State and Trends of River Water Quality in the Manawatū River Catchment

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EXECUTIVE SUMMARY

This study provides a thorough assessment of water quality state and trends in the Manawatū River catchment as part of a detailed report on progress on the Manawatū River Accord to the community by the Manawatū River Leaders' Forum.

Horizons Regional Council has an extensive network of water quality and water flow monitoring sites throughout the Manawatū River catchment for monitoring and reporting on policy effectiveness. Prior to mid-2007, there were fewer monitoring sites in the Manawatū River catchment. Subsequent to July 2007, a suite of monitoring data, including physical, chemical and microbiological water quality variables and biological indicators (invertebrates and periphyton), has been collected at 80 sites on a monthly and annual basis. The majority of these sites (70) are sampled for physical-chemical and microbiological variables on a monthly basis. At some sites, periphyton (biomass, filamentous periphyton cover, and mats periphyton cover) is sampled on a monthly basis, and macro-invertebrates are sampled annually. Cyanobacteria is sampled monthly as part of the periphyton programme. Temperature and dissolved oxygen are measured continuously at 31 and four sites, respectively, most of which are also sampled monthly, but ten of which are dedicated continuous recording sites only. Of the 70 sites that are sampled on a monthly basis, 53 represent State of Environment (SoE) monitoring sites that were chosen to be collectively representative of the water quality conditions in the catchment. The remaining 17 sites Point Source Discharge (PSD) sites, which are located are downstream of point source discharges. These sites are intended to provide information needed to manage the different influences on water quality state and trends.

This study describes water quality state and trends in the catchment on the basis of 19 water quality variables and biological indicators. Nine water quality variables were assessed, comprising physical and chemical variables (clarity, temperature, pH, dissolved oxygen, ammoniacal nitrogen, oxidised nitrogen, dissolved reactive phosphorus, 5-day biological oxygen demand, and particulate organic matter) and a microbiological variable *Escherichia coli* (*E. coli*). Five biological indicators were assessed, including: periphyton biomass (as chlorophyll *a*); proportion of the river bed covered by filamentous periphyton and periphyton mats; the Macroinvertebrate Community Index (MCI); and proportion of the river bed covered by Cyanobacteria.

Water quality state at SoE sites was assessed by comparing the observations of water quality variables and biological indicators at each site with targets that were generally those set by the Horizons One Plan. The state at the SoE sites was graded as ‘pass’ or ‘fail’ for each variable, depending on whether the assessed state met or failed to meet the target.

A trend assessment was carried out for eight sites for the 20-year period ending in July 2013 and for the 5-year period ending in July 2013 for all site and water quality variable combinations, for which 80% of sampling occasions had data. Trends were formally assessed using the non-parametric Seasonal Kendall Sen Slope Estimator (SKSSE) and its associated test of significance. The SKSE quantifies the magnitude and direction of trends while accounting for seasonal patterns in concentrations. Where there was good evidence that concentrations were affected by flow, we carried out the trend analysis on both the raw data and on flow adjusted concentration data. Where there was not good evidence for a relationship between concentration and flow, we carried out the trend analysis on the raw concentration data.

The most obvious pattern associated with the assessment of water quality state was that sites monitored on a monthly basis almost uniformly met or failed to meet certain targets. The toxic contaminant targets for ammonia and nitrate were met at all monthly monitoring sites (i.e. including SoE and PSD sites) with few exceptions. By contrast, monthly monitoring sites for which there were sufficient observations uniformly failed to meet the water clarity target; only three sites met the annual microbial (*E. coli*) target, and only one site met the bathing target for *E.coli*. There was also widespread failure to meet the targets for the nutrients (DRP and SIN) at monthly monitoring sites. In total, 71% and 77% of the sites, failed the DRP and SIN grades, respectively. These failures were broadly distributed over the Manawatū River catchment. The Mangatainoka sub-catchment had the highest proportion of sites passing the nutrient targets, followed by the Oroua sub-catchment.

The assessment of sites monitored for the biological indicators on a monthly basis indicated that for sites with sufficient observations, the majority (79%) met the cyanobacteria grade. The exceptions to this were all located in the Mangatainoka sub-catchment. The majority (67% and 77%) of sites failed two of the periphyton abundance grades (chlorophyll *a* and filamentous cover, respectively). The majority of sites (70%), however, passed the third periphyton abundance grade for cover by mats. The highest proportion of failures for cover by periphyton mats occurred in the Mangatainoka sub-catchment, which was consistent with the high proportion of failures on the cyanobacteria grade in this sub-catchment. Finally, the majority (52%) of sites failed the macroinvertebrate indicator (MCI). These failures were broadly distributed over the entire Manawatū River catchment, although it is notable that all sites in the Middle Manawatū and Pohangina sub-catchments met the MCI target.

Spatial modelling revealed clear association between land-use and water quality state, with poor water quality (high nutrients and faecal pollution, and low visual clarity) being associated with high pastoral land cover. We found that water quality at SoE sites could be well explained and predicted by catchment characteristics such as the proportion of the catchment with heavy pastoral land cover. This suggests the contaminant contributions in the catchment are generally dominated by non-point sources.

A comparison of the data from the Manawatū River catchment with data from 77 sites that comprise the National River Water Quality Network (NRWQN) indicated the Manawatū sites have relatively poor water quality. The NRWQN is broadly representative of large rivers in New Zealand and, therefore, covers a large gradient in catchment land use. Many sites in the NRWQN represent catchments with very little pastoral land use that have correspondingly high proportions of catchment occupied by natural land cover such as indigenous forest. By contrast, the Manawatū River catchment has a very high proportion of land in productive use (e.g. pasture) and a large number of towns and industry that generate point source discharges. Given that water quality at national to regional scales is strongly associated with the proportion of catchment in agricultural production, our finding that water quality is poor in the Manawatū River compared to a representative cross section of large rivers in New Zealand is unsurprising.

The trend analyses indicated that trend strength and direction are variable across sites in the catchment. Where these were significant, trends for the six sites that had 20 years of data were generally for improving water quality. For the 20-year period, we found meaningful decreases in ammoniacal nitrogen, nitrate and dissolved reactive phosphorus at three sites, and only one significant increasing trend for ammoniacal nitrogen. Decreasing concentrations in phosphorus have been observed at many sites across New Zealand. However, decreasing nitrate concentrations are relatively uncommon, as nitrogen generally increases in response to increasing land use intensity, such as conversion of sheep and beef to dairy farming.

The binomial test was used to indicate whether there were ‘overall trends’ in the catchment based on a larger sample of sites for which we evaluated 5-year trends. Where significant, these overall trends were generally for improving water quality at both the SoE and point source discharge sites. However, the exception to this was for periphyton abundance as measured by chlorophyll *a*. It is difficult to understand why periphyton biomass is increasing when a primary driver of biomass, nutrient concentrations, is decreasing. It is well established, however, that many factors influence periphyton (including flows, light and temperature), and these factors may be affecting the periphyton trends. Analysis of flows during the period may shed further light on the causes of the observed trends.

1 INTRODUCTION

The Manawatū River Leaders' Forum signed an accord to take action to improve the state of the Manawatū River in 2010. In November 2013, the Forum resolved to 4present a detailed report on progress to the community in early 2014. As part of this reporting, Horizons Regional Council commissioned a thorough assessment of water quality state and trends in the Manawatū River catchment.

Horizons Regional Council has an extensive network of water quality and water flow monitoring sites throughout the Manawatū River catchment 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 Manawatū River catchment (Roygard *et al.*, 2011). Following a review, a more extensive and detailed monitoring programme commenced in mid-2007. Since that date, a suite of variables, including physical-chemical and microbiological variables and biological indicators, been measured at 80 sites in the catchment. These data represent State of Environment (SoE) monitoring sites and point source discharge monitoring sites. SoE sites were chosen to be collectively representative of the water quality conditions in the catchment. Point source discharge sites provide information needed to evaluate their impacts on water quality state and trends. In the case of periphyton (i.e. slime) monitoring, the underlying design is intended to inform the development of a regional periphyton model (as well as providing state and trend information; Roygard *et al.*, 2011).

This study analysed the available water quality data for the Manawatū River catchment. We report on the state of water quality in the catchment, on a site by site basis, relative to targets set in the One Plan. These targets are relatively new, having been introduced into the planning process in May 2007 (when the plan was notified). The One Plan statutory process is now complete and the targets were finalised as of 2013, although the One Plan is yet to be finalised by the Environment Court. These targets include variables such as nutrient species that were not previously the focus of the region's regulatory efforts. The study also investigated the geographic pattern of water quality state across the catchment, and compared water quality state in the catchment to other rivers nationally. In addition, the study assessed water quality trends site by site and across the catchment as a whole.

2 METHODS

2.1 Obtaining and formatting river water quality and flow data

We obtained water quality data representing physical-chemical and microbiological variables and biological indicators (Table 1) for 80 monitoring sites in the catchment (Figure 1) from the Horizons database. The majority of these sites (70) are sampled for physical-chemical and microbiological variables on a monthly basis (Table 2). At some sites, periphyton (biomass, filamentous periphyton cover, and mats periphyton cover) is sampled on a monthly basis, and macro-invertebrates are sampled annually. Cyanobacteria is sampled monthly as part of the periphyton monitoring. Temperature is measured continuously at 31 sites, most of which are also sampled monthly, but ten of which are dedicated continuous recording sites only. Dissolved oxygen is also measured continuously at four sites. The sites were categorised according to the Accord Sub-catchments (see Table 2) they belonged to.

The majority of 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 2.4.1). 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 2.5.2). Flows for each water quality monitoring site were either measured at a gauge that was located at or close to the monitoring sites or at a ‘proxy’ gauge that may be located some distance away. Proxy gauges were defined for water quality monitoring sites by Horizons hydrologists on the basis of hydrological similarity. Because the flow data were used only for flow adjustment, there was no need to rescale the proxy site flows to estimate the absolute monitoring site flows (i.e. only the flow percentile on the sampling occasion was needed).

Table 1: Water quality variables included in this study

Variable type	Variable name	Description	Units
Physical and chemical	Clarity	Black disc visibility	m
	Temp	Temperature	^{o}C
	pH	Acidity or basicity	-
	DO	Dissolved oxygen	(%SAT)
	NH_4	Ammoniacal nitrogen	mg/L
	NO_x	Oxidised nitrogen	mg/L
	SIN	Soluble inorganic nitrogen	mg/L
	DRP	Dissolved reactive phosphorus	mg/L
	BOD5	5-day biological oxygen demand	mg/L
	POM	Particulate organic matter	mg/L
Microbiological	*E. coli*	*Escherichia coli*	n/100 mL
Biological	Chl a	Periphyton biomass	mg/m^2
	Fils	Filamentous periphyton cover	%
	Mats	Mats periphyton cover	%
	MCI	Macro-Invertebrate Community score	-
	Cyan	Cyanobacteria cover	%

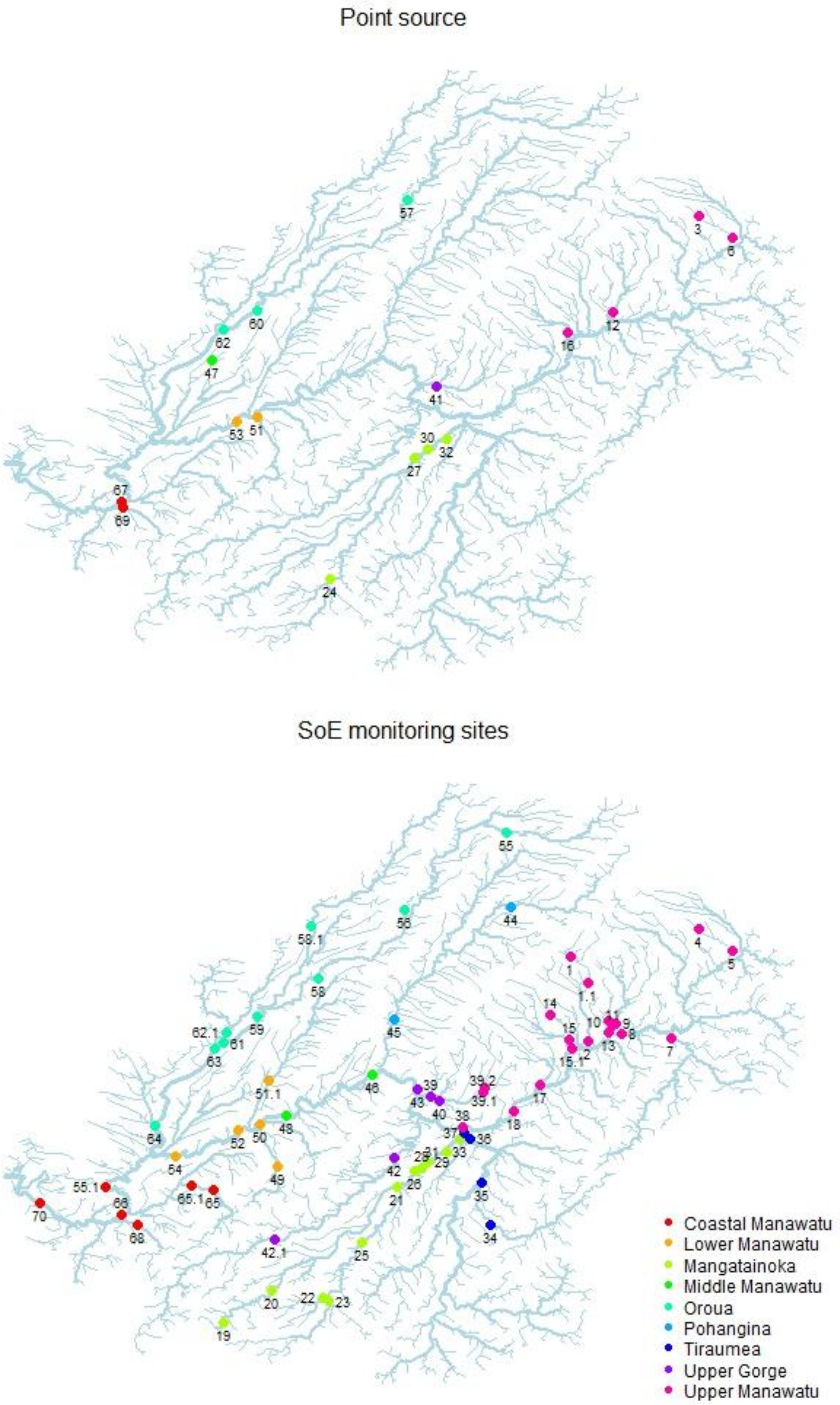

Figure 1: Map of catchment showing location of the SoE and point source monitoring sites classified by their Accord Sub-catchments. See Table 2 for the names and Monitoring Interval of the numbered sites.

Table 2: List of all water quality sites included in the study, including the Accord Sub-catchments they belong to. Sites are classified based on monitoring interval (M=monthly, C=continuous, M&C=monthly and continuously). Sites are also classified as State of Environment (SoE) or Point Source (PS) monitoring.

Site Name	Site Number	Accord Sub-catchment	Monitoring Interval	SoE or PS
Tamaki at Tamaki Reserve	1	Upper Manawatū	M	SoE
Tamaki at Water Supply Weir	1.1	Upper Manawatū	C	SoE
Tamaki at Stephensons	2	Upper Manawatū	M & C	SoE
Mangarangiora trib at ds Norsewood STP	3	Upper Manawatū	M	PS
Mangarangiora Trib at US Norsewood STP	4	Upper Manawatū	M	SoE
Mangarangiora at u/s Ormondville STP	5	Upper Manawatū	M	SoE
Mangarangiora at d/s Ormondville STP	6	Upper Manawatū	M	PS
Mangatoro at Mangahei Road	7	Upper Manawatū	M & C	SoE
Manawatū at Weber Road	8	Upper Manawatū	M & C	SoE
Mangatera at Dannevirke	9	Upper Manawatū	M	SoE
Tapuata at Easton Road	10	Upper Manawatū	M	SoE
Mangatera at u/s T.D.C. Ox Ponds	11	Upper Manawatū	M	SoE
Mangatera at d/s Dannevirke STP	12	Upper Manawatū	M	PS
Mangatera at u/s Manawatū confluence	13	Upper Manawatū	M	SoE
Kumeti at Te Rehunga	14	Upper Manawatū	M & C	SoE
Oruakeretaki at S.H.2 Napier	15	Upper Manawatū	M & C	SoE
Oruakeretaki at Oringi	15.1	Upper Manawatū	C	SoE
Oruakeretaki at d/s PPCS Oringi STP	16	Upper Manawatū	M	PS
Raparapawai at Jackson Rd	17	Upper Manawatū	M & C	SoE
Manawatū at Hopelands	18	Upper Manawatū	M & C	SoE
Mangatainoka at Putara	19	Mangatainoka	M	SoE
Mangatainoka at Larsons Road	20	Mangatainoka	M & C	SoE
Mangatainoka at Scarborough Konini Rd	21	Mangatainoka	M	SoE
Ngatahaka Stream at u/s Makakahi Confl	22	Mangatainoka	M	SoE
Makakahi at u/s Eketahuna STP	23	Mangatainoka	M	SoE
Makakahi at d/s Eketahuna STP	24	Mangatainoka	M	PS
Makakahi at Hamua	25	Mangatainoka	M & C	SoE
Brechin at u/s Fonterra Pahiatua	26	Mangatainoka	M	SoE
Brechin at d/s Fonterra Pahiatua	27	Mangatainoka	M	PS
Mangatainoka at Pahiatua Town Bridge	28	Mangatainoka	M & C	SoE
Mangatainoka at u/s Pahiatua STP	29	Mangatainoka	M	SoE
Mangatainoka at d/s Pahiatua STP	30	Mangatainoka	M	PS
Mangatainoka at Brewery - S.H.2 Bridge	31	Mangatainoka	M	SoE

Site Name	Site Number	Accord Sub-catchment	Monitoring Interval	SoE or PS
Mangatainoka at d/s DB Breweries	32	Mangatainoka	M	PS
Mangatainoka at u/s Tiraumea confluence	33	Mangatainoka	M	SoE
Makuri at Tuscan Hills	34	Tiraumea	M	SoE
Tiraumea at Ngaturi	35	Tiraumea	M & C	SoE
Tiraumea River at Haupokua Reserve	36	Tiraumea	M	SoE
Tiraumea u/s Manawatū Confluence	37	Tiraumea	M	SoE
Manawatū at Ngawapurua Bridge	38	Upper Manawatū	M	SoE
Mangapapa at Troup Rd	39	Upper Gorge	M & C	SoE
Manga-atua at Hopelands Rd	39.1	Upper Manawatū	C	SoE
Manga-atua at Hutchinsons	39.2	Upper Manawatū	C	SoE
Mangaatua at u/s Woodville STP	40	Upper Gorge	M	SoE
Mangaatua at d/s Woodville STP	41	Upper Gorge	M	PS
Mangahao at Ballance	42	Upper Gorge	M & C	SoE
Mangahao at Kakariki	42.1	Upper Gorge	C	SoE
Manawatū at Upper Gorge	43	Upper Gorge	M & C	SoE
Pohangina at Piripiri	44	Pohangina	M & C	SoE
Pohangina at Mais Reach	45	Pohangina	M & C	SoE
Manawatū at u/s Ashhurst STP	46	Middle Manawatū	M	SoE
Manawatū at d/s Ashhurst STP	47	Middle Manawatū	M	PS
Manawatū at Teachers College	48	Middle Manawatū	M & C	SoE
Kahuterawa at Johnstons Rata	49	Lower Manawatū	M & C	SoE
Manawatū at u/s PNCC STP	50	Lower Manawatū	M	SoE
Manawatū at d/s PNCC STP	51	Lower Manawatū	M	PS
Mangaone at Milson Line	51.1	Lower Manawatū	C	SoE
Manawatū at us Fonterra Longburn	52	Lower Manawatū	M	SoE
Manawatū at ds Fonterra Longburn	53	Lower Manawatū	M	PS
Manawatū at Opiki Br	54	Lower Manawatū	M	SoE
Oroua at Apiti	55	Oroua	M	SoE
Oroua Trib at u/s Kimbolton STP	56	Oroua	M	SoE
Oroua Tributary at d/s Kimbolton STP	57	Oroua	M	PS
Oroua at Almadale Slackline	58	Oroua	M & C	SoE
Kiwitea at Haynes Line	58.1	Oroua	C	SoE
Oroua at U/S AFFCO Feilding	59	Oroua	M	SoE
Oroua at d/s AFFCO Feilding	60	Oroua	M	PS
Oroua at U/S Feilding STP	61	Oroua	M	SoE
Oroua at d/s Feilding STP	62	Oroua	M	PS
Makino at Boness Road	62.1	Oroua	C	SoE
Oroua at Awahuri Bridge	63	Oroua	M	SoE
Oroua at Mangawhata	64	Oroua	M	SoE
Manawatū at Moutoa	55.1	Coastal Manawatū	C	SoE
Tokomaru River at Horseshoe bend	65	Coastal Manawatū	M	SoE
Tokomaru at Riverland Farm	65.1	Coastal Manawatū	C	SoE
Manawatū at u/s PPCS Shannon	66	Coastal Manawatū	M	SoE

Site Name	Site Number	Accord Sub-catchment	Monitoring Interval	SoE or PS
Manawatū at d/s PPCS Shannon	67	Coastal Manawatū	M	PS
Mangaore at u/s Shannon STP	68	Coastal Manawatū	M	SoE
Mangaore at d/s Shannon STP	69	Coastal Manawatū	M	PS
Manawatū at Whirokino	70	Coastal Manawatū	M	SoE

We formatted the data as time series of observations of water quality variables and flows on specified dates for each site. The time series increments varied between the variables, depending on the sampling regime as described above. The starting and ending dates differed between sites, and some sample dates were missing for some sites (Figure 2). Missing data for black disc or periphyton generally occur when sites were not able to be sampled on the designated sampling occasion, normally due to high flows. Missing data for chemical variables generally occur due to problems associated with their laboratory analysis.

Temporal coverage of samples for clarity at three sites in the catchment is shown in Figure 2. Gaps in temporal coverage are white, and sample occasions with data are grey. The three sites typify the different types of time series that are available for the catchment. First, there were 19 sites that were monitored prior to 2007. Of these, eight have 20 or more years of monthly data, and four of these, all on the main stem of the Manawatū River, have 24 years of record (dating back to 1989). Three of these sites belong to the National River Water Quality Network (NRWQN). Second, there are permanent sites for which continuous monthly monitoring began after mid-2007. These make up the majority (51) of the 70 water quality monitoring sites in the catchment. Many rolling sites became sites that are now monitored on a continuous monthly basis. The third type are sites that were monitored on a 'rolling site' basis until mid-2007. Rolling sites were monitored for one year in three, this being a strategy to increase spatial coverage without increasing the total sampling effort. The rolling site strategy was abandoned in 2007, primarily because time series that are complete for only one year in three cannot be robustly analysed for trends.

Horizons Regional Council changed the analytical methods for several variables after September 2012 to bring the laboratory analysis into line with best practice nationally for trend analysis (Davies-Colley, 2012). These changes resulted in changes to the detection limits and, therefore, some recorded values post-September 2012 were less than the detection limit prior to September 2012 (the 'assumed detection limit'). For ammoniacal nitrogen, the detection limit increase post-2012, but raw values were provided by the laboratory and provided estimates of concentrations below the detection limit. These changes could confound trend analyses if the data are not adjusted to account for changes to the detection limits. We therefore replaced values post-September 2012 that were less than the assumed detection limit with the assumed detection limit. (Table 3).

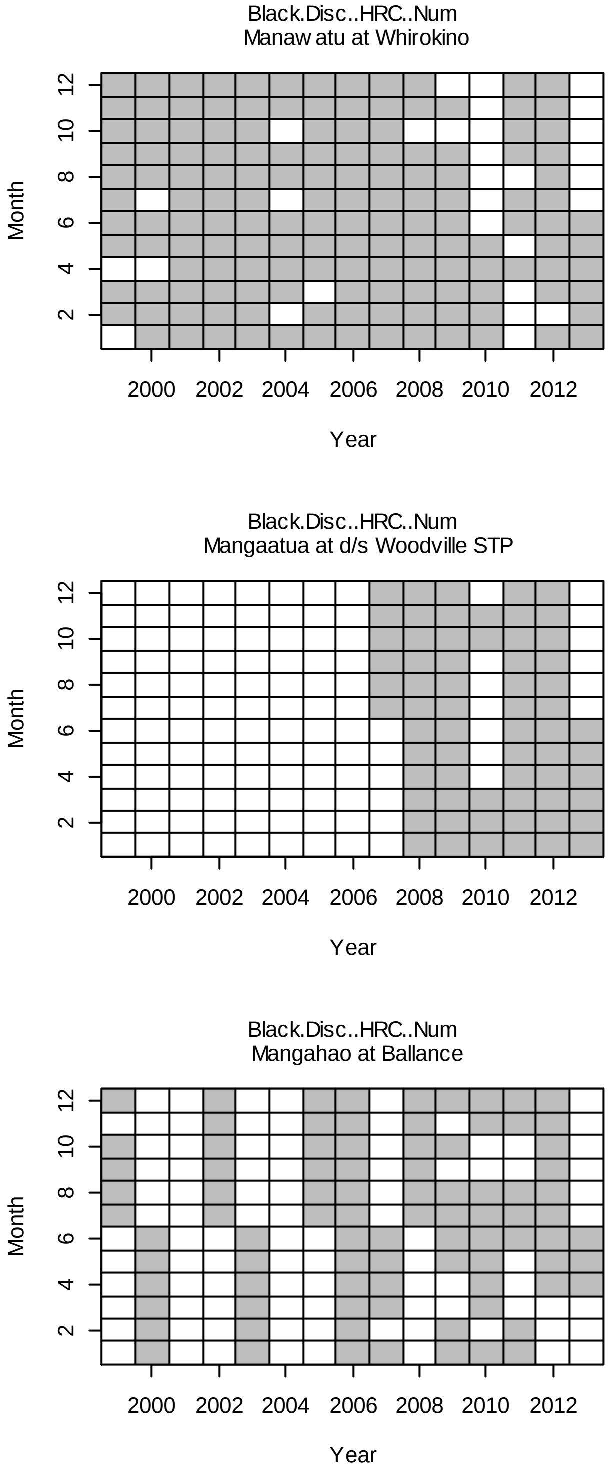

Figure 2: Typical time series (years on the horizontal axis and months on the vertical axis) showing when data was present (in grey) for water clarity as measured by black disc at three sites.

Table 3: Assumed detection limits for the recorded data.

Variable	Detection limit	Units
NH_4[1]	0.005	mg/L
DRP	0.005	mg/L
E. coli	1	MPN/100ml
NO_x	0.002	mg/L
BOD	1	mg/L
POM	3	mg/L

1. The detection limit post-September 2012 was 0.01, whereas previously it had been 0.005. Raw values post-September 2012 that were less than 0.005 were set to half the previous detection limit (i.e. 0.0025).

2.2 Water quality variables

We used a total of 19 variables, comprising physical, chemical and microbiological water quality variables and biological indicators (Table 5). Nine water quality variables were assessed, comprising physical and chemical variables (clarity, temperature, pH, dissolved oxygen, ammoniacal nitrogen, oxidised nitrogen, dissolved reactive phosphorus, 5-day biological oxygen demand, and particulate organic matter) and a microbiological variable Escherichia coli (E. coli). Five biological indicators were assessed, including periphyton biomass (as chlorophyll a), proportion of the river bed covered by filamentous periphyton, periphyton mats or cyanobacteria, and the Macroinvertebrate Community Index (MCI).

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 for smothering the beds of rivers and downstream water bodies. Visual clarity is generally measured as the sighting range of a black disc (MfE, 1994). Low visual clarity has ecosystem effects, including changes in animal behaviour. Water clarity also has implications for contact recreation due to its effect on human visibility through water.

Water temperature affects aquatic ecosystem health because it influences equilibrium points (for instance, the solubility of dissolved oxygen) and the rates of physic-chemical reactions (for instance, the rate of consumption of dissolved oxygen by bacterial respiration). Temperature also 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 Olsen *et al.*, 2012), leading to the establishment of environmental targets for maximum water temperature. Spot measurements of temperature are not particularly useful 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 17 point source discharges, and compared these changes with targets (see Section 2.4.1). We also evaluated state with respect to temperature at 31 sites where continuous temperature records were available.

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, 2013). This means that spot (i.e. once per month samples) of dissolved oxygen and pH are not particularly useful as SoE variables because they must be interpreted with reference to the time of day that the sample was taken. In this study, we evaluated the change in dissolved oxygen and pH between sample locations that were upstream and downstream of 17 point source discharges, and compared these changes with targets (see Section 2.4.1). We also evaluated state with respect to dissolved oxygen at four sites where continuous dissolved oxygen records were available.

The two nutrient species (soluble inorganic nitrogen [SIN], and dissolved reactive phosphorus [DRP]) were included because they stimulate the growth of plants, including periphyton (slime), which in the Manawatū River tends to be attached to substrates. Nutrient contamination 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 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 nitrogen are toxicants that can adversely affect ecosystems. There are, therefore, environmental targets for these contaminants related to these toxic effects. It is noted that toxic effects are generally associated with concentration of nitrate and ammoniacal nitrogen that are significantly higher than levels that are problematic from the point of view of nuisance growth of plants.

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

Prior to 2007, Biological Oxygen Demand (BOD) was monitored at all sites in the catchment. Historically, the Manawatū River catchment had issues with BOD, including fish kill events. Monitoring of BOD therefore continued under the revised monitoring programme that commenced in July 2007. However, the monitoring was gradually reduced as levels decreased, and were generally less than the analytical detection limit. BOD is still monitored at some point source discharge sites (i.e. at the SoE site upstream and the site downstream of discharge points) as required by specific consent conditions. Similarly, Particulate Organic Matter (POM) was formerly monitored quite extensively throughout the catchment, but is now only monitored at point source discharge sites. These two contaminants are, therefore, only reported in relation to point source discharge, and not SoE, sites.

The abundance of periphyton is an indicator of trophic state for gravel bed rivers, which comprise a large proportion of the Manawatū river catchment. Eutrophic states in rivers are associated with frequent high abundance of periphyton ('blooms'). Eutrophic states affect ecosystem health by causing adverse fluctuations in dissolved oxygen and pH, smothering habitat, and altering invertebrate communities (Snelder *et al.*, 2013). Eutrophic conditions 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.MfE, 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.

The most common and problematic mat-forming cyanobacteria genus in the Manawatū River catchment 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 past seven years 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* (MfE & MoH, 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.

Macro-invertebrates 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. Invertebrate organisms are 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 macro-invertebrate community (MCI) scores, which are widely used for environmental monitoring in New Zealand (Stark & 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 & Maxted, 2007).

2.3 Types of monitoring sites

We define two key types of monitoring sites: state of environment (SoE) and point source discharge (PSD). Collectively, SoE sites broadly represent the Manawatū River catchment. These sites represent a range of environments that are common in the catchment, including headwater streams, mid-catchment rivers and the main-stem of the Manawatū River. Of the 70 monitoring sites, 53 are classified as SoE sites, and the remaining 17 are point source discharge sites.

PSD sites are locations that are immediately downstream (i.e. at the end of the mixing zone) of major point sources. These PSD sites are each paired with a corresponding SoE site that is immediately upstream of the discharge. Table 4 shows the 17 major point source discharges and the associated PSD site and paired upstream SoE site.

Table 4: Major point source discharges in the Manawatū River catchment and their associated PSD site and paired upstream SoE site. STP refers to discharges from sewage treatment plants.

Discharge	Downstream PSD site	Upstream SoE site
Ormondville STP	Mangarangiora at d/s Ormondville STP	Mangarangiora at u/s Ormondville STP
Norsewood STP	Mangarangiora trib at ds Norsewood STP	Mangarangiora Trib at US Norsewood STP
Dannevirke STP	Mangatera at d/s Dannevirke STP	Mangatera at u/s T.D.C. Ox Ponds
Scan Power STP	Oruakeretaki at d/s PPCS Oringi STP	Oruakeretaki at S.H.2 Napier
Woodville STP	Mangaatua at d/s Woodville STP	Mangaatua at u/s Woodville STP
Eketahuna STP	Makakahi at d/s Eketahuna STP	Makakahi at u/s Eketahuna STP
Fonterra Pahiatua Condensate	Brechin at d/s Fonterra Pahiatua	Brechin at u/s Fonterra Pahiatua
Pahiatua STP	Mangatainoka at d/s Pahiatua STP	Mangatainoka at u/s Pahiatua STP
DB Breweries	Mangatainoka at d/s DB Breweries	Mangatainoka at Brewery - S.H.2 Bridge
Ashhurst STP	Manawatū at d/s Ashhurst STP	Manawatū at u/s Ashhurst STP
Palmerston North STP	Manawatū at d/s PNCC STP	Manawatū at u/s PNCC STP
Fonterra Longburn and Longburn STP	Manawatū at ds Fonterra Longburn	Manawatū at us Fonterra Longburn
Kimbolton STP	Oroua Tributary at d/s Kimbolton STP	Oroua Trib at u/s Kimbolton STP
AFFCO Feilding	Oroua at d/s AFFCO Feilding	Oroua at U/S AFFCO Feilding
Feilding STP	Oroua at d/s Feilding STP	Oroua at U/S Feilding STP
Silver Fern Farms Shannon STP	Manawatū at d/s PPCS Shannon	Manawatū at u/s PPCS Shannon
Shannon STP	Mangaore at d/s Shannon STP	Mangaore at u/s Shannon STP

2.4 Assessment of water quality state

2.4.1 Grading of SoE sites

The grading of water quality state at SoE sites involved comparing the observations of water quality variables and biological indicators at each site with targets that were generally those set by the Horizons One Plan. Targets for two variables (nitrate and benthic cyanobacteria) were not obtained from the Horizons One Plan, but rather from the proposed National Objectives Framework (NOF)[1].

[1] The National Policy Statement for Freshwater Management 2011 (NPS-FW) was issued under the Resource Management Act 1991. It recognises freshwater management as a nationally significant issue requiring central government direction. In November 2013, the government proposed amendments to the NPS-FW which among other things, proposes a National Objectives Framework (NOF). The NOF specifies a minimum set of nationally applicable values and associated water quality attributes for freshwater bodies that councils need to manage for. The NOF defines four attribute states or ‘bands’ (A, B, C or D), which represent differing levels of protection for national values. A region may choose to manage to band A, B or C (i.e. to maintain or improve), depending

The grading assessments were made for a 5-year period ending in July 2013. The end date for this period was determined by the availability of quality assured information that was loaded in the Horizons database. The duration of the period represents a trade-off between recent data that reflects current conditions and statistical robustness.

The details of the targets for each water quality variable include a threshold value and a method for comparing observations to the threshold, which are summarised in Table 5. Each of the targets used one of two methods for comparing observations to the threshold. The first method compared all observations (i.e. all values in the time series) with the threshold. If any observation fell outside the threshold, the site was deemed to fail. This method was used where the Horizons One Plan targets are expressed as an absolute limit on any observation (e.g. the temperature of the water must not exceed; Table 5). The second method compared a statistic describing the distribution of site observations (e.g. the mean, median, or the 80th percentile) with the threshold. If the relevant statistic fell outside the threshold, the site was deemed to fail.

The actual thresholds for many variables vary by site based on varying expectations for environmental outcomes that have been established by the Horizons One Plan (details are provided in Appendix A). 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).

Several of the Horizons One Plan targets consider only sampling occasions associated with specified dates or flows (Table 5). 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 5) 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 5.

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 target because the confidence that the assessment is ‘correct’ (i.e. that the site has been correctly classified as either passing or failing) increases as the number of samples 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 samples, where samples that are counted for some variables are for flows below the 50th percentile). Although the adoption of the 5-year period is

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on the local context and on national and community aspirations. The D-band represents an unacceptable state, and councils would be required to improve water quality in locations in this state to at least the C-band. For further information: http://www.mfe.govt.nz/publications/water/freshwater-reform-2013/.

nominal, we imposed minimum sample size requirements on all assessments of sites against targets to be transparent (Table 5). We nevertheless did make assessments for site by variable combinations that did not meet the required minimum sample size and indicated that the confidence in these assessments is less than those that met the nominated minimum sample size. In addition, for some variables, the nominated minimum sample size requirement had to be relaxed from 30 because this condition would never be met. Notable examples are Ecoli.Bath (minimum sample size of 15) and MCI (minimum sample size of 5) (Table 5). This means that our confidence in the classification of the sites (i.e. pass or fail) is generally lower for variables with lower sample size requirements.

The Horizons One Plan has nitrogen targets that are associated with managing the trophic state of the Manawatū River and its tributaries. Nitrate is also toxic to fish species at concentrations that are generally much higher than those that are associated with eutrophication. As such, the Horizons One Plan does not specified nitrate toxicity targets. As well as applying the Horizons One Plan targets for management on trophic state (i.e. the SIN target), we also graded sites based on nitrate toxicity targets that were based on the proposed National Objectives Framework (NOF). For each ‘attribute’ proposed in the NOF, there are four ‘attribute states’, which are designated A to D. The D attribute state represents a concentration (in the case of nitrate) that is unacceptable in any water-body nationally, and attribute states C, B and A represent progressively higher levels of protection against toxic effects of nitrate that could be adopted by regions or communities, depending on aspirations for water quality. We adopted the boundary between the C and D attribute states as the grading target for nitrate toxicity because, if the NOF is implemented as proposed, this would become mandatory.

Assessments of benthic cyanobacteria (i.e. cyanobacteria growing attached to the bed of rivers and streams as opposed to suspended in the water column) were undertaken using a target that was based on thresholds suggested in the *New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters* (MfE & MoH, 2009). The Guidelines suggest a benthic cyanobacteria threshold of less than 20% coverage of the river bed substrate by potentially toxigenic cyanobacteria. 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 this when determining the ‘state’ of a river prevented appropriate assessment. 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), and used a sample statistic to assign a grade for planktonic cyanobacteria for secondary contact recreation. This statistic was the 90th percentile of monthly observations (including winter observations), based on the methods proposed for the NOF. For this analysis, we calculated the 90th percentile from all available data (ca. 3 years).

Table 5: Details of the Horizons One Plan targets for each water quality variable used to grade the state of the SoE.

Target name	Method[1]	Flow percentile[2]	Sample size required	Target description[3]
Temp	All	100	30	The temperature of the water must not exceed […] degrees Celsius.
DO	All	100	30	The Dissolved oxygen (DO) must exceed […]% of saturation.
BOD	All	20	30	The monthly average five days' filtered/soluble carbonaceous biochemical oxygen demand when the river flow is at or below the 20th flow exceedance percentile must not exceed […] grams per cubic meter.
POM	Mean	100	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	20	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	20	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 nitrogen must not exceed […] grams per cubic metre.
NH4.Max	All	100	30	The maximum concentration of ammoniacal nitrogen must not exceed […] grams per cubic metre.
NOx	Median	100	30	The median concentration of nitrate must not exceed 6.9 grams per cubic metre.
NOx.95	95	100	30	The 95th percentile concentration of nitrate must not exceed 9.8 grams per cubic metre.
Clar	All	100	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.
Ecoli.Bath	All	50	15	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	20	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 […].

Target name	Method[1]	Flow percentile[2]	Sample size required	Target description[3]
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	90	100	20	The 90th percentile of potentially toxigenic cyanobacteria attached to substrate cover by must not exceed 20%.

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.

2.4.2 Grading of point source discharge monitoring sites

The grading of water quality state at point source discharge sites involved two types of comparisons. First, the observations at the sites downstream of the discharges were compared to the targets set out in Table 5. Second, for the water quality variables set out in Table 6, the difference between the paired upstream and downstream sites (Table 4) were determined and compared against specific thresholds for change set by the Horizons One Plan. If the observations were within the threshold for change, the site was classified as a pass, otherwise it was classified as failing. The details of the grading procedure for each water quality variable is summarised in Table 6. For all standards, 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 B.

Table 6: 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.

2.4.3 Water quality state at continuous monitoring sites

The approach adopted for assessing sites at which water temperature and DO had been continuously monitored was based on the proposed NOF (Davies-Colley *et al.*, 2013; MfE, 2013). It is likely that these attributes will become part of future amendments to the NOF (MfE, 2013).

The proposed NOF Attribute states for the temperature and DO attributes draw on overseas protocols for assessing habitat conditions, as well as experimental data describing the sensitivity of indigenous and exotic species exposed to extreme values of the two variables, for specific periods (Davies-Colley *et al.*, 2013). A comprehensive review of temperature criteria for New Zealand native fauna by Olsen *et al.* (2012) has provided the basis for proposing temperature thresholds. An A/B ('no effect') temperature threshold of 18°C and a C/D ('bottom line') threshold of 24°C have been proposed (Davies-Colley *et al.*, 2013). The proposed NOF limits for temperature and DO require continuous observations (i.e. 15 minute) for the specified summer periods of 1 December – 31 March, and 1 November – 30 April, respectively. Daily minimum, maximum and mean temperature and DO values were provided for 31 and 4 continuously monitored sites within the Manawatū River catchment, respectively.

The continuous temperature monitoring sites were graded based on the proposed NOF limits for temperature in rivers and streams in 'Maritime' regions of New Zealand. The alternate NOF limits are for 'Eastern Dry' regions, and do not apply to the Manawatū River catchment. The analysis of temperature used the Cox-Rutherford Index (CRI) (Cox & Rutherford, 2000). The CRI links single (constant) temperature criteria for species to an index that summarises the diurnally varying temperature regimes. The CRI is the average of the daily maximum and the daily mean temperatures. It will generally be greatest (i.e. the likelihood of thermal stress is greatest) on clear (cloud-free) days when solar radiation is maximal and the amplitude of diel fluctuation is greatest. The CRI values for different NOF Attribute states are given in Table 7.

Table 7: Proposed NOF Attribute state thresholds for temperature regime in rivers and streams in 'Maritime' regions of New Zealand in summer. Summer is defined as the period 1 December – 31 March) (Source: Davies-Colley et al., 2013)

Attribute state	Numeric Attribute state (°C)	Description of habitat conditions
A/B	≤18	No thermal stress for any aquatic organisms present at matched reference (near-pristine) sites
B/C	≤20	Minor thermal stress on occasion on particularly sensitive organisms.
C/D	≤24	Some thermal stress on occasion, with elimination of certain sensitive insects and absence of certain sensitive fish.
National bottom line		
D (unacceptable)	>24	Significant thermal stress on a range of aquatic organisms. Risk of local elimination of keystone species with loss of ecological integrity.

The CRI was applied to the five warmest water temperatures (from inspection of the continuous record) during summer, defined to be the period of 1 December – 31 March. Because protocols for grading sites based on continuous temperature data have not been fully developed (Davies-Colley *et al.*, 2013), we conducted the assessment in two ways: (1) using all of the summer data from 1 December 2005 – 31 March 2013 to obtain the worst result, and (2) calculating the average of each summer's CRI value to get a 'typical' or 'average' CRI value. The daily maximum and mean water temperatures from each summer's warmest water 5-day period were then combined to calculate CRI values. The mean 5-day CRI values were used to give the worst case and average results

The four sites with continuously monitored dissolved oxygen data were also graded based on the proposed NOF attribute states. The analysis was conducted for each site by extracting the daily minimum DO concentrations and 7-day average minimum values during the defined summer period of 1 November – 30 April. These values were compared with the NOF DO thresholds (MfE, 2013) and sites assigned to attribute states A, B, C or D. The DO values for different NOF attribute states are shown in Table 8.

Table 8: Proposed NOF Attribute state thresholds for DO in rivers (MfE, 2013).

Attribute state	Numeric Attribute state (mg/L) 7-day mean minimum in summer*	1-day minimum in summer*	Description
A/B	>8.0	>7.5	No stress caused by low DO on any aquatic organisms that are present in matched reference sites.
B/C	7.0–8.0	5.0–7.5	Occasional minor stress on sensitive organisms caused by short periods of low DO.
C/D	5.0–7.0	4.0–5.0	Moderate stress on a number of aquatic organisms caused by DO falling below preference levels for several hours each day.
National bottom line	5.0	4.0	
D	<5.0	<4.0	Significant, persistent stress on a range of aquatic organisms caused by DO falling below tolerance levels. Risk of extinctions of keystone species and loss of ecological integrity.

*Summer is defined for DO to be the period 1 November – 30 April

2.4.4 Water quality state in Manawatū River catchment compared with national data

We compared water quality in the Manawatū River catchment with a set of sites that represent national water quality (i.e. across New Zealand). Sites belonging to the National River Water Quality Network (NRWQN) (Smith & Maasdam, 1994), which comprise 77 sites, were used to represent national water quality. We note that three of these sites are within the Manawatū River catchment.

We evaluated the median concentration of SIN, DRP, NO_x, NH_4, *E. coli* and the median Clarity for all sites in the NRWQN and the admissible sites in the Manawatū River catchment. Density plots were used to compare the distributions of the site medians for the NRWQN sites and the HRC sites. A density plot is similar to a histogram, and shows the frequency of the values that are represented in a distribution. Density plots are more useful for comparing two distributions than histograms, as they represent the distribution as a line; hence the two distributions being compared can be drawn on the same plot.

2.4.5 Spatial models of water quality state

We generated spatial models of water quality in the Manawatū catchment to characterise variation in water quality at catchment and sub-catchment scale, and to gain insight into the important environmental drivers of this variation. We restricted these analyses to the five most consistently measured water quality variables (Clarity, DRP, *E. coli*, NH_4, NO_X), all of which were measured at least 30 times over the 5-year period ended July 2013, and hence were assumed to yield robust estimates of site-specific medians. Sites immediately below point source discharges (Table 4) were excluded from these analyses, in favour of the paired SOE site immediately upstream, reducing the number of modelled sites from 70 to 53. We used the spatial modelling approach of Unwin *et al.* (2010) to extrapolate these observations to the whole Manawatū River catchment in several steps that are described below.

The rivers and streams of the Manawatū River catchment were represented by a digital river network that was obtained from the River Environment Classification (REC) (Snelder & Biggs, 2002). The REC represents the drainage path map for the country derived from a Digital Elevation Model (DEM). The network has a spatial resolution of 50 m, and comprises approximately 570,000 unique river segments defined by upstream and downstream confluences with tributaries, with a mean segment length of 740 m. Each segment is associated with its upstream catchment, also derived from the DEM. The REC represents the Manawatū River catchment and its associated sub-catchments as a network of 12,377 reaches, with the lower 121 km of the mainstem below the Mangatainoka confluence attaining 7th order.

We used Random Forest (RF) regression modelling to model the site medians of each water quality variable as a function of eight predictor variables obtained from the REC (Table 9). These variables had previously been derived by combining the network with a Geographic Information System (GIS) database describing the climate, topography, geology, land cover and hydrology of New Zealand (Wild *et al.*, 2005), and were largely catchment average values of environmental variables such as rainfall, temperature, slope, geological characteristics, and land cover. Additional predictors for each segment were derived from models (e.g. mean flow estimates; Woods *et al.*, 2006). Further predictor variables are potentially available, with up to 28 being used for the national scale models on which our analyses were based (Unwin *et al*., 2010). But with only 53 data points for each water quality variable, we wished to keep our predictor set as small as possible to minimise the risk of over-fitting. All of the variables listed in Table 9 are strongly associated with spatial variability in water quality over national and regional scales (Unwin *et al*., 2010), suggesting that they are also likely to be important at the sub-catchment scale.

Table 9: Variables used as predictors by the random forest spatial models.

Variable	Description
% indigenous forest	Proportion of catchment under indigenous forest land-cover
% heavy pastoral	Proportion of catchment under heavy pastoral land-cover
Minimum temperature	Minimum annual temperature, upstream catchment
Flow	Modelled mean flow
Rainfall variability	Coefficient of variation of annual rainfall, upstream catchment
% alluvium	% of alluvial gravel in upstream catchment
Reach elevation	Mean reach elevation
Catchment elevation	Mean elevation of upstream catchment

We fitted RF models to the median concentrations of the observations of the water quality variables, and compared the independent predictions of the site values to the observations at all sites in order to evaluate the performance of each model. More details of the performance measures are provided by Unwin *et al.* (2010). To examine the nature of the resulting RF models, we used importance scores and partial dependence plots (Breiman, 2001). Importance scores indicate how much the predictive performance of the model decreases if a specific predictor is not used. It is a measure of how strongly each predictor contributes to the accuracy of the model. Partial dependence plots show the marginal effect of a variable on the response after accounting for the average effects of the other variables in the model. These plots do not perfectly represent the effects of each variable, particularly when predictors are highly correlated or strongly interacting, but provide useful information for interpretation (Breiman, 2001).

2.5 Trends

2.5.1 Statistical analysis

Trends were assessed for two time periods. First, trends were assessed for the 5-year period ending in July 2013. This period is the shortest that trends are commonly evaluated for and corresponds to the longest period of continuous monthly observations for the majority of the 70 monthly monitoring sites in the catchment. As discussed in Section 2.1, there are eight sites in the catchment that have at least 20 years of monthly data. Trends were therefore evaluated for the 20-year period ending July 2013 for these eight sites.

Trends in water quality variables can be evident when the data are viewed graphically. For example, Figure 3 shows time series for NO_x, DRP and Clarity collected over the 5-year period at a site. Trends at all sites and variable combinations that were formally assessed using the non-parametric Seasonal Kendall Sen Slope Estimator (SKSE) (Sen, 1968). The SKSE is used to quantify the magnitude and direction of trends in data that are subject to appreciable seasonality such as water quality data. Regional councils commonly use the Time Trends software (http://www.niwa.co.nz/our-science/freshwater/tools/analysis) to estimate SKSE values. We used the same method provided by Time Trends within alternative (bespoke) software because of the number of sites considered would make trend analysis in the Time Trends software onerous.

The SKSE calculations were accompanied by a Seasonal Kendall test (Helsel & Frans, 2006) of the null hypothesis that there is no monotonic trend. If the associated P-value is ‘small’ (i.e. $P<0.05$), the null hypothesis can be rejected (i.e. the observed trend or any larger trend, either upwards or downwards, is most unlikely to have arisen by chance). To ensure our trend analysis was robust, we limited our analysis to data sets for which at least 80% of sample occasions had data.

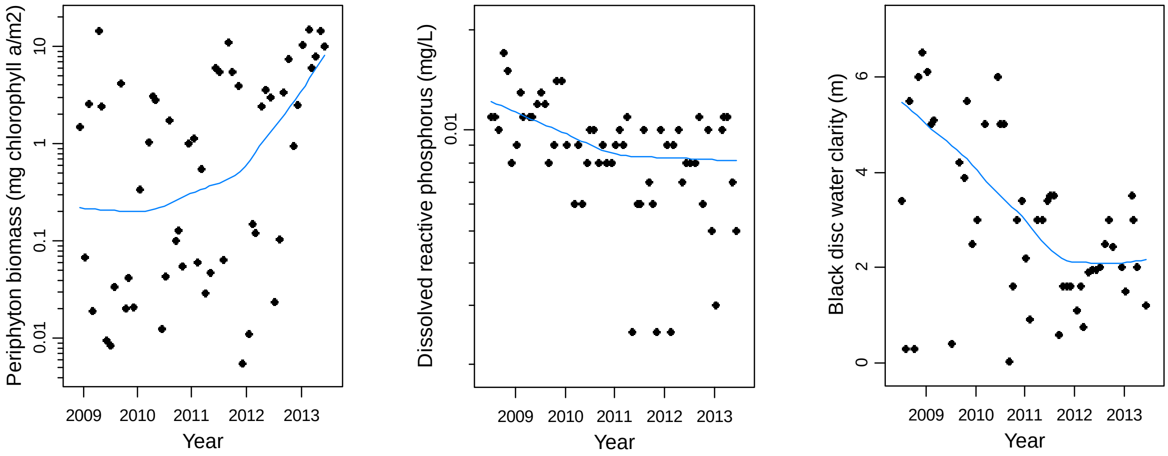

Figure 3: Scatter-plots of periphyton biomass as chlorophyll a, Dissolved Reactive Phosphorus and black disc water clarity data collected over the 5-year period at Tamaki at Tamaki Reserve (Site 1, Figure 1). A smoothed line has been fitted to the data to illustrate any trend. When formal trend analyses were performed on these data the periphyton biomass as chlorophyll a had an increasing (and meaningful) trend, Dissolved Reactive Phosphorus had a statistically significant (and meaningful) decreasing trend and black disc water clarity did not have a statistically significant trend.

2.5.2 Flow adjustment

Flow state at the time that water quality measurement are made can have a significant effect on the observed values because many water quality variables are subject to either dilution (decreasing concentration with increasing flow, e.g. conductivity) or wash-off (increasing concentration with increasing flow, e.g. total phosphorus). Data can be flow adjusted before trend analysis to remove the effects of variation in river flow on water quality variable concentrations. Because changes in river flow are tied to natural changes in precipitation and evapotranspiration, flow adjustment of water quality variable concentrations allows trends caused by other, largely anthropogenic, changes to be more directly assessed.

The flow adjustment procedure was performed by first regressing log10(concentration) against log10(flow). If the coefficient of determination of this model (i.e. the r2 value) exceeded 0.5, we judged that there was good evidence that concentrations were affected by flow. In these cases, every data point in the record was adjusted depending on the value of flow as outlined by Smith et al. (1996): adjusted value = raw value – value predicted by the regression model + mean value.

Where there was good evidence that concentrations were affected by flow, we carried out the trend analysis on both the raw data and on flow adjusted concentration data. Where there was not good evidence for a relationship between concentration and flow, we carried out the trend analysis on the raw concentration data.

2.5.3 Interpretation of trends

Values of the SKSE were normalised by dividing by the median to give the relative trend (or 'relative' SKSE; RSKSE), allowing for direct comparison between sites measured as per cent change per year. The RSKSE may be thought of as an index of the relative rate of change. A positive RSKSE value indicates an overall increasing trend, while a negative RSKSE value indicates an overall decreasing trend.

To provide an interpretation of the trends, we categorised them according to their direction and magnitude. Scarsbrook (2006) recognised that statistical significance of a trend does not necessarily imply a "meaningful" trend (i.e. one that is likely to be relevant in a management context). We followed Scarsbrook in denoting a 'meaningful' trend as one for which the (statistically significant) RSKSE has an absolute magnitude >1 per cent per year. Scarsbrook recognised that the choice of 1 per cent per year as the 'meaningful' threshold is arbitrary, but this has the advantage that it corresponds to a magnitude that people are likely to detect within a human lifetime. Therefore, trends were categorised as follows:

i) no significant trend – the null hypothesis for the Seasonal Kendall test was not rejected (i.e. $P>0.05$).

ii) stable trend – the null hypothesis for the Seasonal Kendall test was rejected (i.e. $P<0.05$) but the trend magnitude was zero.

iii) significant increasing trend – the null hypothesis for the Seasonal Kendall test was rejected (i.e. $P<0.05$) and the magnitude of the trend (SKSE) was positive but less than one per cent per annum of the raw data median (i.e. the RSKSE value was less than 1 per cent year^{-1}).

iv) significant decreasing trend – as for significant increasing trend but the magnitude of the trend was negative.

v) 'meaningful' increasing trend – the null hypothesis for the Seasonal Kendall test was rejected (i.e. $P<0.05$) and the magnitude of the trend (SKSE) was positive and greater than one per cent per annum of the raw data median (i.e. the RSKSE value was greater than 1 per cent year^{-1} or about 10% per decade).

vi) 'meaningful' decreasing trend – as for 'meaningful' increasing trend but the magnitude of the trend was negative.

We used the binomial test to determine 'overall trends' for all sites in the catchment for each variable. We deemed that there was an overall trend in a certain direction if the number of sites that exhibited that trend were greater than could be expected if increasing and decreasing trends were equally likely. The binomial test determined whether there are more trends at sites in the catchment than could be expected by chance. This test was performed on two groups of catchment sites: the SoE sites and the sites downstream of point source discharges.

To perform a binomial test, we first counted the number of positive RSKSE values (increasing trends). Note that all RSKSE values were included regardless of their p values. A 'two-tailed' binomial test was then performed based on expectation that sites have a 50% probability of having an increasing trend. If the resulting p value was less than 0.05, we rejected the null hypothesis, i.e. we concluded that there were more trends in the catchment than could be expected by chance and that there was an 'overall' trend. We then determined the overall trend direction as positive if the proportion of positive trends was greater than 50%, and negative if the reverse were true.

A complication arises because RSKSE values can take the value zero for several reasons, some of which are related to data quality. In particular, RSKSE can be zero if there are many non-detect values in the time-series, or if there are many identical values (ties), which occurs if the precision of the test or recorded concentrations are low. We allocated half of the zero RSKSE values to the increasing trends and the other half to the decreasing trends to reduce the impact of zero trends on the test. Note that the reported values are the number of sites with RSKSE values equal to zero, regardless of their p values, and should not be confused with stable trends (i.e. RSKSE values equal to zero and $P<0.05$).

3 RESULTS FOR STATE ASSESSMENT

3.1 Data for the SoE sites

Box and whisker plots summarise all observations of some illustrative water quality variables and biological indicators for the SoE sites for the 5-year period ending July 2013 (Figure 4 and Figure 5). 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.

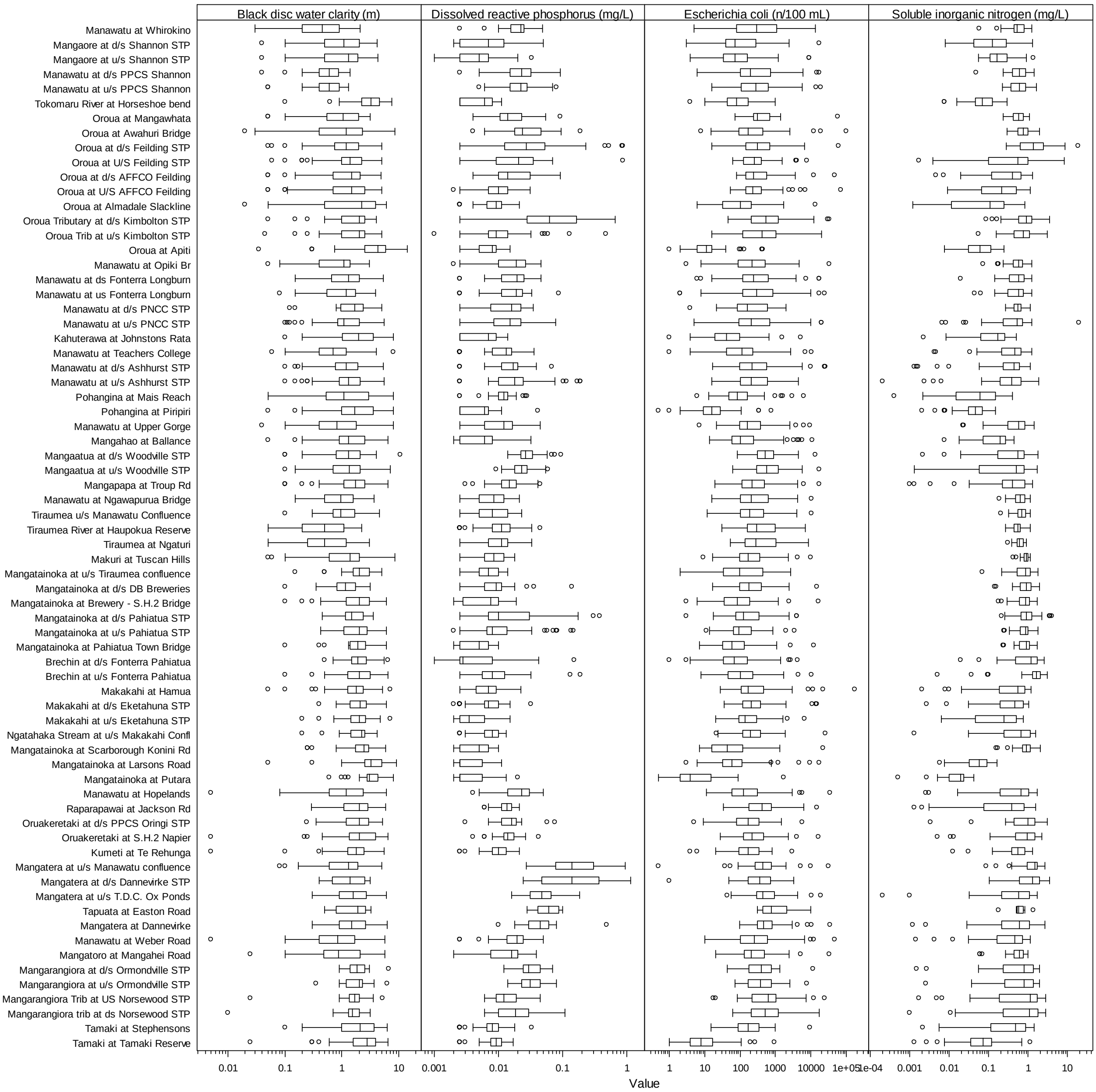

Figure 4: Box and whisker plots representing all observations of selected water quality variables at the SoE sites for the 5-year period ending July 2013. The box indicates the inter-quartile range, the vertical bar within the box indicates the median and 95% of the data lies within the whiskers. Outliers are indicated by open circles.

For some variables, the Accord Sub-catchment groupings highlight patterns in water quality. For example, Dissolved Reactive Phosphorus tends to be high in the Upper Manawatū (Figure 4), and periphyton biomass tends to be high in the Mangatainoka and Tiraumea Accord Sub-catchments (Figure 5).

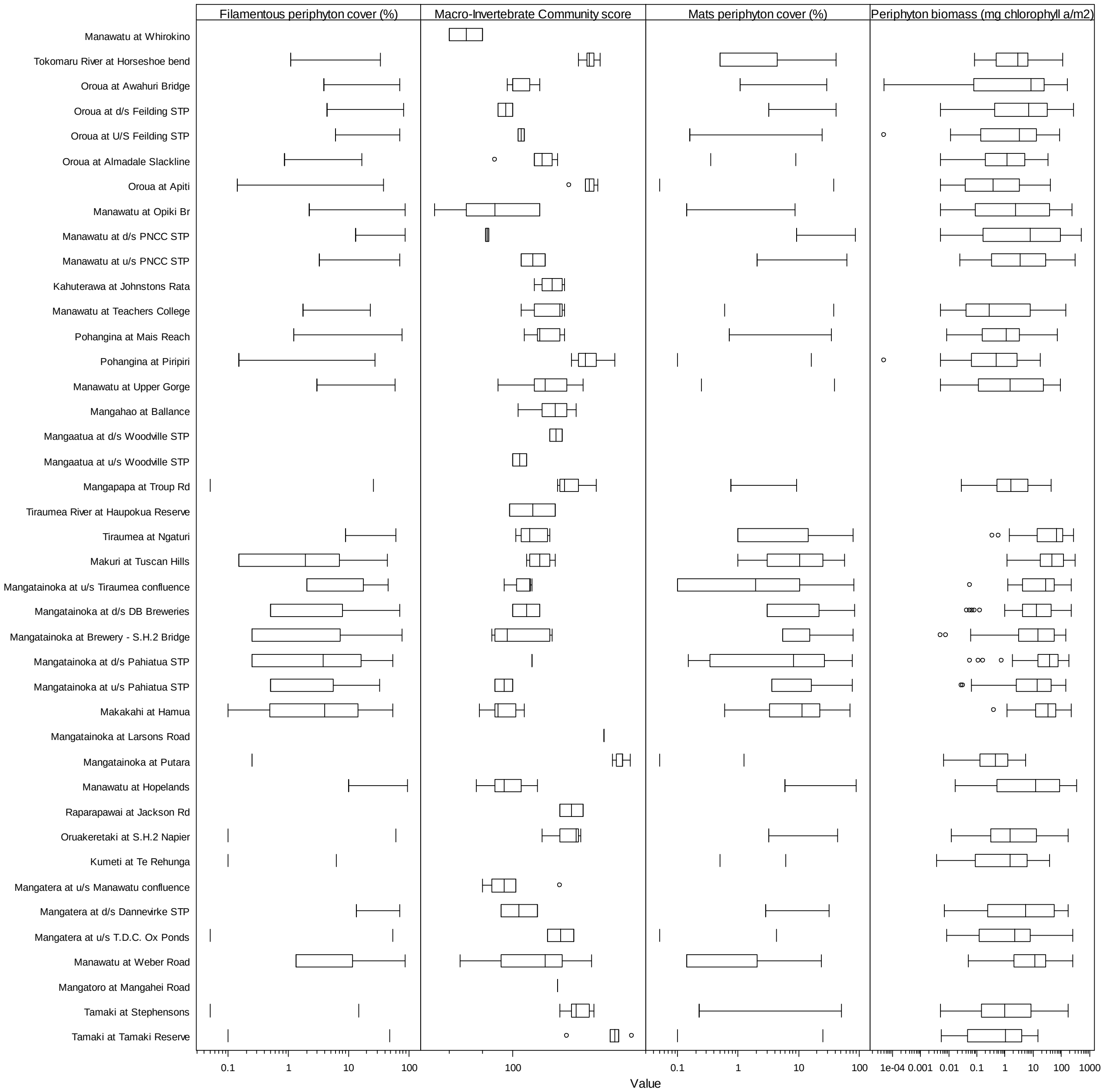

Figure 5: Box and whisker plots representing all observations of selected biological indicators for the 5-year period ending July 2013. The box indicates the inter-quartile range, the vertical bar within the box indicates the median and 95% of the data lies within the whiskers. Outliers are indicated by open circles.

3.2 Grading of SoE sites

The results of grading the SoE sites according to the water quality variable targets are shown in Figure 6, and are mapped on Figure 8. It is noted that the grey cells shown in Figure 6 indicate that there were insufficient variable observations to make statistically robust assessments of state (see Section 2.4.1). This was more likely for variables whose targets included specified flow states, for example E. coli, DRP, and SIN (Table 5).

There are some obvious patterns in water quality state shown in Figure 6. First, sites for which there were sufficient observations almost uniformly met the toxic contaminant targets: ammonia (NH4 and NH4.Max) and nitrate (NO_X and NO_X.95). The only exceptions were for ammonia at single sites in each of the Upper Manawatū, Lower Manawatū and the Oroua sub-catchments (Figure 6). Second, sites almost uniformly failed to meet the water clarity (Clar) and microbial (Ecoli.Year and Ecoli.Bath) targets. However, the nutrient (DRP and SIN) targets were met at a smaller proportion of sites. In total, 66% and 77% of the sites for which there were sufficient observations failed the DRP and SIN grades, respectively. The Mangatainoka sub-catchment had the highest proportion of sites that passed the nutrient targets, followed by the Oroua sub-catchment (Figure 6).

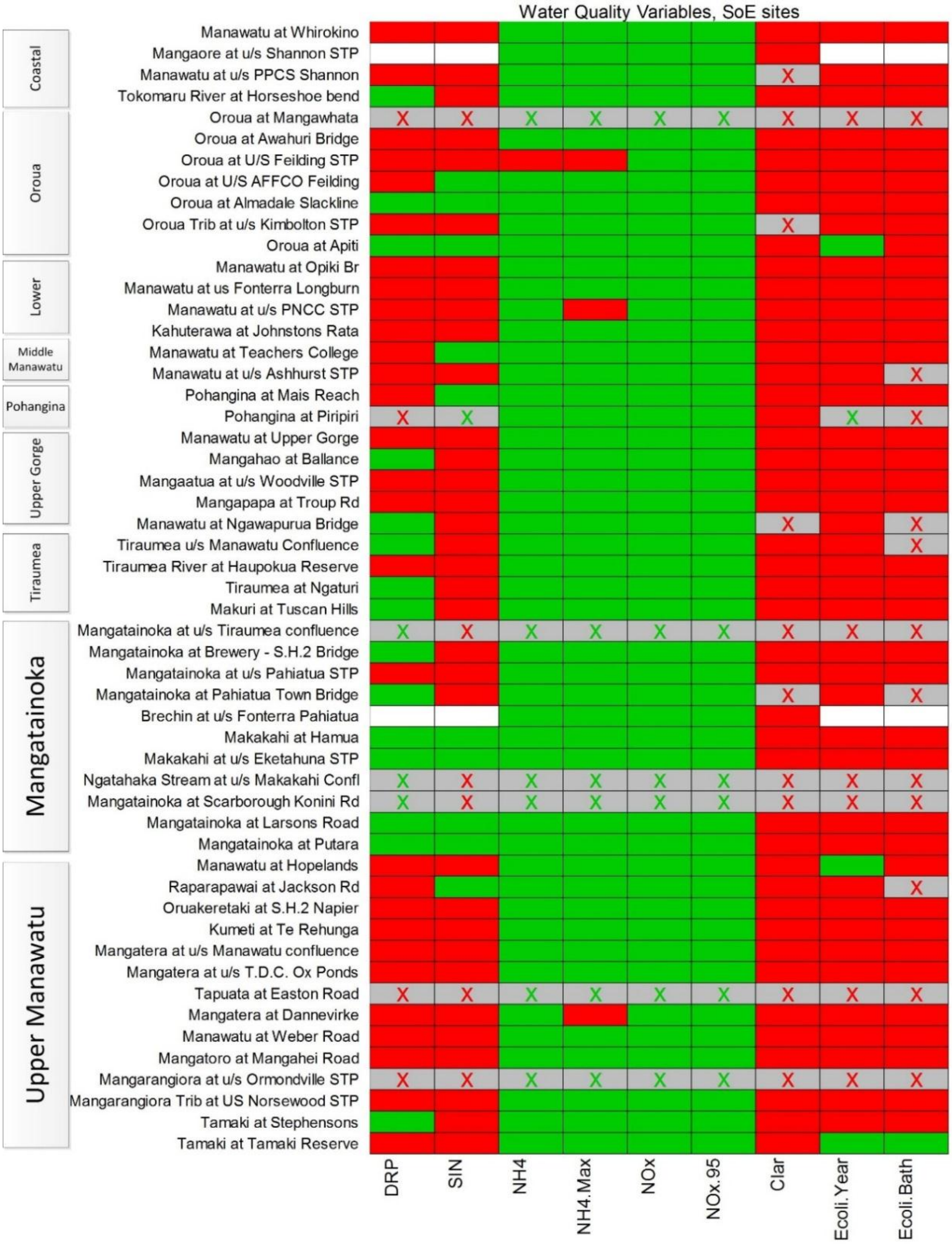

Figure 6: Grading of the SoE sites based on the water quality variables. Green and red cells indicate sites that meet and fail to meet targets, respectively. The grey cells indicate site by variable combinations that have insufficient observations for statistically robust assessment to be made but show the grade based on the available data as the coloured cross. The white cells indicate sites for which flow was not monitored. The Accord Sub-catchments (see Figure 1) that each site belongs to are indicated by the boxes on the left.

The results of grading the SoE sites according to the biological targets are shown in Figure 7, and are mapped on Figure 8. There are some obvious patterns in water quality state shown in Figure 7. First, the majority of sites for which there was sufficient variable observations met the cyanobacteria grade (85%). The exceptions to this were all located in the Mangatainoka sub-catchment. Second, the majority (60% and 72%) of sites failed two of the periphyton abundance grades (chlorophyll a [Chla] and filamentous cover [Peri.Fils]), respectively. However, the majority of sites (76%) passed the third periphyton abundance grade for cover by mats (PeriMats). The highest proportion of failures on Peri.Mats occurred in the Mangatainoka sub-catchment, which was consistent with the high proportion of failures on the cyanobacteria grade in this sub-catchment. Finally, approximately one half (52%) of sites failed the macroinvertebrate indicator (MCI). These failures were broadly distributed over the entire Manawatū River catchment, although it is notable that all sites in the Middle Manawatū and Pohangina sub-catchments passed the MCI grade.

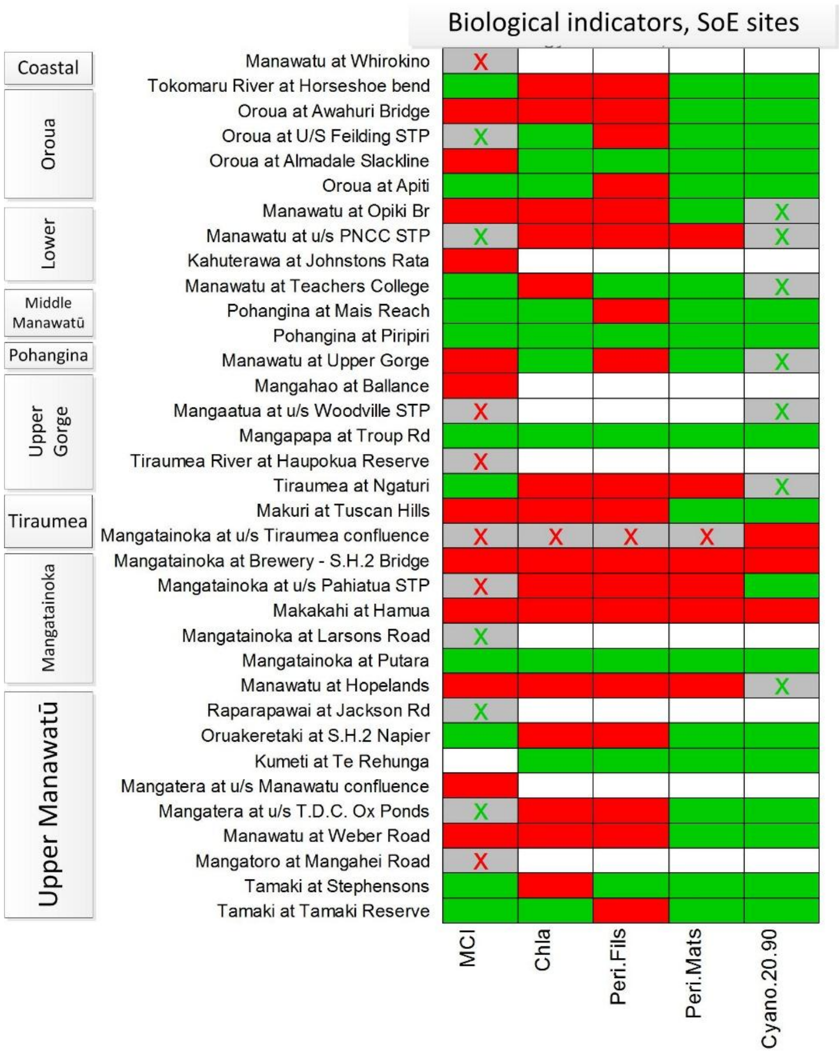

Figure 7: Grading of the SoE sites based on the biological indicators. Green and red cells indicate sites that meet and fail to meet targets respectively. The grey cells indicate site by variable combinations that have insufficient observations for statistically robust assessment to be made, but show the grade based on the available data as the coloured cross. The white cells indicate sites for which the variable was not monitored. The Accord Sub-catchments (see Figure 1) that each site belongs to are indicated by the boxes on the left.

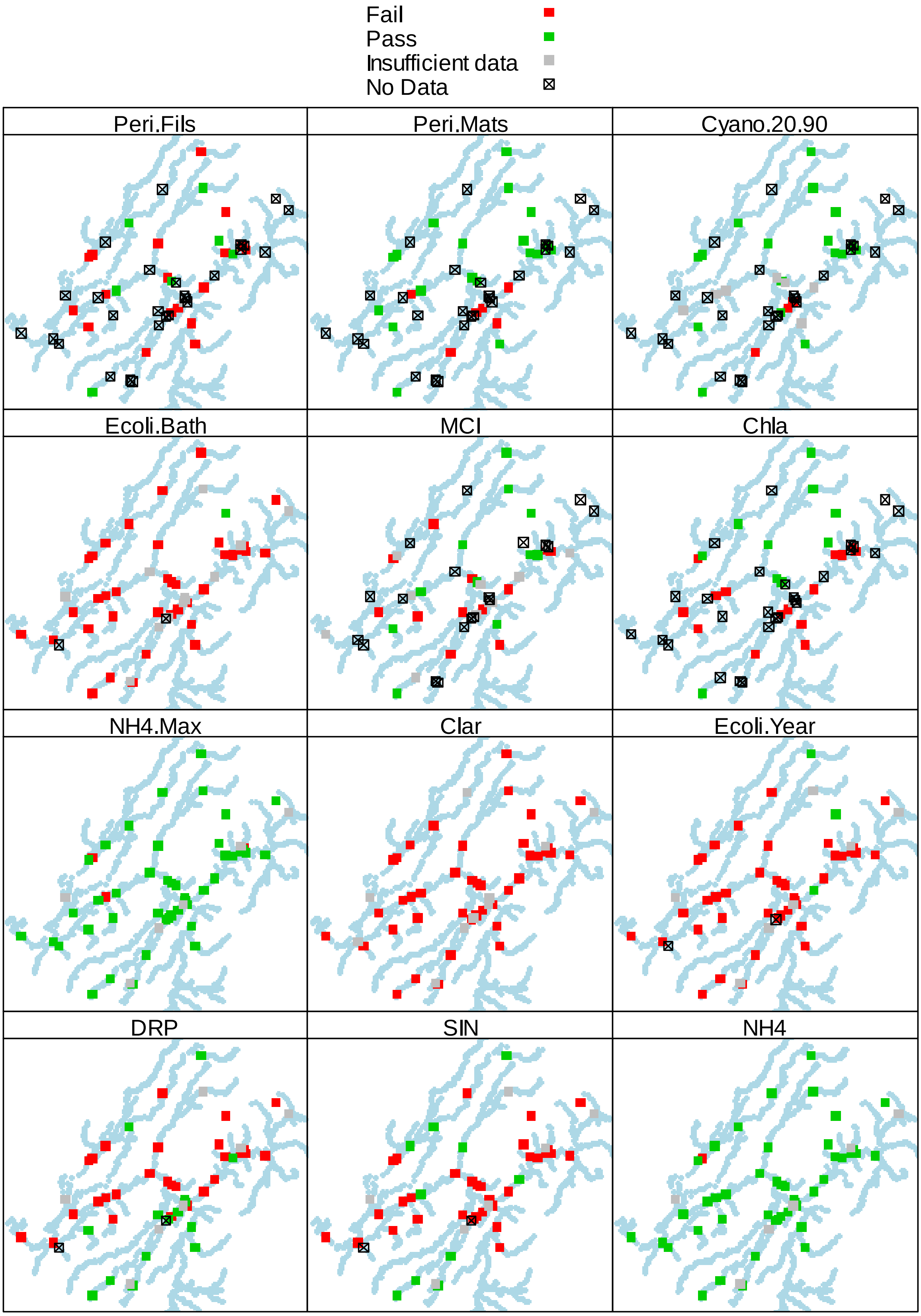

Figure 8: Maps showing SoE site state grades for selected variables.

3.3 Grading of point source discharge sites

The results of grading the point source discharge sites according to the water quality variable targets are shown in Figure 9, and are mapped on Figure 11. All sites, except the Oroua downstream of the Fielding STP met the toxicity target for ammonia (NH4 and NH4Max; Figure 9), and all sites met the toxicity target for and nitrate (NOX and NOX.95). The point source discharge sites uniformly failed to meet the targets for water clarity (Clar), microbial (Ecoli.Year and Ecoli.Bath). All but one site failed to meet the change of pH target (pH.Change). Most sites also failed to meet the nutrient (DRP and SIN) targets. Only one point source discharge site met the DRP grade, and only three met the grade for SIN. Only one site had sufficient sample occasions (>30) for testing the BOD grade. This occurs because the target is only applied to occasions when flow is at or below the 20th flow exceedance percentile (Table 5). Approximately 43% of sites with sufficient observations failed the POM grade.

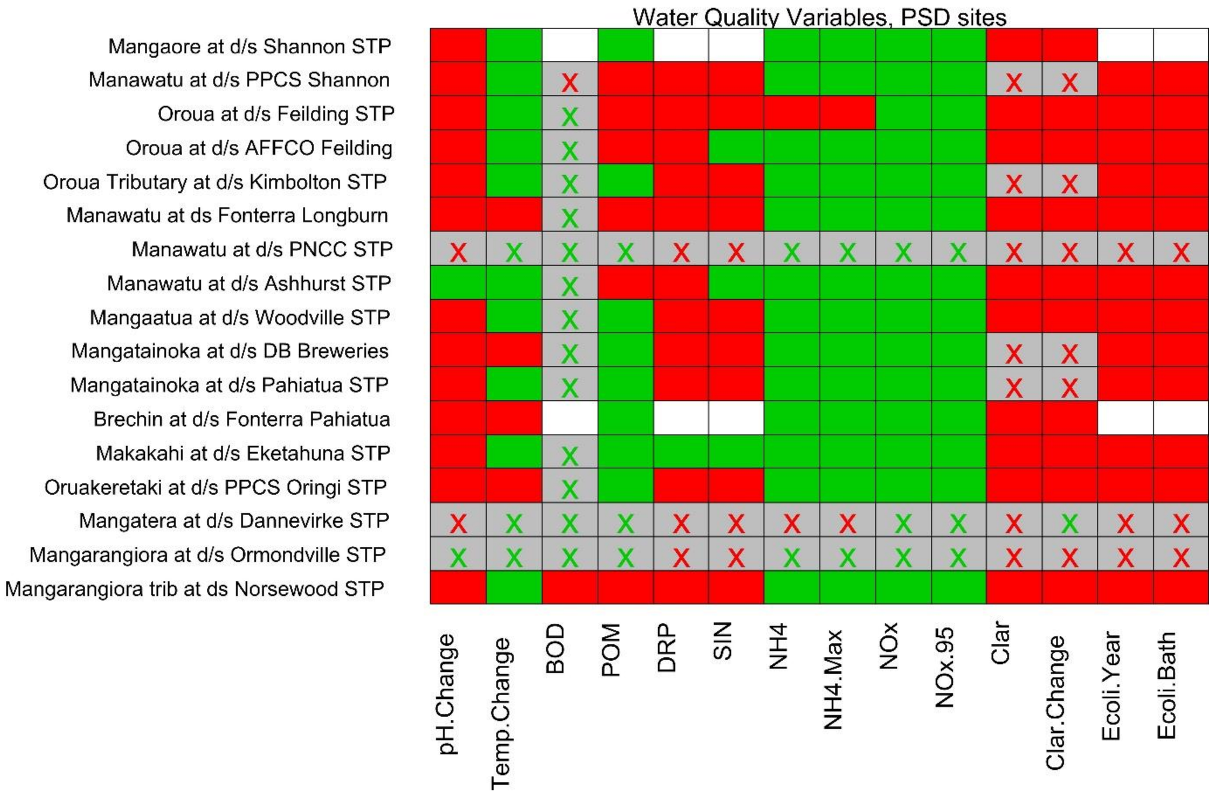

Figure 9: Grading of point source discharge sites based on physical and chemical variables. Green and red cells indicate sites that meet and fail to meet targets, respectively. The grey cells indicate site by variable combinations that have insufficient observations for statistically robust assessment to be made, but show the grade based on the available data as the coloured cross. The white cells indicate sites for which flow was not monitored.

The results of grading the point source discharge sites according to the biological targets are shown in Figure 10. All sites failed to meet the two of the periphyton abundance grades (chlorophyll *a* [Chla] and filamentous cover [Peri.Fils]), respectively. Three of five sites with sufficient data also failed to meet the third periphyton abundance grade for cover by mats (PeriMats). Two of the sites that failed to meet the mats grade also failed to meet the cyanobacteria grade. All sites failed the

MCI grade and the SQMCI.Change target was only met at two sites (Figure 10). It is noted, however, that none of these sites had sufficient observations to meet our criteria for robust assessment (i.e. five observations).

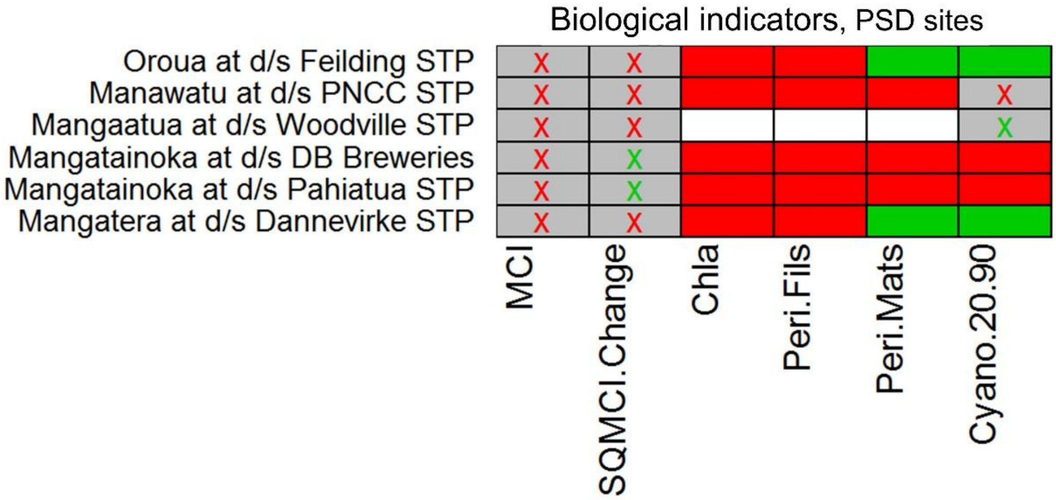

Figure 10: Grading of point source discharge sites based on biological indicators. Green and red cells indicate sites that meet and fail to meet targets, respectively. The grey cells indicate site by variable combinations that have insufficient observations for statistically robust assessment to be made, but show the grade based on the available data as the coloured cross. The white cells indicate sites for which the variable was not monitored.

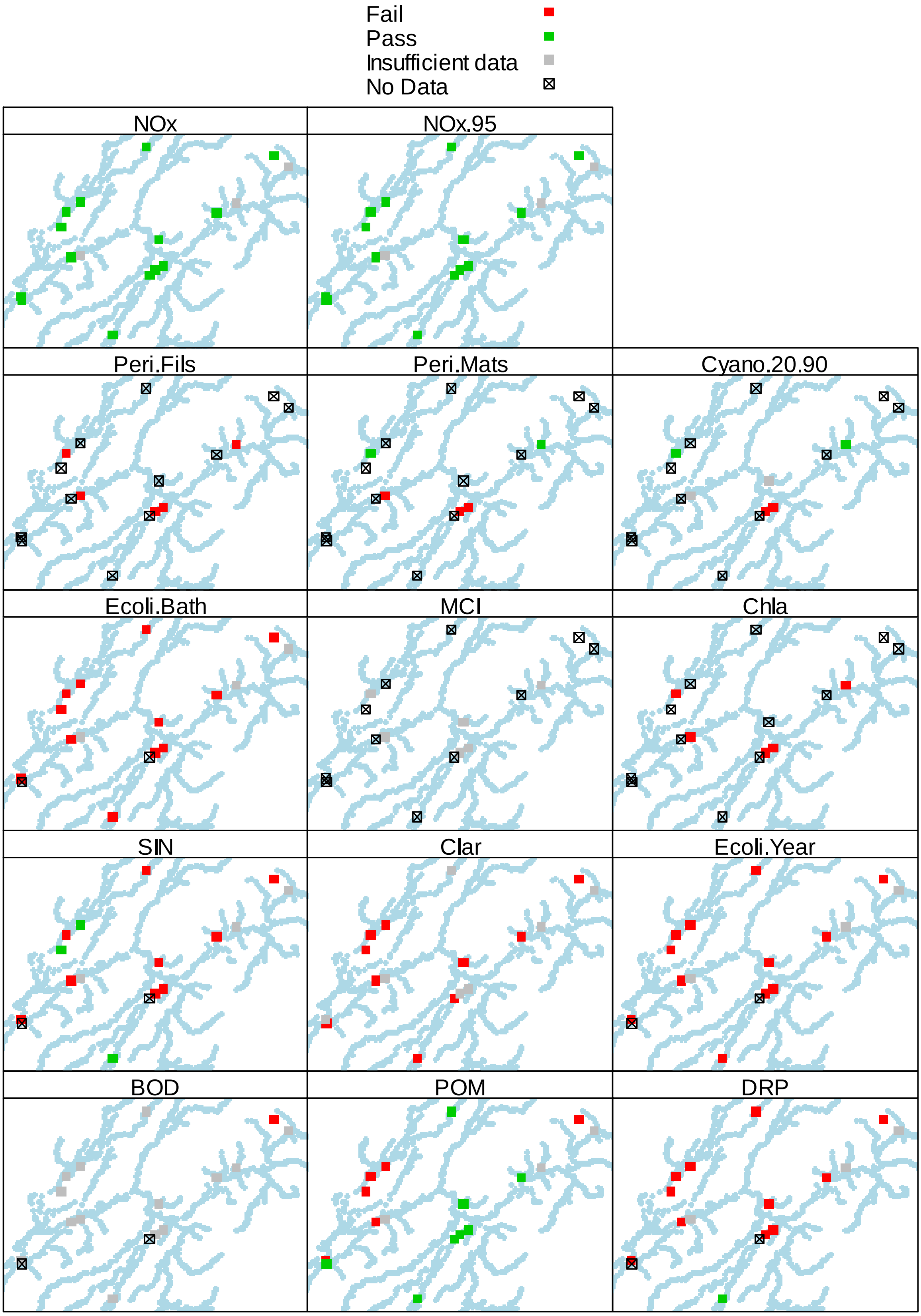

Figure 11: Maps showing point source discharge site state grades for selected variables.

3.4 Grading of continuous recording sites

3.4.1 Temperature

The majority of the continuous temperature monitoring sites were graded as within the proposed NOF attribute state C based on the average annual CRI value. This indicates that the sites are likely to exhibit some thermal stress that may affect the survival of certain sensitive insects, and the absence of sensitive fish species. Five sites, however, were graded as attribute state D based on the average annual CRI value, indicating significant thermal stress for a range of aquatic organisms and subsequent loss of ecological integrity. When sites were graded based on the maximum recorded CRI value (worst case), a significant proportion (52%) were in Attribute state D.

Table 10: Grading of Horizons Regional Council continuous temperature measurement sites in the Manawatū River catchment. CRI calculated during summer periods of 1 December – 31 March (mean±SD). The maximum CRI are the worst case recorded in the whole dataset.

Site	Period	Average annual CRI		Maximum CRI	
		NOF band	CRI °C	NOF band	CRI °C
Kahuterawa at Johnstons Rata	2005-2013	C	22±1	C	23±0
Kiwitea at Haynes Line	2005-2013	D	25±0	D	25±1
Kumeti at Te Rehunga	2003-2013	A	17±1	B	19±1
Makakahi at Hamua	2003-2013	C	22±1	D	24 ±1
Makino at Boness Road	2003-2013	C	22±1	D	24±1
Makuri at Tuscan Hills	2003-2013	B	19±1	B	20±1
Manawatu at Foxton	2004-2013	C	22±1	D	24±0
Manawatu at Hopelands	2004-2014	C	23±1	D	25±1
Manawatu at Moutoa	2008-2013	D	24±1	D	25±1
Manawatu at Teachers College	2004-2014	C	23±1	D	25±0.5
Manawatu at Upper Gorge	2003-2013	C	23±1	D	25±1
Manawatu at Weber Road	2004-2014	C	22±2	D	24±0.5
Manga-atua at Hopelands Rd	2010-2014	C	22±1	C	23±0.5
Manga-atua at Hutchinsons	2005-2013	C	21±2	D	25±1
Mangahao at Ballance	2003-2013	D	24±1	D	25±1
Mangahao at Kakariki	2003-2013	C	20±1	C	23±1
Mangaone at Milson Line	2003-2013	D	25±2	D	27±1
Mangapapa at Troup Rd	2006-2013	C	21±2	C	23±0.5
Mangatainoka at Larsons Road	2002-2011	C	22±1	C	23±1
Mangatainoka at Pahiatua Town Bridge	2004-2014	C	22±1	C	23±2
Mangatoro at Mangahei Road	2004-2014	C	22±1	D	24±0.5
Oroua at Almadale Slackline	2005-2013	D	24±1	D	26±1
Oruakeretaki at Oringi	2003-2007	C	22±1	C	23±1
Oruakeretaki at SH2	2007-2013	C	21±1	C	22±0.5
Pohangina at Mais Reach	2003-2013	C	23±1	D	24±0.5
Pohangina at Piripiri	2001-2006	B	19±0.5	B	19±1
Raparapawai at Jackson Rd	2004-2013	C	22±1	D	24±1
Tamaki at Stephensons	2003-2013	C	22±1	C	23±1
Tamaki at Water Supply Weir	2004-2014	B	19±2	C	22±1
Tiraumea at Ngaturi	2003-2013	B	20±1	C	22±1
Tokomaru at Riverland Farm	2009-2013	C	22±1	C	23±0.5

3.4.2 Dissolved Oxygen

All of the continuous DO monitoring sites were within the proposed NOF Attribute states B and C. Sites in Attribute state B are likely to have occasional minor stress on sensitive organisms as a result of low DO concentrations. Sites in Attribute state C will have moderate levels of stress associated with low DO concentrations in summer, with some risk of sensitive fish and invertebrate species loss. No sites were below the national bottom line.

Table 11: Grading of Horizons Regional Council continuous DO measurement sites in the Manawatū River catchment. Grading is based on average annual 7-day mean minimum and 1-day minimum DO concentrations, and relevant proposed NOF bands (Attribute states), for summer periods of 1 November – 30 April (mean ±SD).

		7-day mean minimum		1-day minimum	
Site	**Period**	**Proposed NOF Attribute state**	**DO (mg/L)**	**Proposed NOF Attribute state**	**DO (mg/L)**
Manawatū at Hopelands	2011-2013	C	5.6±1.1	C	4.5±1.8
Manawatū at teachers College	2011-2013	B	7.4±0.4	B	7.0±0.4
Manawatū at Weber Rd	2011-2013	B/C	7.0±0.9	B	5.6±1.0
Mangatainoka at Pahiatua Town Bridge	2011-2013	C	6.0±0.5	C	4.6±1.3

3.5 Spatial models

The performance of the spatial models varied between variables, with the cross validated percentage of variance explained (r^2) ranging from 55% for the poorest model (DRP) to 71% for the best model (NO_x; Table 12). However, cross validated r^2 values exceeded 60% for four of the five models, which we consider a highly satisfactory result given the small size of the data set and the small number of predictor variables used. The *E. coli* and NO_x models were the best performing, which is also consistent with the results of national scale modelling (Unwin *et al*., 2010; Table 12).

Table 12: Performance statistics for the random forest models for each variable, together with cross-validated r^2 values for a similar national model.

	Cross validated r^2		
Variable	**This study**	**National model (Unwin *et al*., 2010)**	**Prediction error (RMSD of log_{10} values)**
Clarity	62	62	0.13
DRP	55	59	0.22
E. coli	67	70	0.26
NH_4	62	57	0.28
NO_x	71	69	0.24

Predictor importance score (IS) and order varied among variables, but a comparison of the leading predictors suggested some consistent underlying patterns. All models were characterised by two or three leading predictors with IS of 10 or above, which spanned a broad and well dispersed continuum of values (i.e. represented a broad range of environments) and had markedly higher importance values than lower ranked predictors for the same model (Figure 12 to Figure 16 and Table 13). For most variables, the land cover variables % indigenous forest and % heavy pasture were the leading predictors (Table 13). The exception to this was Clarity, for which the leading predictor was mean flow (Flow). Reach (i.e. site) elevation was important for only one model (NH_4), and mean catchment elevation was not important for any model, suggesting that the spatial patterns apparent in Figure 12 to Figure 16 are related more to land cover than to topography.

The response of the variables to the leading predictors was generally monotonic (i.e. consistently increasing or decreasing) throughout their observed range, suggesting a well-defined and plausible underlying relationship. For example, all concentrations increased with increasing % heavy pasture and decreased with increasing % indigenous forest, while Clarity decreased with increasing flow (see Figure 12 to Figure 16).

Table 13: Importance scores for predictors of water quality variables. Scores greater than 10 are shown in red.

Variable	Clarity	DRP	*E. coli*	NH_4	NO_X
% indigenous forest	9.5	13.7	12.5	13.2	12.9
% heavy pastoral	8.7	11.3	12.2	14.1	14.0
Minimum temperature	11.0	12.5	11.5	7.7	12.8
Flow	21.9	6.2	3.6	10.1	2.2
Rainfall variability	7.0	14.8	4.1	9.8	6.5
% alluvium	7.8	4.3	9.8	7.5	10.7
Reach elevation	8.8	8.0	5.8	12.6	5.4
Catchment elevation	3.1	4.7	8.9	8.1	9.4

Common to all five models was a well-defined tendency for water quality to be highest along the forested Tararua and Ruahine ranges, and – to a lesser extent – along the western slopes of the Puketoi Range in the southeast portion of the catchment. Spatial gradients were strongest for *E.coli* and NO_x, both of which increased rapidly and uniformly over spatial scales of approximately 10 km, particularly along the eastern slopes of the Ruahine Ranges. By contrast, model predictions were generally relatively uniform over areas of the catchment away from the main ranges, with little evidence of any marked spatial gradients between the upper and lower catchment. The main exceptions to this trend were Clarity and NH_4, both of which showed a tendency to increase over the lower 20-30 km of the catchment.

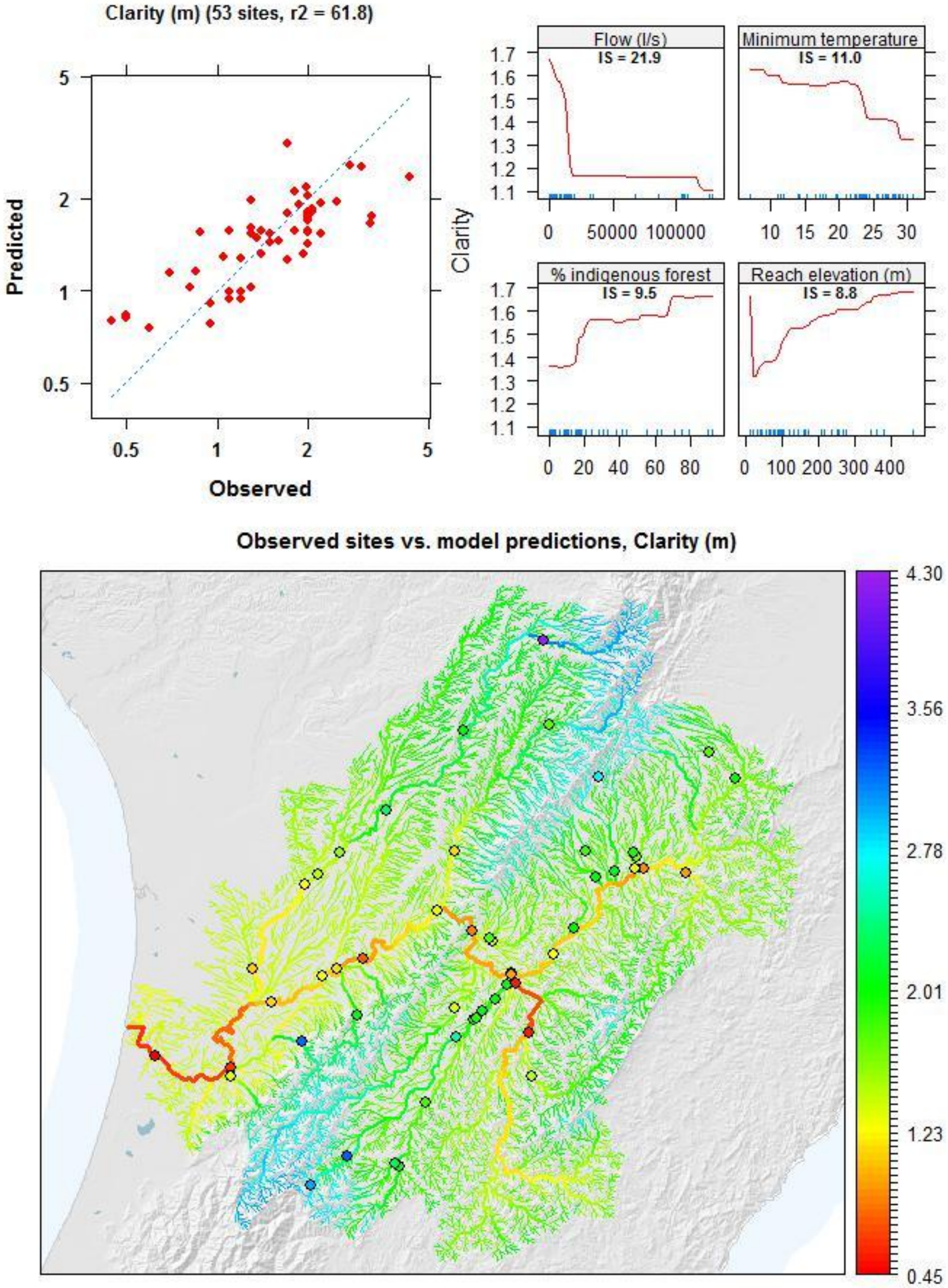

Figure 12: Random forest model diagnostics and predictions for Clarity.

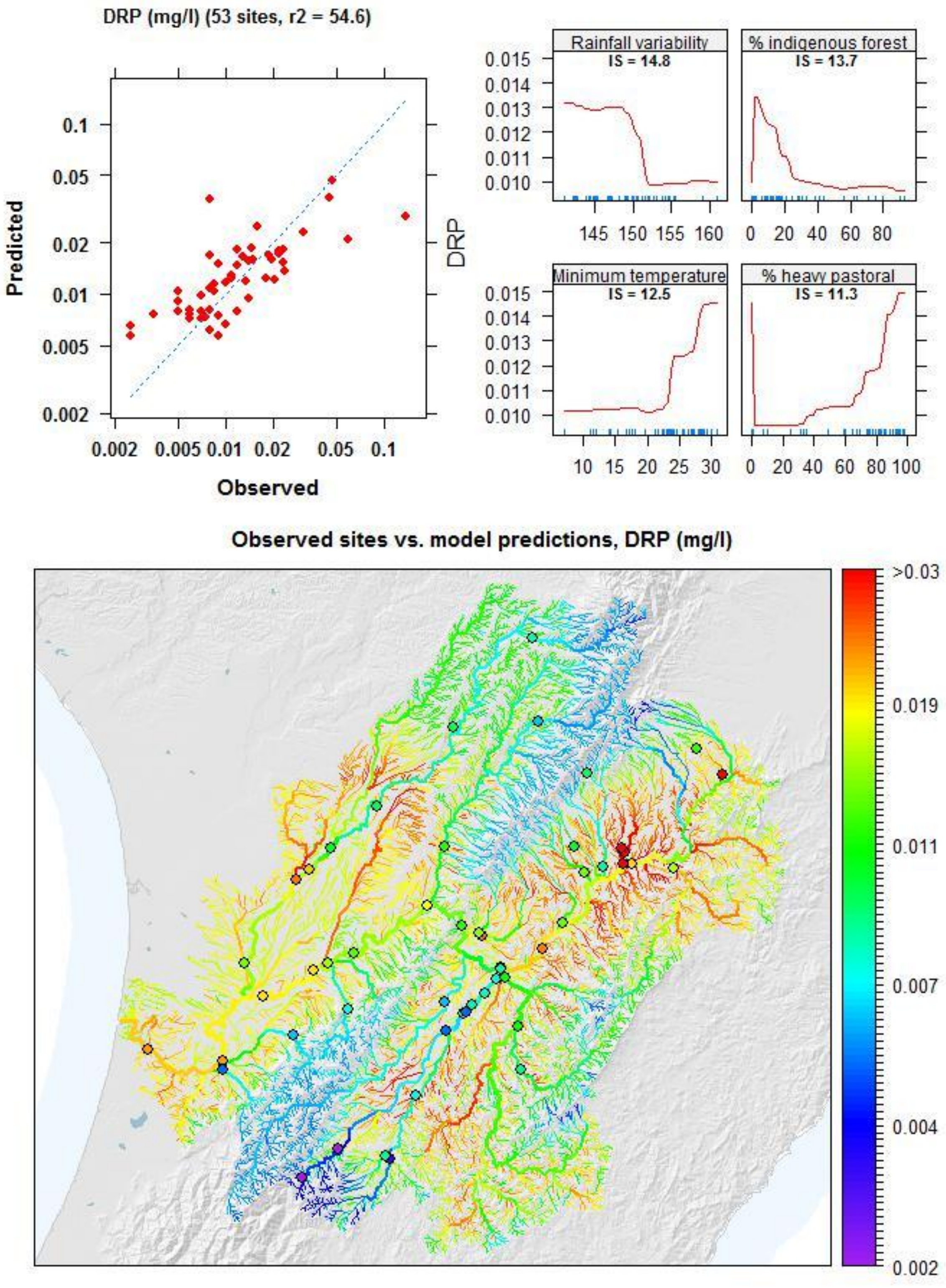

Figure 13: Random forest model diagnostics and predictions for DRP.

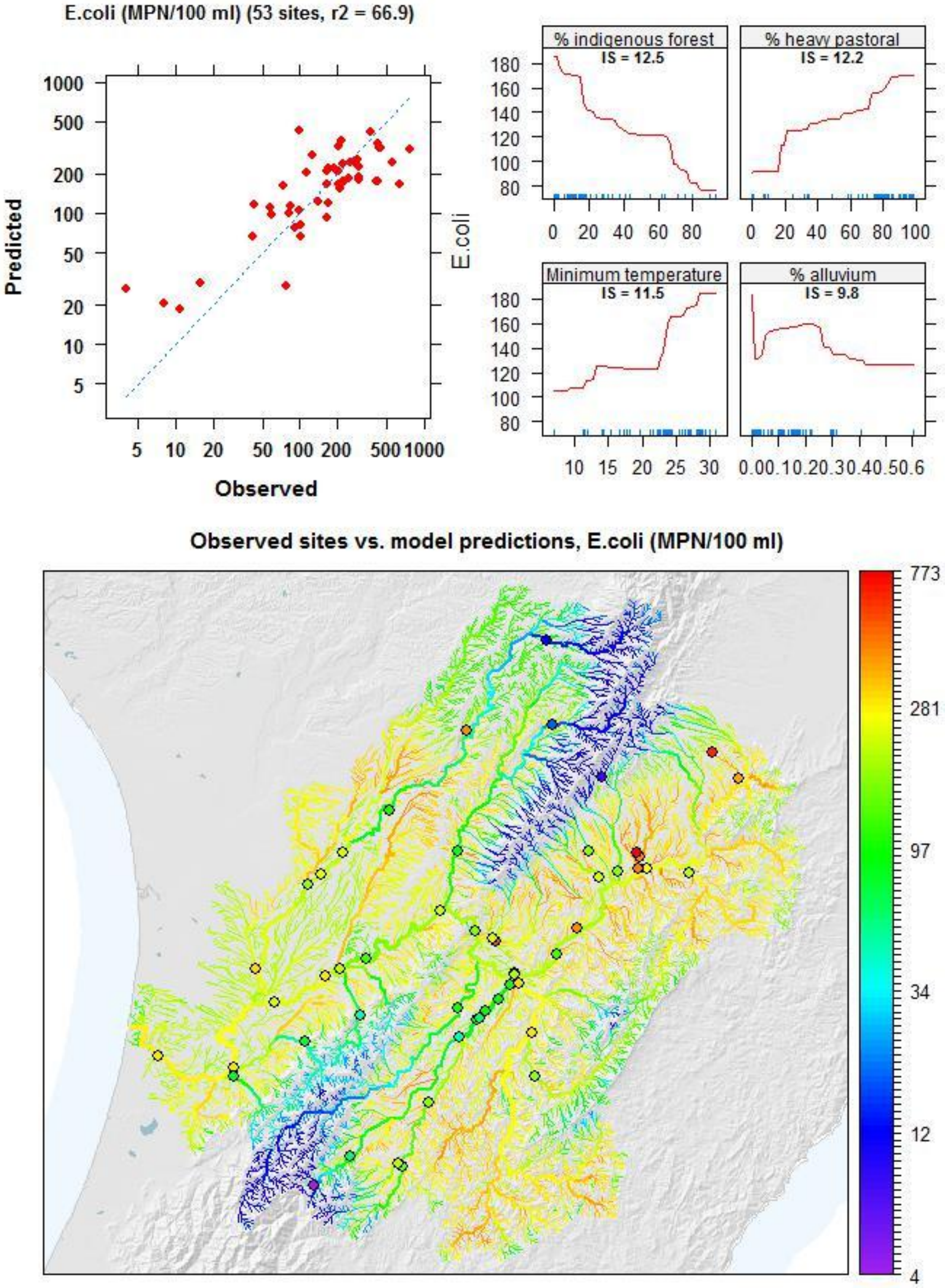

Figure 14: Random forest model diagnostics and predictions for E. coli.

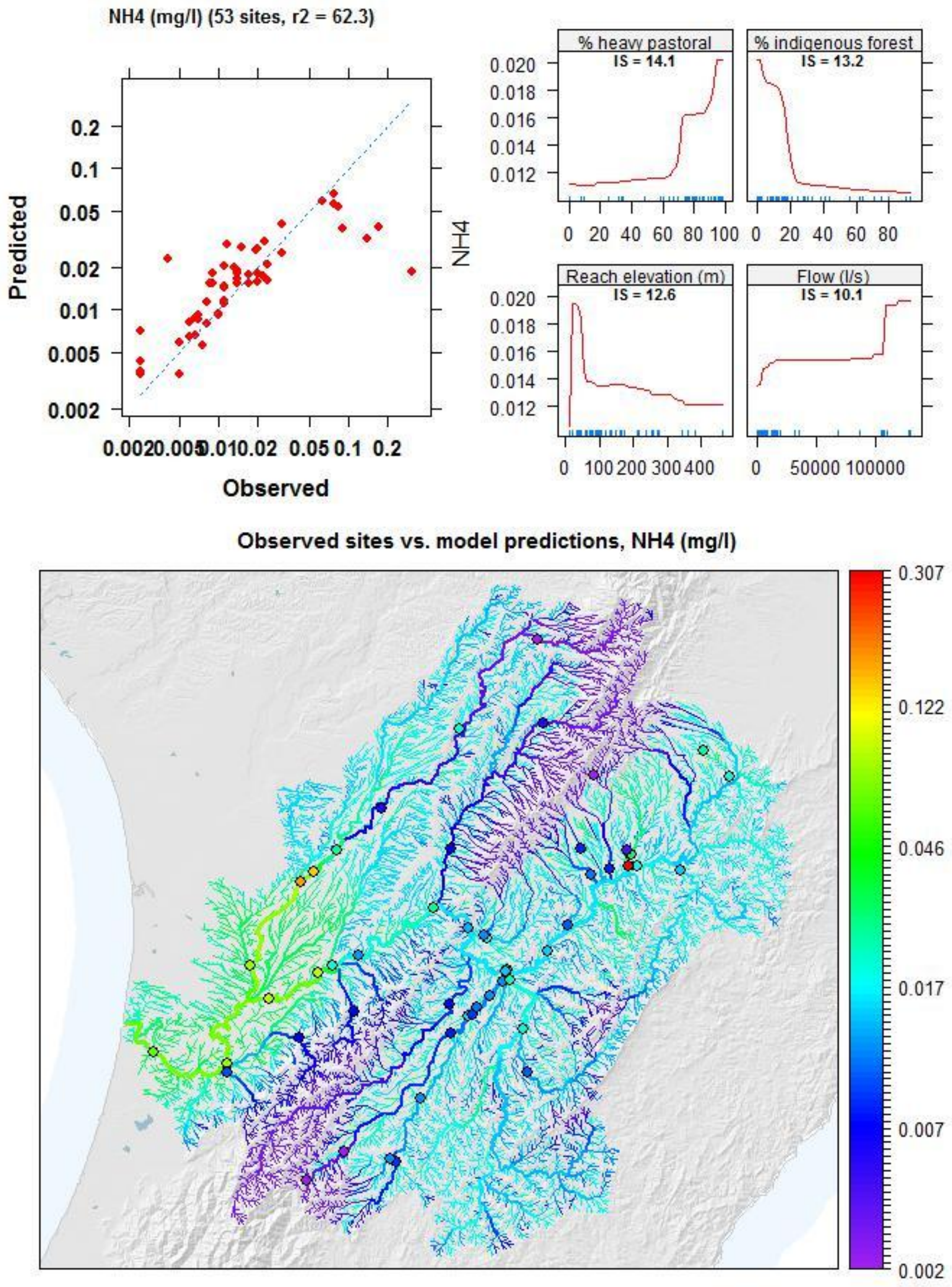

Figure 15: Random forest model diagnostics and predictions for NH_4.

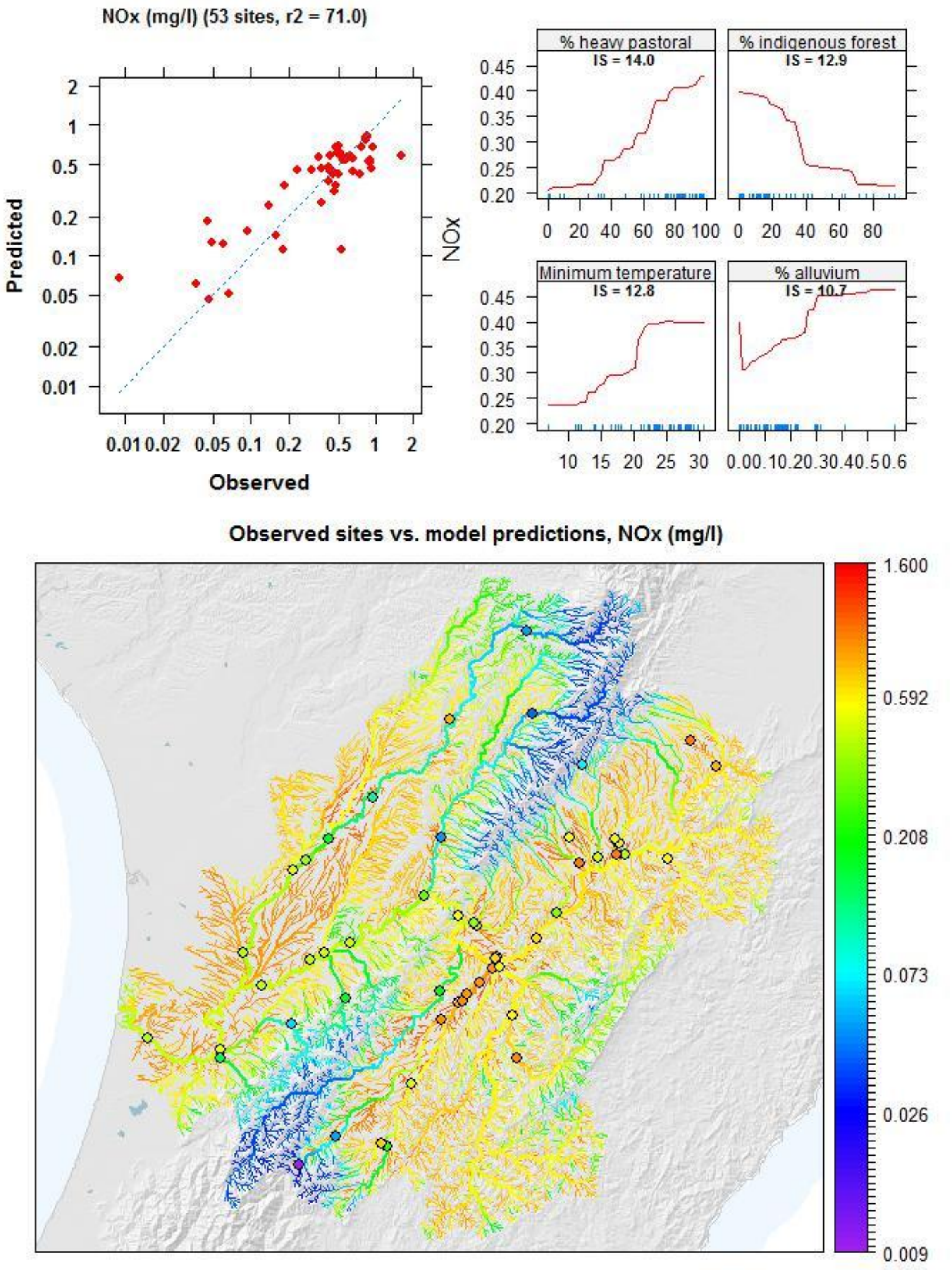

Figure 16: Random forest model diagnostics and predictions for NOx.

3.6 Comparison with national data

Distributions of site median values of water quality variables for the 5-year period ended July 2013 for the 70 monthly monitoring sites in the Manawatū River catchment, and the NRWQN are shown in Figure 17. It can be seen from Figure 17 that sites in the Manawatū catchment have a higher median concentration of DRP, *E.*

coli and NH_4, compared to the NRWQN sites, but the inverse is true for NO_x and Clarity. These plots also indicate that the modes (i.e. the most frequently occurring value) of the Manawatū River catchment sites were almost an order of magnitude larger than the NRWQN sites for *E. coli*, DRP and NH_4N. The difference between the distributions was less for NO_x. However, the mode of the Manawatū River catchment sites was approximately half an order of magnitude larger[2] than the NRWQN sites. The mode for Clarity for the Manawatū River catchment sites was approximately the same as the NRWQN sites. Results for a similar analysis without the 17 point-discharge sites (not shown) were almost identical, confirming that the differences apparent in Figure 17 are not an artefact of point-source discharges.

The differences between the two distributions are enumerated further in Table 14. For each percentile (50th and 80th) and water quality variable, the third column shows the value from the NRWQN distribution. For example, the 50th percentile of Clarity for the NRWQN sites is 1.64 m. The 4th column shows the number of Manawatū River catchment sites that exceed the NRWQN figure, based on all 70 available sites (i.e. including the point source monitoring sites). The 5th column shows the number of Manawatū River catchment sites that exceed the NRWQN figure, based on the 53 SoE sites (i.e. excluding the point source monitoring sites).

The plots (Figure 17) and table (Table 14) indicate that water quality tends to be poorer in the Manawatū River catchment, compared to the NRWQN. Relative to the NRWQN medians, by definition the value which is exceeded at exactly half the sites in New Zealand, all variables (except Clarity) are markedly higher in the Manawatū catchment, with 87-94% of sites exceeding the national median. By contrast, median Clarity values for the Manawatū sites are almost identical to the NRWQN median. These figures change little if the analysis is limited to the 53 SOE sites, confirming again that large-scale water quality variation in the Manawatū catchment is not greatly influenced by point-source discharges.

Comparisons with the NRWQN 80th percentiles reinforce these conclusions. By definition, the NRWQN 80th percentile is exceeded at only one in five, or 20%, of the NRWQN sites. The corresponding figures for the Manawatū catchment are 46% for DRP, 36% for *E. coli*, and 60% for NH_4 and NO_x. The latter two results are particularly striking: NH_4 and NO_x concentrations at three of every five Manawatū sites are higher than a level exceeded at only one in every five of the NRWQN sites. As with the median comparisons, Clarity is a marked exception to this trend: at only 46% (~ one in 20) of Manawatū sites is Clarity below a level exceeded at one in five sites elsewhere in New Zealand.

In order to provide a context to understand the differences in water quality between the Manawatū River catchment and the NRWQN, the distributions of land cover in the catchments of sites in both monitoring networks were assessed (Figure 18). We found that in contrast to the NRWQN, sites in the Manawatū River catchment represented areas with a high proportion of land in productive use (e.g. pasture) and a low proportion of natural use (as indicated by proportion of catchment in indigenous forest; Figure 18).

[2] An order of magnitude is 10 times greater.

Table 14: Proportion of the 70 Horizons monthly water quality sites whose median and 80th percentile values for five water quality variables exceed the equivalent percentile values for the 77 NRWQN sites. Note that for Clarity, 'exceeds' refers to sites where water clarity is less than (instead of greater than) the corresponding NRWQN metric.

Percentile	Variable	NRWQN value at percentile	HRC > NRWQN N_{sites} (% of total): All HRC sites (N = 70)	HRC > NRWQN N_{sites} (% of total): HRC d/s sites excluded (N = 53)
50th (median)	Clarity	1.64	32 (46%)	26 (49%)
	DRP	0.046	66 (94%)	50 (94%)
	E. coli	48	64 (91%)	47 (89%)
	NH_4	0.005	65 (93%)	48 (91%)
	NOx	0.12	61 (87%)	45 (85%)
80th	Clarity	0.53	3 (4%)	3 (6%)
	DRP	0.014	32 (46%)	20 (38%)
	E. coli	228	25 (36%)	17 (32%)
	NH_4	0.012	42 (60%)	26 (49%)
	NOx	0.451	42 (60%)	30 (57%)

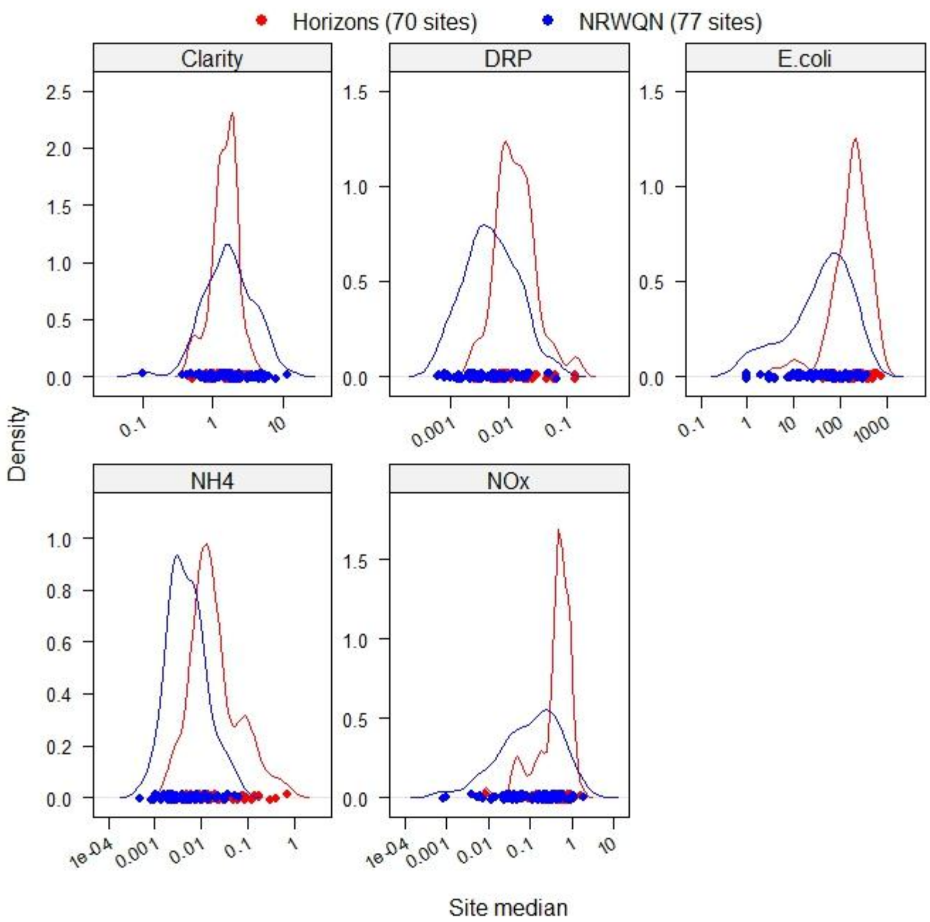

Figure 17: Density plots showing distribution of site median values for the Manawatū River catchment and the NRWQN. This plot includes all monthly monitoring sites (SoE and Point Source discharge sites).

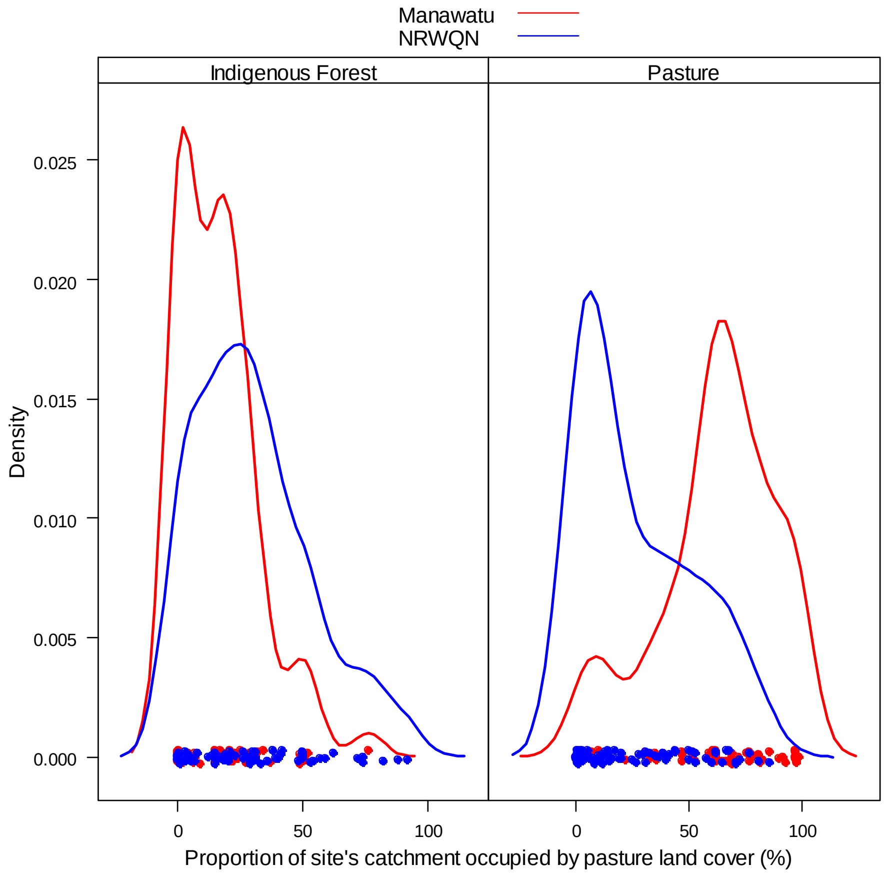

Figure 18: Density plots showing distribution of the proportion of catchment area occupied by indigenous forest and pasture for monitoring sites in the Manawatū River catchment and the NRWQN. This plot includes all monthly monitoring sites (SoE and Point Source discharge sites).

4 TRENDS

4.1 5-year trends

4.1.1 Trends at SoE sites

Categorised trends at the SoE sites for the five years ending July 2013 are shown in Figure 19 and are summarised in Table 15 Many trends were not statistically significant, this reflecting variability between the sampling occasions and the relatively short (5-year) period of record. Where trends were statistically significant, they were always meaningful (i.e. the magnitudes were more than 1% per year; Table 15).

For the majority of the water quality variables where trends were detected, the trends at most SoE sites were for improving water quality. For NH_4N, DRP, *E. coli*, NO_x and BOD, the meaningful trends were decreasing (i.e. improving water quality) for all but one site. For Clarity, the one meaningful trend (Oroua at Almadale Slackline) was increasing (i.e. improving water quality). However, there were 18 meaningful increasing trends for periphyton biomass as measured by chlorophyll *a* (Chl *a*), which indicates degrading water quality.

Table 15: Summary of the numbers trends by category at the SoE sites for the 5-year period ending July 2013 for eight water quality variables. The table contains the numbers of sites in the various trend categories by variable. "No Test" indicates sites that had insufficient data (e.g. >80% of months with data).

Variable	n	Stable	Not Significant	Significant Increasing	Significant Decreasing	Meaningful Increasing	Meaningful Decreasing	No Test
NH_4	53	1	38	0	0	1	2	11
Clarity	53	0	23	0	0	1	0	29
Chla	26	0	11	0	0	12	0	3
DRP	53	1	23	0	0	0	18	11
E.coli	53	0	38	0	0	1	4	10
NOX	53	0	30	0	0	0	8	15
BOD	20	0	2	0	0	1	0	17
POM	45	0	2	0	0	0	0	43

For the SoE sites, there were decreasing overall catchment trends for DRP, *E. coli*, and NO_X (Table 16), which indicate improving water quality. There was an overall increasing trend for periphyton biomass as chlorophyll *a* (Chla; Table 16), which indicates degrading water quality.

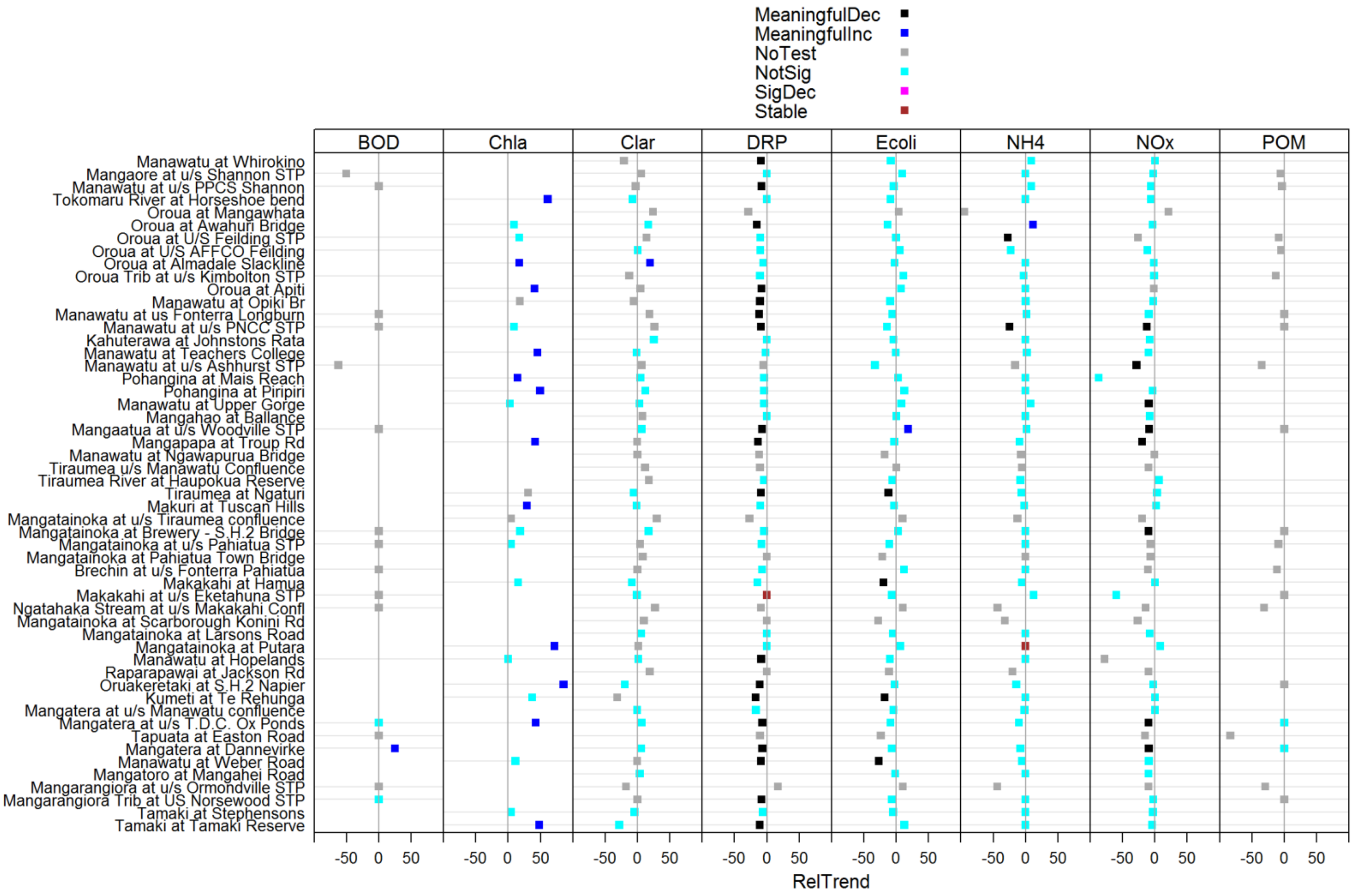

Figure 19: Relative trends (i.e. RSKSE [% yr^{-1}]) at the SoE sites for the 5-year period ending July 2013 for eight water quality variables. The trends are categorised based on Scarsbrook (2006). Note that there are 18 trends that are not shown in this figure because they had RSKSE values that were outside the range of -55 to +55.

Table 16: *Results of binomial test carried out using trends for SoE sites. Zero trends were assigned equally to either increasing or decreasing trends.*

Variable	n	p	Overall trend direction	Number of zero trends
NH4	53	0.53	Not Significant	20
Clarity	52	0.07	Not Significant	3
Chla	26	0	Increasing	0
DRP	53	0	Decreasing	10
E.coli	53	0.03	Decreasing	0
NOX	53	0	Decreasing	0
BOD	16	0.80	Not Significant	13
POM	20	0.01	Decreasing	9

4.1.2 Trends at point source discharge sites

Categorised trends at the PSD sites for the five years ending July 2013 are shown in Figure 20, and the numbers in each trend category are summarised in Table 17. The trends as SKSE values are tabulated for all sites in Appendix C. Many trends were not statistically significant, this reflecting variability between the sampling occasions and the relatively short (5-year) period of record. Where trends were statistically significant, they were always meaningful (i.e. the magnitudes were more than 1% per year; Table 17).

For the majority of the water quality variables, the trends at most PSD sites were for improving water quality. For NH_4 and *E. coli*, the meaningful trends were decreasing (i.e. improving water quality) for all but one site (Brechin at d/s Fonterra Pahiatua, and Mangaatua at d/s Woodville STP, respectively). For DRP and NOX, the meaningful trends were all decreasing (i.e. improving water quality). For Clarity (Clar), all trends were insignificant, and for chlorophyll *a* (Chla), there was one meaningful increasing trend (i.e. indicating degrading water quality) at site Manawatū at d/s PNCC STP.

Table 17: *Summary of the numbers of trends by category at the PSD sites for the 5-year period ending July 2013 for eight water quality variables. The table contains the numbers of sites in the various trend categories by variable. "No Test" indicates sites that had insufficient data (e.g. >80% of months with data).*

Variable	n	Stable	Not Significant	Significant Increasing	Significant Decreasing	Meaningful Increasing	Meaningful Decreasing	No Test
NH_4	17	0	11	0	0	1	2	3
Clarity	17	0	3	0	0	0	0	14
Chla	5	0	4	0	0	1	0	0
DRP	17	0	7	0	0	0	7	3
E. coli	17	0	11	0	0	1	2	3
NO_x	17	0	6	0	0	0	4	7
BOD	17	0	1	0	0	0	0	16
POM	17	0	0	0	0	0	0	17

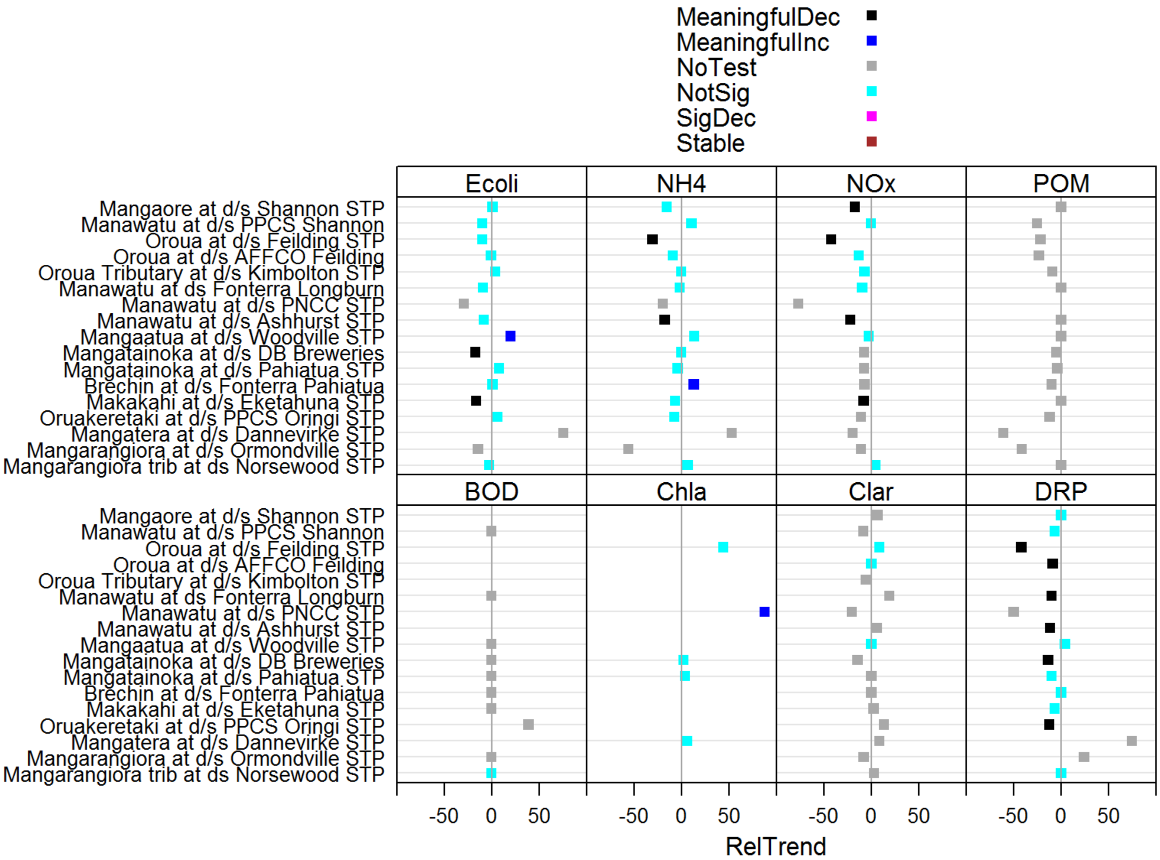

Figure 20: Relative trends (i.e. RSKSE [% yr^{-1}]) at the PSD sites for the 5-year period ending July 2013 for eight water quality variables. The trends are categorised based on Scarsbrook (2006).

For the PSD sites, there were decreasing overall regional trends for NO_x and POM (Table 7), which indicates water quality improvement. None of the other variables had significant overall trends.

Table 18: Results of binomial test carried out using trends for the PSD sites. Zero trends were assigned equally to either increasing or decreasing trends.

Variable	n	p	Overall trend direction	Number of zero trends
NH_4	17	0.143	Not Significant	1
Clarity	17	0.629	Not Significant	4
Chla	5	0.062	Not Significant	0
DRP	17	0.143	Not Significant	3
E. coli	17	0.629	Not Significant	0
NO_x	17	0	Decreasing	0
BOD	11	1	Not Significant	9
POM	17	0.013	Decreasing	6

4.2 20-year trends

Time series plots for the eight sites that have at least 20 years of monthly data for the period ending July 2013 are shown for DRP and NO_x in Figure 21 and Figure 22, respectively. Decreasing trends in DRP are visible in these plots for Manawatū at

Opiki Br, Manawatū at Teachers College, Manawatū at Whirokino, Mangatainoka at Brewery-SH2 Bridge, and Oroua at Awahuri Bridge (Figure 21). Decreasing trends in NO_x are visible in these plots for Manawatū at Hopelands, Manawatū at Opiki Br, Manawatū at Teachers College, Manawatū at Whirokino, and Oroua at Awahuri Bridge (Figure 22). Seasonal variations in NO_x concentrations (saw tooth pattern in the concentration through time) were also evident at all sites.

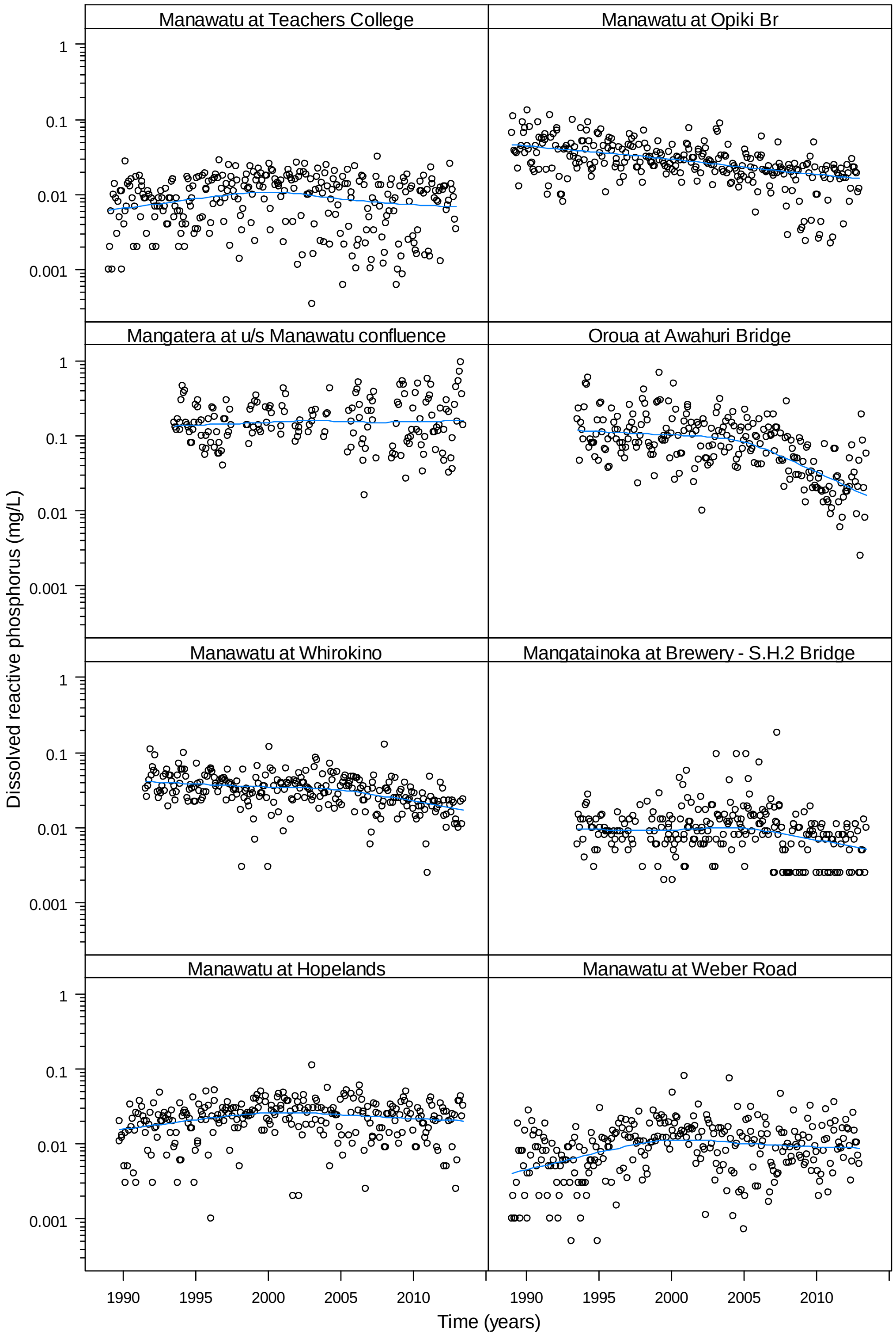

Figure 21: Plot of the time series of DRP concentrations at the six SoE sites for which data was available for a 20-year period ending July 2013. The

smooth blue line is fitted to the data to emphasise the change through time.

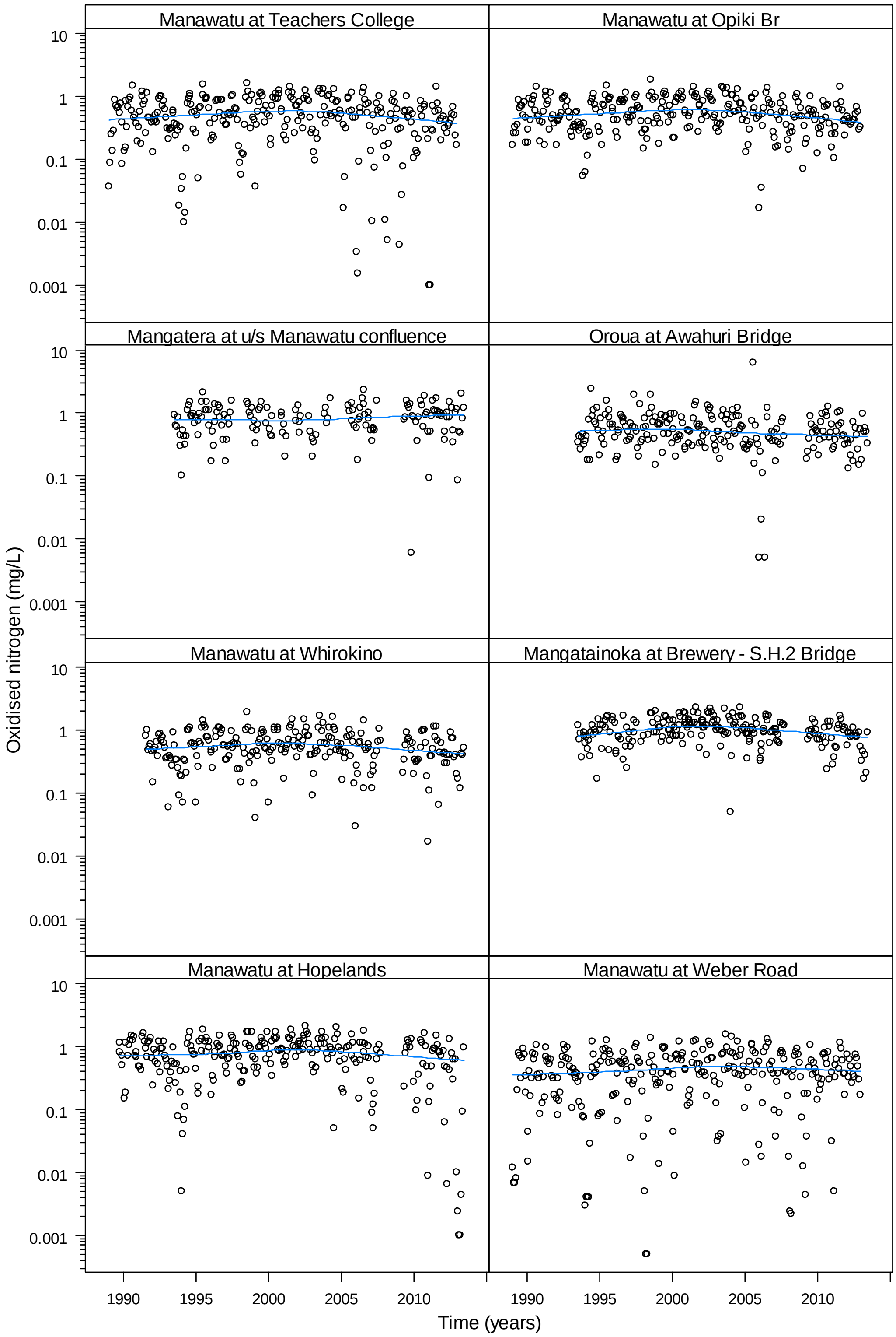

Figure 22: Plot of the time series of NO_x concentrations at the six SoE sites for which data was available for a 20-year period ending July 2013. The smooth blue line is fitted to the data to emphasise the change through time.

The results of the formal trend tests for five water quality variables are shown in Figure 23. Where the trends were significant, they were generally decreasing and meaningful (i.e. the magnitude of the relative trends were more than 1% per year). There was one meaningful increasing trend for ammonical nitrogen (NH_4) at Oroua at Awahuri Bridge.

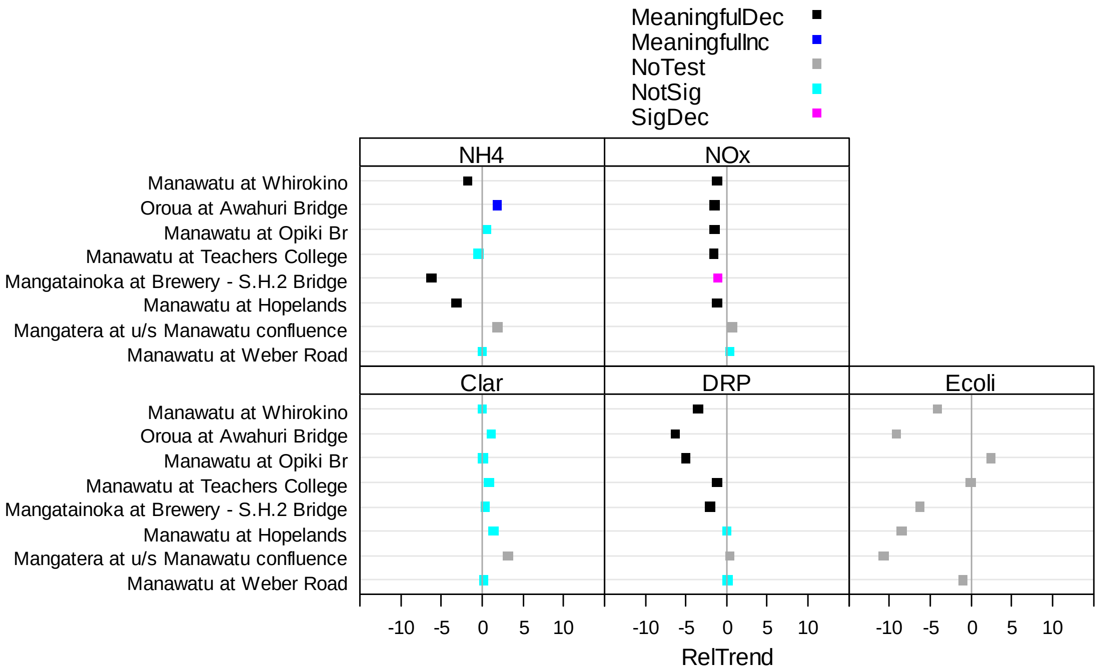

Figure 23: Relative trends (i.e. RSKSE [% yr^{-1}]) at the eight SoE sites for which data was available for the 20-year period ending July 2013 for five water quality variables. The trends are categorised based on Scarsbrook (2006).

A comparison of trends indicated that the direction and significance of trends were not consistent between the 5- and 20-year periods (Table 19). The exception was *E. coli*, for which all trends were downward (negative) for both the 5- and 20-year periods, although only one of the 5-year trends was significant. However, as noted above, the overall 5-year trends were decreasing for DRP, *E. coli* and NO_X, which is consistent with the majority of significant trends over the 20-year period.

Table 19: Comparison of trends (SKSE values) for the 20- and 5-year periods. Trends that were significant (i.e. P<0.05) are shaded orange.

SiteName	NH_4		Clar		DRP		*E.coli*		NO_x	
	20	5	20	5	20	5	20	5	20	5
Manawatu at Hopelands	-0.001	0.000	0.017	0.015	0.000	-0.002	-18	-12	-0.010	-0.486
Manawatu at Opiki Br	0.001	0.000	0.005	-0.067	-0.002	-0.002	-4	-20	0.000	-0.011
Manawatu at Teachers College	0.001	0.000	-0.017	-0.008	0.000	0.000	-4	-1	-0.010	-0.042
Manawatu at Weber Road	-0.001	-0.001	0.002	-0.005	0.000	-0.002	-29	-69	0.005	-0.041
Manawatu at Whirokino	-0.001	0.006	0.000	-0.094	-0.001	-0.002	-11	-24	-0.006	0.002
Mangatainoka at Brewery - S.H.2 Bridge	-0.001	0.000	0.008	0.344	0.000	0.000	-7	3	-0.010	-0.082
Mangatera at u/s Manawatu confluence	0.004	-0.005	0.030	-0.005	0.009	-0.024	-56	-18	0.006	0.002
Oroua at Awahuri Bridge	0.002	0.020	0.011	0.200	-0.005	-0.004	-26	-23	-0.008	-0.017

5 DISCUSSION

5.1 Water quality state

The most obvious pattern associated with the assessment of water quality state was that sites monitored on a monthly basis almost uniformly met or failed to meet certain targets. The toxic contaminant targets for ammonia and nitrate were met at all monthly monitoring sites (i.e. including SOE and point source discharge monitoring sites) with few exceptions. By contrast, monthly monitoring sites uniformly failed to meet the water clarity target, only four sites met the annual microbial (*E. coli*) target, and only one site met the bathing target for *E. coli*. There was also widespread failure to meet the targets for the nutrients (DRP and SIN) at monthly monitoring sites. In total, 74% and 81% of these sites failed the DRP and SIN grades, respectively. These failures were broadly distributed over the Manawatū River catchment.

The high proportion of sites that failed to meet the nutrient targets was consistent with a broad majority of sites that failed to meet the targets for two types of the periphyton abundance grades (chlorophyll *a* [60%] and filamentous cover [73%]). In addition, half of the sites did not meet the target for the MCI. These failures were broadly distributed over the entire Manawatū River catchment. The results of the site grading based on the biological indicators were more variable.

In contrast to the periphyton targets, the majority of sites (86%) met the cyanobacteria grade. All sites that 'failed' in this study have previously been identified as having experienced prolonged or intermittent Phormidium blooms, and high levels of toxins have been detected (Wood & Young, 2011; Wood & Young, 2012). Studies have previously identified that Phormidium blooms generally occur when there are stable flows for prolonged periods (ca. >10 days), low dissolved reactive phosphorous (ca. <0.01 mg/L) and elevated dissolved inorganic nitrogen (ca. >0.1 mg/L). Because Phormidium have only been discriminated from other mat-forming periphyton for the last three years, it is not yet possible to establish if blooms are increasing in prevalence in these rivers.

The majority of the continuous temperature monitoring sites were graded as proposed NOF attribute state C based on the average annual CRI value. This means that they are likely to exhibit some thermal stress that may affect the survival of certain sensitive insects and the absence of sensitive fish species. Five sites were graded as proposed NOF attribute state D (i.e. below the proposed national bottom line) based on the average annual CRI value. When sites were graded based on the maximum recorded CRI value (worst case), a significant proportion (52%) were in Attribute state D. This disparity between assessment methods indicates that protocols for grading sites based on continuous temperature data need to be fully developed (Davies-Colley *et al.*, 2013). The relatively warm summer water temperatures and the failures to meet the national bottom line at the monitoring sites is associated with their being located on relatively large streams and rivers. Large streams and rivers in the Manawatū River catchment tend to be wide, with shallow gravel-beds that have little effective shading and which are prone to heating in summer.

All of the continuous DO monitoring sites were within proposed NOF attribute states B and C. Sites in attribute state B are likely to have occasional minor stress on sensitive organisms as a result of low DO concentrations. Sites in attribute state C will have moderate levels of stress associated with low DO concentrations in summer, with some risk of sensitive fish and invertebrate species loss. No sites were below the national bottom line. In the past, erroneous sensor data from the Hopelands site was used to generate ecosystem modelling results that suggested very high levels of water pollution. In 2007, the Hopelands site, affected largely by diffuse source pollution from agriculture and a few consented point sources (e.g. brewery wastes, community sewage pond discharges), had similar levels organic pollution to those in the Manawatū River immediately downstream of major point source discharges, in the 1980s (Wilcock *et al*., 2011). Current DO concentrations indicate that the Hopelands site is affected by oxygen-demanding substances but that it is not grossly contaminated, as was previously reported by the Dominion Post, who described the Manawatū River as the 'worst in the west' .

Spatial modelling revealed clear association between land use and water quality state, with poor water quality (high nutrients and faecal pollution, and low visual clarity) being associated with high pastoral land cover. These patterns with land cover are consistent with reports by other authors in previous studies (e.g. Ballantine & Davies-Colley, 2009; Hamill & McBride, 2003; Larned *et al.*, 2003; Larned *et al*., 2004). We found that water quality at SoE sites could be well explained and predicted by catchment characteristics such as the proportion of the catchment with heavy pastoral land cover. This suggests that the contaminant contributions in the catchment are generally dominated by non-point sources. However, it is noted that at specific locations and at certain times, point sources may nevertheless have a large effect on water quality. This finding is consistent with recent work by Roygard *et al*. (2012)

A comparison of the data from the Manawatū River catchment with data from NRWQN sites indicated that the Manawatū sites have relatively poor water quality. This is unsurprising given the level of catchment land use in the Manawatū River catchment. The NRWQN is broadly representative of large rivers in New Zealand, and therefore covers a large gradient in catchment land use. Many sites in the NRWQN represent catchments with very little pastoral land use that have correspondingly high proportions of catchment occupied by natural land cover, such as indigenous forest. By contrast, the Manawatū River catchment has a very high proportion of land in productive use (e.g. pasture) and a large number of towns and factories that are associated with point source discharges. Studies have shown that water quality at national to regional scales is strongly associated with the proportion of catchment in agricultural production (e.g., Unwin *et al.,* 2010). Therefore, our finding that water quality is poor compared to a representative cross section of large rivers in New Zealand is consistent with the level of development in the Manawatū River catchment and its known effect on water quality.

5.2 Trends

The trend analyses indicate that trend strength and direction is variable across sites in the catchment. Trends for the eight sites that had 20 years of data were generally for improving water quality where these were significant. For the 20-year period, we found meaningful decreases in ammoniacal nitrogen, nitrate and dissolved reactive phosphorus at three sites, and only one significant increasing trend for ammoniacal nitrogen. Meaningful decreases in nitrate and phosphorus trends in the Manawatū-Whanganui region have been found in other studies (e.g. Snelder *et al.,* 2011). Decreasing concentrations in phosphorus has been observed at many sites across New

Zealand. However, decreasing nitrate concentrations are relatively uncommon, as nitrogen generally increases in response to increasing land use intensity, such as conversion of sheep and beef to dairy farming.

Where significant, 5-year ‘overall trends’ were generally for improving water quality at both the SoE and PSD sites. However, the exception to this was for periphyton abundance as measured by chlorophyll *a*. This result is the reverse of that expected based on the trends for the nutrient species (SIN and DRP). This study did not attempt to understand why periphyton biomass is increasing when its primary driver, nutrient concentrations, was decreasing. However, many factors influence periphyton, including flows, light and temperature (Snelder *et al*., 2013), and these factors may be affecting the periphyton trends. Analysis of flows during the period may shed further light of the causes of the observed trends.

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Appendix A: State grading thresholds for SoE sites

Site Number	Site Name	pH	Temp	DO	BOD5	POM	Chl a	DRP	SIN	MCI	NH4	NH4Max	Toxicity	Clar	EcoliBath	EcoliYear	Fils	Mats
1	Tamaki at Tamaki Reserve	7 to 8.2	19	80	1.5	5	50	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
2	Tamaki at Stephensons	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
3	Mangarangiora trib at ds Norsewood STP	7 to 8.5	19	80	1.5	5	120	0.01	0.167	120	0.4	2.1	99	3	260	550	30	60
4	Mangarangiora Trib at US Norsewood STP	7 to 8.5	19	80	1.5	5	120	0.01	0.167	120	0.4	2.1	99	3	260	550	30	60
5	Mangarangiora at u/s Ormondville STP	7 to 8.5	19	80	1.5	5	120	0.01	0.167	120	0.4	2.1	99	3	260	550	30	60
6	Mangarangiora at d/s Ormondville STP	7 to 8.5	19	80	1.5	5	120	0.01	0.167	120	0.4	2.1	99	3	260	550	30	60
7	Mangatoro at Mangahei Road	7 to 8.5	19	80	1.5	5	120	0.01	0.11	120	0.4	2.1	99	3	260	550	30	60
8	Manawatū at Weber Road	7 to 8.5	19	80	1.5	5	120	0.01	0.167	120	0.4	2.1	99	3	260	550	30	60
9	Mangatera at Dannevirke	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
10	Tapuata at Easton Road	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
11	Mangatera at u/s T.D.C. Ox Ponds	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
12	Mangatera at d/s Dannevirke STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
13	Mangatera at u/s Manawatū confluence	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
14	Kumeti at Te Rehunga	7 to 8.2	19	80	1.5	5	50	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
15	Oruakeretaki at S.H.2 Napier	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
17	Oruakeretaki at d/s PPCS Oringi STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
18	Raparapawai at Jackson Rd	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	99	2.5	260	550	30	60
19	Manawatū at Hopelands	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
20	Mangatainoka at Putara	7 to 8.2	19	80	1.5	5	50	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
21	Mangatainoka at Larsons Road	7 to 8.2	19	80	1.5	5	50	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
22	Mangatainoka at Scarborough Konini Rd	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
23	Ngatahaka Stream at u/s Makakahi Confl	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
24	Makakahi at u/s Eketahuna STP	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60

Site Number	Site Name	pH	Temp	DO	BOD5	POM	Chl a	DRP	SIN	MCI	NH4	NH4Max	Toxicity	Clar	EcoliBath	EcoliYear	Fils	Mats
25	Makakahi at d/s Eketahuna STP	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
26	Makakahi at Hamua	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
27	Brechin at u/s Fonterra Pahiatua	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
28	Brechin at d/s Fonterra Pahiatua	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
29	Mangatainoka at Pahiatua Town Bridge	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
30	Mangatainoka at u/s Pahiatua STP	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
31	Mangatainoka at d/s Pahiatua STP	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
32	Mangatainoka at Brewery - S.H.2 Bridge	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
33	Mangatainoka at d/s DB Breweries	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
34	Mangatainoka at u/s Tiraumea confluence	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
35	Makuri at Tuscan Hills	7 to 8.5	19	80	1.5	5	120	0.01	0.11	120	0.4	2.1	99	3	260	550	30	60
36	Tiraumea at Ngaturi	7 to 8.5	23	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2	260	550	30	60
37	Tiraumea River at Haupokua Reserve	7 to 8.5	23	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2	260	550	30	60
38	Tiraumea u/s Manawatū Confluence	7 to 8.5	23	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2	260	550	30	60
39	Manawatū at Ngawapurua Bridge	7 to 8.5	19	80	1.5	5	120	0.01	0.444	120	0.4	2.1	99	3	260	550	30	60
40	Mangapapa at Troup Rd	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
41	Mangaatua at u/s Woodville STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
42	Mangaatua at d/s Woodville STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
43	Mangahao at Ballance	7 to 8.2	19	80	1.5	5	50	0.006	0.167	120	0.32	1.7	99	3	260	550	30	60
44	Manawatū at Upper Gorge	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
45	Pohangina at Piripiri	7 to 8.2	19	80	1.5	5	120	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
46	Pohangina at Mais Reach	7 to 8.5	22	70	2	5	120	0.01	0.11	100	0.4	2.1	95	2.5	260	550	30	60
47	Manawatū at u/s Ashhurst STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
48	Manawatū at d/s Ashhurst STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
49	Manawatū at Teachers College	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60

Site Number	Site Name	pH	Temp	DO	BOD5	POM	Chl a	DRP	SIN	MCI	NH4	NH4Max	Toxicity	Clar	EcoliBath	EcoliYear	Fils	Mats
50	Kahuterawa at Johnstons Rata	7 to 8.2	19	80	1.5	5	50	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
51	Manawatū at u/s PNCC STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
52	Manawatū at d/s PNCC STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
53	Manawatū at us Fonterra Longburn	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
54	Manawatū at ds Fonterra Longburn	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
55	Manawatū at Opiki Br	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
56	Oroua at Apiti	7 to 8.5	22	70	2	5	120	0.01	0.167	100	0.4	2.1	95	2.5	260	550	30	60
57	Oroua Trib at u/s Kimbolton STP	7 to 8.5	22	70	2	5	120	0.01	0.167	100	0.4	2.1	95	2.5	260	550	30	60
58	Oroua Tributary at d/s Kimbolton STP	7 to 8.5	22	70	2	5	120	0.01	0.167	100	0.4	2.1	95	2.5	260	550	30	60
59	Oroua at Almadale Slackline	7 to 8.5	22	70	2	5	120	0.01	0.167	100	0.4	2.1	95	2.5	260	550	30	60
60	Oroua at U/S AFFCO Feilding	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
61	Oroua at d/s AFFCO Feilding	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
62	Oroua at U/S Feilding STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
63	Oroua at d/s Feilding STP	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
64	Oroua at Awahuri Bridge	7 to 8.5	22	70	2	5	120	0.01	0.444	100	0.4	2.1	95	2.5	260	550	30	60
65	Oroua at Mangawhata	7 to 8.5	24	70	2	5	200	0.015	0.444	100	0.4	2.1	95	2.5	260	550	30	60
66	Tokomaru River at Horseshoe bend	7 to 8.2	19	80	1.5	5	50	0.006	0.07	120	0.32	1.7	99	3	260	550	30	60
67	Manawatū at u/s PPCS Shannon	7 to 8.5	24	70	2	5	200	0.015	0.444	100	0.4	2.1	95	2.5	260	550	30	60
68	Manawatū at d/s PPCS Shannon	7 to 8.5	24	70	2	5	200	0.015	0.444	100	0.4	2.1	95	2.5	260	550	30	60
69	Mangaore at u/s Shannon STP	7 to 8.5	22	70	2	5	120	0.01	0.167	100	0.4	2.1	95	2.5	260	550	30	60
70	Mangaore at d/s Shannon STP	7 to 8.5	22	70	2	5	120	0.01	0.167	100	0.4	2.1	95	2.5	260	550	30	60
71	Manawatū at Whirokino	7 to 8.5	24	70	2	5	200	0.015	0.444	100	0.4	2.1	95	2.5	260	550	30	60

Appendix B: State grading thresholds for point source discharge sites

Site Number	Site Name	pH.Change	Temp.Change	ClarChange	QMCIChange
1	Tamaki at Tamaki Reserve	0.5	2	20	20
2	Tamaki at Stephensons	0.5	3	30	20
3	Mangarangiora trib at ds Norsewood STP	0.5	3	20	20
4	Mangarangiora Trib at US Norsewood STP	0.5	3	20	20
5	Mangarangiora at u/s Ormondville STP	0.5	3	20	20
6	Mangarangiora at d/s Ormondville STP	0.5	3	20	20
7	Mangatoro at Mangahei Road	0.5	3	20	20
8	Manawatū at Weber Road	0.5	3	20	20
9	Mangatera at Dannevirke	0.5	3	30	20
10	Tapuata at Easton Road	0.5	3	30	20
11	Mangatera at u/s T.D.C. Ox Ponds	0.5	3	30	20
12	Mangatera at d/s Dannevirke STP	0.5	3	30	20
13	Mangatera at u/s Manawatū confluence	0.5	3	30	20
14	Kumeti at Te Rehunga	0.5	2	20	20
15	Oruakeretaki at S.H.2 Napier	0.5	3	30	20
17	Oruakeretaki at d/s PPCS Oringi STP	0.5	3	30	20
18	Raparapawai at Jackson Rd	0.5	3	30	20
19	Manawatū at Hopelands	0.5	3	20	20
20	Mangatainoka at Putara	0.5	2	20	20
21	Mangatainoka at Larsons Road	0.5	2	20	20
22	Mangatainoka at Scarborough Konini Rd	0.5	3	20	20
23	Ngatahaka Stream at u/s Makakahi Confl	0.5	3	20	20
24	Makakahi at u/s Eketahuna STP	0.5	3	20	20
25	Makakahi at d/s Eketahuna STP	0.5	3	20	20
26	Makakahi at Hamua	0.5	3	20	20
27	Brechin at u/s Fonterra Pahiatua	0.5	3	20	20
28	Brechin at d/s Fonterra Pahiatua	0.5	3	20	20
29	Mangatainoka at Pahiatua Town Bridge	0.5	3	20	20
30	Mangatainoka at u/s Pahiatua STP	0.5	3	20	20
31	Mangatainoka at d/s Pahiatua STP	0.5	3	20	20
32	Mangatainoka at Brewery - S.H.2 Bridge	0.5	3	20	20
33	Mangatainoka at d/s DB Breweries	0.5	3	20	20
34	Mangatainoka at u/s Tiraumea confluence	0.5	3	20	20
35	Makuri at Tuscan Hills	0.5	2	20	20

Site Number	Site Name	pH.Change	Temp.Change	ClarChange	QMCIChange
36	Tiraumea at Ngaturi	0.5	3	30	20
37	Tiraumea River at Haupokua Reserve	0.5	3	30	20
38	Tiraumea u/s Manawatū Confluence	0.5	3	30	20
39	Manawatū at Ngawapurua Bridge	0.5	3	20	20
40	Mangapapa at Troup Rd	0.5	3	30	20
41	Mangaatua at u/s Woodville STP	0.5	3	30	20
42	Mangaatua at d/s Woodville STP	0.5	3	30	20
43	Mangahao at Ballance	0.5	2	20	20
44	Manawatū at Upper Gorge	0.5	3	30	20
45	Pohangina at Piripiri	0.5	2	20	20
46	Pohangina at Mais Reach	0.5	3	30	20
47	Manawatū at u/s Ashhurst STP	0.5	3	30	20
48	Manawatū at d/s Ashhurst STP	0.5	3	30	20
49	Manawatū at Teachers College	0.5	3	30	20
50	Kahuterawa at Johnstons Rata	0.5	2	20	20
51	Manawatū at u/s PNCC STP	0.5	3	30	20
52	Manawatū at d/s PNCC STP	0.5	3	30	20
53	Manawatū at us Fonterra Longburn	0.5	3	30	20
54	Manawatū at ds Fonterra Longburn	0.5	3	30	20
55	Manawatū at Opiki Br	0.5	3	30	20
56	Oroua at Apiti	0.5	3	30	20
57	Oroua Trib at u/s Kimbolton STP	0.5	3	30	20
58	Oroua Tributary at d/s Kimbolton STP	0.5	3	30	20
59	Oroua at Almadale Slackline	0.5	3	30	20
60	Oroua at U/S AFFCO Feilding	0.5	3	30	20
61	Oroua at d/s AFFCO Feilding	0.5	3	30	20
62	Oroua at U/S Feilding STP	0.5	3	30	20
63	Oroua at d/s Feilding STP	0.5	3	30	20
64	Oroua at Awahuri Bridge	0.5	3	30	20
65	Oroua at Mangawhata	0.5	3	30	20
66	Tokomaru River at Horseshoe bend	0.5	2	20	20
67	Manawatū at u/s PPCS Shannon	0.5	3	30	20
68	Manawatū at d/s PPCS Shannon	0.5	3	30	20
69	Mangaore at u/s Shannon STP	0.5	3	30	20
70	Mangaore at d/s Shannon STP	0.5	3	30	20
71	Manawatū at Whirokino	0.5	3	30	20

Appendix C: Trend results (5-year trends as SKSE values and associated P-values)

SiteName	Variable															
	NH4		Clar		Chla		DRP		Ecoli		NOx		BOD		POM	
	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value
Brechin at d/s Fonterra Pahiatua	0.01	0.03	0.00	0.00			0.00	0.15	0.75	0.94	-0.08	0.18	0.00	0.00	-0.20	0.00
Brechin at u/s Fonterra Pahiatua	0.00	0.81	0.00	0.00			0.00	0.47	12.00	0.58	-0.17	0.20	0.00	0.00	-0.33	0.39
Kahuterawa at Johnstons Rata	0.00	1.00	0.50	0.00			0.00	0.88	-1.67	0.22	-0.01	0.36			0.00	0.00
Kumeti at Te Rehunga	0.00	1.00	-0.56	0.00	0.58	0.10	0.00	0.00	-29.75	0.04	0.00	0.92				
Makakahi at d/s Eketahuna STP	0.00	0.27	0.05	0.92			0.00	0.08	-33.67	0.02	-0.04	0.04	0.00	0.00	0.00	0.63
Makakahi at Hamua	0.00	0.56	-0.16	0.47	5.17	0.29	0.00	0.05	-32.17	0.02	0.00	1.00			0.00	0.00
Makakahi at u/s Eketahuna STP	0.00	0.06	-0.02	0.93			0.00	0.03	-9.00	0.36	-0.14	0.41	0.00	0.00	0.00	0.81
Makuri at Tuscan Hills	0.00	0.45	-0.02	0.82	13.25	0.02	0.00	0.09	-6.00	0.71	0.02	0.65			0.00	0.00
Manawatū at d/s Ashhurst STP	-0.01	0.02	0.08	0.70			0.00	0.00	-18.17	0.32	-0.08	0.00	0.00	0.00	0.00	0.76
Manawatū at d/s PNCC STP	-0.03	0.00	-0.34	0.00	7.00	0.01	-0.01	0.00	-47.00	0.00	-0.26	0.00	0.00	0.00	-5.50	0.00
Manawatū at d/s PPCS Shannon	0.01	0.12	-0.05	0.00			0.00	0.14	-19.75	0.27	0.00	1.00	0.00	0.62	-1.69	0.16
Manawatū at ds Fonterra Longburn	0.00	0.83	0.25	0.14			0.00	0.03	-20.83	0.39	-0.05	0.06	0.00	0.64	0.00	0.83
Manawatū at Hopelands	0.00	0.94	0.02	0.74	0.01	1.00	0.00	0.03	-12.38	0.38	-0.49	0.01	0.00	0.00	0.00	0.00
Manawatū at Ngawapurua Bridge	0.00	0.58	0.00	0.00			0.00	0.26	-37.00	0.45	0.00	0.91				
Manawatū at Opiki Br	0.00	1.00	-0.07	0.00	0.44	0.00	0.00	0.03	-20.17	0.52	-0.01	0.52			0.00	0.00
Manawatū at Teachers College	0.00	0.45	-0.01	0.00	0.12	0.00	0.00	0.41	-0.50	1.00	-0.04	0.32			0.00	0.00
Manawatū at u/s Ashhurst STP	0.00	0.13	0.09	0.00			0.00	0.76	-68.75	0.07	-0.09	0.00	-0.63	0.00	-1.75	0.03
Manawatū at u/s PNCC STP	0.00	0.01	0.29	0.01	0.32	0.80	0.00	0.04	-28.54	0.17	-0.06	0.02	0.00	0.00	0.00	1.00
Manawatū at u/s PPCS Shannon	0.01	0.42	-0.02	0.00			0.00	0.02	-10.92	0.51	-0.03	0.30	0.00	0.60	-0.19	0.04
Manawatū at Upper Gorge	0.00	0.37	0.02	0.80	0.05	0.00	0.00	0.18	14.71	0.47	-0.05	0.03			0.00	0.00
Manawatū at us Fonterra Longburn	0.00	0.94	0.23	0.12			0.00	0.00	-18.75	0.32	-0.04	0.08	0.00	0.64	0.00	1.00
Manawatū at Weber Road	0.00	0.61	0.00	0.83	1.32	0.17	0.00	0.00	-68.83	0.01	-0.04	0.22			0.00	0.00
Manawatū at Whirokino	0.01	0.47	-0.09	0.00			0.00	0.00	-23.67	0.52	0.00	0.93			0.00	0.00
Mangaatua at d/s Woodville STP	0.00	0.31	0.00	1.00			0.00	0.22	100.75	0.03	-0.01	0.58	0.00	0.00	0.00	0.72
Mangaatua at u/s Woodville STP	0.00	0.67	0.09	0.52			0.00	0.01	100.63	0.01	-0.04	0.00	0.00	0.00	0.00	0.91
Mangahao at Ballance	0.00	0.75	0.10	0.00			0.00	0.14	0.17	1.00	-0.01	0.15			0.00	0.00
Mangaore at d/s Shannon STP	0.00	0.48	0.07	0.00			0.00	0.94	0.83	0.77	-0.02	0.02	0.00	0.00	0.00	1.00
Mangaore at u/s Shannon STP	0.00	0.54	0.08	0.00			0.00	0.26	6.75	0.12	0.00	0.77	-0.50	0.00	-0.13	0.57
Mangapapa at Troup Rd	0.00	0.15	-0.01	0.00	0.69	0.02	0.00	0.00	-6.50	0.94	-0.07	0.02			0.00	0.00
Mangarangiora at d/s Ormondville STP	-0.01	0.00	-0.15	0.00			0.01	0.00	-55.00	0.00	-0.08	0.00	0.00	0.00	-1.25	0.00

SiteName	Variable															
	NH4		Clar		Chla		DRP		Ecoli		NOx		BOD		POM	
	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value
Mangarangiora at u/s Ormondville STP	-0.01	0.00	-0.35	0.00			0.01	0.00	38.25	0.00	-0.07	0.00	0.00	0.00	-0.83	0.00
Mangarangiora trib at ds Norsewood STP	0.00	0.52	0.04	0.60			0.00	1.00	-13.13	0.83	0.04	0.65	0.00	0.76	0.00	0.76
Mangarangiora Trib at US Norsewood STP	0.00	1.00	0.00	1.00			0.00	0.01	-40.75	0.43	-0.02	0.41	0.00	0.22	0.00	0.75
Mangatainoka at Brewery - S.H.2 Bridge	0.00	1.00	0.34	0.05	2.79	0.10	0.00	0.20	2.63	0.56	-0.08	0.04	0.00	0.00	0.00	0.00
Mangatainoka at d/s DB Breweries	0.00	0.65	-0.17	0.00	0.27	0.81	0.00	0.00	-31.00	0.01	-0.07	0.10	0.00	1.00	-0.10	0.00
Mangatainoka at d/s Pahiatua STP	0.00	0.00	0.00	0.00	1.42	0.00	0.00	0.00	9.67	0.00	-0.07	0.00	0.00	0.00	-0.13	0.00
Mangatainoka at Larsons Road	0.00	0.35	0.18	0.86			0.00	0.70	-3.00	0.52	0.00	0.26			0.00	0.00
Mangatainoka at Pahiatua Town Bridge	0.00	0.73	0.15	0.00			0.00	1.00	-13.00	0.07	-0.06	0.33				
Mangatainoka at Putara	0.00	0.01	0.03	0.69	0.32	0.00	0.00	0.66	0.25	0.57	0.00	0.14			0.00	0.00
Mangatainoka at Scarborough Konini Rd	0.00	0.00	0.25	0.00			0.00	0.00	-12.00	0.00	-0.24	0.00				
Mangatainoka at u/s Pahiatua STP	0.00	0.00	0.08	0.00	0.67	0.18	0.00	0.00	-9.67	0.00	-0.06	0.00	0.00	0.00	-0.25	0.00
Mangatainoka at u/s Tiraumea confluence	0.00	0.00	0.60	0.00	1.25	0.00	0.00	0.00	9.75	0.00	-0.16	0.00				
Mangatera at d/s Dannevirke STP	0.22	0.00	0.12	0.00	0.35	0.09	0.10	0.00	274.50	0.00	-0.10	0.00	0.75	0.00	-1.70	0.00
Mangatera at Dannevirke	0.00	0.22	0.08	0.38			0.00	0.02	-30.38	0.72	-0.05	0.02	0.13	0.00	0.00	0.92
Mangatera at u/s Manawatū confluence	-0.01	0.71	-0.01	0.76			-0.02	0.61	-18.25	0.52	0.00	0.85			0.00	0.00
Mangatera at u/s T.D.C. Ox Ponds	0.00	0.14	0.10	0.52	0.92	0.02	0.00	0.02	-37.17	0.16	-0.05	0.01	0.00	0.09	0.00	0.93
Mangatoro at Mangahei Road	0.00	1.00	0.03	0.58			-0.05	0.23	-3.17	0.94	-0.06	0.16			0.00	0.00
Ngatahaka Stream at u/s Makakahi Confl	0.00	0.00	0.60	0.00			0.00	0.00	20.75	0.00	-0.10	0.00	0.00	0.00	-0.63	0.00
Oroua at Almadale Slackline	0.00	0.70	0.43	0.01	0.21	0.02	0.00	0.28	-2.33	0.72	0.00	0.29			0.00	0.00
Oroua at Apiti	0.00	0.62	0.20	0.25	0.16	0.01	0.00	0.02	0.83	0.55	0.00	0.92			0.00	0.00
Oroua at Awahuri Bridge	0.02	0.02	0.20	0.07	0.76	0.00	0.00	0.01	-22.50	0.29	-0.02	0.59			0.00	0.00
Oroua at d/s AFFCO Feilding	0.00	0.16	0.00	1.00			0.00	0.04	-1.00	0.94	-0.03	0.08	0.00	0.00	-0.70	0.16
Oroua at d/s Feilding STP	-0.22	0.00	0.10	0.33	3.09	0.12	-0.01	0.00	-30.42	0.48	-0.29	0.00	0.00	0.00	-0.88	0.14
Oroua at Mangawhata	-0.07	0.00	0.25	0.00			0.00	0.00	12.00	0.00	0.09	0.00				
Oroua at U/S AFFCO Feilding	-0.01	0.05	0.00	1.00			0.00	0.10	11.75	0.82	-0.02	0.10	0.00	0.00	-0.10	0.59
Oroua at U/S Feilding STP	-0.04	0.01	0.20	0.06	0.55	0.09	0.00	0.06	-0.50	1.00	-0.10	0.00	0.00	0.00	-0.25	0.26
Oroua Trib at u/s Kimbolton STP	0.00	0.83	-0.25	0.00			0.00	0.25	46.17	0.29	-0.01	1.00	0.00	0.00	-0.40	0.12
Oroua Tributary at d/s Kimbolton STP	0.00	1.00	-0.13	0.00			-0.15	0.01	22.00	0.67	-0.06	0.17	0.00	0.00	-0.38	0.53
Oruakeretaki at d/s PPCS Oringi STP	0.00	0.25	0.27	0.00			0.00	0.00	10.75	0.55	-0.11	0.30	0.25	0.00	-0.27	0.19
Oruakeretaki at S.H.2 Napier	0.00	0.13	-0.39	0.25	1.33	0.03	0.00	0.00	-5.83	0.83	-0.02	0.44			0.00	0.91
Pohangina at Mais Reach	0.00	0.64	0.05	0.51	0.16	0.02	0.00	0.11	2.75	0.62	-0.04	0.78			0.00	0.00
Pohangina at Piripiri	0.00	0.81	0.21	0.19	0.23	0.01	0.00	0.10	2.00	0.10	0.00	0.58			0.00	0.00
Raparapawai at Jackson Rd	0.00	0.24	0.38	0.29			0.00	0.67	-46.67	0.47	-0.03	0.14				

	Variable															
	NH4		Clar		Chla		DRP		Ecoli		NOx		BOD		POM	
SiteName	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value
Tamaki at Stephensons	0.00	0.24	-0.10	0.86	0.05	0.80	0.00	0.07	-8.58	0.43	-0.01	0.70			0.00	0.00
Tamaki at Tamaki Reserve	0.00	0.06	-0.78	0.00	0.49	0.00	0.00	0.00	1.00	0.35	0.00	0.85			0.00	0.00
Tapuata at Easton Road	-0.01	0.00	0.00	0.00			-0.01	0.00	-183.50	0.00	-0.08	0.00	0.00	1.00	-1.25	0.00
Tiraumea at Ngaturi	0.00	0.54	-0.03	0.31	20.17	0.00	0.00	0.03	-34.13	0.04	0.02	0.46			0.00	0.00
Tiraumea River at Haupokua Reserve	0.00	0.41	0.09	0.00			0.00	0.29	-16.50	0.71	0.03	0.06			0.00	0.00
Tiraumea u/s Manawatū Confluence	0.00	0.63	0.11	0.00			0.00	0.31	0.07	0.71	-0.06	0.23				
Tokomaru River at Horseshoe bend	0.00	0.21	-0.25	0.18	1.70	0.00	0.00	0.31	-7.00	0.43	0.00	0.65			0.00	0.00

Appendix D: Trend results (20-year trends as SKSE values and associated P-values)

SiteName	Variable									
	NH4		Clar		DRP		Ecoli		NOx	
	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value	Trend	P-value
Manawatū at Hopelands	0.00	0.00	0.02	0.09	0.00	0.83	-18.33	0.00	-0.01	0.01
Manawatū at Opiki Br	0.00	0.02	0.00	0.59	0.00	0.00	-4.00	0.83	0.00	0.97
Manawatū at Teachers College	0.00	0.12	-0.02	0.62	0.00	0.86	-4.17	0.57	-0.01	0.49
Manawatū at Weber Road	0.00	0.00	0.00	0.75	0.00	0.65	-28.75	0.04	0.01	0.04
Manawatū at Whirokino	0.00	0.00	0.00	0.74	0.00	0.00	-10.77	0.11	-0.01	0.03
Mangatainoka at Brewery - S.H.2 Bridge	0.00	0.00	0.01	0.49	0.00	0.00	-6.56	0.01	-0.01	0.03
Mangatera at u/s Manawatū confluence	0.00	0.02	0.03	0.01	0.01	0.12	-55.82	0.01	0.01	0.10
Oroua at Awahuri Bridge	0.00	0.03	0.01	0.19	-0.01	0.00	-26.19	0.00	-0.01	0.01

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