Canterbury River Water Quality State and Trend Analysis

Periods ending 30th June 2017

April 2018

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LWP Client Report Number:	2018-03
Report Date:	April 2018
LWP Project:	LWP Client Report 2018-03

Quality Assurance Statement

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Executive Summary

This report outlines a state and trend analysis conducted on the most up to date available data from the Environment Canterbury river water quality monitoring program. This report is primarily methodological. Interpretation of the outputs is beyond the scope of our project, although some brief interpretation is provided in the results section, in particular in relation to overall trends. Full outputs from the analyses are provided as supplementary files.

We evaluated water quality state at each monitoring site as the median and 95th percentile for each water quality variable over the most recent 1, and 5 years of data (see results section 4.1). We evaluated trends at each monitoring site and variable as the Sen slope estimator (SSE), which has been commonly used for trend analysis of water quality for several decades (Hirsch *et al.*, 1982) (see results section 4.2.1).

We also assessed the probability that the evaluated trend is increasing (the inverse of which is the probability that the trend is decreasing). This probability was then used to evaluate whether trend direction had been established at the 95% level of confidence (see results section 4.2.2).

We used new methods to aggregate site-trend probabilities to produce tabular and graphical summaries that provide a useful overview of recent water quality changes over the whole region (see results section 4.2.3). The new methods are an improvement on previous methods as they are able to incorporate trend information from all sites, regardless of the confidence in trend direction, and also use this information to determine uncertainty on the aggregate trend results.

The river water quality state for chemical variables (Ammonia and Nitrate) over the most recent 5-years has generally been above the national bottom lines (>”D” band) outlined in the national objectives framework (NOF) of the National Policy Statement for Freshwater Management (2017). Performance against the NOF criteria for *E. coli* was poorer, with many of the coastal streams draining the Canterbury plains being categorised in the “D” or ”E” bands.

The results of the trend analysis generally show that there are more improving trends over the past 5-years, compared to trends for the past 20-years, although this does vary between water quality variables. The 5-year trends indicate that, across all variables, 60% or more of sites had improving trends and conversely, fewer than 40% of sites had degrading trends.

1 Introduction

This report details a study of state and trends at river water quality monitoring sites in the Canterbury Region using the most up to date available data. The scope of the study included evaluating trends for all river sites for three time-periods and a selection of monitored variables, as well as state for the most recent year of monitoring and the most recent 5-years. The scope did not include interpretation of the outputs from the state and trends analysis. Therefore, this report describes the methodology used and summarises the results for trend and state. Although beyond the project scope, we have also provided some brief interpretation in relation to overall trends. A complete set of analytical results is provided as supplementary files.

2 Data

The data used in this study were supplied by Environment Canterbury and comprised 144,263 observations at 156 monitoring sites of the eight variables at shown in Table 1. Each observation was associated with a value and date. Each site was associated with meta data, in particular the geographic location and the unique site identification number.

Table 1. River water quality variables, measurement units and site numbers used in this study.

Variable	Abbreviation	Units	Number of monitoring sites
Ammoniacal nitrogen	NH4N	mg/m^3	156
Nitrate-Nitrite-nitrogen	NNN	mg/m^3	156
Dissolved Inorganic Nitrogen[1]	DIN	mg/m^3	156
Total nitrogen	TN	mg/m^3	156
Dissolved reactive phosphorus	DRP	mg/m^3	156
Total phosphorus (unfiltered)	TP	mg/m^3	151
Suspended Solids	SS	mg/L	146
Turbidity	Turbidity	NTU	152
Escherichia coli	Ecoli	cfu/100 mL	156

A visual summary of the available data is presented in the supplementary file DataAvailabilitySummaryPlots_Canty2.pdf: The time series for each variable and site are also plotted in the supplementary file WQTimeseries_Canty2.pdf.

The data were inspected for obvious errors such as incorrect units, but no other pre-processing was required prior to analysis. The only exception to this was to summarise multiple observations at a site that occurred on a single day by their median value. This only affected one day of observations in 2015 at the site “Hook Drain at Beach Road”.

[1] DIN calculated by summing NNN+NH4N. Where one of the two observations was censored, then half the censored value was added to the non-censored value. When both observations were censored, the larger censored value was used, and the observation recorded as censored.

3 Methods

3.1 Sampling dates and time periods for analyses

The analyses that follow concern two characterisations of water quality: state and trend. For each variable, the state was characterised by statistics that were calculated from the water quality observations, for example the median value. The trend at all sites was characterised by the rate of change of the central tendency of the values variable through time.

Because water quality changes through time, both the state and trend depend on the time-period over which the state and trends are assessed (e.g., Ballantine *et al.*, 2010; Larned *et al.*, 2016). Therefore, state and trend assessments are specific for a given period of analysis. In addition, the statistical confidence in determinations of water quality state and trends depends on the variability in the measurements between sampling dates and on sample size (i.e., the number of sampling dates). Generally, the rate at which confidence increases for estimates of population statistics reduces above a sample size greater than 30 (i.e., above this size there are diminishing returns on increasing confidence with increasing sample size; McBride, 2005).

Because water quality data tends to be seasonal, it is also important that each season is well represented over a period of record. In this study, where possible seasons are represented by months. However, because formerly many sites were sampled less frequently, seasons were also represented by quarters where insufficient monthly observations were available. To avoid biases that could be introduced due to changes in sampling frequency over time, the input data was converted to be one value per season-year by taking the median value of observations in any one season-year, prior to conducting the trend analyses.

The dataset had variable starting and ending dates, variable sampling frequencies, and variable numbers of missing values. Because the analyses that follow are concerned with assessing regional patterns in state and trends, it was important to maintain the maximum number of sites for each time-period analysed, while ensuring the characterisation of state and trends represented a consistent time period for all sites.

Filtering rules for trends were used to achieve a reasonable trade-off between length of time-period, sample size and numbers of sites. In a recent national analysis, Larned *et al.* (2015) used filtering rules such that site and variable combinations were restricted to those for which there were observations for at least 90% of the years and at least 90% of seasons within the time-period being analysed. This study adopted similar filtering rules but with criteria relaxed to 80% of years and sample seasons, as suggested by Helsel and Hirsch (1992). All site by variable combinations that did not comply with these filtering rules were excluded from the analysis.

No filtering rules were applied to the evaluations of state. For each time period, the state statistics were evaluated using all available data, irrespective of the number of observations. To provide the information needed to assess the statistical confidence in the assessment, the number of observations (i.e., the sample size) used to evaluate the state statistics is provided in the supplementary output files.

3.2 Assessment of water quality state

For each of the eight variables listed in Table 1, the 95th percentile and median values over the most recent one and five-year periods (up to 30 June 2017) were evaluated. In addition, the proportion of *E.coli* observations greater than 540 cfu/100 ml and 260 cfu/100 ml were evaluated.

For the five-year period, where the evaluated state measures corresponded to national standards in the National Objectives Framework (NOF)[2] (Table 2), sites were assigned grades based on the performance against the NOF criteria outlined in Table 3. The NOF combined *E. coli* standard (short name: “Ecoli.combined”) was also evaluated, which was determined as the lowest NOF band assigned to the four individual *E.coli* statistics (Median, 95th percentile, G260 and G540; Table 2).

Table 2: Details of the NOF for each water quality variable used to grade the sites.

Target	Target name	Sample size required	Target description[1]
Ammonia Toxicity - Median	NH4.Med	30	The median concentration of Ammoniacal Nitrogen must not exceed … mg/l
Nitrate Toxicity - Median	NO3N.Med	30	The median concentration of Nitrate must not exceed … mg/l
Nitrate Toxicity – 95th percentile	NO3N.p95	30	The 95th percentile concentration of Nitrate … mg/l
Proportion E. coli samples > 260	Ecoli.G260	30	% exceedances over 260 cfu/100 mL must be less than …%
Proportion E. coli samples > 540	Ecoli.G540	30	% exceedances over 540 cfu/100 mL must be less than …%
E. coli median	Ecoli.Med	30	The median concentration of E. coli (cfu/100 ml) must be less than ...
E. coli 95th percentile	Ecoli.p95	30	The 95th percentile concentration of E. coli (cfu/100 ml) must be less than …

Table 3: NOF band thresholds

Target name	A	B	C	D	E
NH4.Med	≤0.03	≤0.24	≤1.3	>1.3	
NO3N.Med	≤1	≤2.4	≤6.9	>6.9	
NO3N.p95	≤1.5	≤3.5	≤9.8	>9.8	
Ecoli.G260	≤20%	≤30%	≤34%	≤50%	>50%
Ecoli.G540	≤5%%	≤10%	≤20%	≤30%	>30%
Ecoli.Med	≤130	≤130	≤130	≤260	>260
Ecoli.p95	≤540	≤1000	≤1200	≤1200	>1200

3.3 Analysis of trends

Trends were assessed for three time-periods: 5, 10 and 20 years, ending on 30th June 2017. The method used for statistical trend analyses in this study was the Sen slope estimator (SSE),

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

which has been used for trend analysis of water quality for several decades (Hirsch et al., 1982). However, this study did not use the statistical test of significance developed by Hirsch et al. (1982). Rather, the trend direction assessment procedure developed by Larned et al. (2015) was used to evaluate the statistical confidence in the trend direction (i.e., the probability that the evaluated direction was the same as the true trend). Briefly, confidence intervals are used to draw inferences about trend direction; if a symmetric confidence interval around the trend (i.e., the SSE) does not contain zero, then the trend direction (either positive or negative) is “established with confidence”. If it does contain zero, it is concluded that there are insufficient data to determine the trend direction and the assessment is that the trend is “uncertain”.

This study included some advances on the method used by Larned *et al.* (2015) associated with the treatment of censored values and seasonality, which are discussed briefly below.

3.3.1 Missing data and censored values

Trends are most robust when there are few censored values in the time-period of analysis. It has been common in environmental reporting in New Zealand 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).

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). However, 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. The restriction rules used by Larned *et al.* (2015) avoided making incorrect determinations of trend magnitude because this quantity is unaffected by censoring when fewer than 15% of the data are censored values.

Different methods for dealing with censored values and missing data to that of Larned *et al.* (2015) were adopted in this study. The methods were based on handling of censored values in trend analysis (Helsel, 2012), which have recently been implemented in the TimeTrends software (Jowett, 2017) that is commonly used by regional councils in New Zealand. The method does not impute replacement values for censored values, making it unnecessary to restrict analysis of sites based on the number of censored values. Instead, the analysis generally treats censored values as unknown and does not use them in the estimation of the trend slope. In addition, the analysis treats comparisons of observations that are both censored values as ties, which are accounted for in the evaluation of statistical confidence. Ties decrease the statistical confidence of the evaluation, which means that when there are many censored values and missing data, the analysis produces a low degree of confidence in the evaluated trend direction. Where there are fewer than five total and three unique, non-censored observations, the method will not analyse the data and these cases are reported as “not analysed”.

3.3.2 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 and its probability. Therefore, in this study, the trend analysis commenced 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 was a statistically significant effect ($p \leq 0.05$) of season on the value of a variable, the SSSE was evaluated. Where the effect of season was not significant (Kruskal Wallis $p > 0.05$), the SSE was evaluated.

3.4 Interpretation of trends

The relatively new trend assessment procedure used here facilitates a more nuanced inference rather than the 'yes/no' output corresponding to the chosen acceptable misclassification error rate. The probability allows the confidence in the direction to be expressed at different levels and a categorisation can be used to convey that information. The approach to presenting levels of confidence of the Intergovernmental Panel on Climate Change (IPCC; Stocker *et al.*, 2014) is one way of conveying the certainty of trend directions (Table 4). These same categorical levels of confidence were used to express the likelihood that water quality was improving[3] for each site and variable in this report. Note, the probability of degradation is the inverse of the probability of improvement.

Each site trend was assigned a categorical level of confidence that the trend was improving according to its evaluated probability, direction and the categories shown in Table 4. Improvement is indicated by decreasing trends (i.e., decreasing concentrations) for all the water quality variables assessed in this study (Table 1). The aggregate proportion of sites in each category shown in Table 4 can be calculated for sites 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 (i.e. probabilities of improvement <50%) trends at the levels of confidence indicated by the categories.

[3] Note the trend analysis outputs include a probability of decreasing trend; the conversion of the trend probability to improving (and its inverse, degrading) depends on whether decreasing represents improvement or degradation and varies between commonly used indicators of water quality.

Table 4. 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 et al., 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

Outputs from the trend analysis were also classified into four direction categories: improving, degrading, uncertain, and not analysed. An increasing or decreasing trend category was assigned when the 90% confidence interval did not contain zero (i.e., when probability ≥95%) and the Sen slope was positive or negative, respectively (i.e., the trend direction is established with confidence; Larned *et al.*, 2016). An uncertain trend category was assigned when the 90% confidence interval contained zero (i.e. when probability ≤95%; the trend direction was uncertain; 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 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, and this then results in ties.

3.4.1 Aggregating multiple site trends

Trend analyses performed on many sites are regularly aggregated by water quality variable and presented in tabular or graphical form in state of environment reports as part of environmental reporting (e.g., Ministry for the Environment, 2015, 2017). These tabulations 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).

State of environment reports tend to tabulate the numbers or proportions of site trends in three categories (increasing, decreasing, and statistically insignificant or uncertain). The uncertain category has been defined by adopting a default alpha value (generally 0.05) leading to substantial proportion of the sites being uncertain. The tabulation of uncertain sites results in two problems. First, the uncertain trends can be misinterpreted as “no change” or “stable”. This is an incorrect inference; an uncertain outcome simply indicates a lack of confidence in the analysis at a level defined by alpha. The second problem is that uncertain trends contain information about the general direction of change that is effectively ignored. For example, a trend’s direction may be uncertain 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 certain 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 uncertain, implying that nothing is known about the aggregate trend direction. However, this is incorrect; there is clearly a general 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 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, a ‘count-based’ assessment of the proportion of trends in a given direction for a domain of interest is made by simply counting the number of trends with face values in the direction of interest and dividing by the total number of trends. However, the inclusion of ‘uncertain’ site trends (i.e., those with a misclassification error risk of greater than 5%) in assessments in this manner implies an uncertainty in the derived statistic. For example, if the proportion of improving trends is the statistic being derived, the estimated proportion has an uncertainty that is associated with the use of the uncertain site trends.

The evaluated probability that the trend is improving enables the uncertainty associated with accepting trends at their face value to be incorporated in any analysis that aggregates trends over many sites. It follows that for any individual trend, the probability that the trend is improving is a binomially distributed variable. Thus, a trend with an evaluated probability of 0.75 indicates the probability that there has been improvement is 75% and the probability that there has been degradation is 25%. Another way to think about the evaluated probability is that if the monitoring and trend evaluation were carried out many times, the trend direction would be correctly classified and misclassified 75% and 25% of the time respectively. The idea of repeated sampling and analysis is the basis for Monte Carlo analyses. Monte Carlo analysis can be used to simulate different realisations of the trend analysis results over all sites, which in turn provides a ‘probability-based’ assessment of the proportion of improving trends.

We conducted a Monte Carlo analysis to evaluate a ‘probability-based’ assessment of the proportion of improving trends for each trend time-period and water quality variable (note, the proportion of degrading trends is the inverse of this number). Briefly, for each variable, we assigned a trend direction for each site in the region by taking a random sample from the site’s binomial distribution of trend improvement, which is characterised by the probability of trend improvement evaluated from the trend analysis. We then evaluated the proportion of sites with improving trends for this ‘realisation’ and repeated this for 1000 realisations. We then evaluated the ‘probability-based’ assessment of the proportion of improving trends as the mean result over all realisations. We characterised the uncertainty of the assessment by the standard error of this statistic, which we evaluated as the standard deviation of the results over all realisations.

4 Results

The results from the analysis (both state and trends) are provided in the supplementary file: ECAN_StateandTrends_12Apr18.xlsx.

4.1 State

The results from the state analysis are provided in the supplementary excel file in the sheets: “State” and “NOF Classes”. A description of the data provided in these sheets is provided in the tables below:

Table 5: Description of Supplementary Data: State

Column Name	Description
sID	Site ID
npID	Variable name
Site.Name	Site Name
Period	Time period for analysis (years)
n	Number of samples
variable	Description of statistic calculated (e.g. Ptl_95: 95th percentile)
Statistic	State value
CenType	Is the statistic a censored value? (T/F)

Table 6: Description of Supplementary Data: NOF Classes

Column Name	Description
sID	Site ID
npID	Variable name
Site.Name	Site Name
Period	Time period for analysis (years)
n	Number of samples
Indicator	Indicator name (see Table 2)
NOFstate	State category (“Not analysed” is sample numbers do not meet the criteria in Table 2)
CenType	Is the statistic a censored value? (T/F)

4.1.1 Maps of NOF State

The grading of river sites according to the NOF attribute states over the past five years are shown in Figure 1. These maps show a gradient in water quality from the west to the east of the region, most likely reflecting the influence of land use intensity from low intensity in the western mountainous and hill country to high intensity on the plains. All sites meet the NOF bottom lines (>D band) for median ammonia concentrations (NH4.Med), and only a small number of sites in south Canterbury fail to reach the national bottom line for Nitrate concentrations (both median – NO3N.Med, and 95th percentile – NO3N.p95). Performance against the NOF criteria is much poorer for the *E. coli* attribute, with most of the coastal monitoring locations draining the plains failing to meet the 'D' NOF band.

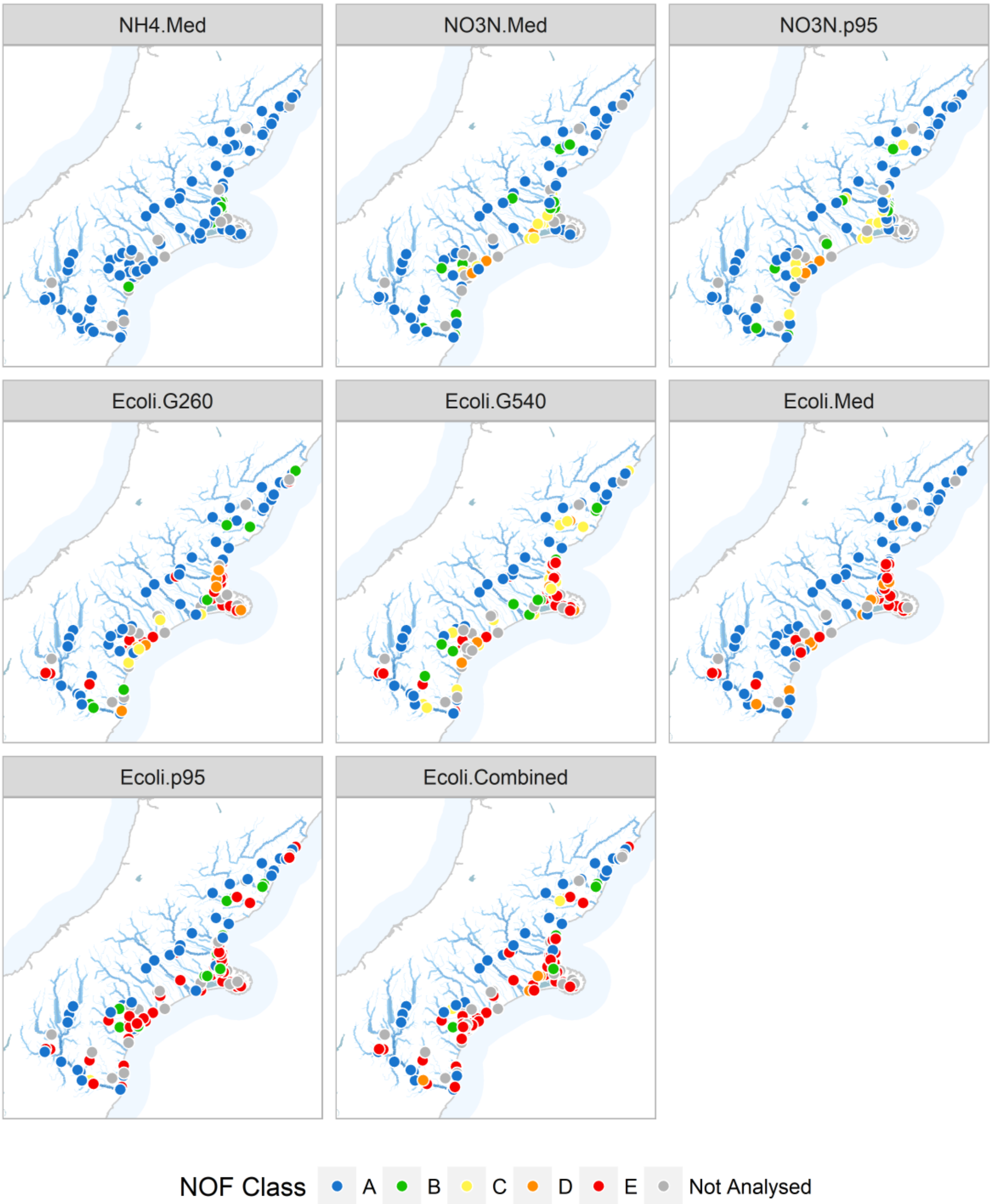

Figure 1. Map of sites classified by their NOF attribute states for the most recent 5-years of data. Refer to tables 1 and 2 as for panel headings.

4.2 Trends

The results from the trend analyses are provided in the supplementary excel file in the sheet: “Trends”. A description of the data provided in these sheets is provided in the Table 6 below:

Table 7: Description of Supplementary Data: Trends

Column Name	Description
sID	Site ID
npID	Variable name
Site.Name	Site Name
segXcentroid	Site x coordinate (NZGD 1949)
segYcentroid	Site y coordinate (NZGD 1949)
Period	Time Period for Analysis
Zone	ECAN zone name
River.Type	ECAN river type classifications
nSamples	Number of observations
S	S-statistic
VarS	Variance
D	n * (n - 1)/2
tau	Kendall’s tau
Z	Z-statistic
p	p-value for Mann-Kendall or Seasonal Kendall test
Median	Median value for the time period
AnnualSenSlope	Annual Sen Slope (attribute units/year)
Intercept	Predicted value at time t=t[1]
Lci	Lower confidence interval for annual sen slope
Uci	Upper confidence interval for annual sen slope
TrendCategory	Trend Category (at 95% confidence interval) increasing/dereasing/uncertain
TrendDirection	Trend Direction (face value direction) increasing/decreasing/indeterminate
Probability	The probability that the true trend was decreasing (value between 0 and 1)[4]
Percent.annual.change	Percent annual change in Sen slope
Seasonal	TRUE if data is seasonal and Seasonal Kendall test performed
Freq	The sampling frequency used as seasons in the analysis (either monthly or quarterly)
TrendDescription	Improving/Degrading/Uncertain
DirectionConf	IPCC style description of confidence of improving trend

[4] Note that the conversion of the trend probability to improving (and its inverse, degrading) depends on whether decreasing represents improvement or degradation and varies between commonly used indicators of water quality.

4.2.1 Trend Description

Figures 2, 3, and 4 show the trend directions for the 5, 10 and 20-year trend periods, respectively. For all time periods, a significant proportion of the trends analysed are classified as uncertain; across all time periods 50-65% of trends were classified uncertain. For the 5-year trends, there is a dominance of improving or uncertain trends. Sentence here on small number of degrading trends and where they are. There are many “Not analysed” trends for NH4N for the 5-year record. This arises because for NH4N because there are many samples with censored values and this variable has low measurement precision.

There was not a strong geographical pattern associated with the distribution of increasing or decreasing trends for any variables or time periods, although there may be some patterns associated with river size or catchment characteristics that are not immediately evident from the maps. A notable anomaly in the maps are the 10-year trends for Turbidity, which, particularly in south Canterbury, generally show opposite trends to both the 5 and 20-year trend predictions. This may be related to climate variation rather than anthropogenic forcing.

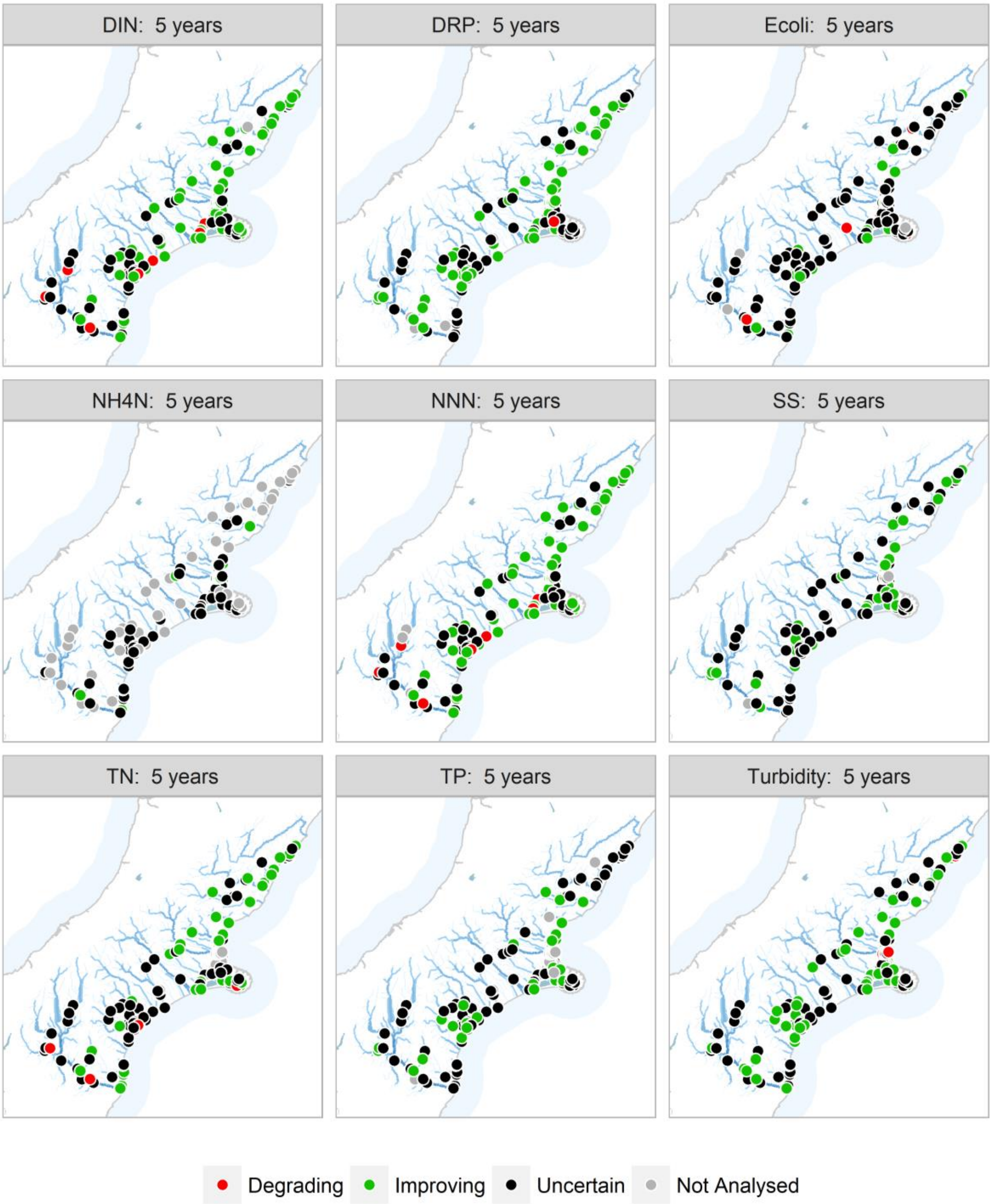

Figure 2. Map of sites classified by their five-year raw water quality variable trend descriptions. Site and variable combinations for which water quality trend descriptions are 'not analysed' either had many missing or censored values. Abbreviated variable names are explained in Table 1.

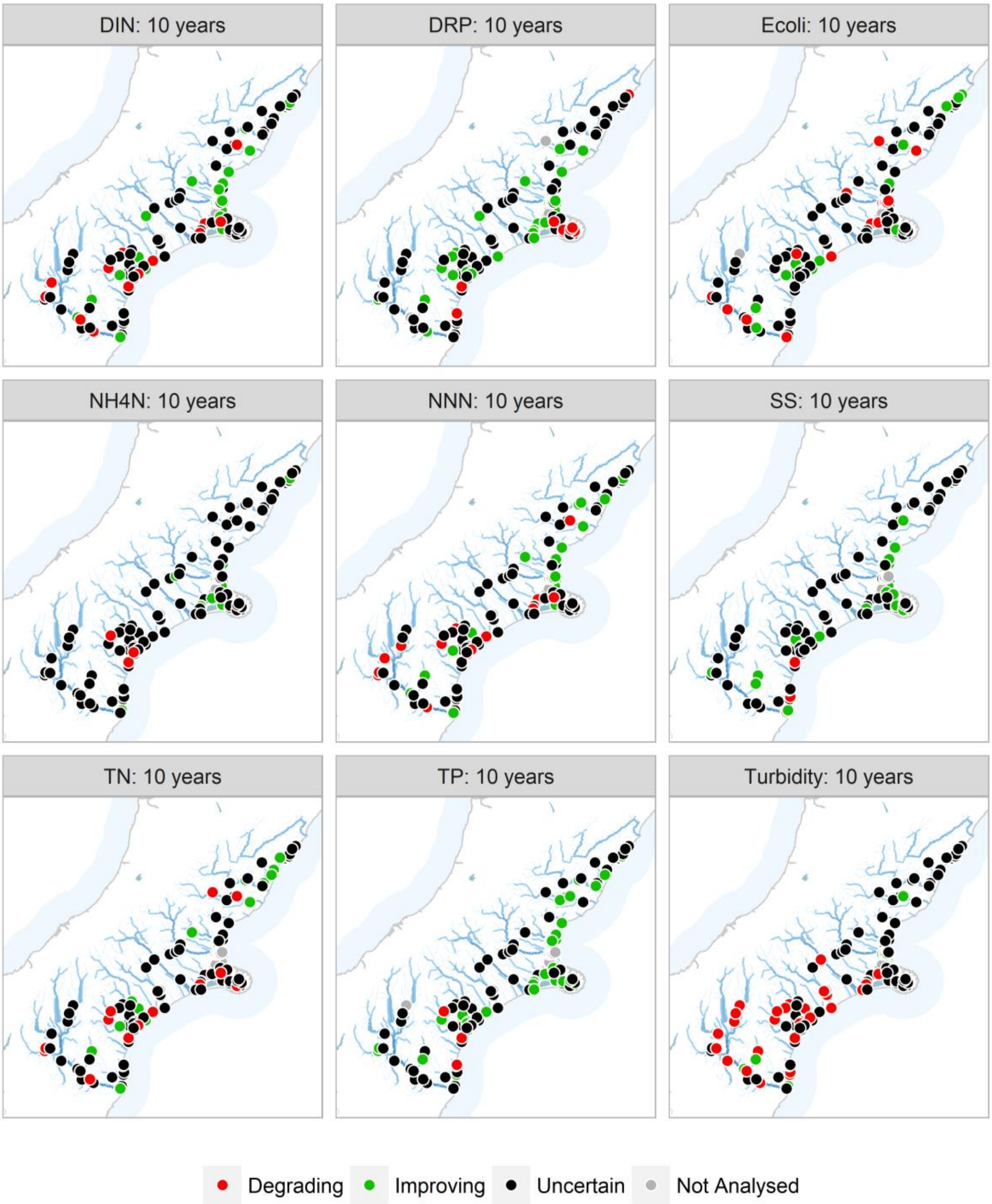

Figure 3. Map of sites classified by their ten-year raw water quality variable trend descriptions. Site and variable combinations for which water quality trend descriptions are 'not analysed' either had many missing or censored values. Abbreviated variable names are explained in Table 1.

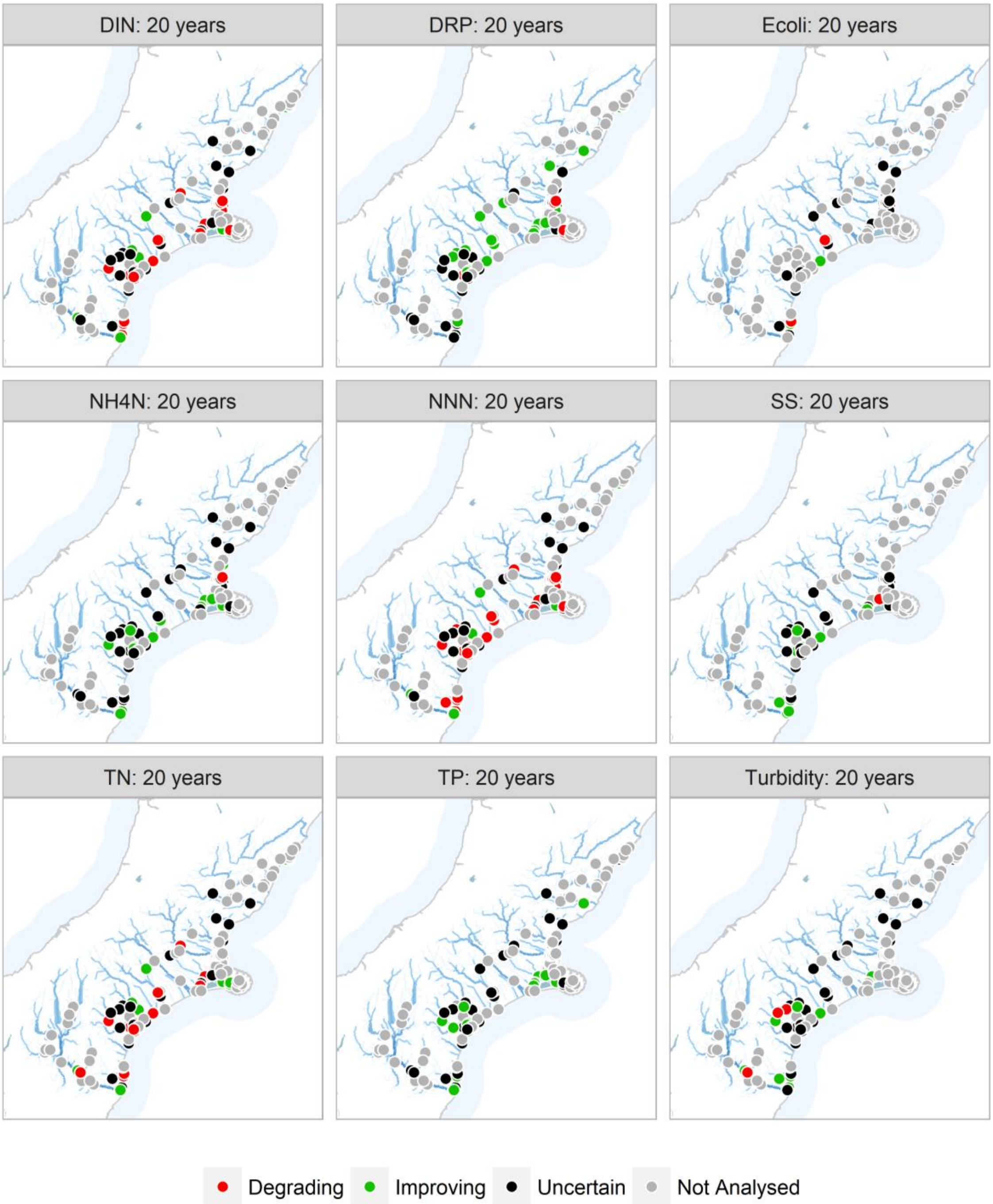

Figure 4. Map of sites classified by their 20-year raw water quality variable trend descriptions. Site and variable combinations for which water quality trend descriptions are 'not analysed' either had many missing or censored values. Abbreviated variable names are explained in Table 1.

4.2.2 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 "uncertain" sites are placed on a continuous colour spectrum between green and red, based on their evaluated probability of trend improvement (Figure 5, Figure 6, Figure

7). Note, because probability of improvement is the inverse of the probability of degradation, “unlikely” improvement, could also be classed as “likely” degradation. The maps indicate that many of the previously classified “uncertain” trends, have positive (i.e., improving) trends; there is a dominance of yellow to green in the 5-year period plots particularly for the 5-year period.

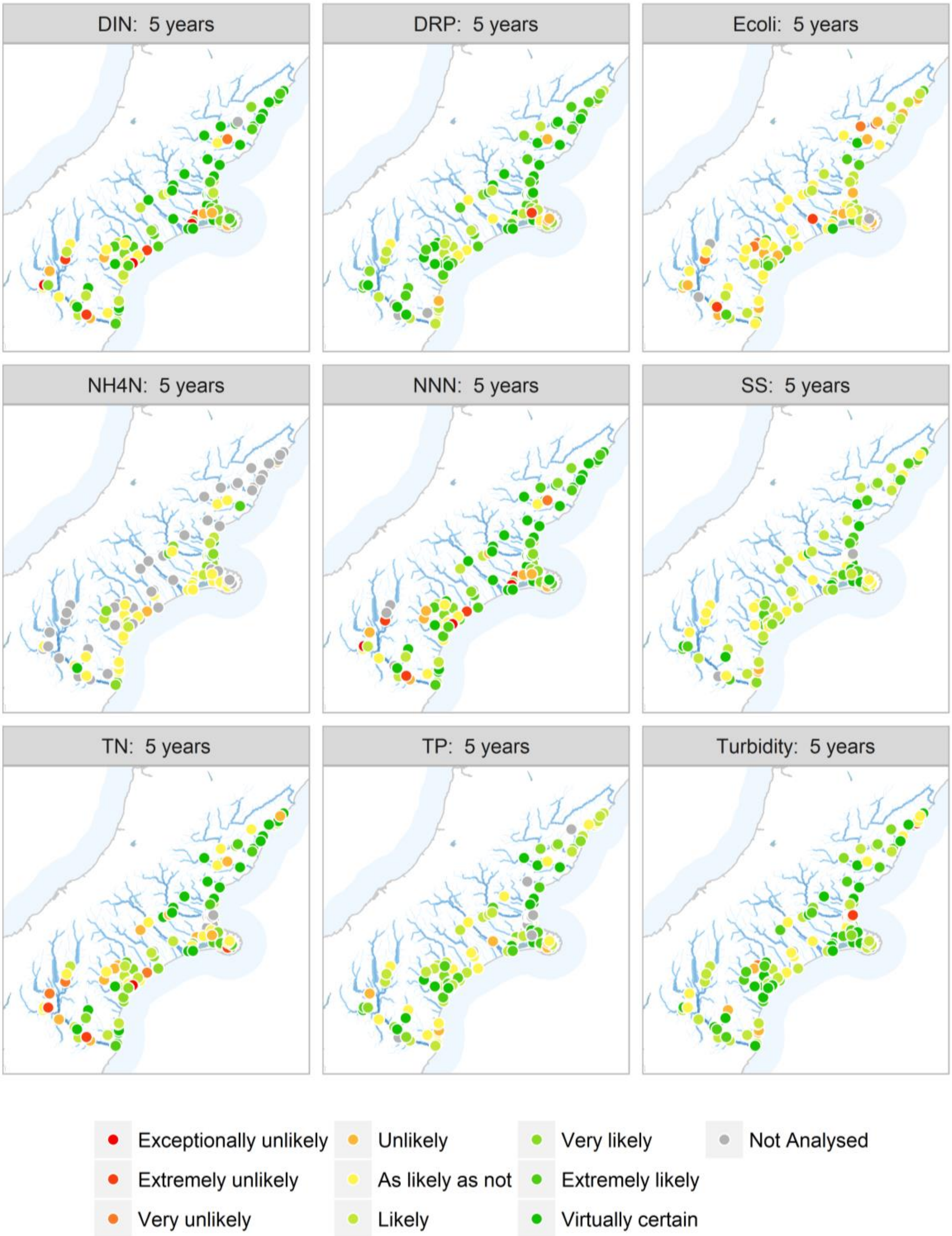

Figure 5. Map of sites classified by their 5-year raw water quality trend probability of improvement. Probability or improvement is expressed in terms of levels of confidence defined in Table 4. Abbreviated variable names are explained in Table 1.

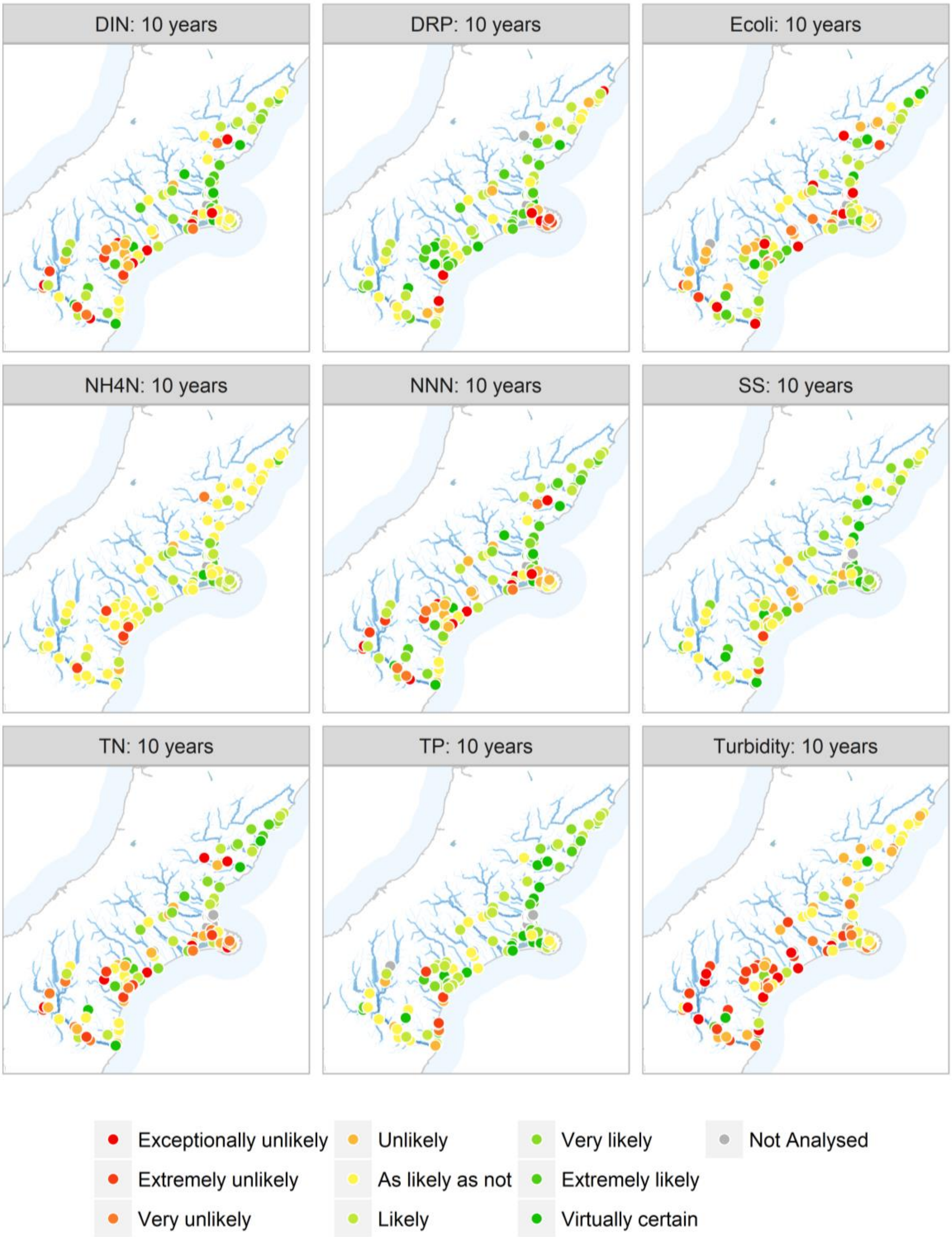

Figure 6. Map of sites classified by their 10-year raw water quality trend probability of improvement. Probability or improvement is expressed in terms of levels of confidence defined in Table 4. Abbreviated variable names are explained in Table 1.

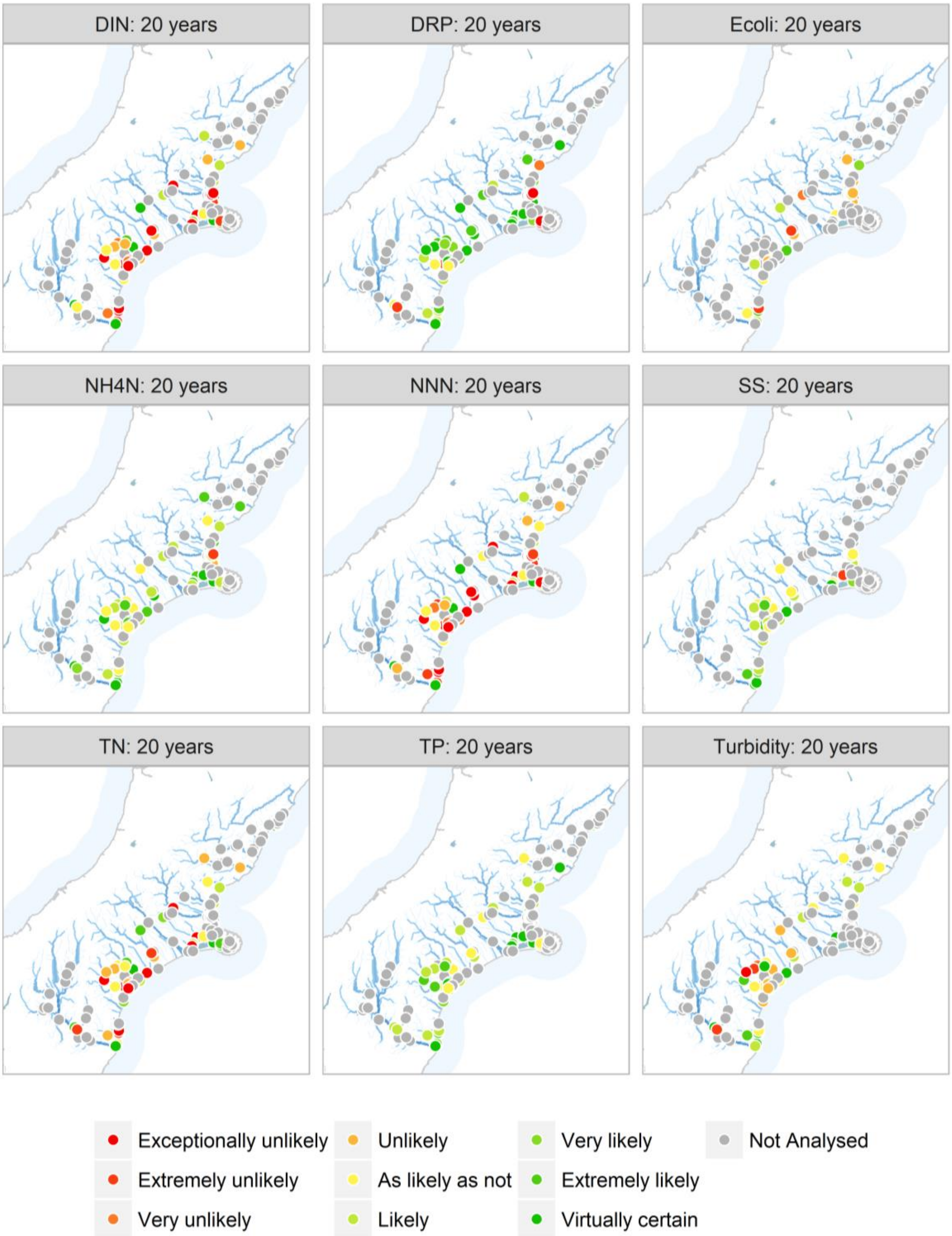

Figure 7. Map of sites classified by their 20-year raw water quality trend probability of improvement. Probability or improvement is expressed in terms of levels of confidence defined in Table 4. Abbreviated variable names are explained in Table 1.

4.2.3 Aggregate Trends

Figures 8, 9 and 10 show the proportion of all sites by variable, for which 5, 10 and 20-year (respectively) water quality trends indicated improvement at the nine categorical levels of confidence defined in Table 4. These plots allow an overall impression of the relative proportion of improving versus degrading sites to be formed by comparing the relative amounts of green and red in each bar. The probabilistic estimates of the proportion of improving site trends and the standard errors of these estimates derived by Monte Carlo analysis for the three time-periods are summarised in Table 8.

The probabilistic estimate of the proportion of sites with improving 5-year trends indicated that 60% or more of sites had improving trends for all variables. The variables with the largest proportion of improving sites were DRP (80%), DIN (79%), NNN (77%), Turbidity and SS (76%), TN and TP (75%), NH4N (67%) and E. coli (60%).

In broad terms, the results indicate that more degradation occurred over the 20-year period than the more recent periods (i.e., a smaller proportion of sites were degrading for the most recent 5 years compared to the 20-year period). The 5-year trends had a greater percentage of improving sites compared to those for the twenty-year trends for NNN (77% increasing for 5 years compared to 34% for 20 year), DIN (79% increasing for 5 years compared to 37% for 20 year), TN (75% increasing for 5 years compared to 45% for 20 years), and Turbidity (76% increasing for 5 years compared to 65% for 20 years). It is noted that the differences between the time periods in the proportion of sites with improving trends in DIN, NNN, TN and Turbidity were larger than the uncertainties of the estimated proportions. Differences between the proportion of sites with improving DRP, SS, and *E. coli* trends between the 5-year and 20-year periods were not significant because they were less than the standard errors of the probabilistic estimates. The estimated proportion of improving trends were lower for the 5-year trends compared to the 20-year trends for NH4N (decrease of 10%) and TP (decrease of 11%).

It should be noted that Figures 8, 9 and 10 are based on a different set of sites, which, if the sites are not a random subset of all sites, could potentially lead to misleading inferences being made when comparing these plots. However, to check for this a series of tests were conducted using a subset of sites available across all periods, and the same general pattern of increasing improving trends was observed.

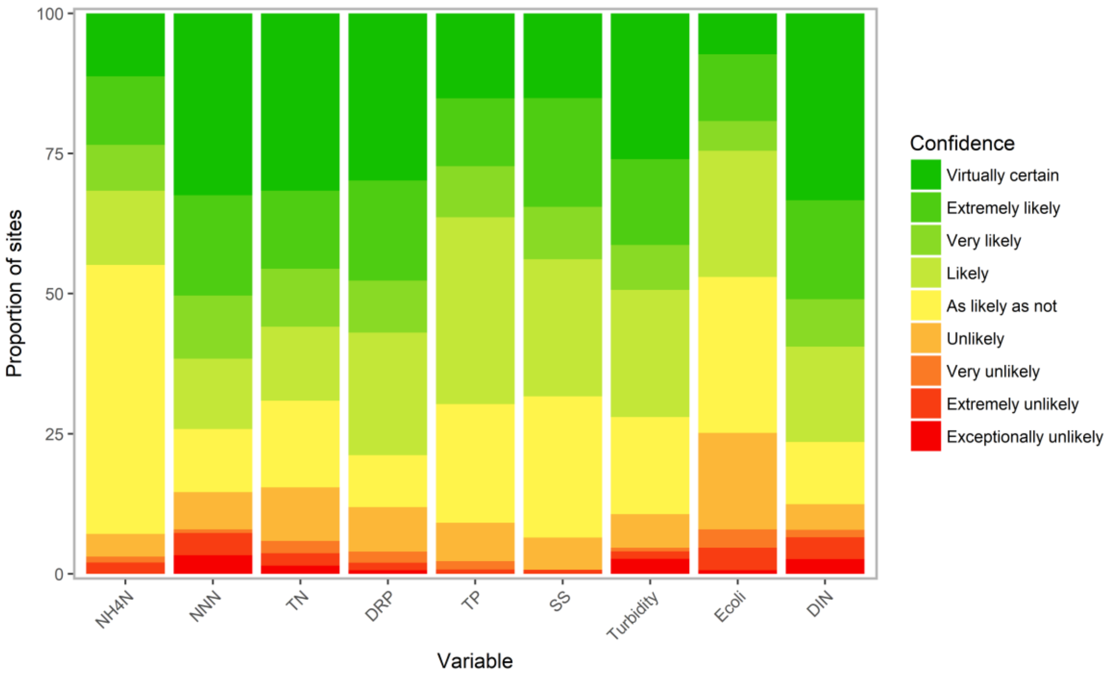

Figure 8. Summary plot representing the proportion of sites with improving 5-year time-period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 4. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Abbreviated variable names are explained in Table 1.

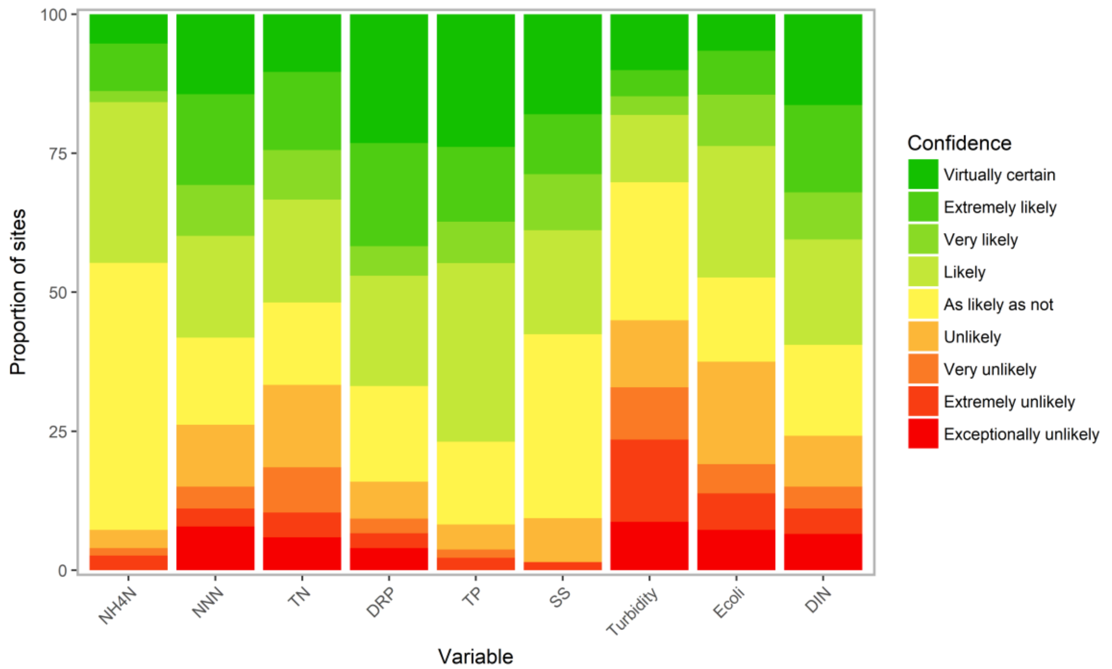

Figure 9. Summary plot representing the proportion of sites with improving 10-year time-period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 4. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Abbreviated variable names are explained in Table 1.

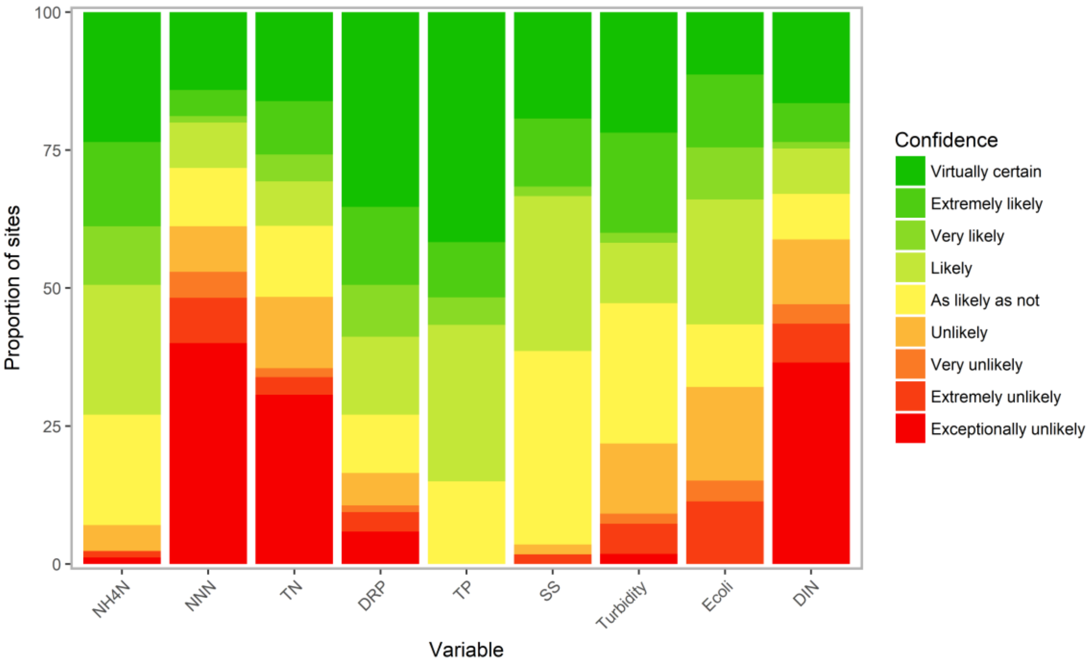

Figure 10. Summary plot representing the proportion of sites with improving 20-year time-period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at levels of confidence defined in Table 4. Green colours indicate improving sites, and red-orange colours indicate degrading sites. Abbreviated variable names are explained in Table 1.

Table 8. Proportion of sites with improving trends for 5, 10 and 20-year time-periods. The probabilistic estimate of the proportion of improving sites and the standard error of this estimate were derived by Monte Carlo analysis. The count-based proportion of improving sites was based on accepting the trend directions at face value. Proportions of degrading sites are 100 minus these values. Abbreviated variable names are explained in Table 1.-

Time Period	Variable	Number of sites	Probabilistic estimate of proportion improving	Standard error of probabilistic estimate	Count estimate of proportion improving
5	NH4N	98	67	4	67
	NNN	151	77	2	79
	DIN	153	79	2	80
	TN	136	75	3	72
	DRP	151	80	2	83
	TP	132	75	3	83
	SS	139	76	3	81
	Turbidity	150	76	3	77
	Ecoli	151	60	3	60
10	NH4N	152	63	3	75
	NNN	153	64	3	64
	DIN	153	65	2	67
	TN	135	59	3	61
	DRP	151	73	3	75
	TP	134	79	3	89
	SS	139	72	3	81
	Turbidity	149	43	3	40
	Ecoli	152	53	3	51
20	NH4N	85	77	4	79
	NNN	85	34	3	33
	DIN	85	37	3	35
	TN	62	45	3	42
	DRP	85	75	3	75
	TP	60	86	4	90
	SS	57	74	5	82
	Turbidity	55	65	5	64
	Ecoli	53	60	4	60

Acknowledgements

We thank Shirley Hayward of Environment Canterbury for provision of the water quality data and advice on the history of the collection and storage of this dataset.

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