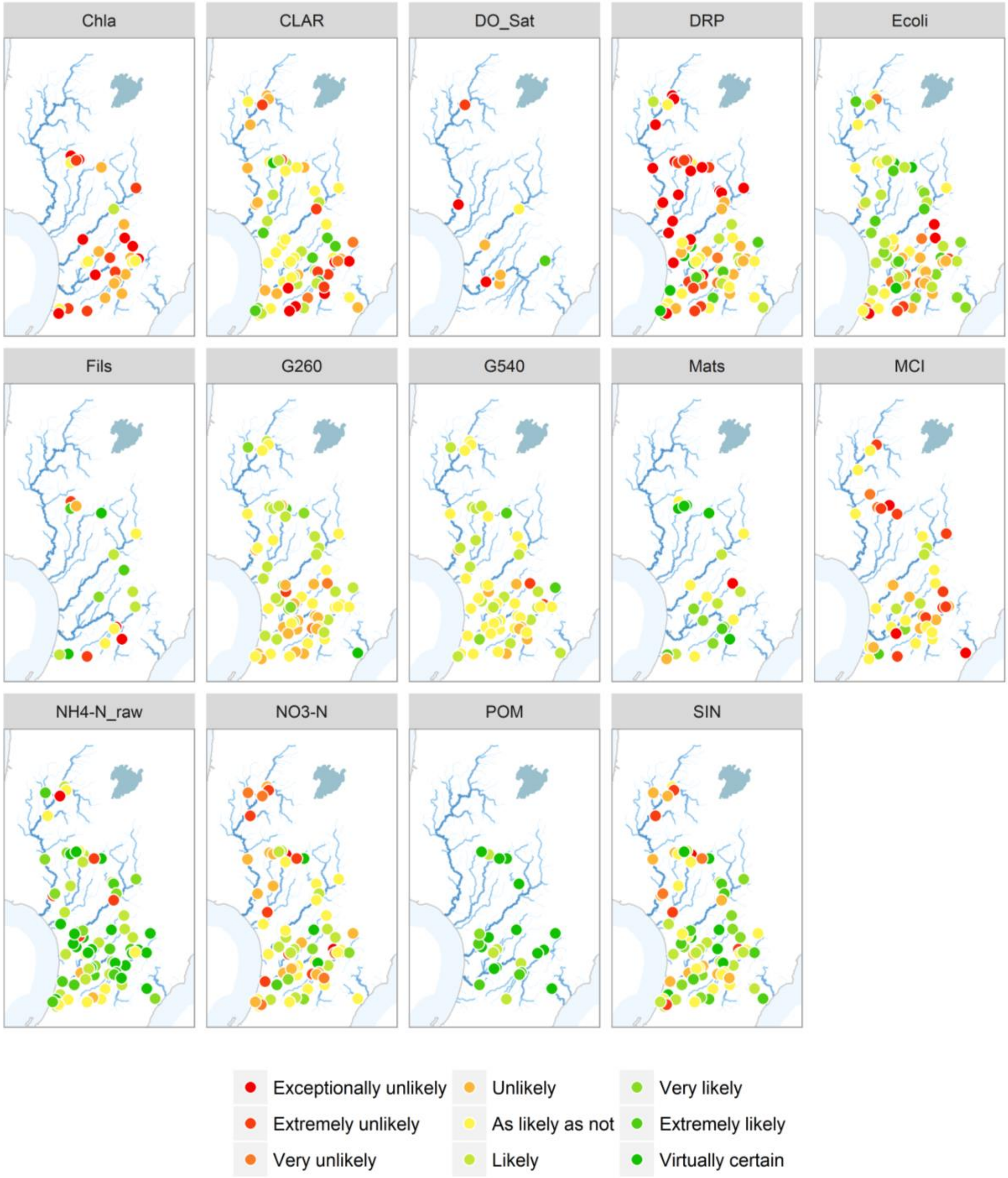

Figure 23. Map of SoE sites categorised by their 10-year raw water quality trend probability of improvement. Probability of improvement is expressed using the categorical levels of confidence defined in Table 6.

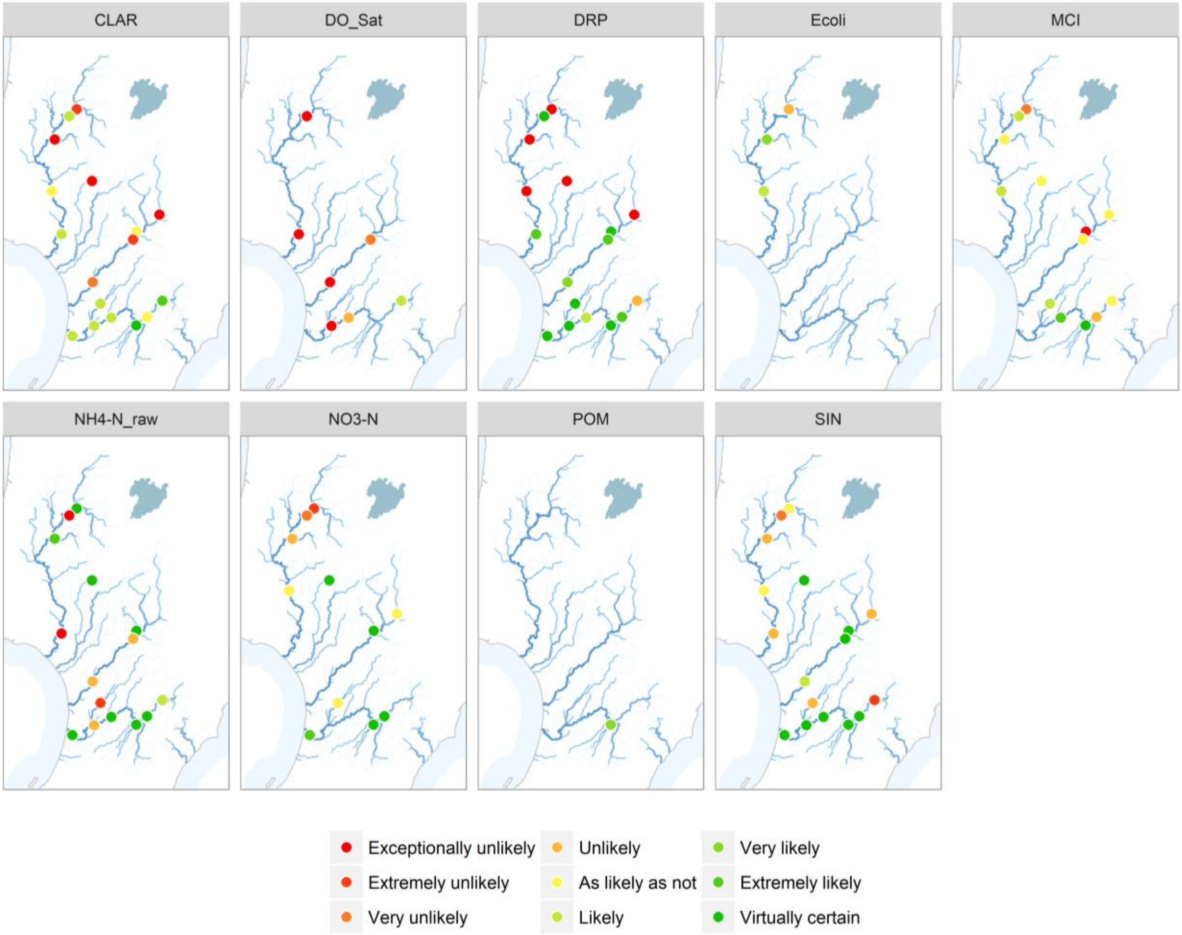

Figure 24. Map of sites categorised by their 20-year raw water quality trend probability of improvement. Probability of improvement is expressed using the categorical levels of confidence defined in Table 6.

5.1.3 Aggregate trends

Figure 25 and Figure 26 show the proportion of all sites by variable, for which 10 and 20-year (respectively) water quality trends indicated improvement at the nine categorical levels of confidence defined in Table 6. These plots provide an overall impression of the relative proportion of improving versus degrading sites by comparing the relative amounts of green and red in each bar. The proportion of improving trends (PIT) and the standard errors of these estimates for the two time periods are summarised in Table 9.

The 10-year proportion of improving trends (PIT) varied between variables, from 10-100% (Table 10). Five of the variables had a majority (i.e., <50%) of degrading trends, at the 95% confidence level (chlorophyll-*a*, MCI, DRP, clarity and DO), although it is noted that trends in dissolved oxygen point measurements are potentially misleading, due to between observation differences in the time of sampling. Five of the variables had a majority of improving (i.e., >50%) trends, at the 95% confidence level (G540, DO-sat, NH_4-N, SIN, POM). The remaining four variables had 95% confidence intervals for the PIT that included 50%. We cannot be confident at the 95% level about the majority trend direction, and therefore there is no evidence of region-wide degradation or improvement for these variables.

The 20-year PIT varied significantly between variables, from 14-100 % (Table 10). Two of the variables had a majority of improving trends at the 95% confidence level (DRP, NH_4-N). Dissolved oxygen had a majority of degrading trends at the 95% confidence level (although note the caution above). The remaining six variables had 95% confidence intervals for PIT that included 50%.

Comparing the 10 and 20-year PIT indicates variable differences between the two time periods. SIN, NH_4-N and DO all show larger PIT values for the shorter time period. Clar, DRP, E. coli, MCI and NO_3-N all show lower PIT values for the shorter time period. However, it is noted that the 20-year trend dataset is based on a much smaller number of sites, and once confidence intervals are considered, we found that these differences were well within the uncertainty in the predicted proportions, with the exception of DRP, where the uncertainty bounds for the PIT values for the two time periods do not overlap, suggesting high confidence in the change from a majority of improving trends to a majority of degrading trends.

Appendix H provides further details of aggregate trends, broken down by FMU.

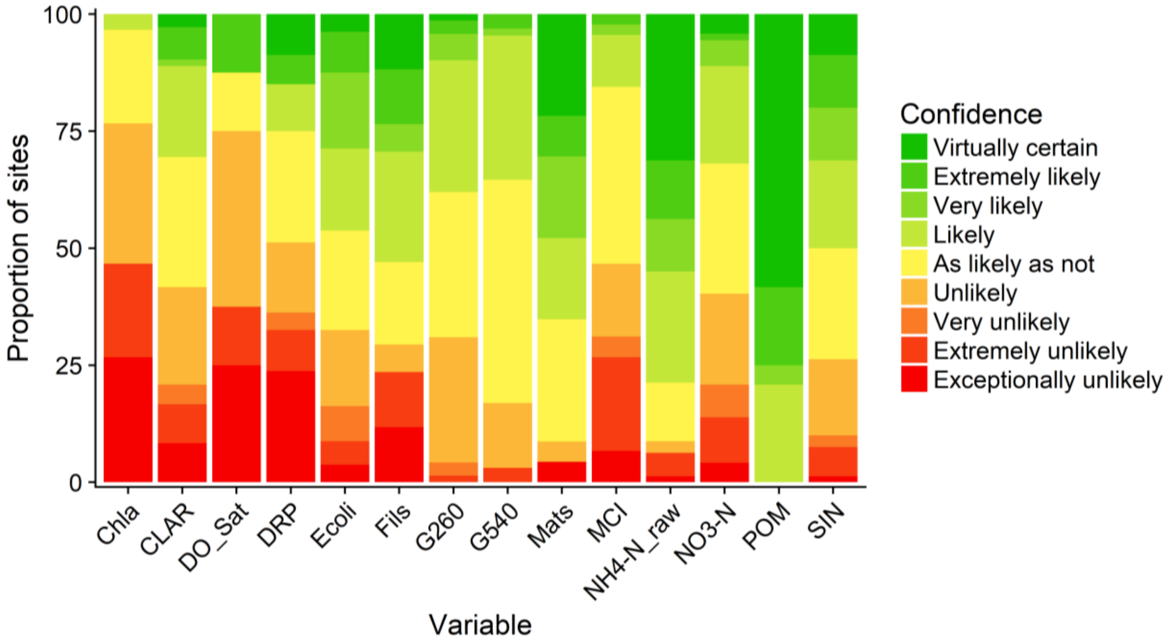

Figure 25. Summary plot representing the proportion of SoE sites with improving 10-year time period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 6. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Trends used in this graph are not flow adjusted.

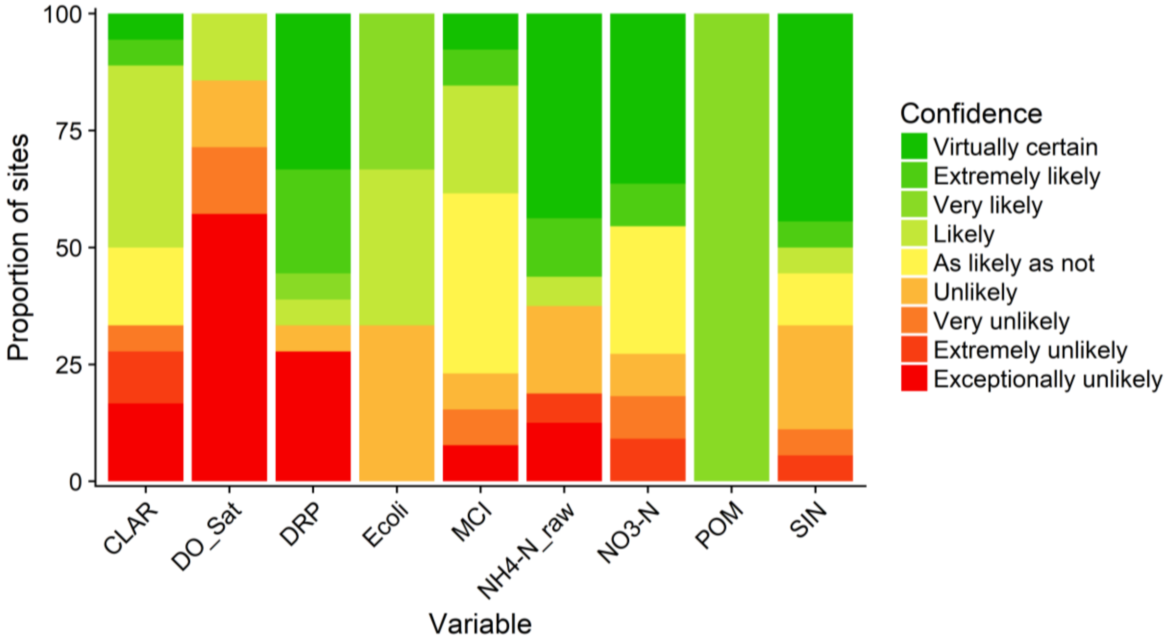

Figure 26. Summary plot representing the proportion of SoE sites with improving 20-year time period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 6. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Trends used in this graph are not flow adjusted.

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Table 10. Proportion of improving trends (PIT) at SoE for 10 and 20-year time periods. Proportions of degrading sites are 100 minus these values. Trends used in this analysis are not flow adjusted. Abbreviated variable names are explained in Table 1.

Time Period	Variable	PIT	Standard error of PIT	Number of sites
10	Chla	10	6	30
	CLAR	37.5	4.5	72
	DO_Sat	25	10.7	8
	DRP	37.5	3.5	80
	Ecoli	52.5	4	80
	Fils	64.7	7.5	17
	G260	56.3	5	71
	G540	63.1	5.4	65
	Mats	82.6	7.1	23
	MCI	35.6	5.8	45
	NH4-N	84.4	3.2	80
	NO3-N	48.6	4.4	72
	POM	100	4.2	24
	SIN	65	4	80
20	CLAR	52.8	8.1	18
	DO_Sat	14.3	9.2	7
	DRP	66.7	4	18
	Ecoli	66.7	17.7	3
	MCI	50	10.7	13
	NH4-N	62.5	4.9	16
	NO3-N	59.1	8.9	11
	POM	100	28.8	1
	SIN	55.6	6.3	18

5.1.4 Trend magnitudes

The distribution of the site trend Sen slopes for each variable and each time period are shown in box and whisker graphs in Figure 27. The units of Sen slope are variable units per year, where the variable units are provided in Table 1. Although the analysis of proportion of trends improving in the previous section provides an overview of the aggregate trend directions, it does not provide any information about the magnitude of the trends. Trend magnitude may be an important management consideration.

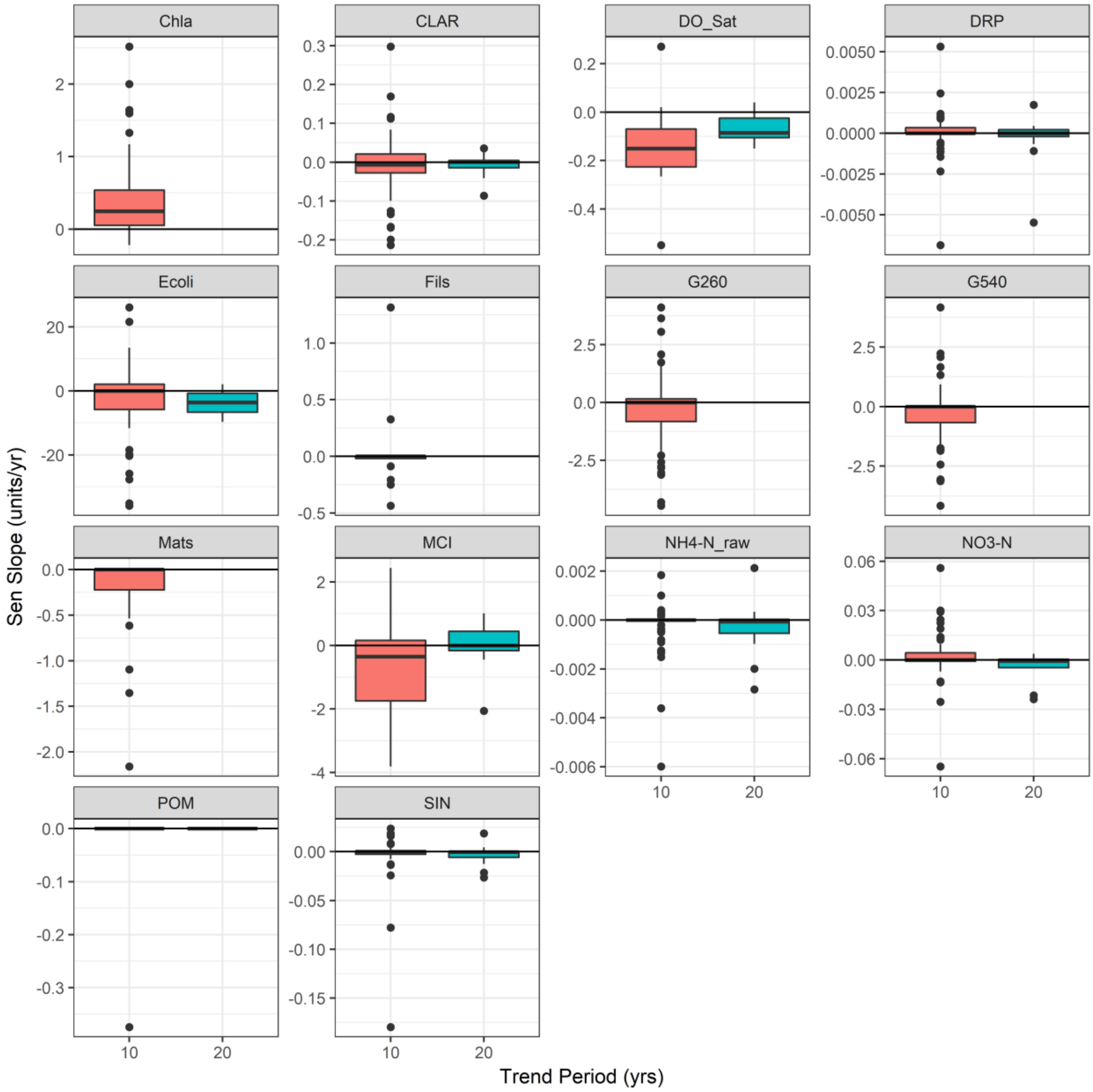

Figure 27: Box and whisker plot of raw Sen slopes (units/year), for both the 10 (red) and 20-year (blue) periods. Negative trends indicate improvement, except for MCI, CLAR and DO_sat, where positive trends indicate improvement.

A useful way to provide a context for considering the trend magnitudes is to express them relative to the censoring limits (mode from the dataset), the measurement precision (mode from the dataset), and the magnitude of the state criteria (e.g. Table 4, Table 2 and Appendix C). Table 11 presents a summary of the precision and censoring limits for each variable as well as the percentage of degrading or improving 10-year trends that had an absolute magnitude less than either the precision or censor limit. Also included in the table is the percentage of degrading or improving trends that had an absolute trend magnitude greater than 20% of the bottom line (note, the bottom line varies by site, as demonstrated in Appendix C and where there is both a NOF and One Plan criteria, the more stringent of the two is used for the comparison).

All trends were smaller than a rate of the precision/year for G260, G540, and POM (largely due to the very low precision of these variables), and the majority of trends were smaller than this rate for DRP, filaments, mats, MCI, NH_4-N. Improving trends in *E. coli* at 23 sites (29%) had magnitudes of >20% of the bottom line/year. Conversely, 8 sites (10%) had degrading *E. coli* trends with magnitudes of >20% of the bottom line/year. A small number of sites also had large relative improving trends and other sites had large relative degrading trends for DRP and SIN.

Table 11: Summary of 10-year trend magnitudes relative to precision, censor values and bottom lines. Units as per Table 1.

	Precision[1]	Censor Limit[1]	Improving				Degrading			
			>20% of bottom line	<20% of bottom line & >Censor Limit	<Censor Limit	< Precision	< Precision	<Censor Limit	<20% of bottom line & >Censor Limit	>20% of bottom line
Chla	0.0005	NA	0	10		0	0		90	0
CLAR	0.01	0.05	0	15	13	7	18	32	15	0
DO_Sat	0.1	NA	0	13		13	0		75	0
DRP	0.001	0.001	3	3	0	34	55	0	5	1
Ecoli	0.1	4	23	8	15	8	5	28	8	8
Fils	0.05	NA	0	24		41	24		12	0
G260	8.3	NA	0	0		61	39		0	0
G540	8.3	NA	0	0		71	29		0	0
Mats	0.05	NA	0	35		48	17		0	0
MCI	1	NA	0	7		24	29		40	0
NH4-N	0.001	0.005	0	1	5	79	14	0	0	0
NO3-N	0.0001	0.002	0	19	25	6	8	11	31	0
POM	1	3	0	0	0	100	0	0	0	0
SIN	0.001	0.002	3	25	18	21	9	4	19	3

1. Where more than one precision of censor limit existed in the dataset, the most common value was used.

Where there are both 10 year and 20-year trends, the 20-year trends are generally better (i.e., fewer degrading and more improving) than those of the 10-year period. A site by site comparison of the differences in Sen slopes (including uncertainty) between time periods is shown in Figure 28. The red line indicates the 1:1 line. When the points lie below the 1:1 line (or above, in the case of clarity, MCI and dissolved oxygen), the evaluated Sen slope of the 10-year period is worse (i.e., more degrading or less improving) than that for the 20-year period. Particularly notable are a number of sites across all nitrogen species where the 90% confidence intervals do not overlap.

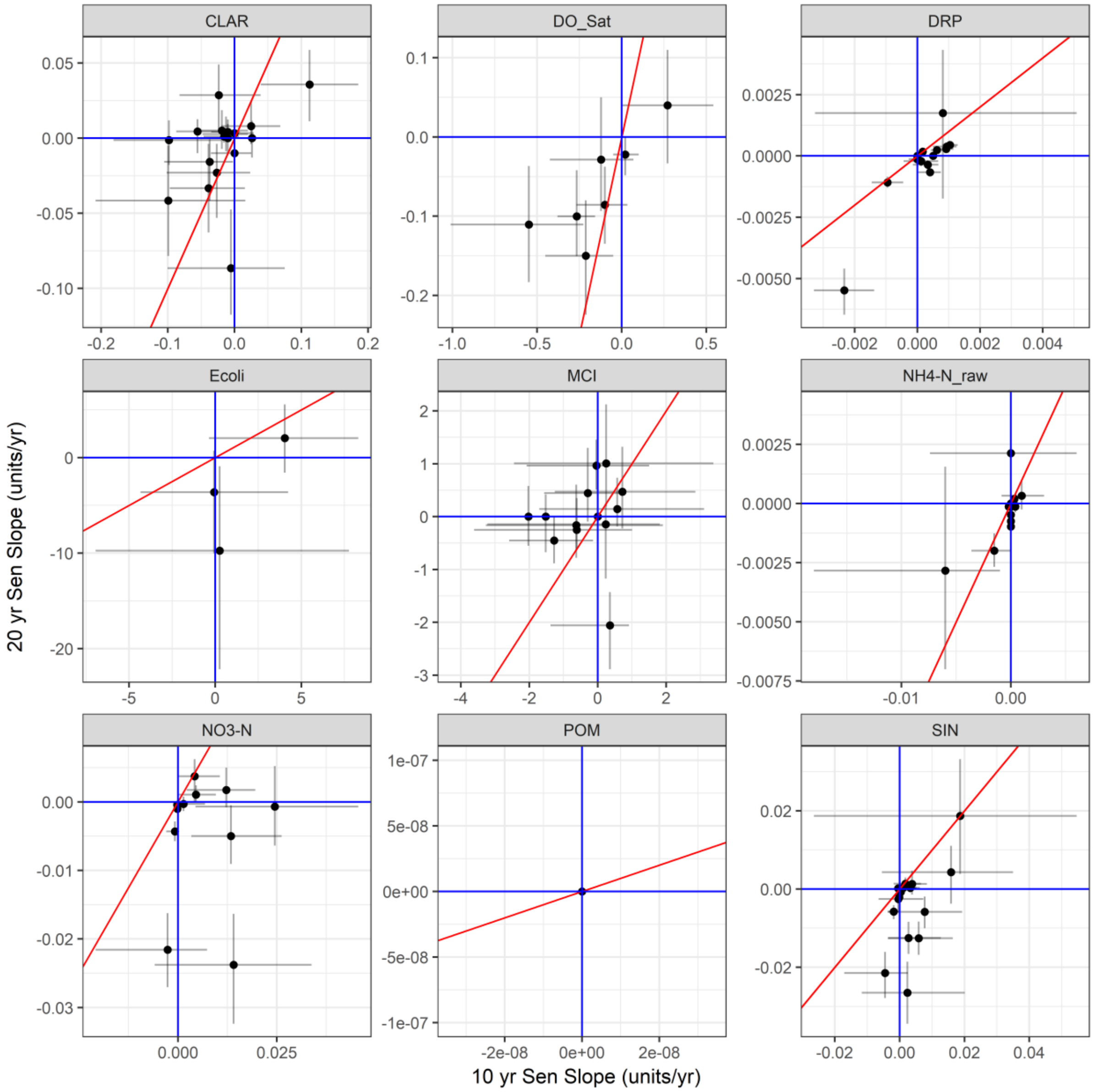

Figure 28: Comparison of the 10-year and 20-year Sen slopes, including uncertainty. The red-line is the 1:1 line. Grey error bars indicate the 90% confidence interval for the Sen slope. Negative trends indicate improvement, except for MCI, CLAR and DO_sat, where positive trends indicate improvement.

5.2 Trends at discharge and impact Sites

5.2.1 Trends classification

Figure 29 and Figure 30 show the 10-year trend classifications for the impact and discharge site, respectively. For the impact sites, a significant proportion of the trends (56%) analysed are classified as having “insufficient data”. For the 10-year trends defined with confidence, there was a mix of both improving (34%) and degrading (10%) trends at the impact sites. The relative proportion of improving and degrading sites is consistent with what was found for the SoE sites. Across all variables, 43% of discharge site trends were classified as having “insufficient data”, 40% as improving and 16% degrading. There was no geographical pattern associated with the distribution of increasing or decreasing trends for any variables, although there may be some patterns associated with river size or catchment characteristics that are not immediately evident from the maps.

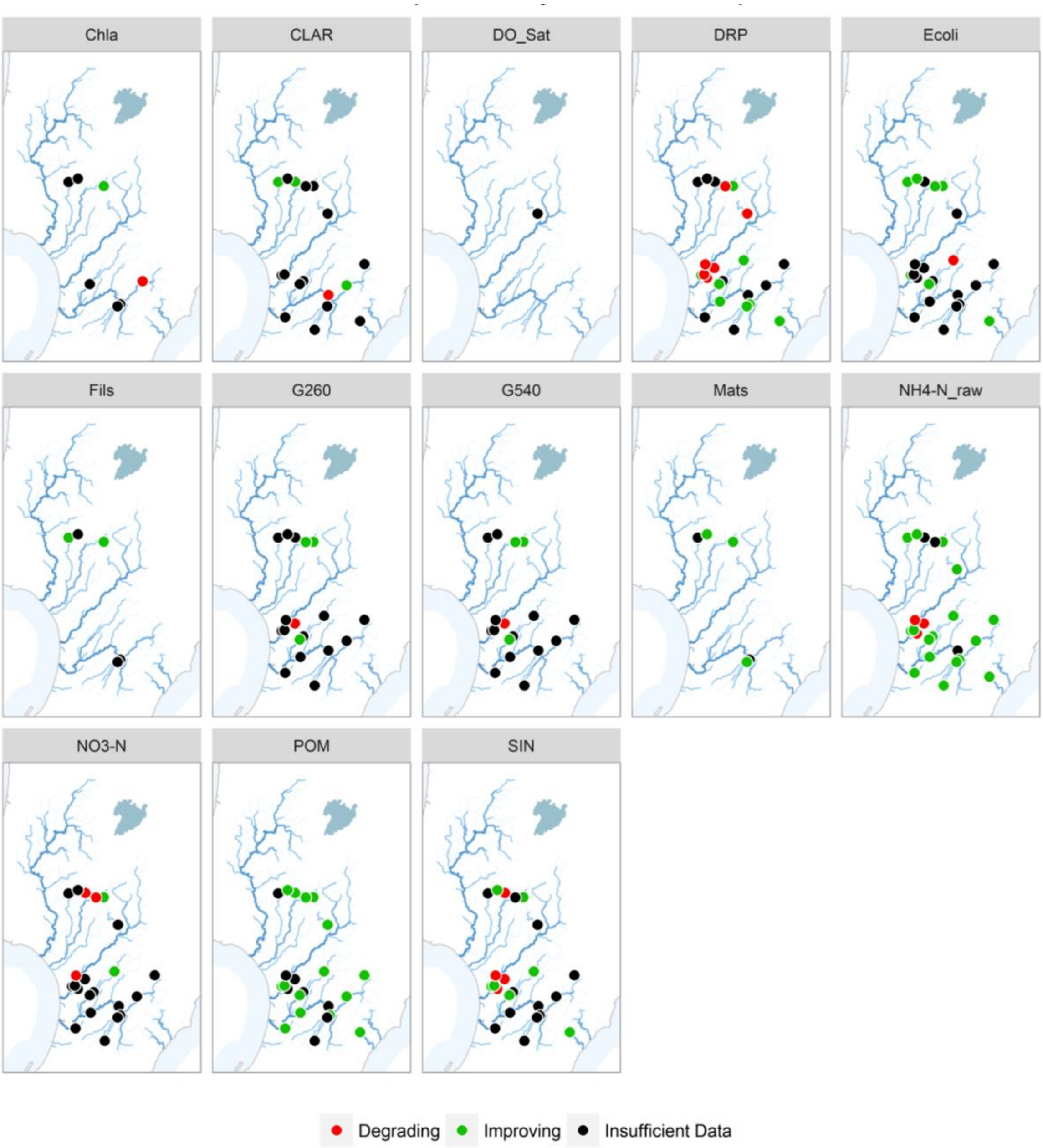

Figure 29. Map of impact sites classified by their 10-year raw water quality variable trend descriptions. Site and variable combinations for which there were many missing or censored values are not shown in the plots. Note that trend descriptions indicate degrading and improving (rather than trend direction of the water quality variable).. Trends are all based on analyses performed using raw (i.e., not flow adjusted) data.

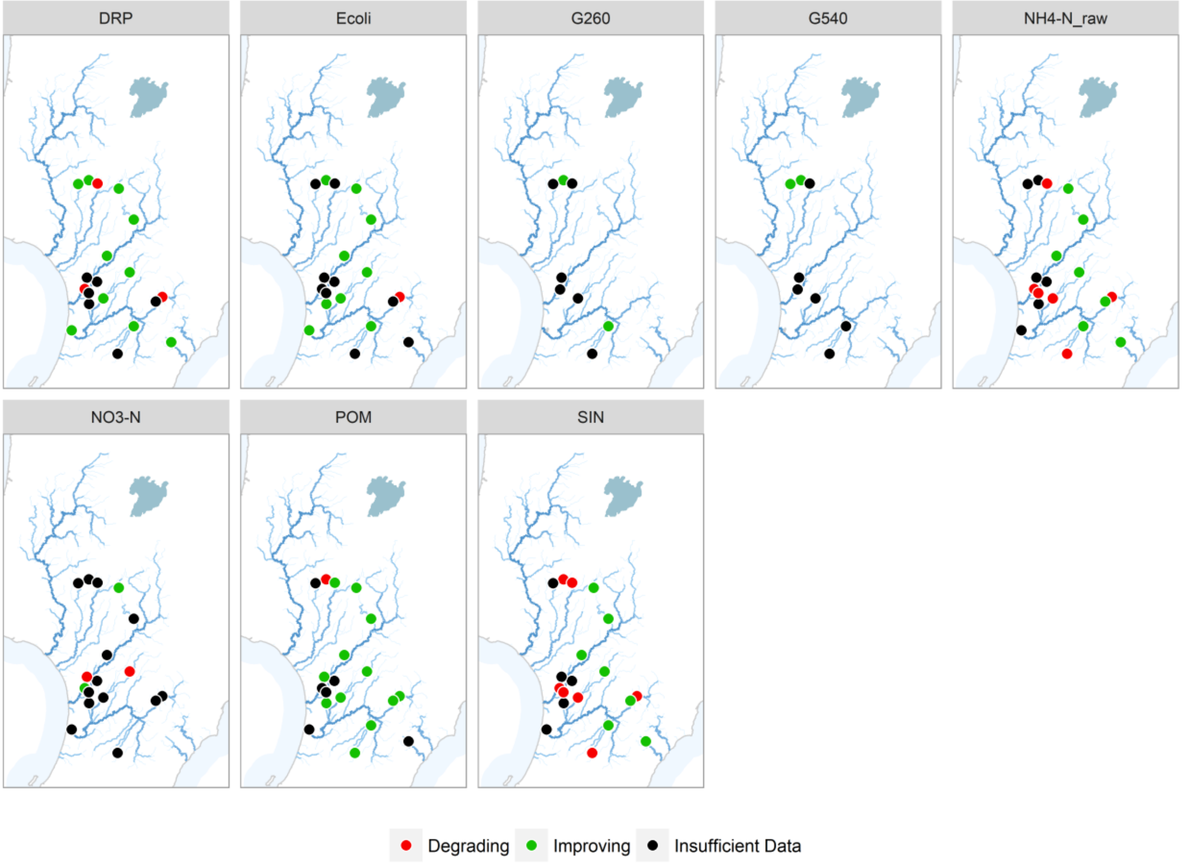

Figure 30. Map of discharge sites classified by their 10-year raw water quality variable trend descriptions. Site and variable combinations for which there were many missing or censored values are not shown in the plots. Note that trend descriptions indicate degrading and improving (rather than trend direction of the water quality variable). Trends are all based on analyses performed using raw (i.e., not flow adjusted) data.

5.2.2 Probability of improvement

Figure 31 and Figure 32 map the probability of improvement (expressed using the categorical levels of confidence defined in Table 6) across the region for the impact and discharge sites, respectively. The maps indicate that for many of the impact sites, and most variables, there are approximately equal numbers of increasing, decreasing trends for sites previously categorised as having insufficient data (e.g., compared to Figure 30). However, in some cases, the impact sites with "insufficient data" are dominated by degrading trends (e.g., clarity, NO_3-N) or conversely, by improving trends (e.g. POM, NH_4-N, G260).

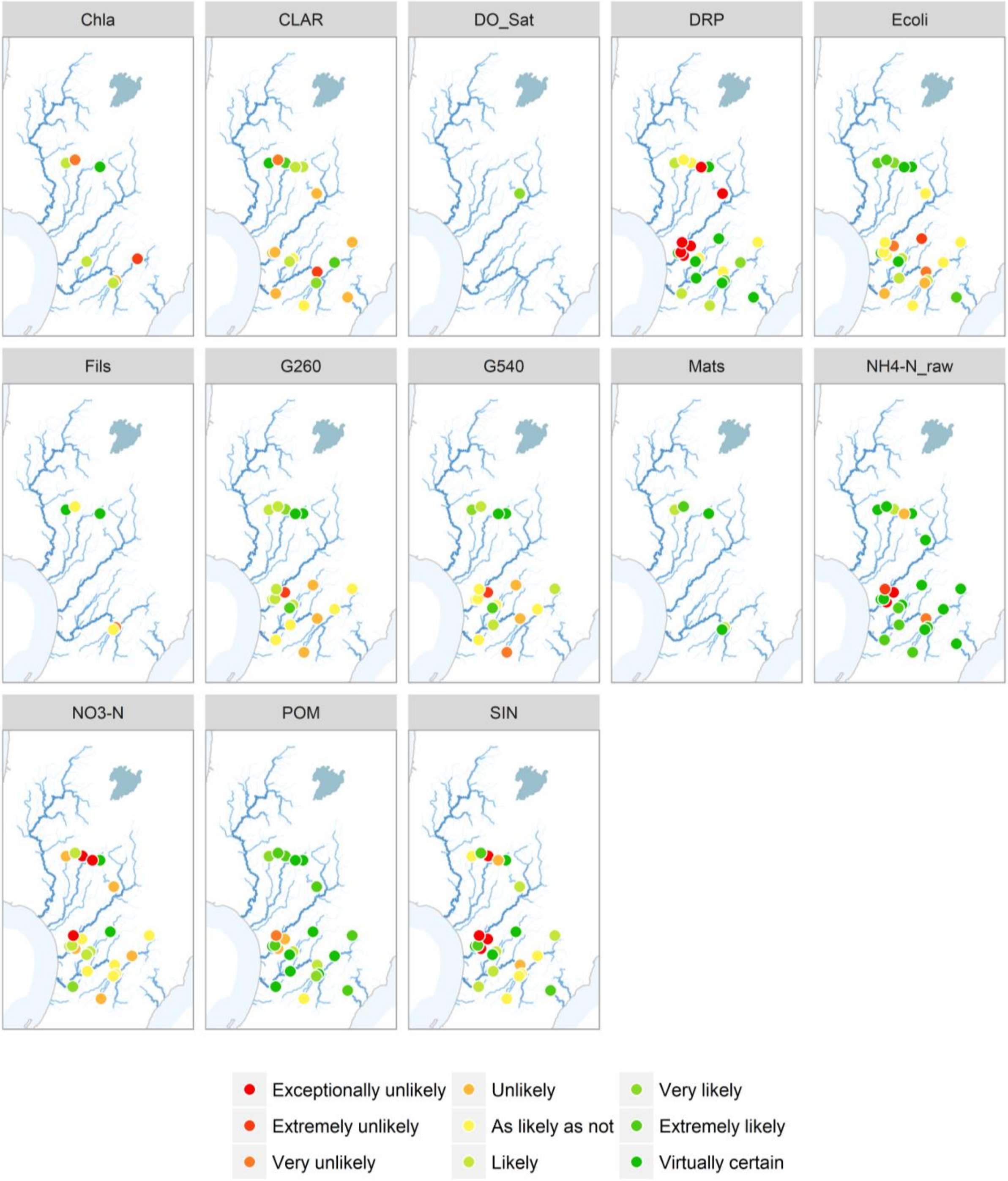

Figure 31. Map of impact sites categorised by their 10-year raw water quality trend probability of improvement. Probability of improvement is expressed using the categorical levels of confidence defined in Table 6.

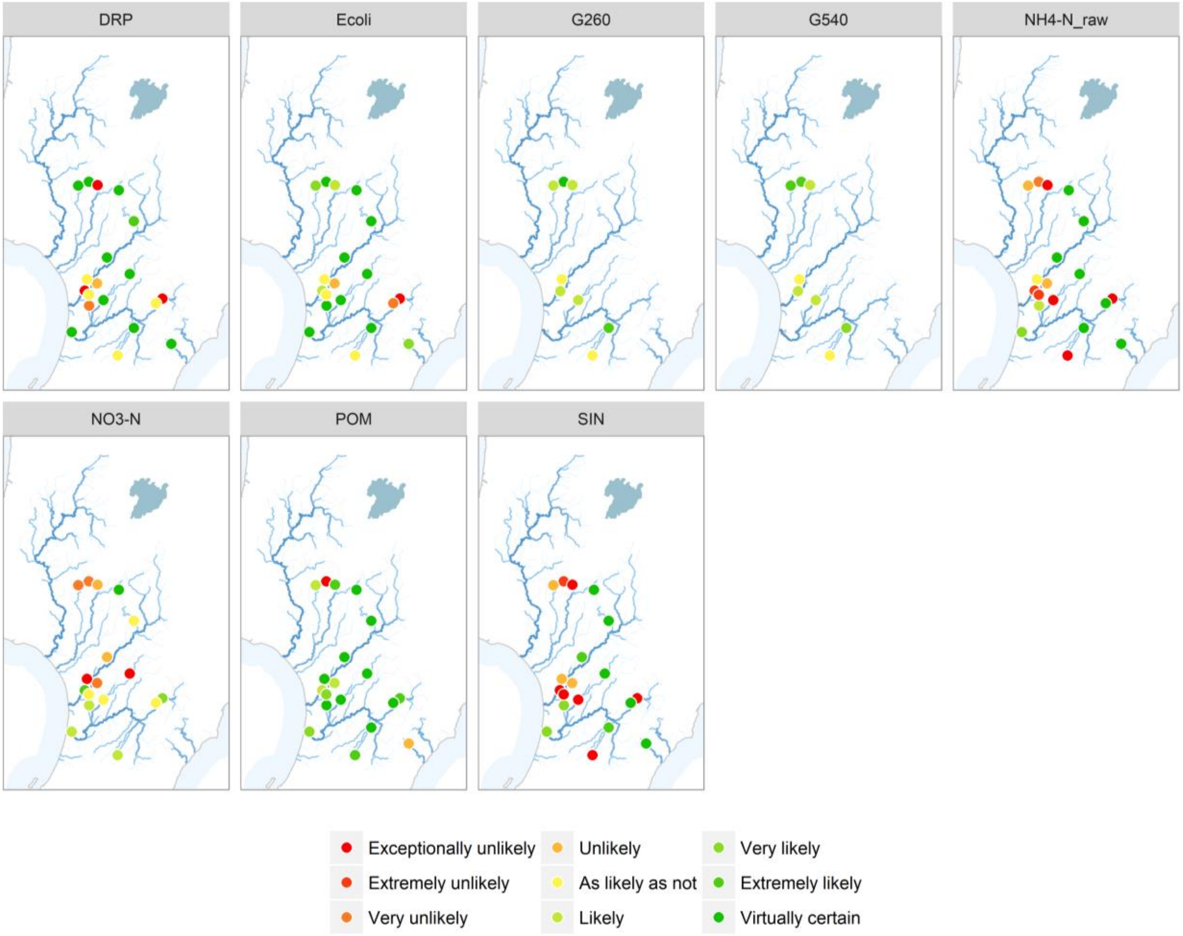

Figure 32. Map of discharge sites categorised by their 10-year raw water quality trend probability of improvement. Probability of improvement is expressed using the categorical levels of confidence defined in Table 6.

5.2.3 Aggregate trends

Figure 33 and Figure 34 show the proportion of all sites by variable, for which impact and discharge (respectively) 10-year water quality trends indicated improvement at the nine categorical levels of confidence defined in Table 6. The probabilistic estimates of the PIT and the standard errors of these estimates for the two time periods are summarised in Table 12.

The 10-year PIT for impact sites varied between 36% and 100 %, depending on the variable. No variables a majority of degrading trends at the 95% confidence level. Six of the variables had a majority of improving trends at the 95% confidence level (DRP, *E. coli*, Mats, NH$_4$-N, POM and SIN). The remaining seven variables had 95% confidence intervals for PIT that included 50%; therefore, we cannot be confident at the 95% level about the majority trend direction, and hence there is no evidence of region-wide degradation or improvement for these variables.

The 10-year PIT of discharge sites varied from 47 to 94 % depending on the variable. Four of the variables had a majority of improving trends at the 95% confidence level (POM, *E. coli*, G540 and G260). The remaining four variables had 95% confidence intervals for the probability proportion of improving that included 50%.

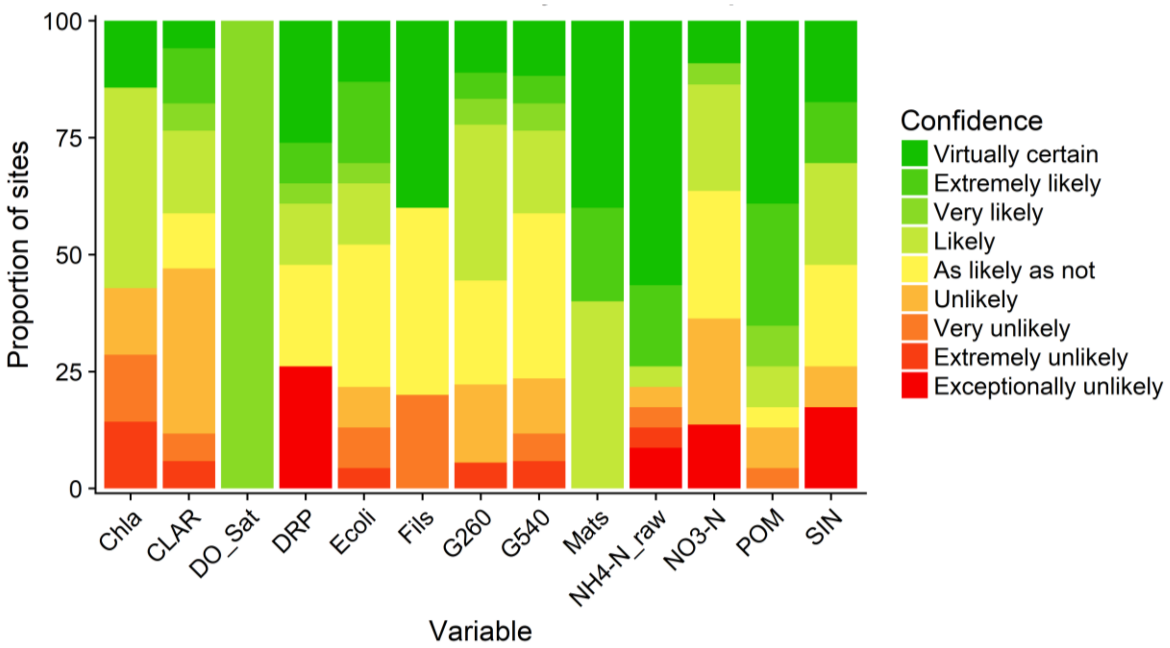

Figure 33. Summary plot representing the proportion of impact sites with improving 10-year time period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 6. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Trends used in this graph are not flow adjusted.

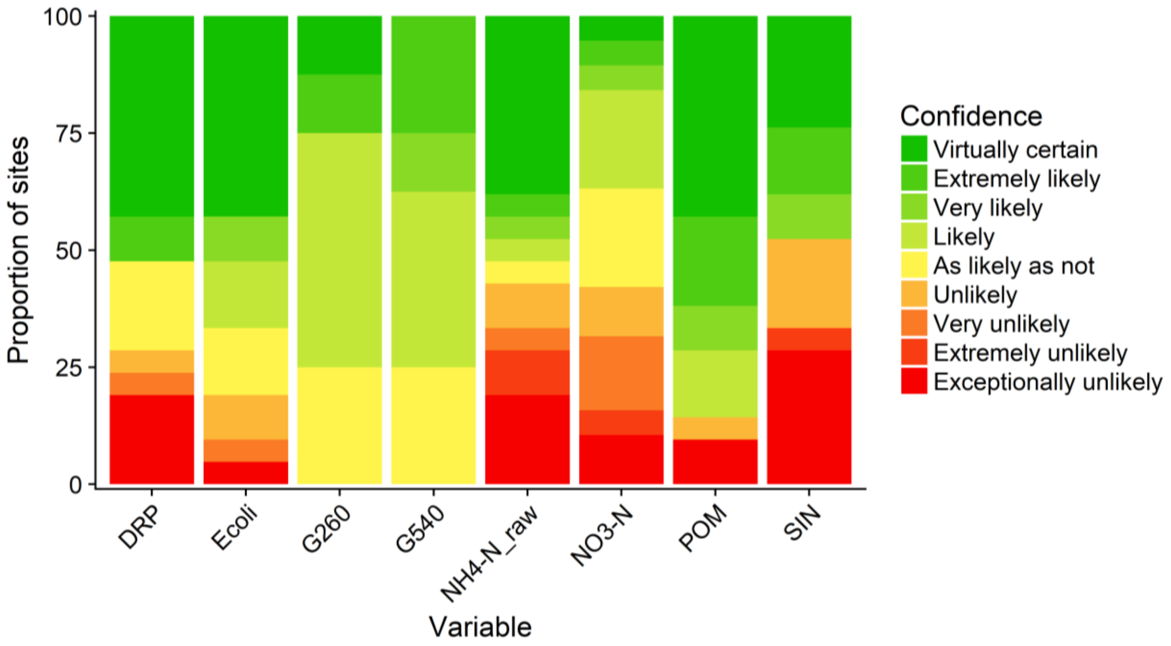

Figure 34. Summary plot representing the proportion of discharge sites with improving 10-year time period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 6. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Trends used in this graph are not flow adjusted.

Table 12. Proportion of improving trends (PIT) for impact and discharge sites for 10 -year time- period. Proportions of degrading sites are 100 minus these values. Trends used in this analysis are not flow adjusted. Abbreviated variable names are explained in Table 1.

Site Type	Variable	PIT	Standard error of PIT	Number of sites
Impact	Chla	57.1	11.5	7
	CLAR	47.1	8.8	17
	DO_Sat	100	29.9	1
	DRP	65.2	5.8	23
	Ecoli	65.2	7.5	23
	Fils	60	15.2	5
	G260	66.7	8.9	18
	G540	67.6	9.4	17
	Mats	100	10.9	5
	NH4-N	78.3	3	23
	NO3-N	36.4	8.2	22
	POM	87	4.8	23
	SIN	69.6	6.8	23
Discharge	DRP	59.5	5.5	21
	Ecoli	76.2	5.9	21
	G260	93.8	13	8
	G540	75	12.6	8
	NO3-N	57.1	4.9	21
	POM	47.4	8.1	19
	SIN	85.7	4.7	21

5.2.4 Trend magnitudes

The distribution of the Sen slopes for each of the variables and both the impact and discharge sites are shown in box and whisker graphs in Figure 35. The units of Sen slope are shown in variable units per year, where the variable units are defined in Table 1. The large decreasing trend in *E. coli* at a discharge site is for the Waiouru STP which was upgraded in 2013 leading to very large improvements in all water quality variables.

Figure 36 compares trends at discharge sites with their associated downstream impact sites (Site pairs are listed in Appendix B) for each water quality variable. The strongest correlation between discharge site trend magnitudes and downstream impact site trend magnitudes was for *E. coli*, with a correlation coefficient of 0.79. The large improving trend at the Waiouru STP is reflected with a large improving trend at the downstream impact site. There were weak to no relationships between the pairs for POM, SIN and DRP. Although G260 actually had a negative correlation coefficient, we note that the trend directions were always consistent between the discharge and impact sites.

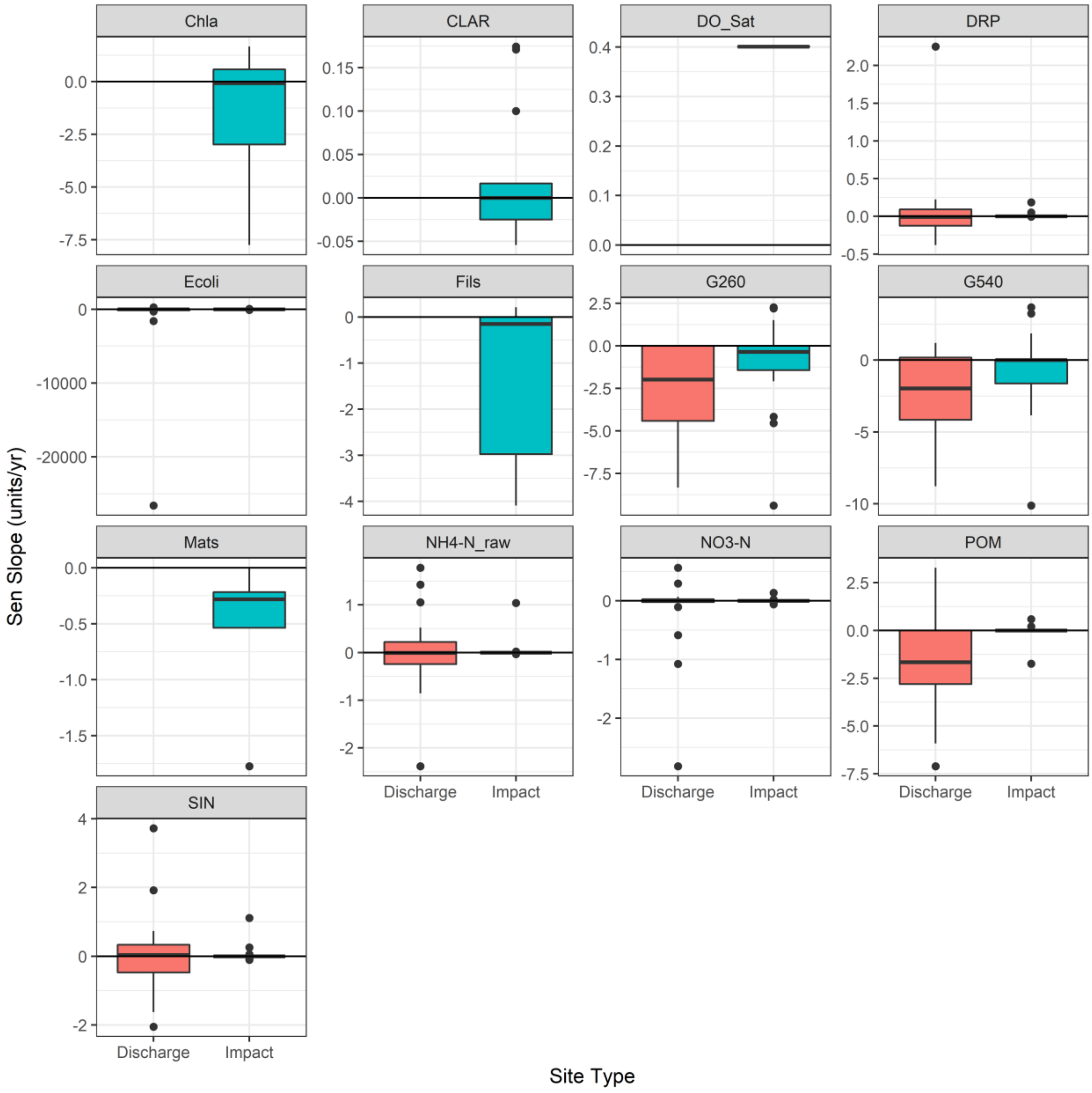

Figure 35: Box and whisker plot of raw 10-year Sen slopes (units/year), for both the impact (red) and discharge sites (blue).

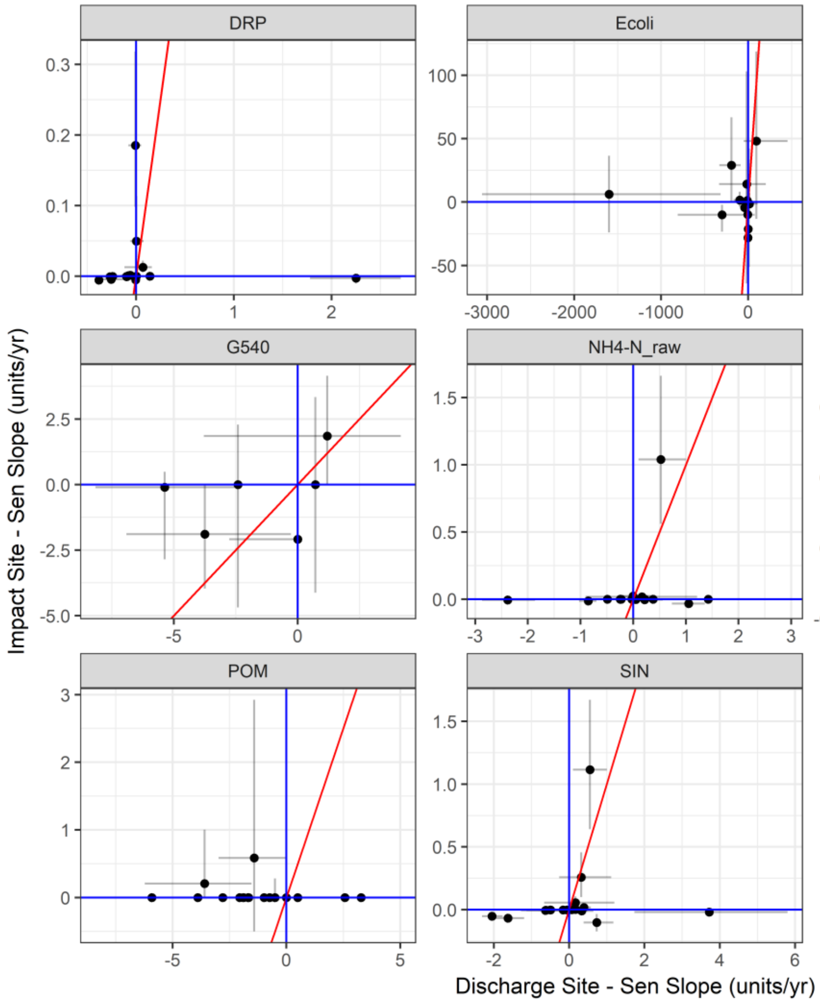

Figure 36: Comparison of the discharge and linked impact site Sen slopes, including uncertainty. The red-line is the 1:1 line. Grey error bars indicate the 90% confidence interval for the Sen slope.

6 Comparison of state and trends

The relevance of trends and identification of appropriate management actions is dependent on many factors, including the current state and the direction and magnitude of the trends. Figure 37 and Figure 38 show the distribution of 10-year Sen slopes for each variable separated by One Plan grades, or NOF band (evaluated for the most recent 5 years). Note, (1) in some cases the state criteria did not have a corresponding trend calculated (i.e. maximum ammoniacal-N, *E. coli* bathing); in these cases, the Sen slopes shown in the figures represent the trends evaluated for all data for the corresponding variable; (2) the state for NH_4-N is based on pH adjusted values, whereas the NH_4-N trend uses non-adjusted values . The same data are presented in Appendix H but shown as scatter plots with the continuous criteria test statistic (i.e. 95th percentile Nitrate) on the x-axis and the 90% confidence intervals for the Sen slopes.

Sites of all grades were associated with both improving and degrading trends. For both the One Plan and the NOF criteria, the largest degrading trends were associated with poor state grades, almost uniformly across all variables. For the *E. coli* grades, the largest improving trends were also associated with the lowest state grades.

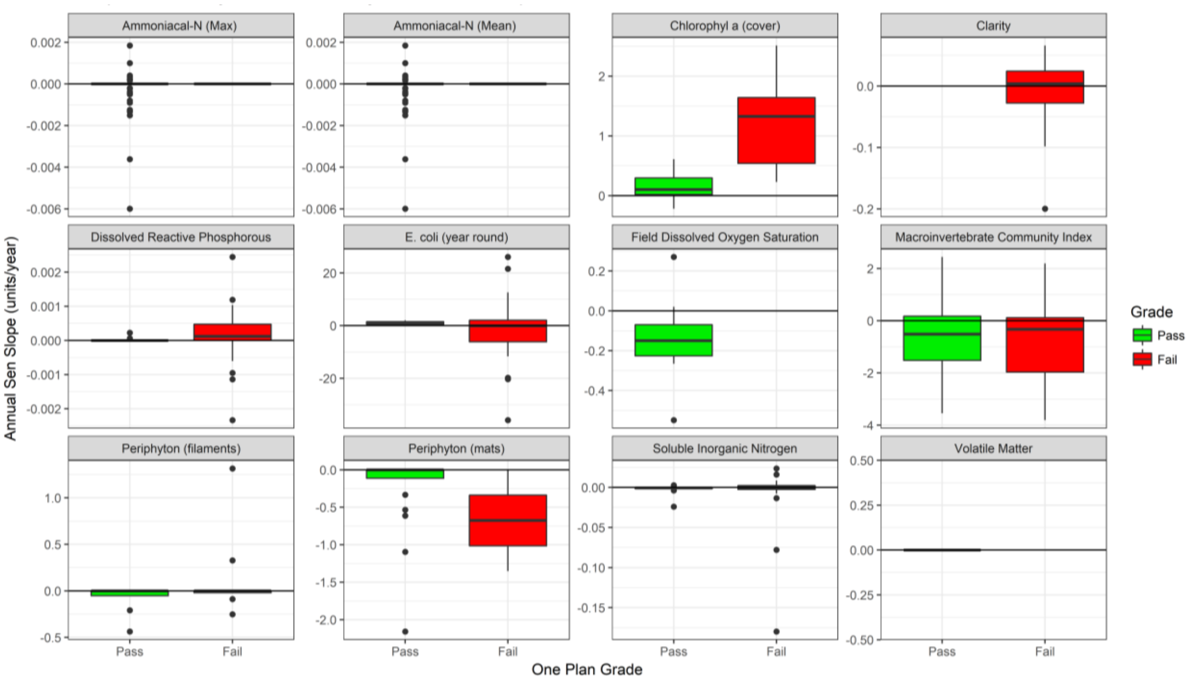

Figure 37: Box and whisker plot showing distribution of 10-year trend magnitudes (Sen slopes) for sites categorised by their (5-year) One Plan grades. Sen slopes are for raw trends (i.e., not flow adjusted).

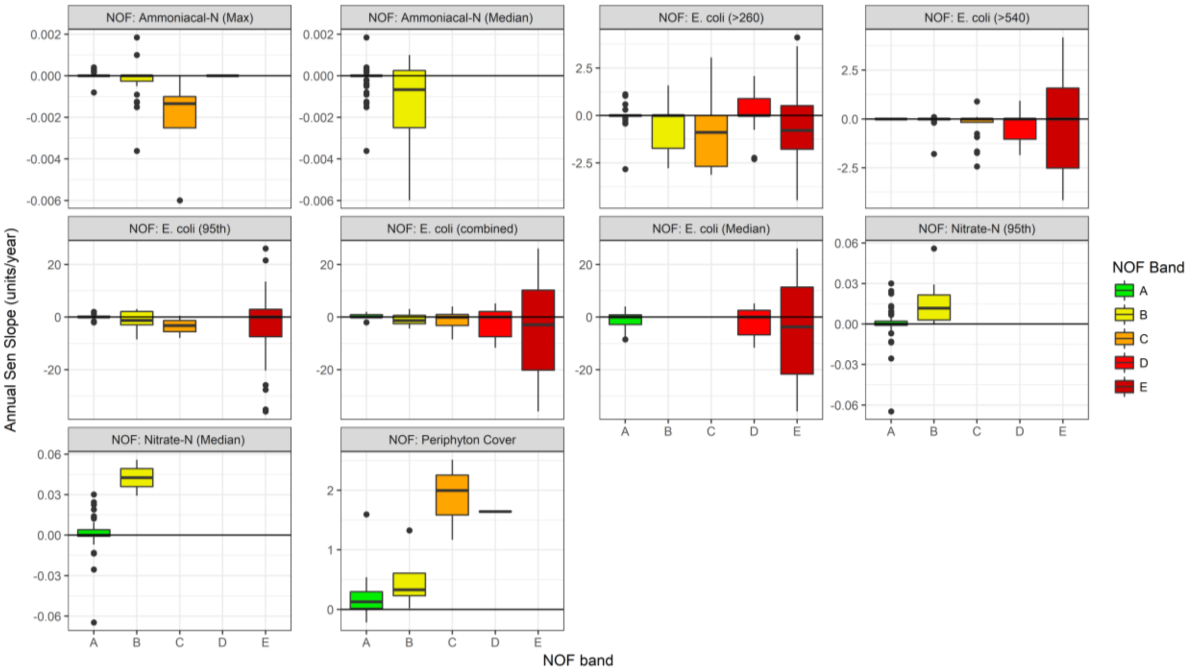

Figure 38: Box and whisker plot showing distribution of 10-year trend magnitudes (Sen slopes) for sites categorised by their (5-year) NOF grade. Sen slopes are for raw trends (i.e., not flow adjusted).

7 Discussion

7.1 Water quality state

The most obvious pattern associated with the assessment of water quality state was that for many variables the individual sites almost uniformly passed or failed targets. Site grades based on the Horizons One Plan criteria were dominated by failing sites for DRP, *E. coli* and clarity. Conversely, almost all sites passed the One Plan criteria for ammoniacal-N, cyanobacteria, periphyton (mats) and volatile matter, and NOF criteria for nitrate (mean and 95th percentile) and ammoniacal-N (median). Similarly, most sites across the region passed the NOF criteria for NH_4-N (maximum) and periphyton. There were similar numbers of passing and failing sites for the One Plan criteria for dissolved oxygen, chlorophyll-*a*, MCI, periphyton (filaments) and SIN, and NOF *E. coli* criteria.

There are no immediately obvious spatial patterns associated with the variation in grades, however this does not mean that there are not associations with, for example, river size or catchment land cover. Generally, the patterns in grades were similar for the impact sites. These relationships will be explored in more detail in a second state and trends spatial modelling study.

At the discharge sites, there was a dominance of sites failing the criteria for change in pH, and percent reduction in clarity. Conversely, the change in temperature criteria was met at most sites across the region. There were very few sites with QMCI data available to evaluate reduction in QMCI.

7.2 Water quality trends

7.2.1 Trend classifications

Ten-year water quality trends were able to be calculated for at least one variable at 131 sites (approximately 55% of all River sites currently monitored). Twenty-year trends could be calculated at only 20 sites. The difference reflects the significant efforts of Horizons Regional Council to expand its monitoring network over the period 2007-2010.

A majority of trends at SoE sites had “insufficient data” to determine trend direction at the 95% level of confidence for the 10-year time period. However, relaxation of this misclassification (of trend direction) error risk of 5% provided greater insight into the general trend direction at the regional scale (Figure 23 and Figure 24). Maps of sites categorised by confidence that trends were improving indicate that, for many variables, there are approximately equal numbers of increasing and decreasing trends. However, some variables were dominated by degrading trends (e.g. chlorophyll-*a* and MCI) or conversely, by improving trends (e.g. Pom, SIN and NH_4-N,).

7.2.2 Aggregate trends

The 10-year proportion of improving trends (PIT) for SoE sites varied between 10% to 100%, depending on the variable. Five of the variables had a majority (i.e., <50%) of degrading trends, at the 95% confidence level (chlorophyll-*a*, MCI, DRP, clarity and DO), although it is noted that trends in dissolved oxygen point measurements are potentially misleading, due to between observation differences in the time of sampling. Five of the variables had a majority of improving (i.e., >50%) trends, at the 95% confidence level (G540, DO-sat, NH_4-N, SIN, POM). The relative difference in PIT statistics between variables for the impact sites was similar to the SoE sites, but there was generally a greater proportion of improving trends for the impact sites.

For the 10-year monitoring period, we found that there were strong relationships between decreasing *E. coli* trends at discharge sites and decreasing *E. coli* trends at paired downstream impact sites. This is strong evidence of regional improvement in *E. coli* associated with improvements to point source discharge quality over the past decade. However, there were weak to no relationships between the pairs for POM, SIN and DRP. Interpretation of these results must take into consideration the time period of analysis. There have been upgrades more recently that may take time to affect trends i.e. improving trends might be detected at the discharge sites, but improvements are not yet detectable at the downstream impact site.

7.2.3 Trend magnitudes

Trend magnitudes were highly variable between sites. In general, we found that the largest degrading trends were associated with those sites that also had the poorest state grades based on the One Plan and/or NOF state criteria (e.g. *E. coli* at Mangaatua at u/s Woodville STP; DRP at Turakina at ONeills Bridge; clarity at Oruakeretaki at S.H.2 Napier; chlorophyll-*a* at Manawatu at Hopelands). It is these sites that are likely to warrant the greatest effort to slow/reverse degrading trends. The largest magnitude improving trends for *E. coli* were at sites (such as Manakau at S.H.1 Bridge, Mangarangiora Trib at us Norsewood STP, Ohura at Tokorima) that currently have *E. coli* in the NOF E band, which may reflect some targeted efforts to improve practices in catchments upstream of these sites; this will be explored as part of the state and trends spatial modelling report.

To provide some context to magnitude of the trends, we compared the Sen slopes to both the censoring levels, the monitoring precision and NOF/One Plan criteria (sections 5.1.4 and 5.2.4). All trend magnitudes were smaller than a rate equivalent to the variable measurement precision for *E. coli* variables G260 and G540, and POM (largely due to the very low precision of these variables), and a majority of trend magnitudes were smaller than this rate for DRP, filaments, mats, MCI, NH_4-N. This indicates that, even if the data followed a perfectly linear trend, it may take several years for these trends to be detected (and it would take even longer to be identified with confidence) given current measurement precision. There were improving trends in *E. coli* at 23 sites (29%) at rates of >20% of the bottom line/year. Conversely, 8 sites (10%) show degrading trends >20% of the bottom line/year. A small number of sites had large improving trends and others had large degrading trends for DRP, and SIN, relative to the magnitude of the bottom line target. It is noted that scaling by the bottom line (as described in section 5.1.4) may not be the most appropriate comparison point for some variables, particularly when the range for the variable does not include zero (i.e., MCI). Further consideration of methods for standardising trends to assist in prioritisation of management effort is recommended.

We also found that trend magnitudes were generally worse (i.e. smaller degrees of improvement or greater levels of degradation) for the 10-year time period compared to the 20-year time period. Particularly notable are several sites across all nitrogen species where the 90% confidence intervals for the Sen slopes between the two periods do not overlap, suggesting that in these cases we can be confident that improving trends are now improving at a lower rate (or degrading), and that degrading trends are degrading at a greater rate.

7.2.4 Covariate adjustment

This study considered in detail whether to flow adjust water quality data as part of trend assessment (see Appendix E). There are good reasons to flow adjust. Adjusting data to account for flow (or any covariate) decreases variation and increases statistical power; i.e., increases the likelihood of detecting a trend with certainty; (Helsel and Hirsch, 1992). In addition, flow adjustment can improve trend detection if there has been a bias in the flow on sample occasion (i.e., increasing or decreasing flow on sample occasion with time). However, decisions concerning the appropriateness of water quality variable - flow models that underlie flow adjustment are subjective and site specific. This means that inspection of the data for all trend analysis is required and that trends based on automatic (i.e., non-supervised) flow adjustment should not be relied on.

Based on the examination of a subset of sites with adequate flow data, it was concluded that the regional-scale findings of this study do not differ between analyses based on raw or flow adjusted trends. It is not known whether this finding can be extended to other studies and it is recommended similar analyses are undertaken for any study of water quality trends to investigate the importance of flow adjustment in each case.

Ideally there would be a more objective basis for choosing to flow adjust (and for choosing the appropriate model for doing so). There have also been recent developments of techniques for trend analysis that incorporate flow in a more flexible and robust manner than the traditional methods (e.g., Hirsch *et al.*, 2015). Given the importance of trend analysis, it is recommended that flow adjusting and trend assessment in general are further investigated.

7.2.5 Uncertainties in site trends associated with censoring

Trends may be induced in a timeseries on water quality samples if the censoring limit changes through the time period. Systematic changes in censoring levels occurred for some variables considered in this study (i.e. DRP changing from 0.01 to 0.05 in 2005). This study examined the influence of varying censoring limits as part of trend assessment (see Appendix F). We did this by comparing trend analysis outputs calculated using all data (irrespective of varying censoring levels) with outputs calculated on a dataset where the rule that all values below the highest censored value were treated as censored (hi-censored) was applied. Although applying the highest censoring value across all time provides an evaluation of trends that limits bias through time, it generally leads to larger confidence intervals and more trends categorised as having “insufficient data” and fails to capitalise on the full information content on any given dataset.

Based on this investigation we found that the regional-scale findings of this study do not differ between analyses based on raw or hi-censored trends and that applying the high censoring rule excluded a greater number of sites due to the data requirement filtering rules. Further, differences between trends for individual sites calculated using all data or hi-censored data were generally very small, except for some sites where anomalous high censoring values occasionally occurred.

As noted in the methodology, Sen slopes evaluated from data sets with high levels of censoring should be treated with caution. In this study, some variables had large numbers of sites with greater than 15% censoring (e.g., for the 10-year period the percentage of sites with more than 15% censoring were: NH4-N (83%); POM (74%); DRP (23%); NO3-N (23%), E. coli (8%); clarity 7%); SIN (6%)). The magnitude of the Sen slope is increasingly less precisely determined as the proportion of censored values increases and the confidence intervals for the Sen slope are more likely to be underestimated. A rule of thumb that Sen slope estimates are affected when the proportion of censored observations is greater than 15% is a reasonable guide but is not always correct. The supplementary data provides additional information concerning the influence of censored values on the estimated Sen slopes. However, where the censoring is predominantly left censoring (i.e., below detection limit), the additional uncertainty in the trend magnitude will be similar to the censor level (i.e. very small).

Note that because censored values are taken into account in the determination of the probability the trend was decreasing and the confidence in the trend direction, these statistics can be used with confidence irrespective of the proportion of censored observations.

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Appendix A List of supplementary files

DataAvailabilitySummaryPlots_Aug18_2.pdf

Heat plots showing availability of observations by site and through time

DataBoxandWhiskerSummaryPlots_Aug18_2.pdf

Box and whisker plots of all observations

WQTimeseries_SoE_Sites_Aug18_2.pdf

WQTimeseries_Impact_Sites_Aug18_2.pdf

WQTimeseries_Discharge_Sites_Aug_18_218.pdf

WQTimeseries_BeachEstuaryandLake_Sites_Aug18_2.pdf

Time series of water quality data (after 1998)

FlowvsVar_withfits_10yr.pdf

FlowvsVar_withfits_10yloglog.pdf

Plots of water quality variable by covariate, by site, with fitted models (raw of log adjusted plots)

StateandTrendOutputs_20181005.xlsx

Sheets:

- MetaData - Explanation of columns in all subsequent sheets
- One Plan – State: State variables compared against One Plan criteria
- One Plan – Discharge: Discharge sites compared against One Plan criteria
- NOF State – State variables compared against NOF criteria
- All Variables – State: Summary statistics for state of ALL variables and sites
- Flow Adjusted Trends – Results from Flow adjusted trend analysis
- Raw Trends – Results from trend analysis with raw observations

TrendPlots…. (5-28yrs).pdf

Time series of water quality data, with fitted trend (and confidence bounds). The manipulated data (i.e. summarised by season) is shown as well as the original raw data.

Appendix B Monitoring site supplementary information

Table 13: Summary of discharge sites and associated up and downstream monitoring sites

Discharge Site	Downstream Site (Impact)	Upstream Site (SoE)
AFFCO Fielding at Industrial Waste water	Oroua at d/s AFFCO Feilding	Oroua at U/S AFFCO Feilding
Bulls STP at Secondary oxpond waste	Rangitikei at us Riverlands STP	Rangitikei at u/s Bulls STP
Dannevirke STP at microfiltered oxpond	Mangatera at d/s Dannevirke STP	Mangatera at u/s T.D.C. Ox Ponds
DB Breweries at Industrial wastewater	Mangatainoka at d/s DB Breweries	Mangatainoka at Brewery - S.H.2 Bridge
Eketahuna STP at Secondary oxpond waste	Makakahi at d/s Eketahuna STP	Makakahi at u/s Eketahuna STP
Feilding STP at Secondary oxpond waste	Oroua at d/s Feilding STP	Oroua at U/S Feilding STP
Halcombe at Secondary oxpond	Rangitawa Stream at ds Halcombe oxpond	Rangitawa Stream at us Halcombe oxpond
Hunterville STP at Microfiltration Plant	Porewa at d/s Hunterville STP site A	Porewa at u/s Hunterville STP site A
Kimbolton STP at oxpond waste	Oroua tributary at d/s Kimbolton STP	Oroua Trib at U/S Kimbolton STP
Marton STP at Rock filtered oxpond waste	Tutaenui Stream at d/s Marton STP	Tutaenui Stream at u/s Marton STP[1]
Norsewood STP at oxpond waste	Mangarangiora Trib at DS Norsewood STP	Mangarangiora trib at US Norsewood STP
Ohakune STP at Secondary oxpond waste	Mangawhero at d/s Ohakune STP	Mangawhero at u/s Ohakune STP
Ormondville STP at 2nd oxpond waste	Mangarangiora at d/s Ormondville STP	Mangarangiora at u/s Ormondville STP
Pahiatua STP at Tertiary oxpond waste	Mangatainoka at d/s Pahiatua STP	Mangatainoka at u/s Pahiatua STP
PNCC STP at Tertiary Treated Effluent	Manawatu at d/s PNCC STP	Manawatu at u/s PNCC STP
Pongaroa STP at 2nd oxpond waste	Pongaroa at d/s Pongaroa STP	Pongaroa at u/s Pongaroa STP
PPCS Oringi STP at oxpond waste	Oruakeretaki at d/s PPCS Oringi STP	Oruakeretaki at u/s PPCS Oringi STP
Raetihi STP at Secondary oxpond waste	Makotuku at d/s Raetihi STP	Makotuku at Above Sewage Plant
Rangataua STP at Secondary oxpond waste	Mangaehuehu at d/s Rangataua STP	Mangaehuehu at u/s Rangataua STP
Ratana STP at Secondary oxpond waste	Unnamed Trib of Waipu at ds Ratana STP	Unnamed Trib of Waipu at us Ratana STP
Riverlands at Industrial wastewater	Rangitikei at d/s Riverlands	Rangitikei at us Riverlands STP
Sanson STP at Secondary oxpond waste	Piakatutu at d/s Sanson STP	Piakatutu at u/s Sanson STP
Shannon STP at oxpond waste	Mangaore at d/s Shannon STP	Mangaore at U/S Shannon STP
Taihape STP at oxpond waste	Hautapu at d/s Taihape STP	Hautapu at Papakai Road Bridge[2]
Taumarunui STP at Tertiary treated waste	Whanganui at d/s Taumarunui STP	Whanganui at u/s Taumarunui STP
Waiouru STP at oxpond waste	Waitangi at d/s Waiouru STP	Waitangi at u/s Waiouru STP
Winstone Pulp WWTP at oxpond waste	Whangaehu at d/s Winstone Pulp	Whangaehu at u/s Winstone Pulp
Woodville STP at Secondary oxpond waste	Mangaatua at d/s Woodville STP	Mangaatua at u/s Woodville STP

Notes: 1. Relevant upstream SoE site for QMCI is “Tutaenui Stream at Curls Bridge”.
2 . Relevant upstream SoE site for QMCI is “Hautapu at Alabasters”.

Appendix C Horizons One Plan state grading thresholds

Site.Name	Status	FMU	Criteria Variables														
			DO	POM	Chla	DRP	SIN	NH4	NH4.Max	Clar	Ecoli.Bath	Ecoli.Year	MCI	Peri.Mats	Peri.Fils	Cyano.Alert	Cyano.Action
Owahanga at Branscombe Bridge	SoE	East Coast	70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Pongaroa at u/s Pongaroa STP	SoE		70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Pongaroa at d/s Pongaroa STP	Impact		70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Arawhata Drain at Hokio Beach Road	SoE	Horowhenua	60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Hokio at Lake Horowhenua	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
KuKu at North Johnstone Road	SoE		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	NA	NA	NA	NA
L Horowhenua Inflow at culv d/s Queen St	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
L Horowhenua Inflow at Hokio Sand Rd	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
L Horowhenua Inflow at Lindsay Road	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Makahika Above Ohau Confluence	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makaretu Above Ohau Confluence	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makomako Road Drain at L Horowhenua	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Makorokio at Tirohanga Station	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Manakau at Cemetry	SoE		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	NA	NA	NA	NA
Manakau at S.H.1 Bridge	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Manganaonao at Ohau West Road	SoE		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	NA	NA	NA	NA
Ohau at Gladstone Reserve	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Ohau at Haines Property	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Ohau at State Highway Bridge	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50

Ohau at u/s Makahika Confluence	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Patiki Stream at Kawiu Road	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Queen Street Drain at L Horowhenua	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Waikawa at North Manakau Road	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Waikawa at u/s Manakau Confluence	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Waikawa Stream at Huritini	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Kahuterawa at Johnstons Rata	SoE	Manawatū	80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Kahuterawa at Keebles Farm	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Kiwitea at Kimbolton Rd	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	120	60	30	20	50
Koputaroa at Tavistock Rd	SoE		60	5	200	0.015	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Kumeti at Te Rehunga	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makakahi at end Kaiparoro Road	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Makakahi at Hamua	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Makakahi at u/s Eketahuna STP	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Makuri at Tuscan Hills	SoE		80	5	120	0.01	0.11	0.4	2.1	3	260	550	120	60	30	20	50
Manawatu at Hopelands	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Manawatu at Ngawapurua Bridge	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Manawatu at Opiki Br	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at Teachers College	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at u/s PNCC STP	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at u/s PPCS Shannon	SoE		70	5	200	0.015	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at Upper Gorge	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at us Fonterra Longburn	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at Weber Road	SoE		80	5	120	0.01	0.167	0.4	2.1	3	260	550	120	60	30	20	50
Manawatu at Whirokino	SoE		70	5	200	0.015	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangaatua at u/s Woodville STP	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangahao at Ballance	SoE		80	5	50	0.006	0.167	0.32	1.7	3	260	550	120	60	30	20	50
Mangaore at U/S Shannon STP	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangapapa at Troup Rd	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50

Mangarangiora at u/s Ormondville STP	SoE		80	5	120	0.01	0.167	0.4	2.1	3	260	550	120	60	30	20	50
Mangarangiora Trib at us Norsewood STP	SoE		80	5	120	0.01	0.167	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at Brewery - S.H.2 Bridge	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at Hukanui	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at Larsons Road	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangatainoka at Pahiatua Town Bridge	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at Putara	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangatainoka at Scarborough Konini Rd	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at u/s Pahiatua STP	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at u/s Tiraumea Confluence	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatera at Dannevirke	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangatera at u/s Manawatu confluence	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangatera at u/s T.D.C. Ox Ponds	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangatewainui at Hardys	SoE		80	5	120	0.01	0.167	0.4	2.1	3	260	550	120	60	30	20	50
Mangatoro at Mangahei Road	SoE		80	5	120	0.01	0.11	0.4	2.1	3	260	550	120	60	30	20	50
Ngatahaka Stream at u/s Makakahi Confl	SoE		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Oroua at Almadale Slackline	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at Apiti	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at Awahuri Bridge	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at Mangawhata	SoE		70	5	200	0.015	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at U/S AFFCO Feilding	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at U/S Feilding STP	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua Trib at U/S Kimbolton STP	SoE		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Oruakeretaki at S.H.2 Napier	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Pohangina at Mais Reach	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Pohangina at Piripiri	SoE		80	5	120	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Raparapawai at Jackson Rd	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Tamaki at Stephensons	SoE		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Tamaki at Tamaki Reserve	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50

Tiraumea at Ngaturi	SoE		70	5	120	0.01	0.444	0.4	2.1	2	260	550	100	60	30	20	50
Tiraumea u/s Manawatu Confluence	SoE		70	5	120	0.01	0.444	0.4	2.1	2	260	550	100	60	30	20	50
Tokomaru River at Horseshoe bend	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Turitea at No1 Dairy	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makakahi at d/s Eketahuna STP	Impact		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Manawatu at d/s PNCC STP	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Manawatu at ds Fonterra Longburn	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangaatua at d/s Woodville STP	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangaore at d/s Shannon STP	Impact		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Mangarangiora at d/s Ormondville STP	Impact		80	5	120	0.01	0.167	0.4	2.1	3	260	550	120	60	30	20	50
Mangarangiora trib at ds Norsewood STP	Impact		80	5	120	0.01	0.167	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at d/s DB Breweries	Impact		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatainoka at d/s Pahiatua STP	Impact		80	5	120	0.01	0.444	0.4	2.1	3	260	550	120	60	30	20	50
Mangatera at d/s Dannevirke STP	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at d/s AFFCO Feilding	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua at d/s Feilding STP	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Oroua tributary at d/s Kimbolton STP	Impact		70	5	120	0.01	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Oruakeretaki at d/s PPCS Oringi STP	Impact		70	5	120	0.01	0.444	0.4	2.1	2.5	260	550	100	60	30	20	50
Hautapu at Alabasters	SoE	Rangitikei	80	5	120	0.01	0.11	0.4	2.1	3	260	550	120	60	30	20	50
Hautapu at Papakai Road Bridge	SoE		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Hautapu at US Rangitikei River Conf	SoE		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Moawhango at Waiouru	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Piakatutu at u/s Sanson STP	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Porewa at Onepuhi Road	SoE		70	5	120	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Porewa at u/s Hunterville STP	SoE		70	5	120	0.01	0.11	0.4	2.1	1.6	260	550	100	60	30	20	50
Porewa at U/S Hunterville STP Site A	SoE		70	5	120	0.01	0.11	0.4	2.1	1.6	260	550	100	60	30	20	50
Rangitawa Stream at us Halcombe oxpond	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Rangitikei at Kakariki	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Rangitikei at Mangaweka	SoE		80	5	120	0.01	0.11	0.32	1.7	3.4	260	550	120	60	30	20	50

Rangitikei at McKelvies	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Rangitikei at Onepuhi	SoE		80	5	120	0.01	0.11	0.4	2.1	3	260	550	120	60	30	20	50
Rangitikei at Pukeokahu	SoE		80	5	50	0.006	0.07	0.32	1.7	3.4	260	550	120	60	30	20	50
Rangitikei at u/s Bulls STP	SoE		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Tutaenui Stream at u/s Marton STP	SoE		60	5	200	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Hautapu at d/s Taihape STP	Impact		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Piakatutu at d/s Sanson STP	Impact		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Porewa at d/s Hunterville STP	Impact		70	5	120	0.01	0.11	0.4	2.1	1.6	260	550	100	60	30	20	50
Porewa at d/s Hunterville STP site A	Impact		70	5	120	0.01	0.11	0.4	2.1	1.6	260	550	100	60	30	20	50
Rangitawa Stream at ds Halcombe oxpond	Impact		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Rangitikei at d/s Riverlands	Impact		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Rangitikei at us Riverlands STP	Impact		70	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Tutaenui Stream at d/s Marton STP	Impact		60	5	200	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Makotuku at Above Sewage Plant	SoE	Whangaehu/Turakina	80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makotuku at Raetihi	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makotuku at SH49A	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangaehuehu at u/s Rangataua STP	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangawhero at DOC Headquarters	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangawhero at Pakihi Rd Bridge	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangawhero at Raupiu Road	SoE		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Mangawhero at u/s Ohakune STP	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Tokiahuru at Junction	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Tokiahuru at Karioi Domain Road	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	NA	NA	20	50
Turakina at ONeills Bridge	SoE		70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Unnamed Trib of Waipu at us Ratana STP	SoE		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Waitangi at u/s Waiouru STP	SoE		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whangaehu at Kauangaroa	SoE		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Whangaehu at u/s Winstone Pulp	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Makotuku at d/s Raetihi STP	Impact		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50

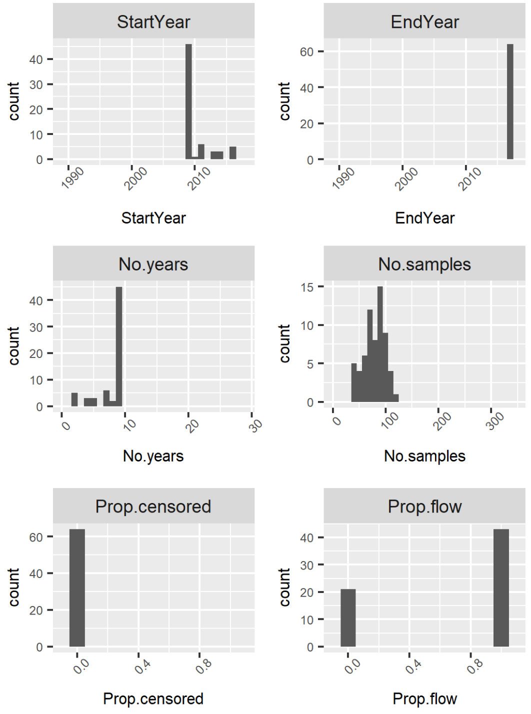
Mangaehuehu at d/s Rangataua STP	Impact		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Mangawhero at d/s Ohakune STP	Impact		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Unnamed Trib of Waipu at ds Ratana STP	Impact		60	5	200	0.015	0.167	0.4	2.1	2.5	260	550	100	60	30	20	50
Waitangi at d/s Waiouru STP	Impact		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whangaehu at d/s Winstone Pulp	Impact		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Kai Iwi at Handley Road	SoE	Whanganui	70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Manganui o te Ao at Ruatiti Domain	SoE		80	5	120	0.01	0.11	0.32	1.7	3.4	260	550	120	60	30	20	50
Mangatepopo at d/s Intake	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Ohura at Tokorima	SoE		70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Ongarue at Taringamotu	SoE		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whakapapa at Footbridge	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Whanganui at Cherry Grove	SoE		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whanganui at Downstream Intake	SoE		80	5	50	0.006	0.07	0.32	1.7	3	260	550	120	60	30	20	50
Whanganui at Paetawa	SoE		70	5	200	0.015	0.167	0.4	2.1	1.6	260	550	100	60	30	20	50
Whanganui at Pipiriki	SoE		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Whanganui at Te Maire	SoE		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whanganui at Te Rewa	SoE		70	5	120	0.01	0.11	0.4	2.1	2	260	550	100	60	30	20	50
Whanganui at u/s Taumarunui STP	SoE		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whanganui at Wades Landing	SoE		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50
Whanganui at d/s Taumarunui STP	Impact		80	5	120	0.01	0.11	0.4	2.1	2.5	260	550	100	60	30	20	50

Site Name	pH.change	Temp.change	Clar.change	QMCI.change
AFFCO Fielding at Industrial Waste water	0.5	3	30	20
Bulls STP at Secondary oxpond waste	0.5	3	30	20
Dannevirke STP at microfiltered oxpond	0.5	3	30	20
DB Breweries at Industrial wastewater	0.5	3	20	20
Eketahuna STP at Secondary oxpond waste	0.5	3	20	20
Feilding STP at Secondary oxpond waste	0.5	3	30	20
Foxton STP at Secondary oxpond waste	0.5	3	30	20
Halcombe at Secondary oxpond	0.5	3	30	20
Hunterville STP at Microfiltration Plant	0.5	3	30	20
Kimbolton STP at oxpond waste	0.5	3	30	20
Marton STP at Rock filtered oxpond waste	0.5	3	30	20
National Park STP at Secondary oxpond	0.5	2	20	20
Norsewood STP at oxpond waste	0.5	3	20	20
Ohakea STP at Effluent outfall	0.5	3	30	20
Ohakune STP at Secondary oxpond waste	0.5	2	20	20
Ormondville STP at 2nd oxpond waste	0.5	3	20	20
Pahiatua STP at Tertiary oxpond waste	0.5	3	20	20
PNCC STP at Tertiary Treated Effluent	0.5	3	30	20
Pongaroa STP at 2nd oxpond waste	0.5	3	30	20
PPCS Oringi STP at oxpond waste	0.5	3	30	20
Raetihi STP at Secondary oxpond waste	0.5	2	20	20
Rangataua STP at Secondary oxpond waste	0.5	2	20	20
Ratana STP at Secondary oxpond waste	0.5	3	30	20
Riverlands at Industrial wastewater	0.5	3	30	20
Rongotea STP at Secondary oxpond waste	0.5	3	30	20
Sanson STP at Secondary oxpond waste	0.5	3	30	20
Shannon STP at oxpond waste	0.5	3	30	20
Taihape STP at oxpond waste	0.5	3	30	20
Taumarunui STP at Tertiary treated waste	0.5	2	30	20
Tokomaru at oxpond waste	0.5	3	30	20
Waiouru STP at oxpond waste	0.5	2	30	20
Winstone Pulp WWTP at oxpond waste	0.5	2	20	20
Woodville STP at Secondary oxpond waste	0.5	3	30	20

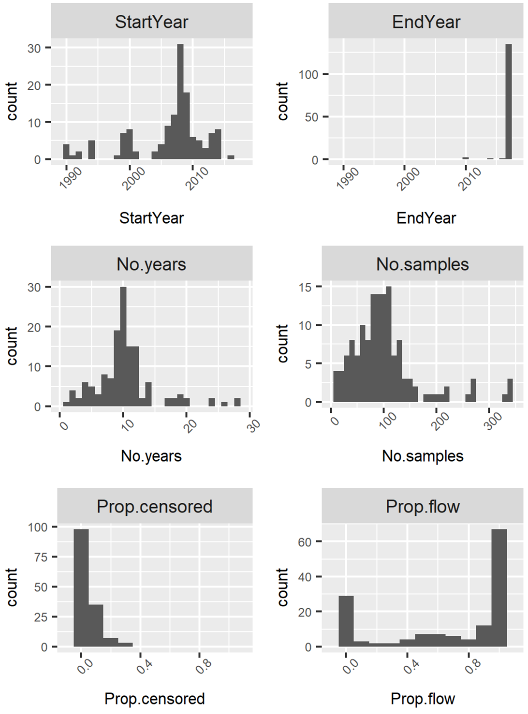
Appendix D Data availability summaries, by variable

The histograms describe, for each variable, the number of measurements of each variable (No.Samples), the proportion of censored values (Prop.censored), the proportion of samples with associated measurement of flow (Prop.flow), the duration of the sampling period (No.years), the start and end year of the samples (StartYear, EndYear).

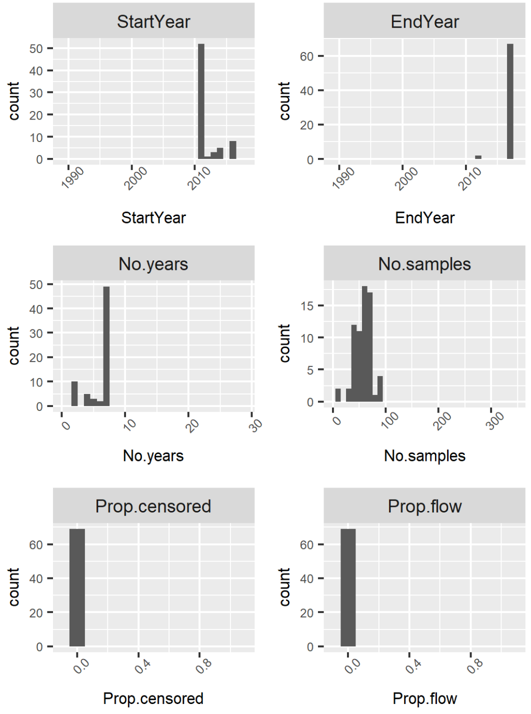
Chlorophyll A (cover)



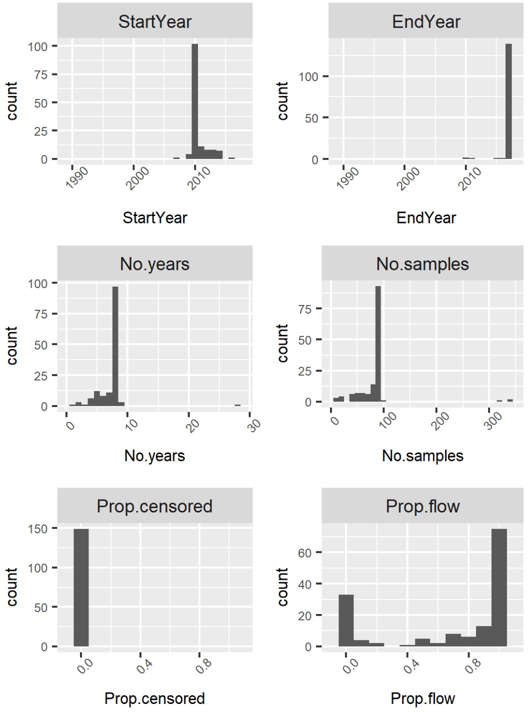
Black Disc

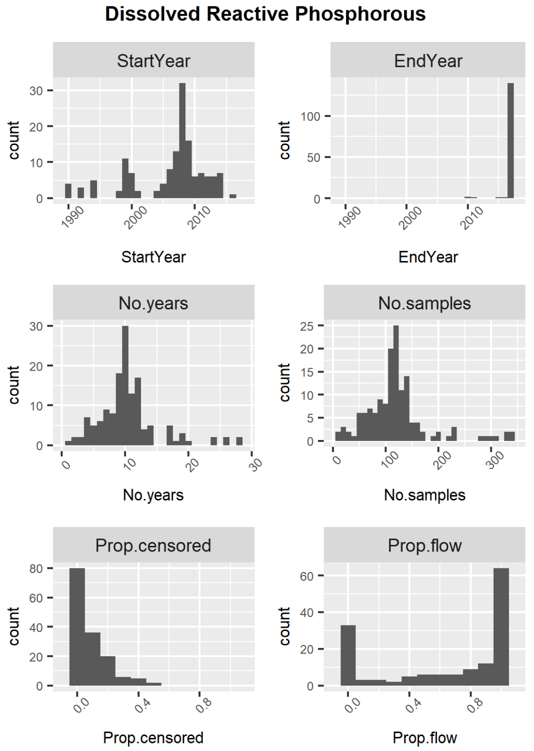


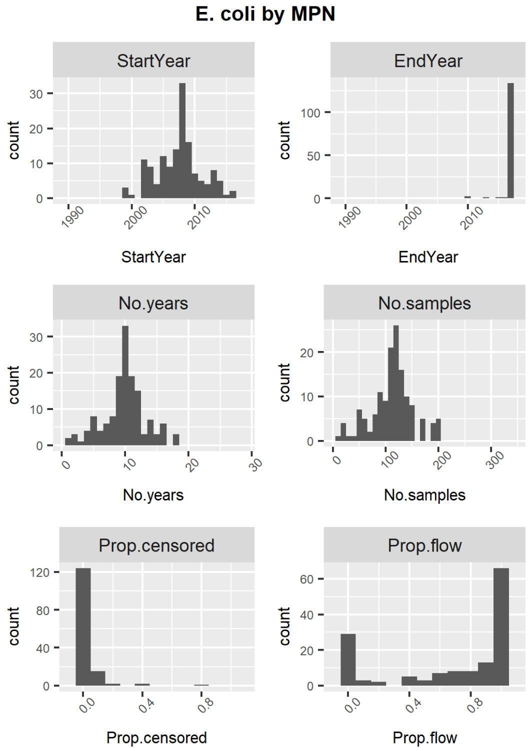
Cyanobacteria cover

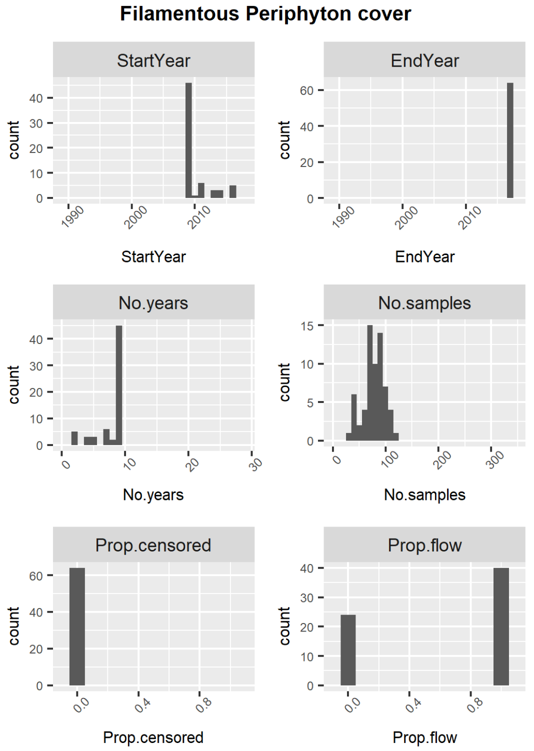


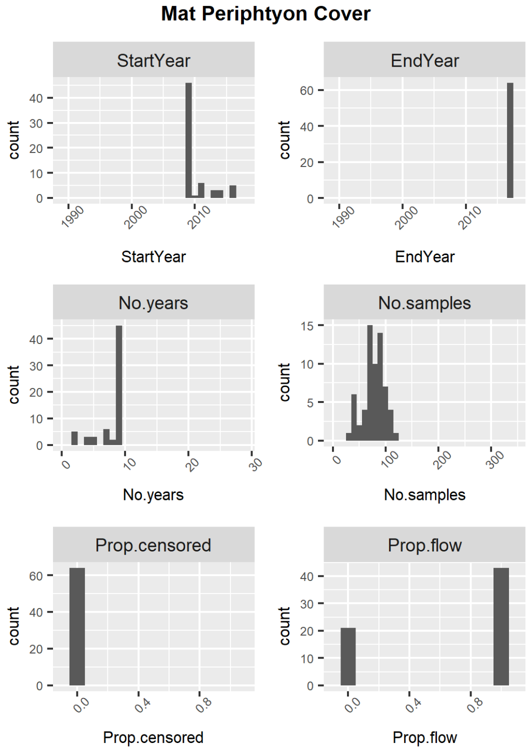
Field DO Saturation

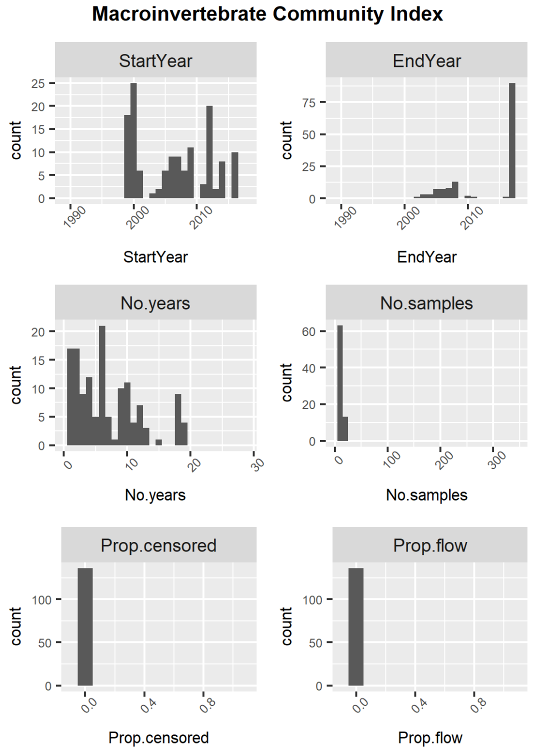


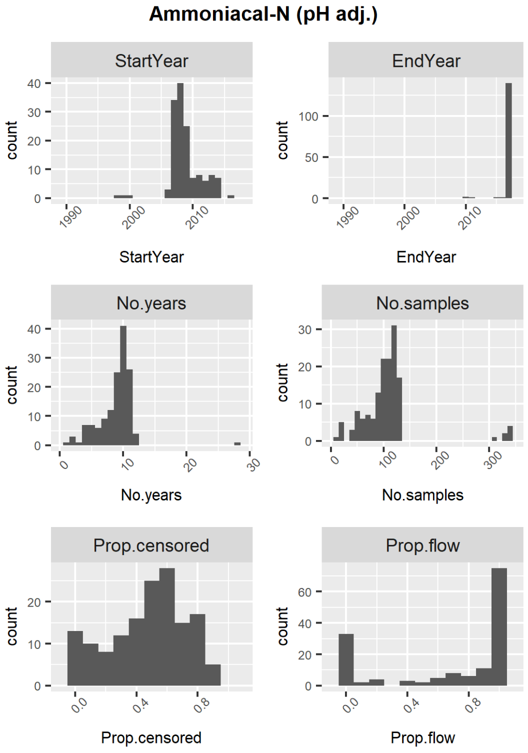

Dissolved Reactive Phosphorous
StartYear
EndYear
No.years
No.samples
Prop.censored
Prop.flow
count
1990
2000
2010
0
10
20
30
100
200
300
0.0
0.4
0.8

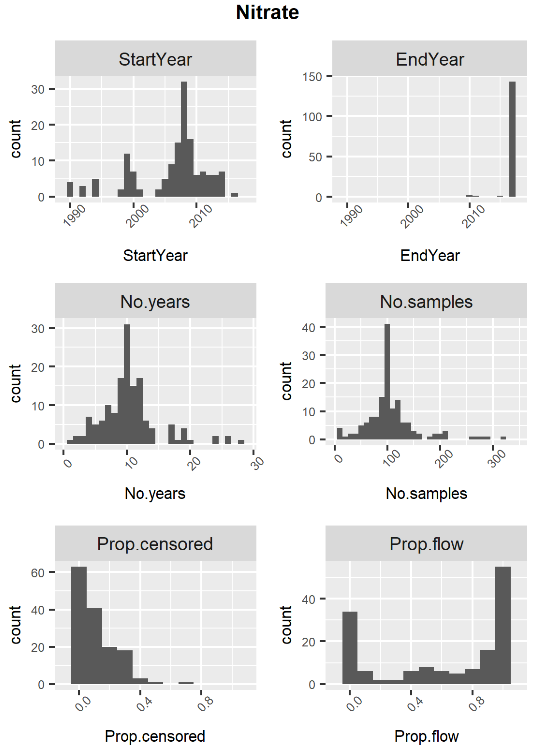

E. coli by MPN
StartYear
EndYear
No.years
No.samples
Prop.censored
Prop.flow
count
1990
2000
2010
0
10
20
30
100
200
300
0.0
0.4
0.8

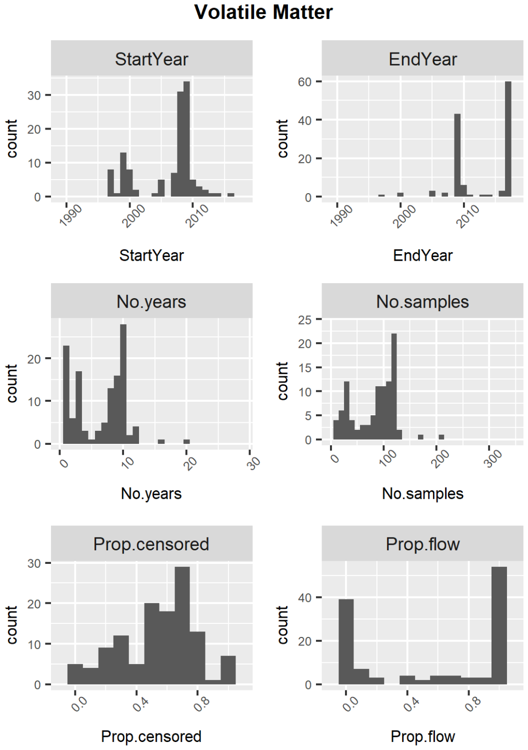

Filamentous Periphyton cover
StartYear
EndYear
No.years
No.samples
Prop.censored
Prop.flow
count
1990
2000
2010
0
10
20
30
100
200
300
0.0
0.4
0.8


Mat Periphtyon Cover
StartYear
EndYear
No.years
No.samples
Prop.censored
Prop.flow
count
1990
2000
2010
0
10
20
30
100
200
300
0.0
0.4
0.8

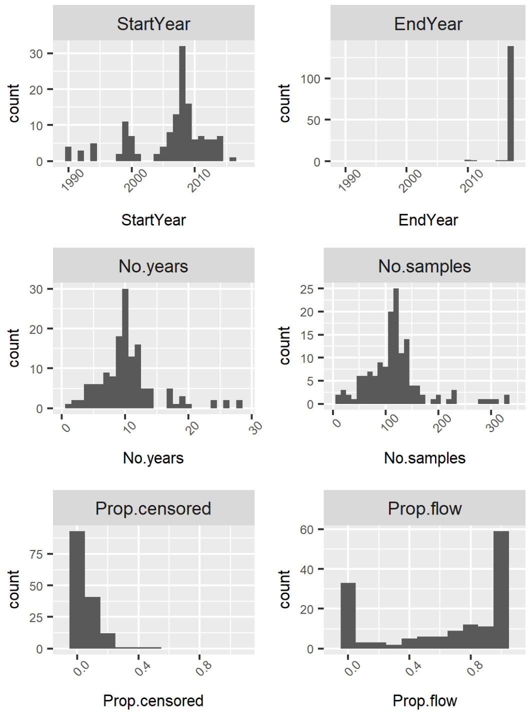

Macroinvertebrate Community Index
StartYear
count
0
5
10
15
20
25
1990
2000
2010
StartYear
EndYear
count
0
25
50
75
1990
2000
2010
EndYear
No.years
count
0
5
10
15
20
0
10
20
30
No.years
No.samples
count
0
20
40
60
0
100
200
300
No.samples
Prop.censored
count
0
50
100
0.0
0.4
0.8
Prop.censored
Prop.flow
count
0
50
100
0.0
0.4
0.8
Prop.flow


Ammoniacal-N (pH adj.)
StartYear
count
0
10
20
30
40
1990
2000
2010
StartYear
EndYear
count
0
50
100
1990
2000
2010
EndYear
No.years
count
0
10
20
30
40
0
10
20
30
No.years
No.samples
count
0
10
20
30
0
100
200
300
No.samples
Prop.censored
count
0
10
20
0.0
0.4
0.8
Prop.censored
Prop.flow
count
0
20
40
60
0.0
0.4
0.8
Prop.flow


Nitrate
StartYear
count
0
10
20
30
1990
2000
2010
StartYear
EndYear
count
0
50
100
150
1990
2000
2010
EndYear
No.years
count
0
10
20
30
0
10
20
30
No.years
No.samples
count
0
10
20
30
40
0
100
200
300
No.samples
Prop.censored
count
0
20
40
60
0.0
0.4
0.8
Prop.censored
Prop.flow
count
0
20
40
0.0
0.4
0.8
Prop.flow


Volatile Matter
StartYear
count
0
10
20
30
1990
2000
2010
StartYear
EndYear
count
0
20
40
60
1990
2000
2010
EndYear
No.years
count
0
10
20
0
10
20
30
No.years
No.samples
count
0
5
10
15
20
25
0
100
200
300
No.samples
Prop.censored
count
0
10
20
30
0.0
0.4
0.8
Prop.censored
Prop.flow
count
0
20
40
0.0
0.4
0.8
Prop.flow

Soluble Inorganic Nitrogen



Appendix E Comparison of raw and flow adjusted trends

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). Different mechanisms may dominate at different sites so that the same water quality variable (e.g., *E. coli*) can exhibit positive or negative relationships with flow (Snelder *et al.*, 2017).

Removing the effect of flow (or any covariate) decreases variation and increases statistical power (i.e., increases the likelihood of detecting a trend with certainty; Helsel and Hirsch, 1992). In addition, a trend in the water quality variable may arise because there is a relationship between time and flow on sample occasion (i.e., increasing or decreasing flow on sample occasion with time). Removing the effect of flow may change the direction and/or magnitude of the trend and may make an undefined (i.e., insignificant) trend direction defined with some degree of confidence.

Flow adjustment uses regression analysis to fit a line or curve to data to represent the relationship between the water quality variable and flow. The differences between the individual water quality measurements and the line or curve are the regression residuals, which represent the variation in the water quality variable that is not explained by, or independent of, flow. Flow adjusted values are derived as outlined by Smith *et al.* (1996):

Flow adjusted value = regression model residuals + median value

Various types of regression models are used to fit a line or curve to the water quality variable and flow data. Traditionally log-log relationships have been used but more flexible relationships have been used since the introduction of locally weighted least squares regression (Schertz *et al.*, 1991). For example, Larned *et al*. (2015) used a generalised additive model (GAM) and Ballantine *et al.* (2010) used locally weighted least squares regression (LOESS).

The problem with flow adjustment is that the adjusted values are sensitive to the underlying model of the water quality variable versus flow relationship. Because the model determines the regression residuals, large differences in trends can arise between raw and adjusted values and between values adjusted using different models. This problem is likely to be encountered when the data are obtained from monthly state of environment monitoring because they tend to be dominated by samples taken at low to median flows, and high flows are poorly represented. This can result in fitted lines or curves that are a poor fit to some of the data. It is therefore difficult to know whether confidence should be placed in trends based on the raw or flow adjusted data or which model is the most reliable basis for flow adjusting.

Advice on assessing the robustness of flow adjustment generally starts by considering if the shape of the fitted relationship is consistent with expectations. For example, typical relationships are monotonic, i.e., increase or decrease as flow increases (Smith *et al.*, 1996). Relationships may be well described by log-log models, but relationships can be curvilinear in log-log space and the rate of change in concentration with flow can plateau or decrease at high flow (Snelder *et al.*, 2017). For this reason, flexible regression methods such as LOESS are promoted, particularly when large numbers of analyses are being carried out by automated methods (Helsel and Hirsch, 1992; Schertz *et al.*, 1991).

Schertz *et al.* (1991) advise inspection of the residual plots of regression models to check for normality and homoscedasticity (constant variance). However, it is not clear how to determine the extent to which deviations from these regression assumptions can be tolerated. Schertz *et al.* (1991) further advise that flow adjustment only be carried out if the model is significant. However, they acknowledge that removal of small amounts of flow related variability in the water quality variable can improve the detection of significant trends (i.e., establishing trend direction with defined degree of certainty) and suggest relaxing alpha values to 0.10 or greater.

A more fundamental issue with use of water quality variable - flow models for flow adjustment is the assumption that the relationship applies over the full flow range and for the full period of record. Both assumptions are probably violated for at least some sites and variables. For example, for sediment the relationship varies with flow because the processes that determine sediment concentrations at high flow (i.e., wash-off, bank and bed erosion) are different from those that apply at low flows (i.e., resuspension of bed sediment). The relationship may change with time because sources in the catchment changes (erosion sources healing or being created).

There is therefore considerable subjectivity associated with flow adjusting water quality data that is probably inescapable. In addition, automation of flow adjustment in large analyses by selecting a single method may result in unrealistic flow adjustment for some sites and variables.

E1 10-year dataset

In order to explore some of these issues, we undertook a comparison of raw and flow adjusted trends for all variables at river sites for the ten-year period ending 30 June 2017. We provide below the results of this comparison and some discussion about the process and outcomes of the flow adjustment.

Of the 132 river sites included in the 10-year time period dataset, 70 had flow data for at least 80% of sample occasions. Regression models based on $\log_{10}$ of the variable versus $\log_{10}$ flow and a LOESS (span 0.9) were reasonably consistent with each other for some sites but exhibited considerable departures from each other at other sites[6]. Some representative examples of flow-concentration (Q-C) relationships encountered in this dataset are provided below (Figure 39, Figure 40, Figure 41, Figure 42). Based on examination of all individual plots of flow and concentration, an appropriate model (or no model) was selected. The percentage of sites that had appropriate Q-C relationships varied from 3-93% (TDP – TurbEPA). In total, we selected log-log covariate adjustment for 32% of site/variable combinations and LOESS 0.9 covariate adjustment for 10%, and for the remainder of sites no adjustment was made. Most of the LOESS 0.9 models were for the nitrogen species (e.g. Figure 40), for which the Q-C relationships tended to flatten off at higher flows, which could not be well represented by a log-log relationship.

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[6] Plots for the complete set of sites are provided in supplementary file 10-year C-Q plots.pdf

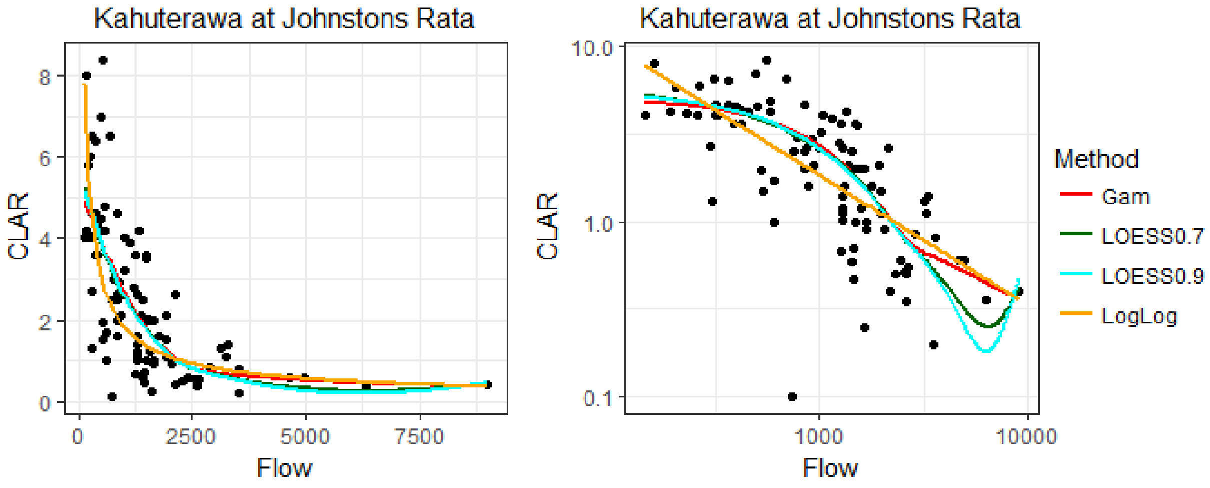

Figure 39 Fitted flow-concentration relationships.Example with a well-deinfed relationship (log-log)

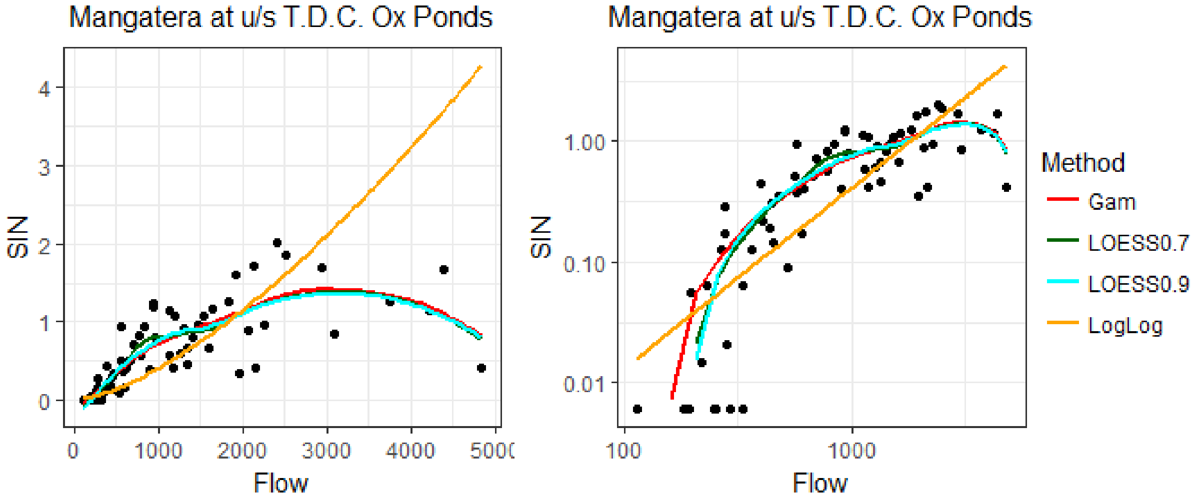

Figure 40 Fitted flow-concentration relationships. Example where a LOESS model was better able to represent non-linearity of the Q-C relationship at high flows.

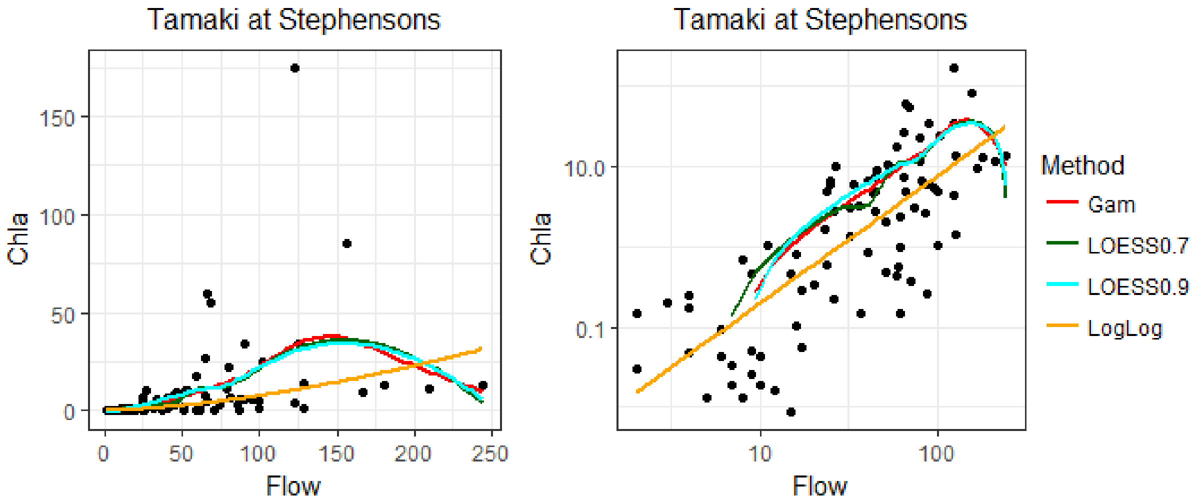

Figure 41 Fitted flow-concentration relationships. Example where a LOESS model had a better R^2 than the log-log relationships but yeidled an unrealistic relationship.

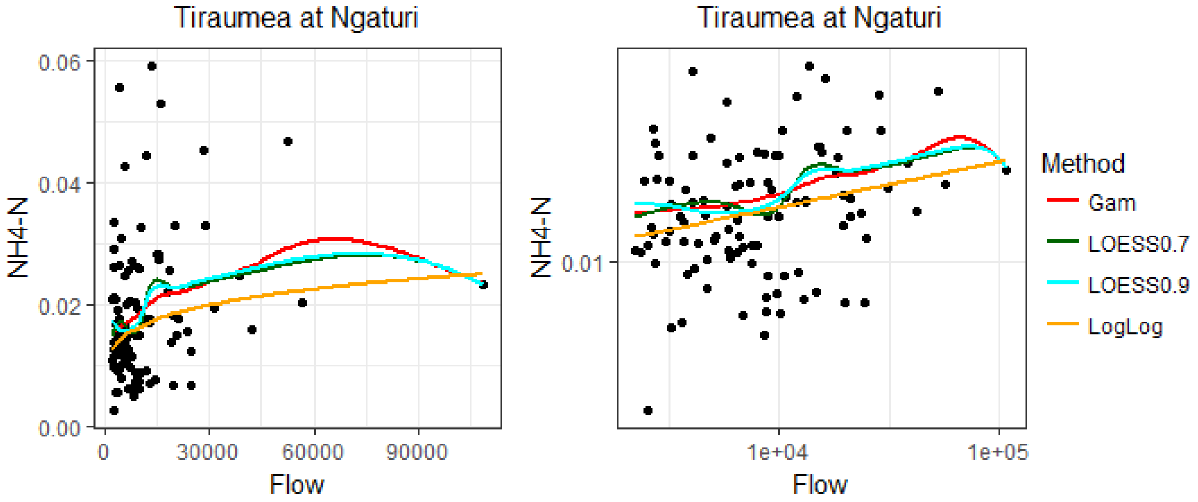

Figure 42 Fitted flow-concentration relationships. Example where no model was selected.

We then followed the trend assessment procedure outlined in sections 3.3 - 3.5 for both the raw and flow adjusted data. We compared the following site and aggregate trend results between the two methods:

- Sen slopes: Figure 43
- Probabilities (that Sen slope <0): Figure 44
- IPCC categories: Figure 45
- Aggregate Probabilities of improvement (stacked bar charts): Figure 46
- Probabilistic proportion improving: Figure 47

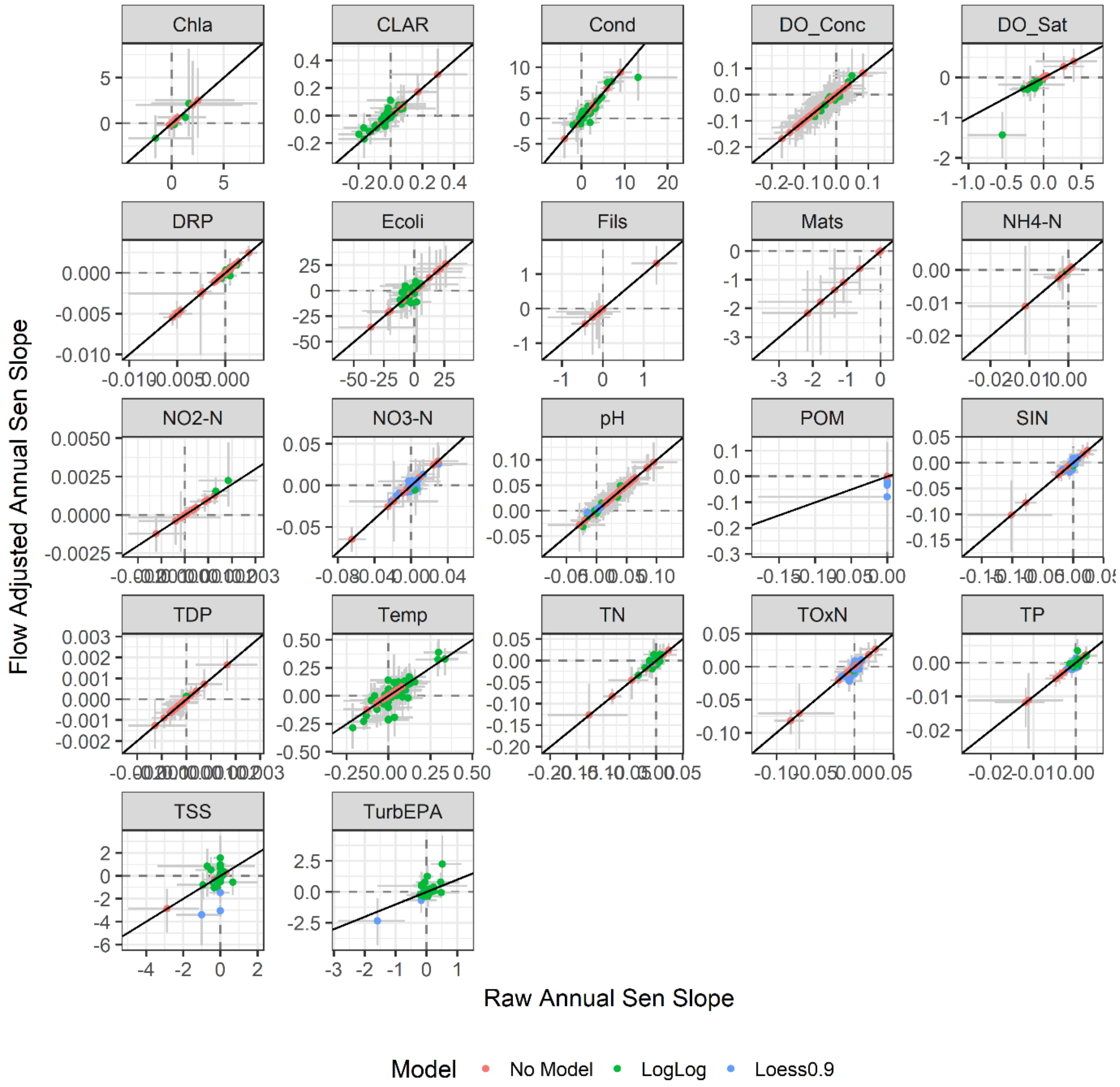

Figure 43: Comparison of raw and flow adjusted annual Sen slope.

There is generally a reasonable agreement between the raw and flow adjusted Sen slopes. Turbidity, clarity, TSS and temperature have the greatest level of disagreement, but also often also had the Q-C relationships with the highest R^2 values (although these values are not shown in this appendix).

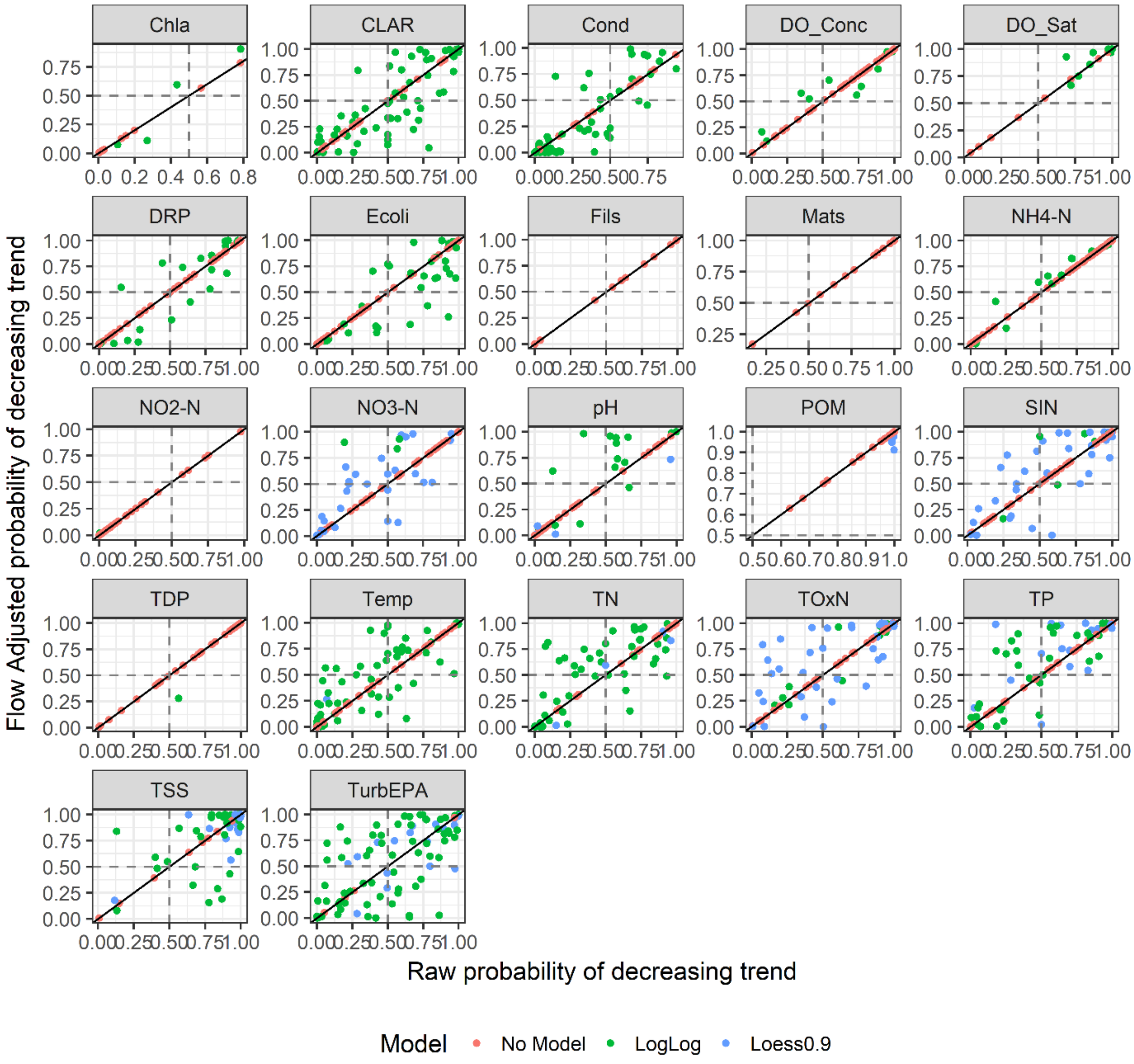

Figure 44: Comparison of Raw and Flow adjusted Probability of Sen slope <0.

There is more variability in the evaluated probabilities[7] compared to the Sen slopes. There does not appear to be any major systematic differences (i.e., bias to one side or other of the 1:1 line). We also note that although many of these probabilities indicate differences in trend direction, that at the 95% confidence level, there was only one disagreement in trend category (where an increasing trend became a trend with "insufficient data"). These same distributions are also demonstrated in different way in Figure 45, where the probabilities are expressed as IPCC trend categories. The dominant pattern in these plots is the 1:1 line.

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[7] The probabilities here are the probability that the Sen slope <0

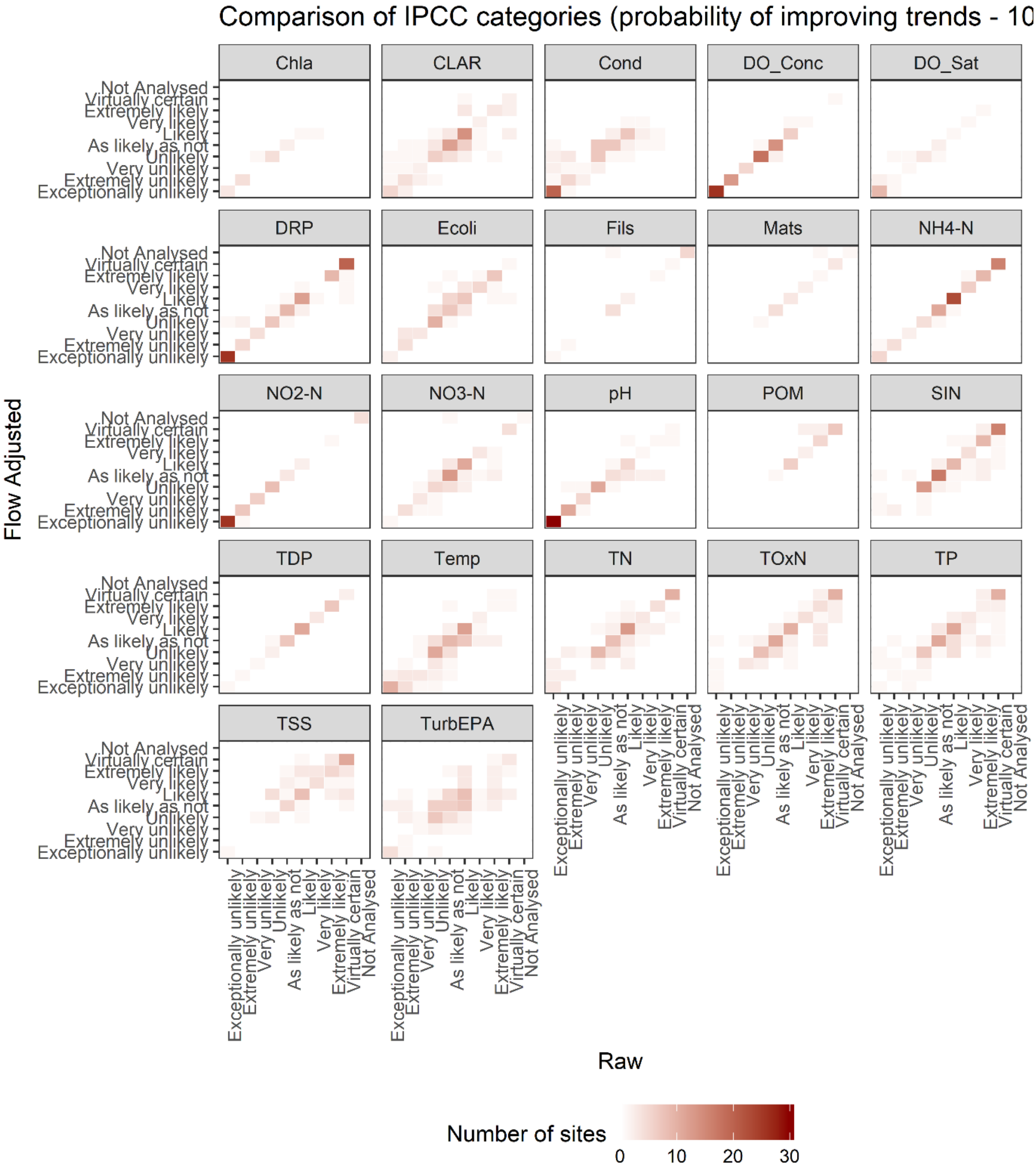

Figure 45: Heat diagram showing comparison of IPCC categories between raw and flow adjusted trends. The colour represents the count of sites with the combination of categories for raw and flow adjusted trends. Perfect agreement would be indicated by a diagonal line from bottom left to top right.

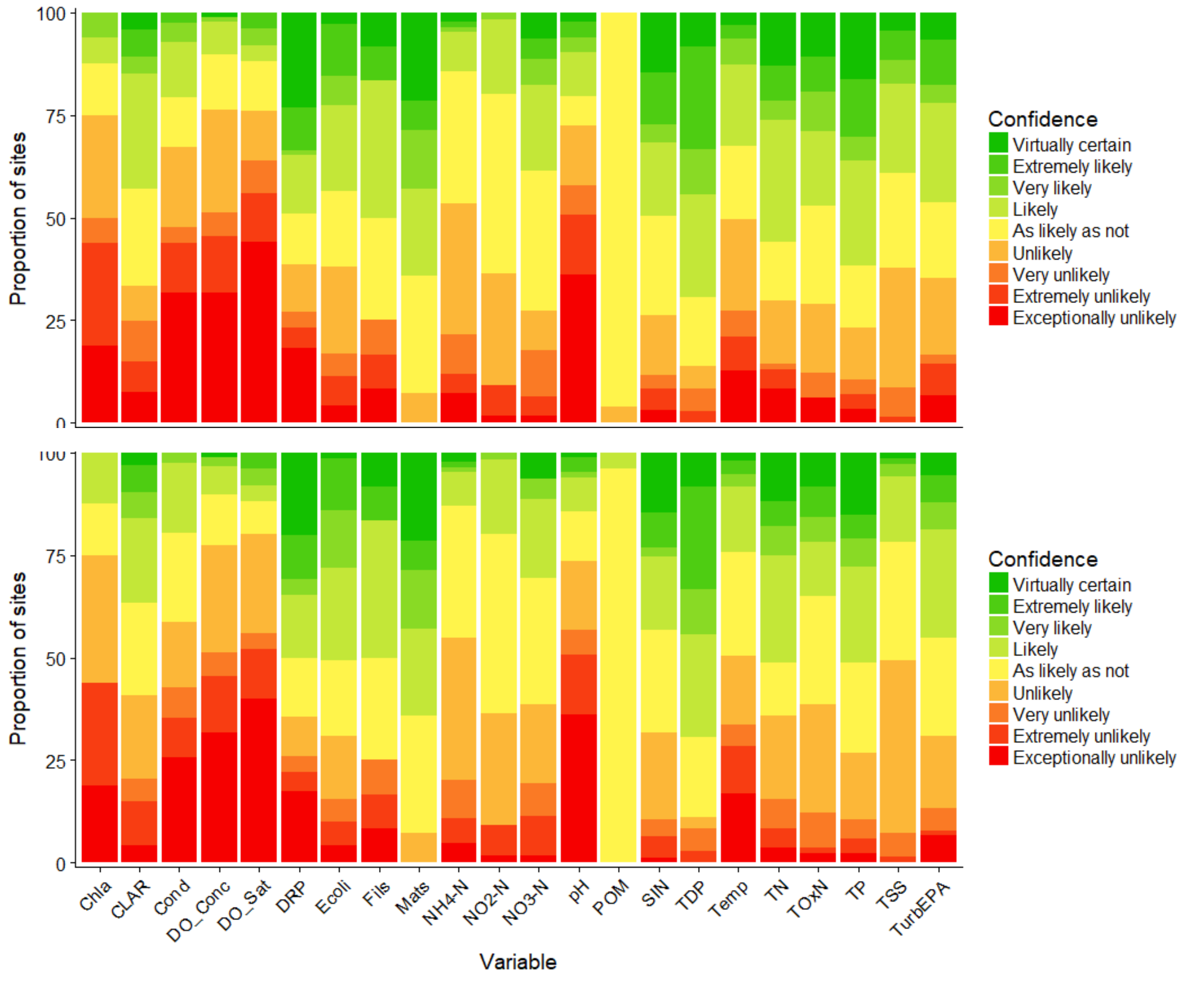

Figure 46: Comparison of summary plots representing the proportion of SoE sites with improving 10-year time period trends at each categorical level of confidence for (top) raw and (bottom) flow adjusted trends.

At first glance the overall conclusions about comparative distribution of trend confidence levels across variables for the raw and flow and adjusted trends would likely be the same (Figure 46). On closer inspection, we can see some deviations between the upper and lower plot for some variables that we had previously found to have poorer matches between the raw and flow adjusted probabilities (e.g. TSS, TO_x-N, NO_3-N, TSS). We calculated the aggregate proportions of improving sites (PIT statistic, section 3.5.3), for both the raw and flow adjusted trends, there are shown in Figure 47. We found that the PIT statistics based on the raw and flow adjusted data were consistent with each other when the uncertainties were taken into account (Figure 47) i.e., the PIT statistic uncertainty bounds in most cases crossed the 1:1 line.

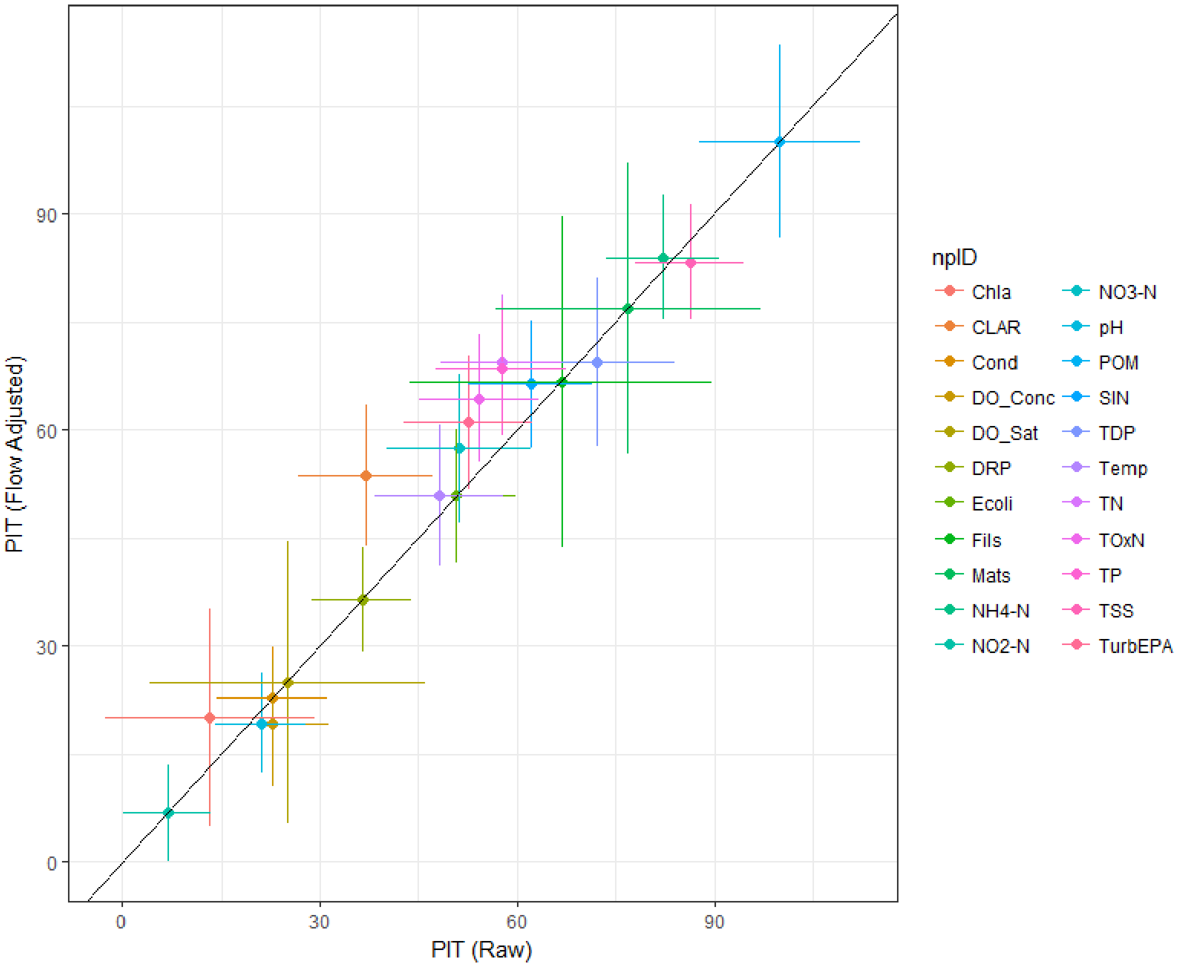

Figure 47: Comparison of the proportion of improving trends (PIT) Error bars show 90% confidence intervals.

E2 Conclusions and recommendations

Based on the examination of a subset of sites with adequate flow data, it is concluded that this study's findings would not be significantly different if flow adjusted trends had been used. However, we do note that on a site basis, that there can be reasonably large departures between the raw and flow adjusted results, so caution should be used when exercised when using site specific results.

The case study above indicates that decisions concerning the appropriateness of water quality variable - flow models that underlie flow adjustment are subjective and site specific. Because water quality variable versus flow relationships vary across sites and variables, automation of flow adjustment in large analyses can result selection of unreliable models. Water quality variable - flow models that are fitted using flexible regression methods, such as LOESS, are more likely to achieve significance and satisfy the assumptions that the residuals are normally distributed and homoscedastic. However, the degree of flexibility (e.g., as defined by the smoothing parameter in a LOESS model) is subjective. Increasing the flexibility, and therefore improving the fit, should not result in obtaining a model whose shape is inconsistent with the mechanisms underlying the relationship. Choosing the most appropriate flow adjustment therefore requires expert judgement and is subjective.

Appendix F Exploration of influence of changing censor limits

The default procedure in the LWP-Trends software is to perform trend analysis using all the data, regardless of whether there is a change in the censoring limit through the time period. While this increases the total available non-censored data, there is the risk that changes in censoring limits through time may induce a trend. An alternative approach is to artificially censor all values that are below the highest censoring limit. This has the advantage that the changes in the censor limit through the time period will no longer induce trends, but with the disadvantage the Sen slope is evaluated from fewer datapoints and uncertainty will be increased (i.e., the confidence interval will be wider)

Figure 48 shows time series of the censored observations. While some of the differences are differences between sites (or random values associated with individual sampling occasions), in many cases there are step changes associated with changes in laboratory procedures (e.g. ammoniacal-N (raw) ~2005).

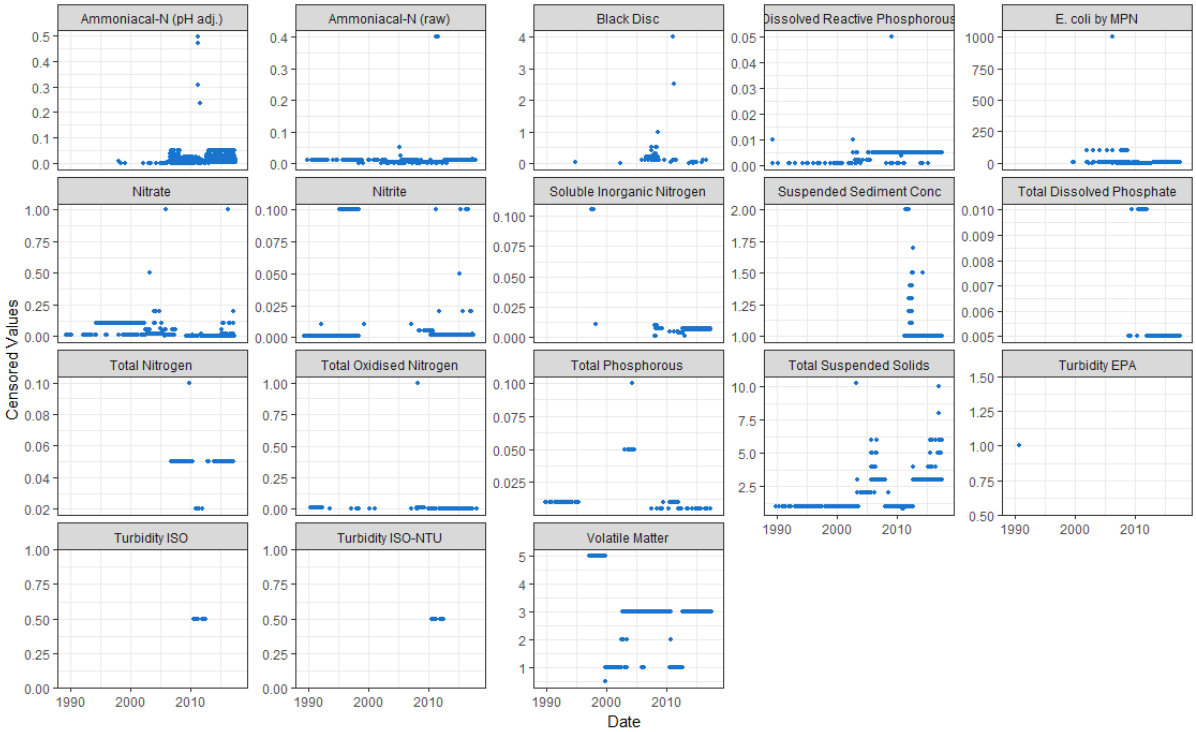

Figure 48: Time series of censored observations (detection limit) for all sites, by variable

To explore the possible effects of changing censoring limits we have performed trend analysis using all data and then using data with values below the maximum censoring limit set as censored (in both cases there are no flow adjustments). In total, the comparison included 1008 trend estimates (for SoE, impact and discharge sites) for the two time periods, over 12 variables (Table 14).

Table 14: Numbers of sites by time period and water quality variable used in the comparison of censoring limit analysis

Time Period	Chla	CLAR	DO_Sat	DRP	Ecoli	Fils	Mats	MCI	NH4-N	NO3-N	POM	SIN
10	37	89	9	125	125	36	36	45	102	117	68	125
20	0	18	7	20	3	0	0	13	7	11	1	19

F1 Trends classifications

Across all 1013 site trends, we compared the trend classifications (i.e. directions at the 95% confidence interval); these are shown in Table 15.

Table 15: Comparison of trend classifications using raw data or hi-censored data.

		Hi-censored Data			
		Degrading	**Improving**	**Insufficient Data**	**Not Analysed**
All Data	**Degrading**	154	0	1	2
	Improving	0	218	13	11
	Insufficient Data	3	4	541	41
	Not Analysed	0	0	0	25

There were no cases where the trend classifications indicated direction was different between the two analyses. However, when trend analyses were performed on the hi-censored data, the total number of trends with directions detected with confidence decreased from 399 sites (39%) to 379 sites (37%). Of the 1013 site-variable combinations where both methods were analysed, 938 (93%) had classifications in agreement. There was an increase in the number of sites that were not analysed (25 using all data, compared to 79 with hi-censored data). In four cases, the introduction of the hi-censoring, produced improving trend classifications (POM at Makotuku at d/s Raetihi STP, *E. coli* and NH_4N at Mangaehuehu at d/s Rangataua STP and NH_4N at Pongaroa at d/s Pongaroa STP, for a 10 year period) and in three case, degrading trend classifications (NO_3N at Ohura at Tokorima for a 10 year period and NO_3N at Whanganui at Te Maire for both 10 and 20 year periods) where the raw results had indicated that there was insufficient data to detect a trend at the 95% confidence interval.

A more stringent comparison is to look at the direction of the trend (i.e. considering just the sign of the Sen slope, regardless of confidence in the predicted trend, Table 16). There were 2 site-variable-period combinations that changed from an increasing direction for a decreasing direction following hi-censoring (NO_3N at Pohangina at Mais Reach and *E. coli* at Whanganui at Pipiriki, for 10 year periods). There was 1 site-variable-period combination that changed from an increasing direction to a decreasing direction following hi-censoring (NO_3N at Mangatainoka at Putara for a 10 year period). These were predominantly nitrogen species trends (SIN, NH_4-N and NO_3-N).

Table 16: Comparison of trend directions using raw data or hi-censored data.

		Hi-censored Data			
		Increasing	**Decreasing**	**S=Zero**	**Not Analysed**
All Data	**Increasing**	374	1	0	7
	Decreasing	2	547	1	47
	S=Zero	0	0	9	0
	Not Analysed	0	0	0	25

F2 Aggregate trends

Figure 49 and Figure 50 show the proportion of all sites by variable, for which 10 and 20-year water quality trends (respectively) indicated improvement at the nine categorical levels of confidence defined in Table 6, for analyses using all data and using hi-censored data. Figure 51 shows a comparison of the PIT statistics derived using all data and those from hi-censored data.

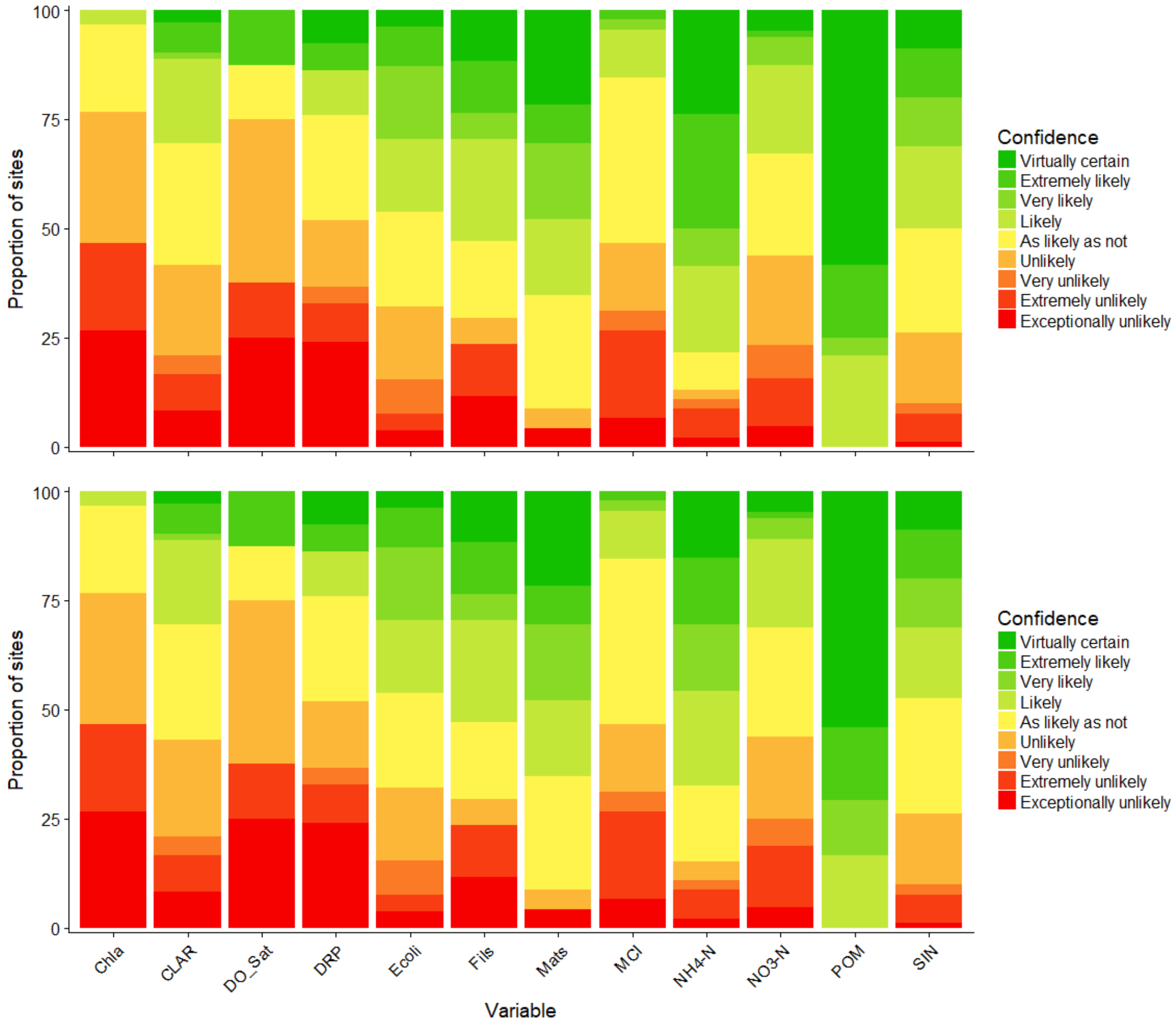

Figure 49: Comparison of summary plots representing the proportion of SoE sites with improving 10-year time period trends at each categorical level of confidence for (top) all data and (bottom) hi-censored data 10-year trends.

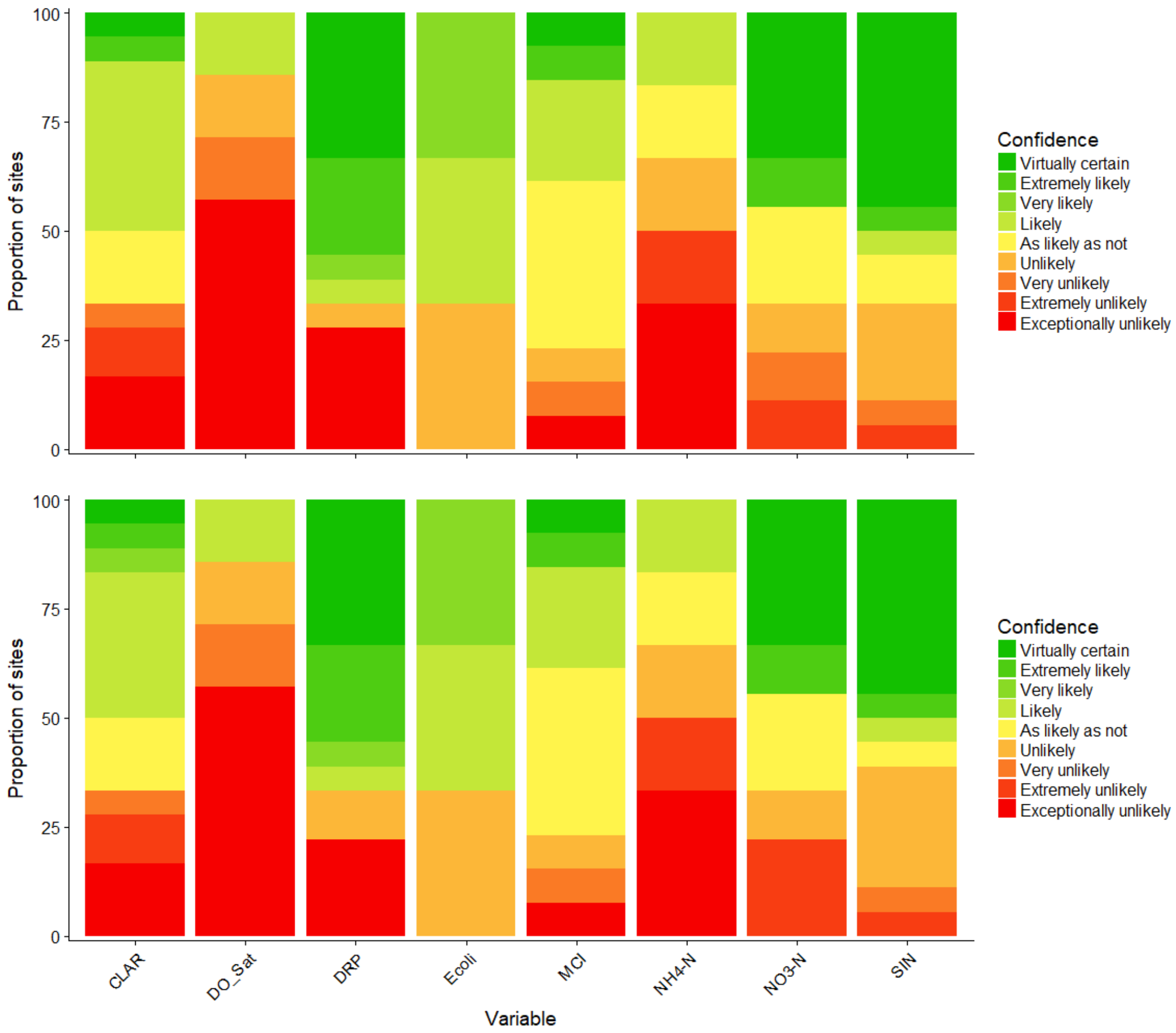

Figure 50: Comparison of summary plots representing the proportion of SoE sites with improving 20-year time period trends at each categorical level of confidence for (top) raw and (bottom) hi-censored 20-year trends..

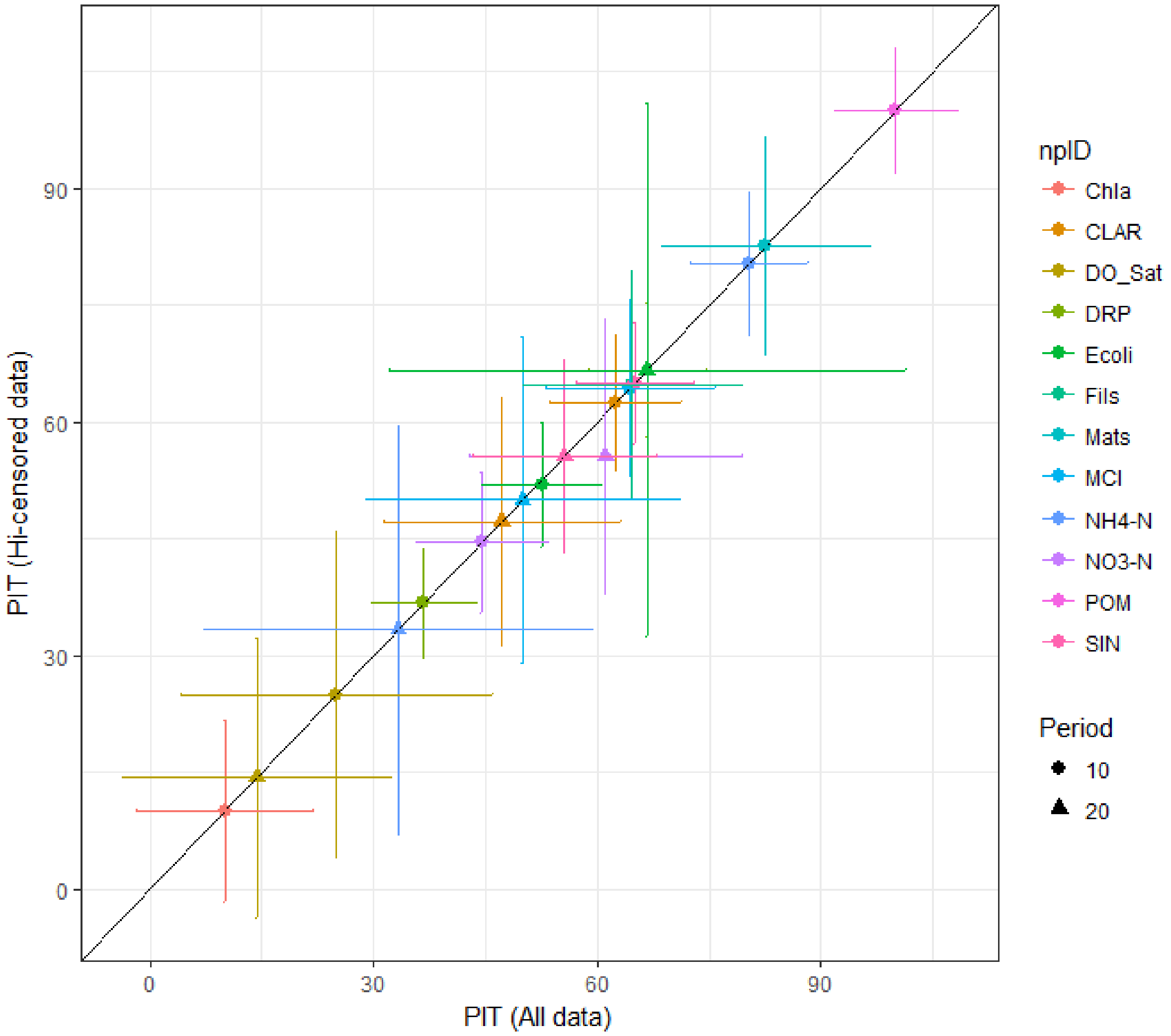

Figure 51: Comparison of the proportion of improving trends (PIT) based on raw and hi-censored data for both 10 and 20-year time periods Error bars show 90% confidence intervals.

The calculated proportion of improving trends (PIT) was exactly the same for 18 of the 20 variable:time period combinations. There was a difference (hi-censored data minus Raw data) of 1 % for for E. coli for the 10 year trend, and 10% for NO_3N for the 20 year trends.

The standard deviation of the PIT statistics was the same for 12 of the 20 variable:time period combinations. Four of the PIT standard deviations were larger for the hi-censored data compared to the raw data (NH_4-N, 10-years: 0.7%, NH_4-N, 20-years: 0.1%,, DRP, 20-years: 0.4%; NO_3-N, 10-years: 0.1%;); this is expected due to reductions in confidence for the individual trends. Four of the PIT standard deviations were smaller for the hi-censored data compared to the raw data (clarity, 10-years: -0.1%, POM, 10-years: -0.1%, *E. coli*, 20-years: -0.2%; NO_3-N, 20-years: -0.3%;);

F3 Trend magnitude and probabilities

We selected four variables, which are typically highly censored, and which had some changes in censor limits, to demonstrate the difference between trend results for hi-censoring compared to using all data: NH_4-N (raw), NO_2-N, DRP and NO_3-N (note, there were no 20-year trends for NO_2-N). We compare the Sen slopes (and uncertainties) and probabilities that the Sen slopes were greater than zero (with uncertainties) between the two methods. These comparisons are demonstrated in Figure 52, Figure 53, Figure 54 and Figure 55. Overall the agreement between the two different evaluations was high and always within the uncertainty of the evaluated Sen slopes or probabilities. Imposing the hi-censor leads to increased number of sen slopes tat are evaluated to be zero, for both NH_4-N and NO_2-N.

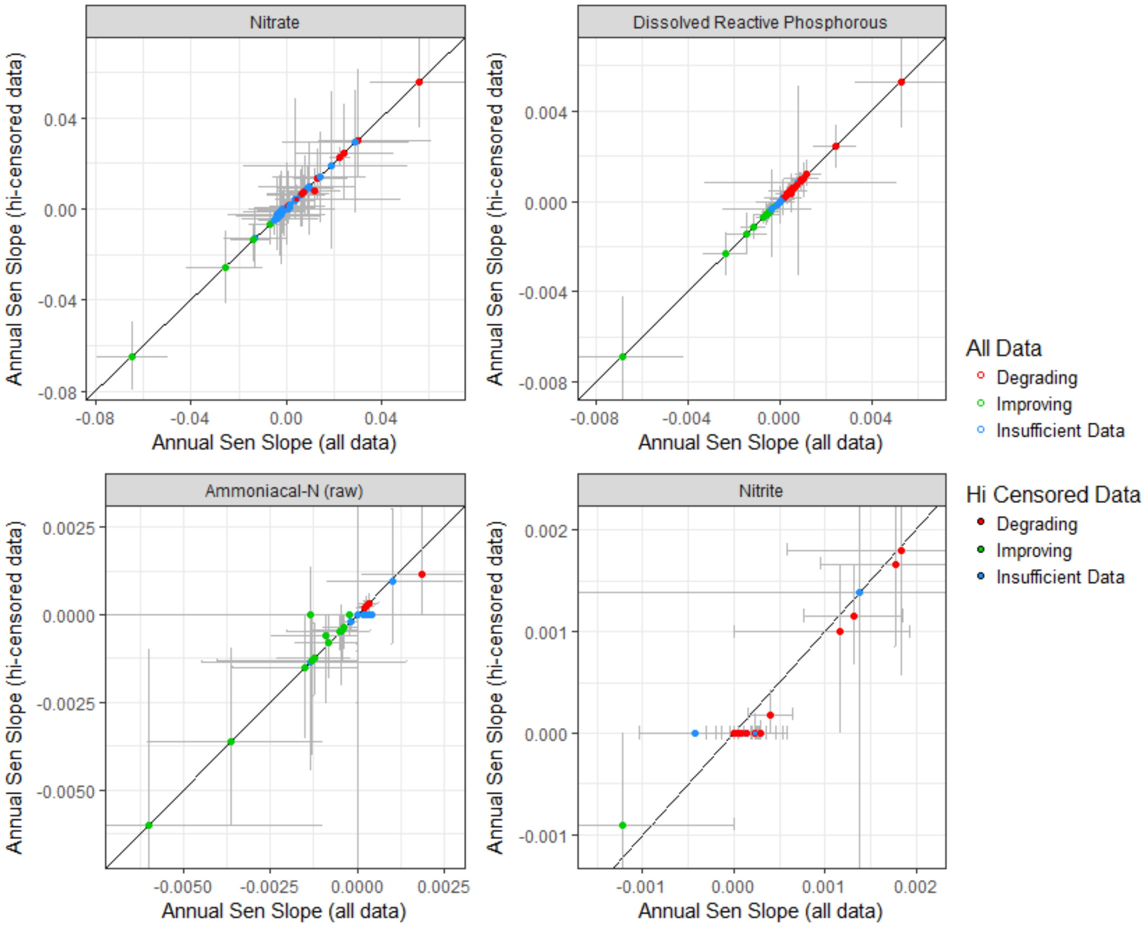

Figure 52: Comparison of annual Sen slope for 10-year trends when calculated with all data, or with a high censor limit (hi-censored). Grey bars indicate Sen slope 90% confidence intervals.

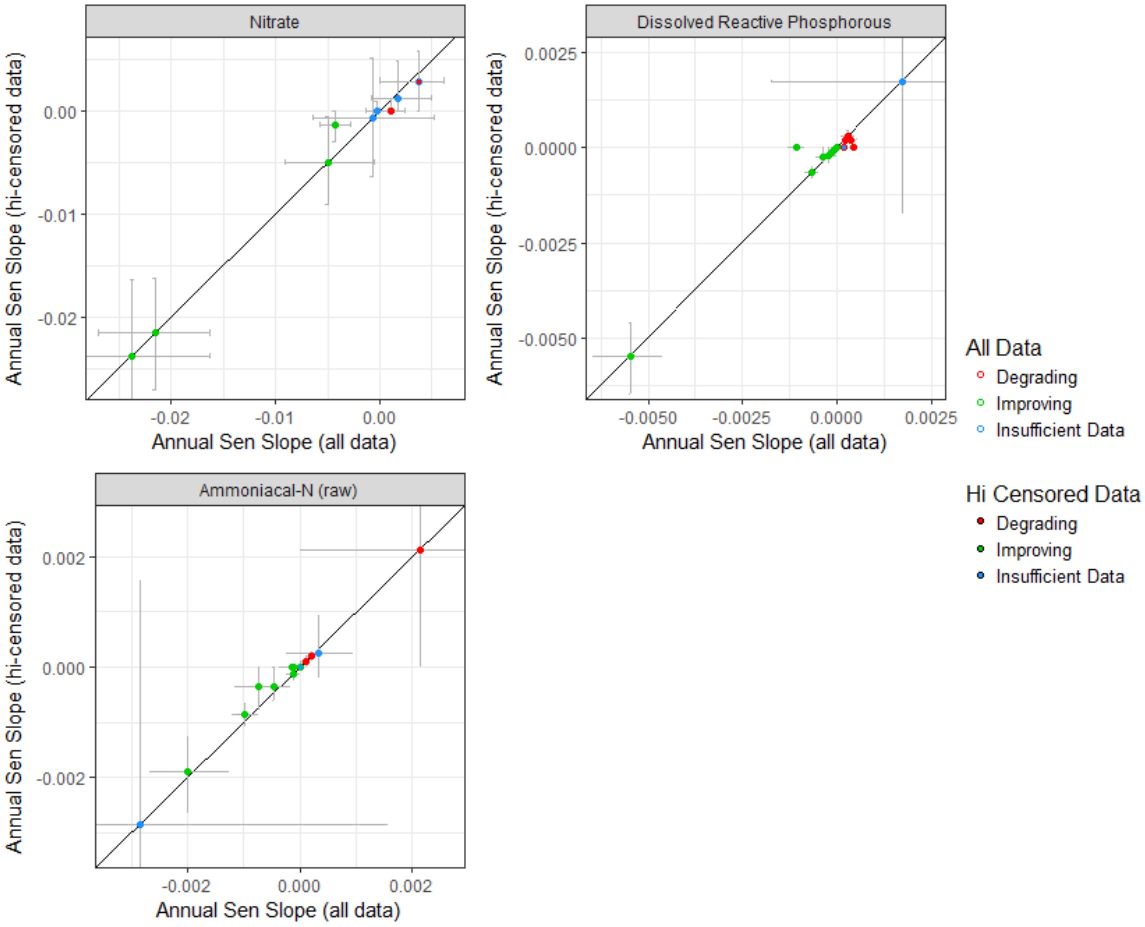

Figure 53: Comparison of annual Sen slope for 20-year trends when calculated with all data, or with a high censor limit (hi-censored). Grey bars indicate Sen slope 90% confidence intervals.

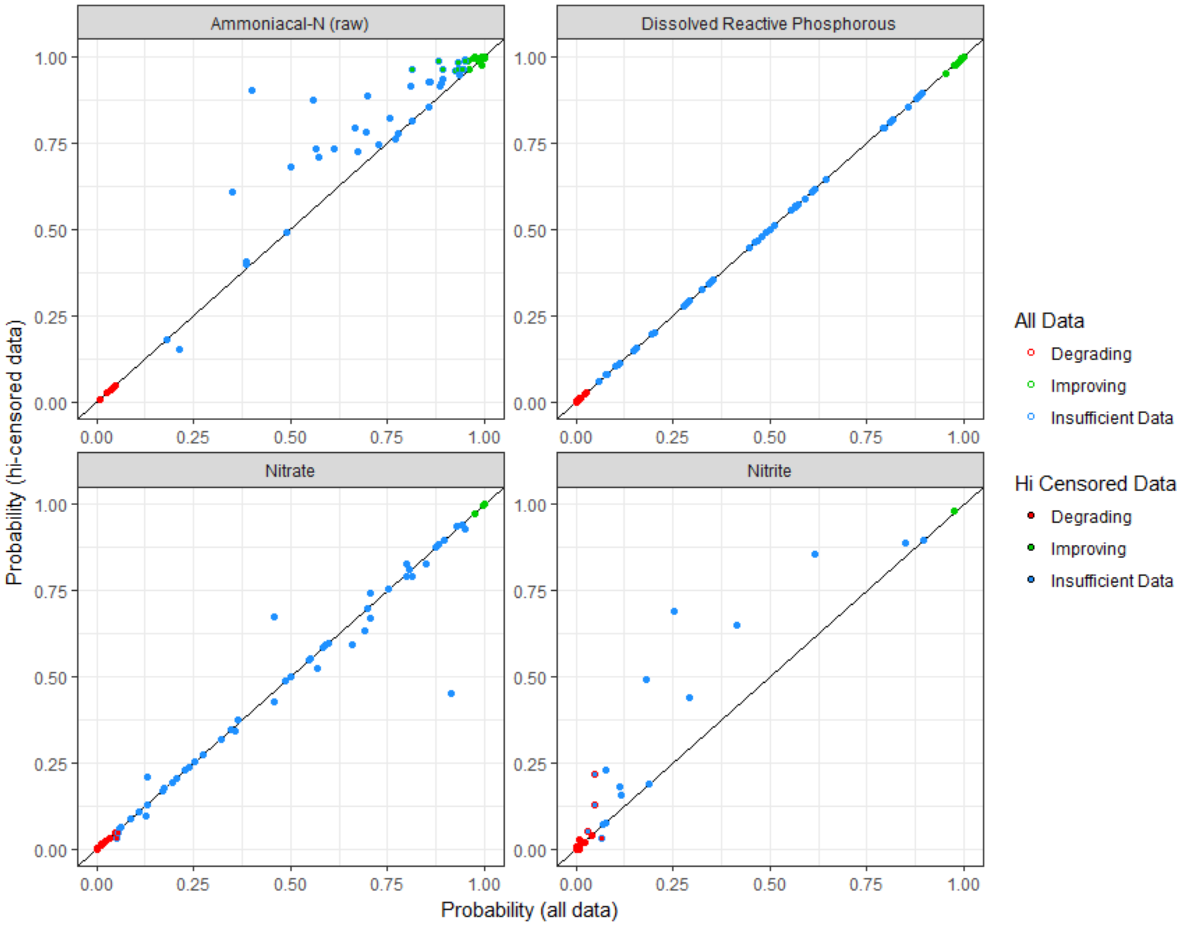

Figure 54: Comparison of probability (of Sen Slope < 0) for a 10-year period when calculated with all data, or with a high censor limit. Grey bars indicate the range in probabilities associated with a Sen slope of zero.

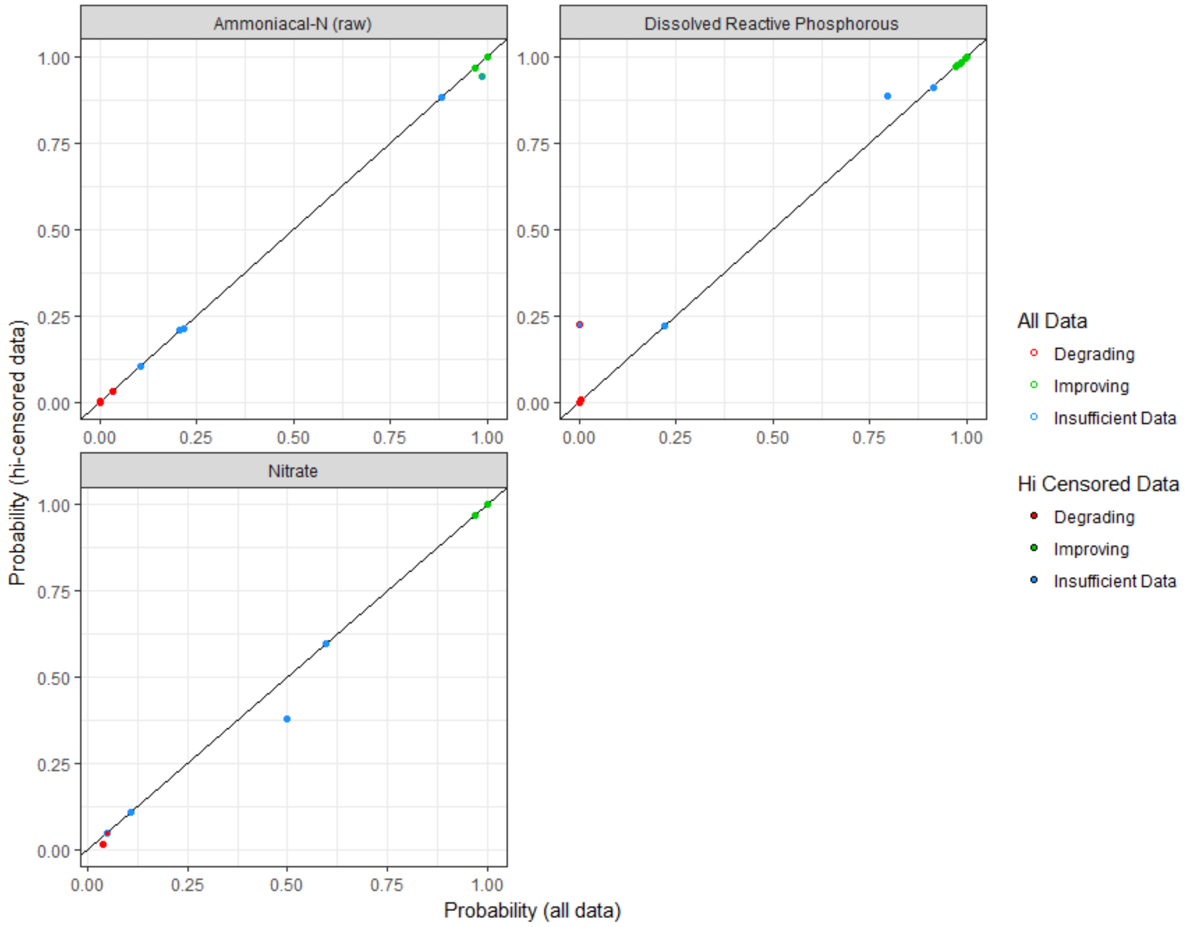

Figure 55: Comparison of probability (of Sen slope < 0) for a 20-year period when calculated with all data, or with a high censor limit. Grey bars indicate the range in probabilities associated with a Sen slope of zero.

F4 Conclusion

Overall, we concluded that the impact that the changes in censoring limit has on the trend analysis is small in relation to the overall uncertainties in the evaluated trends. However, we do note that on a site basis, that there can be differences between trends evaluated using raw and hi-censored data, so caution should be used when exercised when using site specific results.

Appendix G Trends probability summary tables

Figure 56. Summary plot of 10-year time period SoE trend analysis results. The plot shows the level of confidence that water quality was improving at each site and variable. See Table 6 for details of the confidence categories. Sites are grouped by the Freshwater Management Unit, where (A) is the "West Coast" FMU.

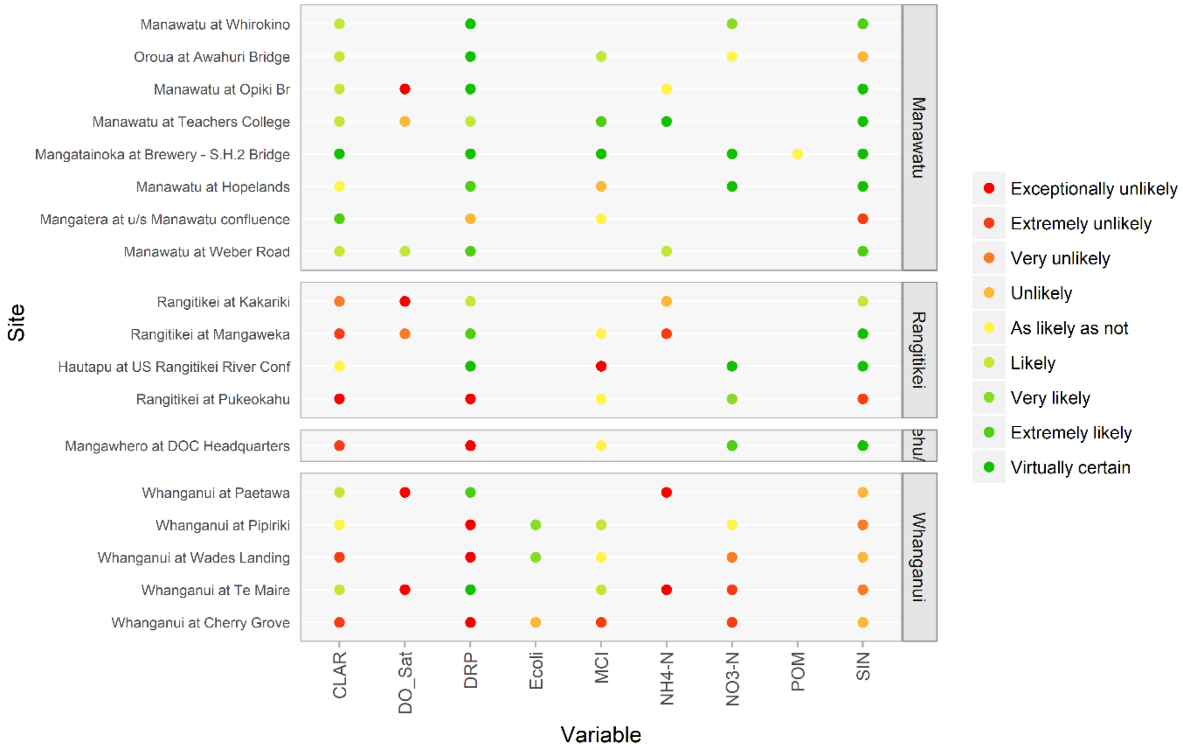

Figure 57. Summary plot of 20-year time period SoE trend analysis results. Notes as per Figure 51

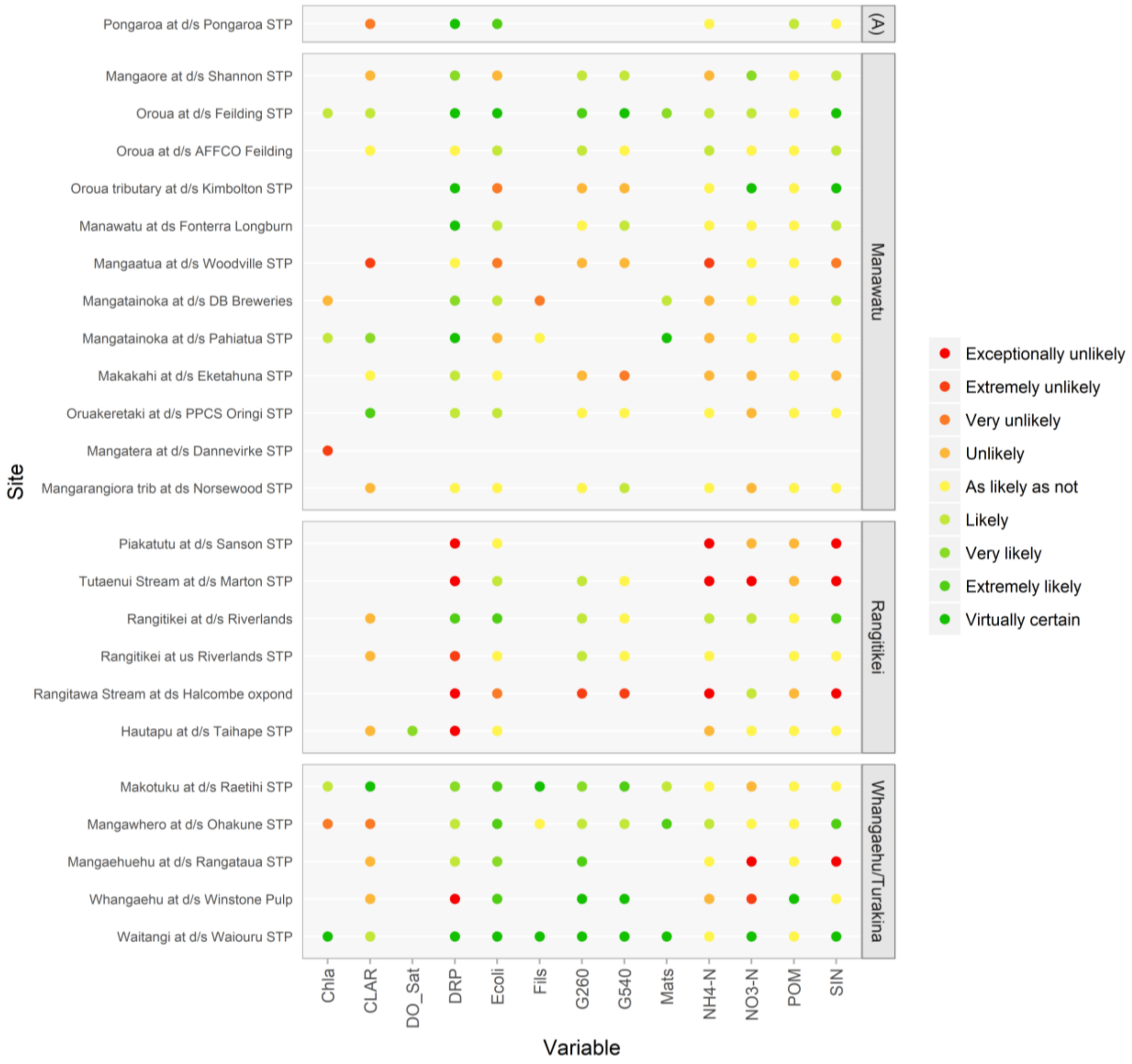

Figure 58. Summary plot of 10-year time period impact trend analysis results. Notes as per Figure 51.

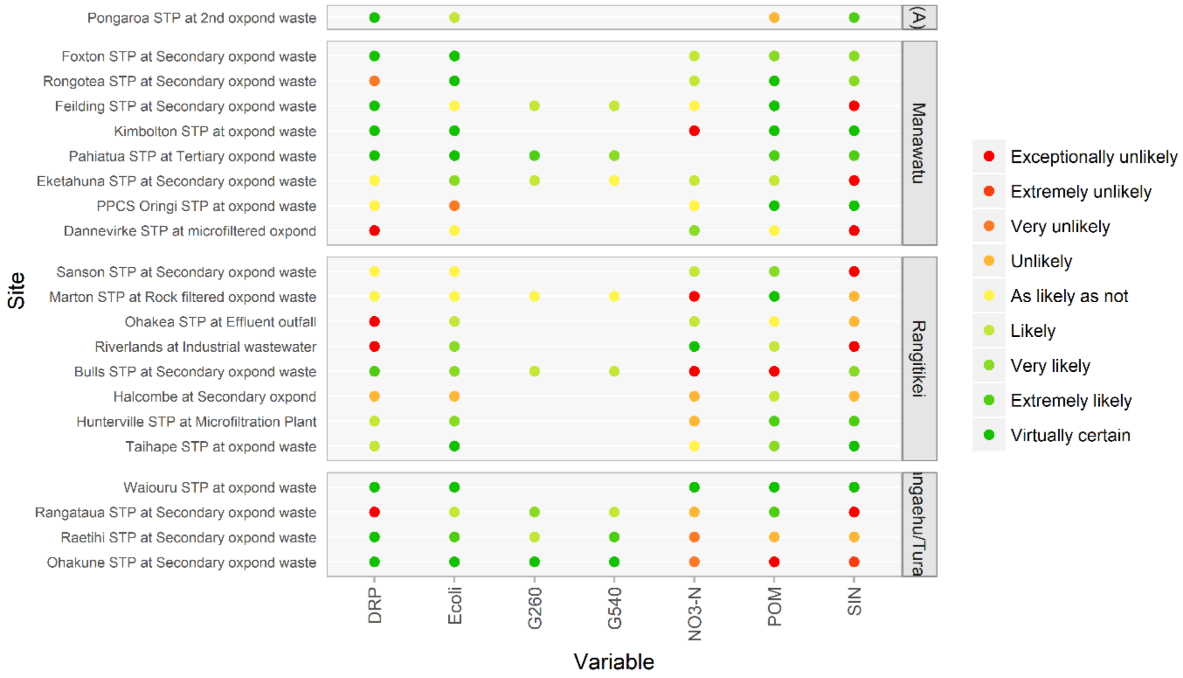

Figure 59. Summary plot of 10-year time period discharge trend analysis results. Notes as per Figure 51

Appendix H Aggregate 10-year trends and PIT by FMU

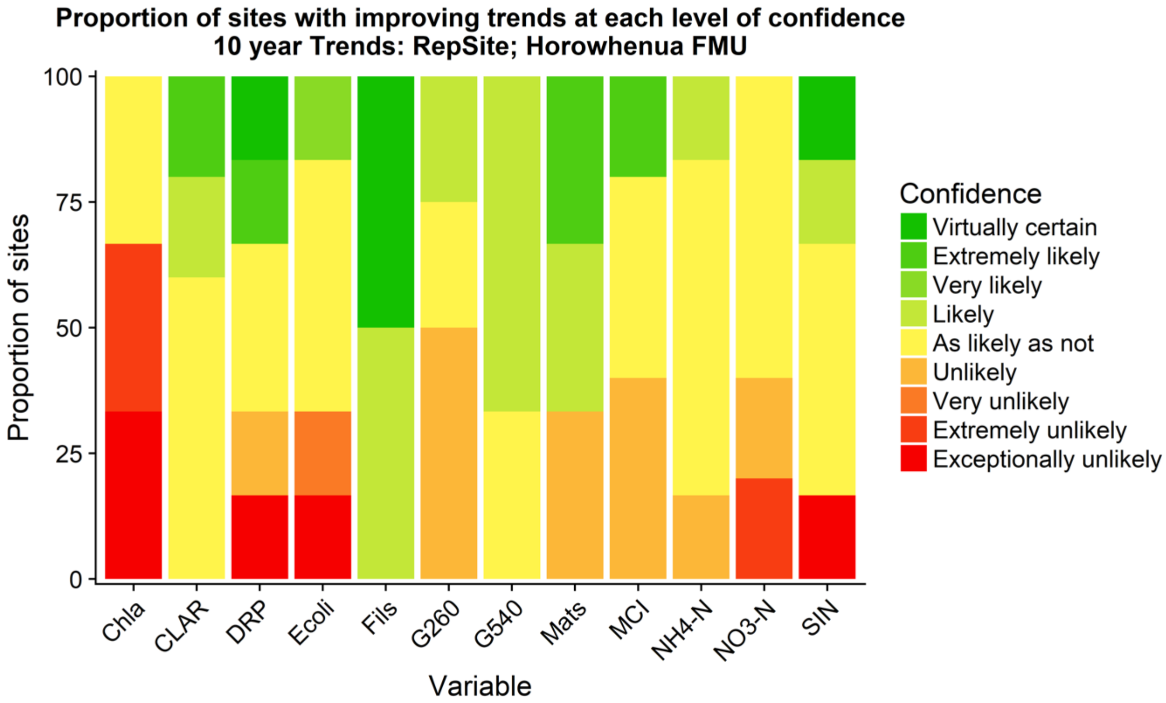

Figure 60. Summary plot representing the proportion of impact sites with improving 10-year time period trends at each categorical level of confidence for the Horowhenua FMU. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 6. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Trends used in this graph are not flow adjusted.

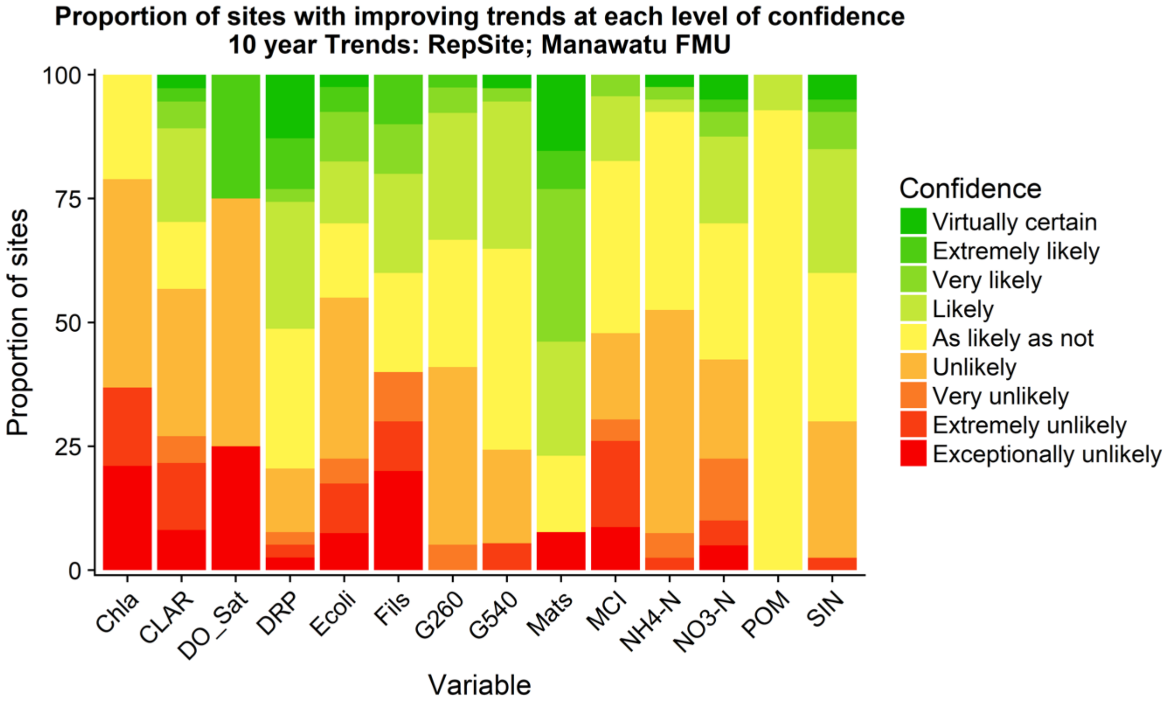

Figure 61. Summary plot representing the proportion of impact sites with improving 10-year time period trends at each categorical level of confidence for the Manawatū FMU. Notes as per Figure 60.

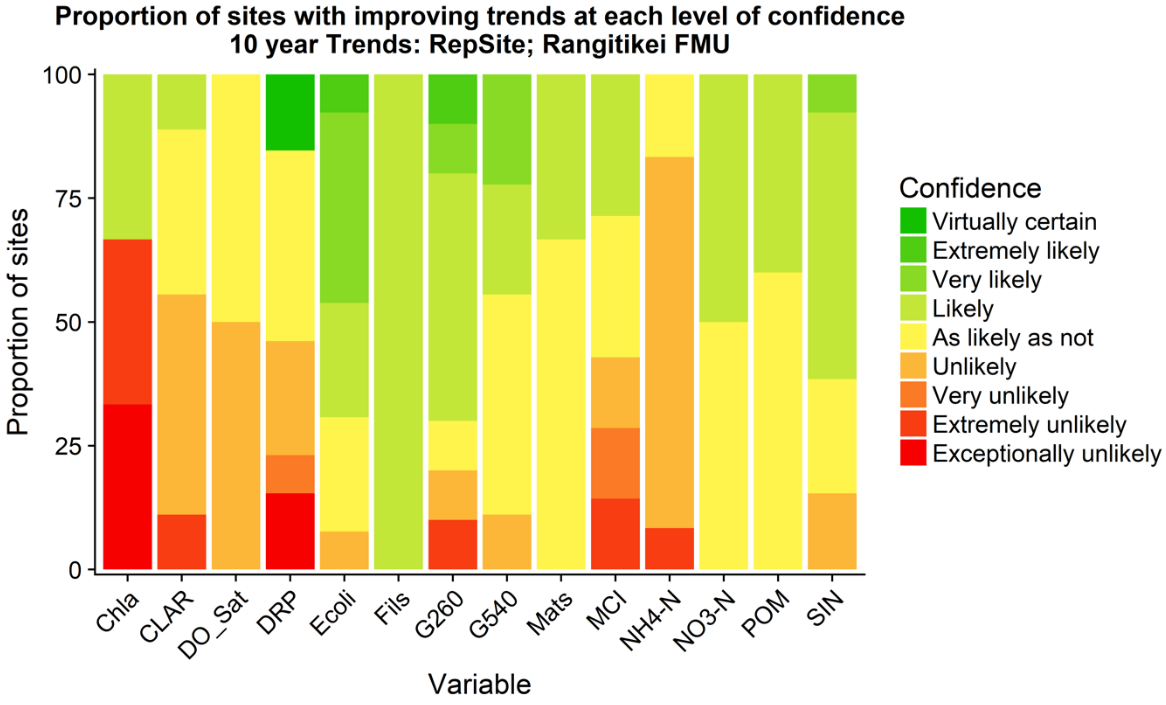

Figure 62. Summary plot representing the proportion of impact sites with improving 10-year time period trends at each categorical level of confidence for the Rangitikei FMU. Notes as per Figure 60.

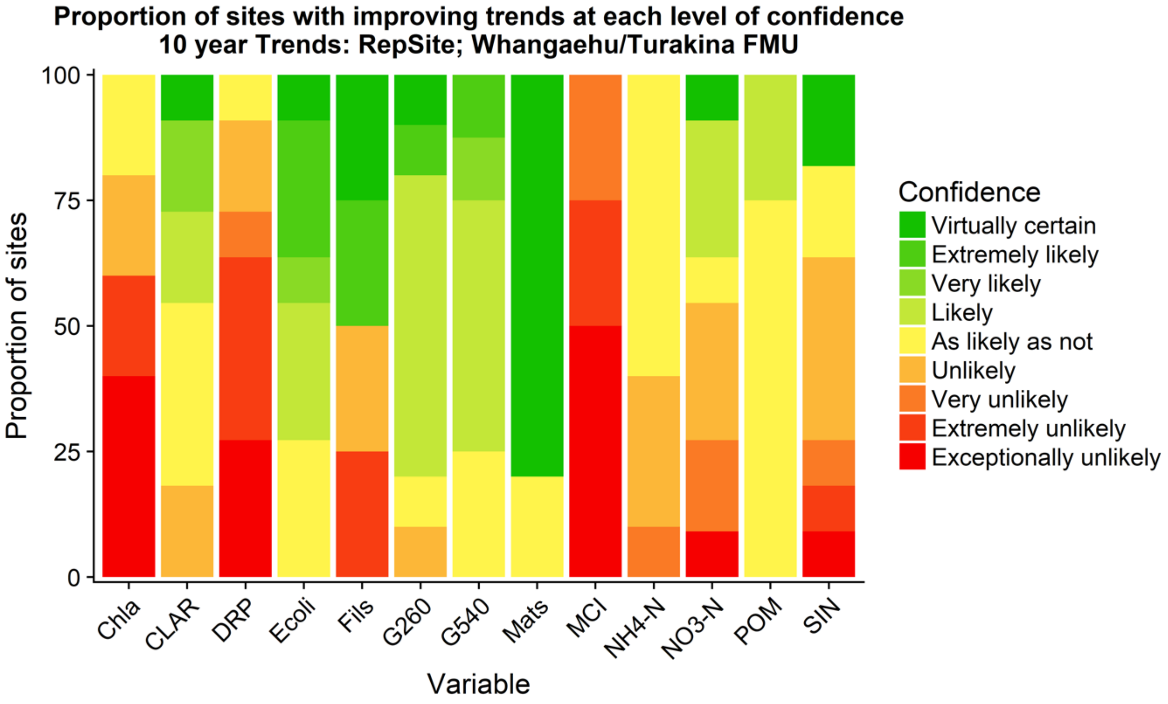

Figure 63. Summary plot representing the proportion of impact sites with improving 10-year time period trends at each categorical level of confidence for the Whangaehu/Turakina FMU. Notes as per Figure 60.

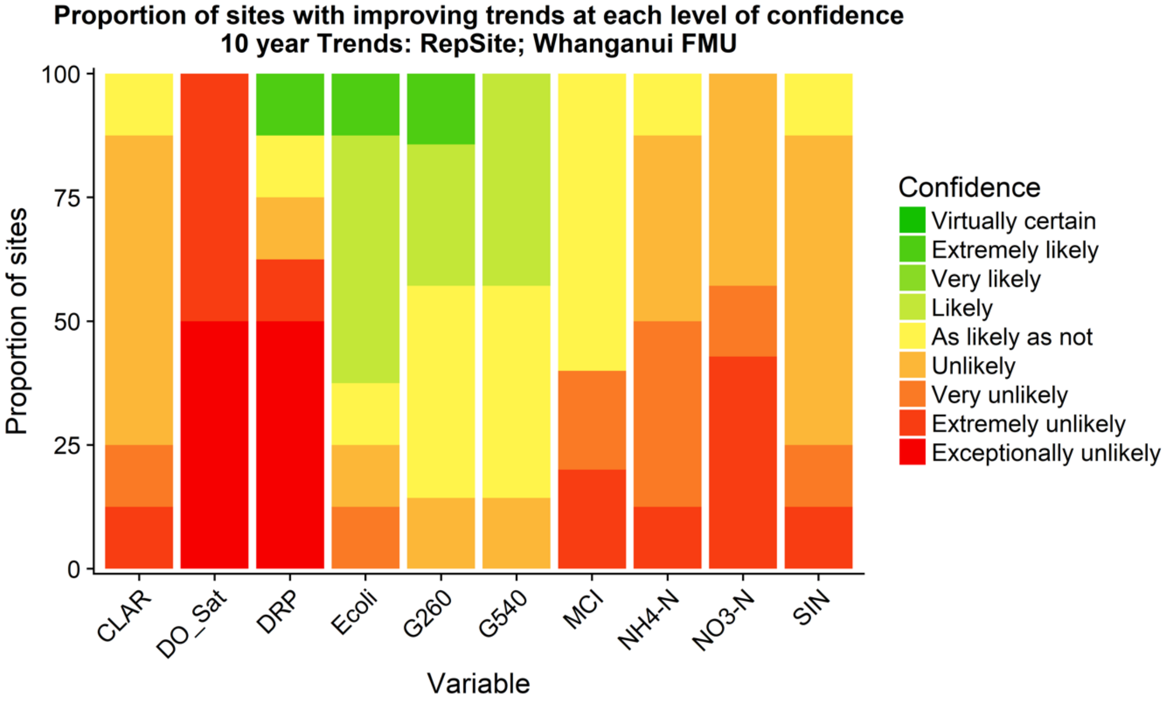

Figure 64. Summary plot representing the proportion of impact sites with improving 10-year time period trends at each categorical level of confidence for the Whanganui FMU. Notes as per Figure 60.

Table 17. Proportion of SoE sites with improving trends for 10 -year time periods, by FMU. Proportions of degrading sites are 100 minus these values. Trends used in this analysis are not flow adjusted. Abbreviated variable names are explained in Table 1.

Variable	**FMU**	**PIT**	**Standard error of PIT**	**Number of sites**
Chla	Horowhenua	0	17.7	3
	Manawatū	10.5	8	19
	Rangitikei	33.3	14.4	3
	Whangaehu/Turakina	0	13.1	5
CLAR	East Coast	0	26.8	2
	Horowhenua	60	19.6	5
	Manawatū	35.1	5.9	37
	Rangitikei	22.2	14.5	9
	Whangaehu/Turakina	54.5	11.9	11
	Whanganui	0	12.9	8
DO_Sat	Manawatū	75	14.6	4
	Rangitikei	50	29.5	2
	Whanganui	100	7	2
DRP	East Coast	100	18	2
	Horowhenua	33.3	13.6	6
	Manawatū	62.8	6	39
	Rangitikei	42.3	10.2	13
	Whangaehu/Turakina	9.1	7.7	11
	Whanganui	25	8	8
Ecoli	East Coast	100	18.9	2
	Horowhenua	33.3	15.3	6
	Manawatū	32.5	5.5	40
	Rangitikei	76.9	10.1	13
	Whangaehu/Turakina	81.8	10.8	11
	Whanganui	75	14.4	8
Fils	Horowhenua	100	16.7	2
	Manawatū	50	9.8	10
	Rangitikei	100	24.2	3
	Whangaehu/Turakina	50	10.2	4
G260	East Coast	100	7	1
	Horowhenua	37.5	23.4	4
	Manawatū	44.9	6.6	39
	Rangitikei	75	11.7	10
	Whangaehu/Turakina	90	11.7	10
	Whanganui	64.3	16	7
G540	East Coast	100	26	1
	Horowhenua	83.3	25.7	3
	Manawatū	62.2	7	37
	Rangitikei	88.9	13.7	9

Mats	Whangaehu/Turakina	75	13.2	8
	Whanganui	71.4	16.4	7
	Horowhenua	66.7	20.1	3
	Manawatū	84.6	9.1	13
	Rangitikei	66.7	25.7	3
	Whangaehu/Turakina	100	9.8	5
MCI	East Coast	0	4.3	1
	Horowhenua	40	18.1	5
	Manawatū	34.8	8.1	23
	Rangitikei	42.9	15.6	7
	Whangaehu/Turakina	0	7.3	4
	Whanganui	20	17.9	5
NH4-N	East Coast	0	29.7	2
	Horowhenua	33.3	19	6
	Manawatū	20	6.9	40
	Rangitikei	0	11.9	12
	Whangaehu/Turakina	0	13.7	10
	Whanganui	0	12.9	8
NO3-N	Horowhenua	0	19.5	5
	Manawatū	48.8	6	40
	Rangitikei	100	18.7	6
	Whangaehu/Turakina	36.4	10.8	11
	Whanganui	0	10.7	7
POM	East Coast	100	44.9	1
	Manawatū	71.4	13.2	14
	Rangitikei	80	20.7	5
	Whangaehu/Turakina	50	23.8	4

Appendix I Comparison of state and trend – supplementary plots

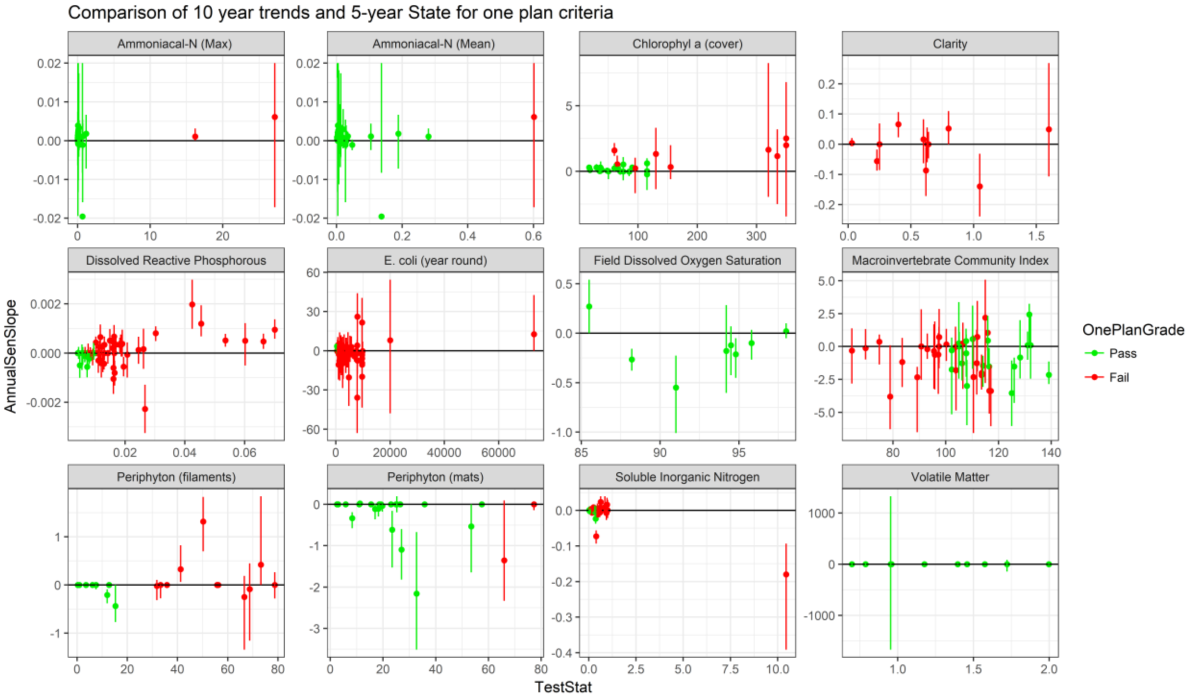

Figure 65: Scatter plot showing state versus 10-year trend magnitudes (Sen slopes), with 90% confidence intervals. Points are coloured based on One Plan grades. Sen slopes are for raw trends (i.e., not flow adjusted).

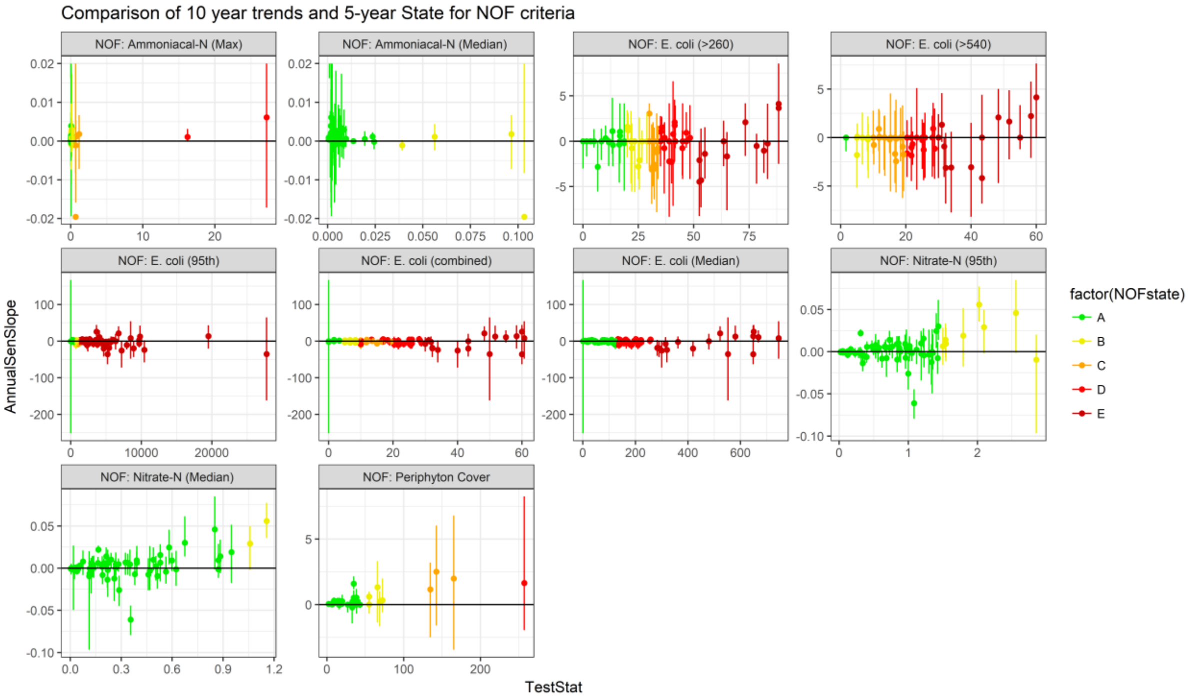

Figure 66: Scatter plot showing state versus 10-year trend magnitudes (Sen slopes), with 90% confidence intervals. Points are coloured based on One Plan grades. Sen slopes are for raw trends (i.e., not flow adjusted).

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