Establishment of reference conditions and trigger values for chemical, physical and micro-biological indicators in New Zealand streams and rivers

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Client Report

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Summary

Central to the management of streams and rivers is establishment of reference conditions and trigger values. Reference conditions are defined as the chemical, physical or biological conditions that can be expected in streams and rivers with minimal or no anthropogenic influence. Trigger values indicate that there is a ‘potential risk’ of adverse effects at a site. Reference conditions and trigger values are strongly linked because of the manner in which ‘trigger values’ have been defined in the ANZECC (2000) framework. Trigger values are defined from the distribution of observed concentrations at pre-identified local reference sites. Trigger values are defined by the 80^{th} percentile of indicators that are harmful at high values (e.g. nitrate; the exception is *Escherichia coli*, which is presented as a 95^{th} percentile) and/or the 20^{th} percentile of indicators that cause problems at low values (e.g., clarity).

Predefined trigger values (referred to as default trigger values), which were derived from existing reference site data, are provided in the ANZECC (2000) guidelines for some physiochemical stressors. The default trigger values apply to two classes of New Zealand rivers; upland and lowland. This coarse subdivision of river environments limits the confidence that users can have in the default trigger values. A high resolution classification of rivers would increase the accuracy of reference conditions and trigger values. However, a significant constraint to improving estimates of reference conditions and trigger values has been the lack of reference sites in water quality datasets. To overcome this constraint, this study used a statistical modelling approach to estimating reference conditions and trigger values.

Data for this study comprised 12 physico-chemical and microbial indicators collected over a five year period at >1000 sites across New Zealand. The indicators included: conductivity, ammoniacal-nitrogen, clarity, *Escherichia coli*, filterable reactive phosphorus, nitrate-nitrogen, suspended solids, total nitrogen, total phosphorus, turbidity, dissolved oxygen, hydrogen ion concentration (pH) and temperature. Statistical models were used to estimate reference conditions and trigger values for classes defined by the second (climate and topography) and third (climate and topography and geology) levels of the hierarchical River Environment Classification (REC; Snelder and Biggs, 2002, MFE, 2004). The REC accounts for a range of natural factors that influence water quality (e.g., climate, topography and geology) and is widely used to study water quality patterns in New Zealand (e.g., Larned et al. 2004).

Statistical modelling was based on two types of regression methods (McDowell et al., In press; Dodds and Oakes, 2004). Both approaches estimated the reference condition and trigger value within each REC class. The percentage of catchment occupied by heavy pasture land cover (as defined by Unwin et al., 2010) represented the human (anthropogenic) use/influence within the catchment upstream of each site and was used as the independent variable in the regression. For each indicator, the reference condition was estimated as the intercept (i.e. where percent heavy pasture is zero) for a regression of the median values against the percentage of heavy pasture. For each indicator, the intercept of a regression of a relevant percentile of site values (i.e. the 80th or 20th percentiles and the 95th percentile for *E. coli*) against percentage of heavy pasture was used to estimate the trigger value for each REC class.

Tables of estimated reference conditions and trigger values for 12 indicators for classes at the two levels of the REC are provided with this report. Statistically significant models could not be defined for either reference conditions or trigger values for Temperature or trigger values for pH. This is unsurprising because Temperature and pH have large diurnal variation and therefore relationships of monthly samples of these indicators with REC class and catchment land cover can be expected to be weak.

The reference concentrations and trigger values derived in this study are a significant advance on the current ANZECC (2000) guidelines in three respects. First, the methods used in the current study use all the relevant available water quality data, including many regional council datasets. Second, the environmental specificity of the reference and trigger values is greatly increased from two classes (upland and lowland) provided by the ANZECC (2000) guidelines to at least 18 classes at the second (topography) level of the REC. Third, confidence intervals are provided for the reference condition and trigger values. These confidence intervals provide a measure of the accuracy of the estimates. We note that if the estimated trigger values presented here are used to revise the ANZECC guidelines (i.e. to become the default trigger values), a decision needs to be made about how to handle the uncertainties. Default trigger values could be made more or less conservative by taking into account the uncertainty in the estimated value (e.g., a less conservative value for indicators that are harmful at high values would be the 95% confidence interval for the estimate).

The use of regression models to estimate median reference conditions and trigger values involves several assumptions. First, it is assumed that the proportion of the catchment area occupied by heavy pasture land cover is a good surrogate for the influence of anthropogenic disturbance on water quality indicators. The heavy pasture land cover category applies to most pastoral land in New Zealand and studies have shown it is the dominant signal of anthropogenic influence on water quality at the national scale (Unwin et al., 2010). Studies in other countries have emphasised either the percentage of cropland (Dodds and Oakes, 2004) or the total percentage of agriculture within a catchment as explanatory variables (Chambers et al., 2012). The use of heavy pasture in this study reflects the domination of New Zealand agriculture by the pastoral sector (Larned et al., 2003). Second, the analysis was based on assumptions about the input data including, that the sites used to fit the model span a sufficient range of percent heavy pasture to yield a good estimate of the intercept; that they are a representative, unbiased sample of the population of sites within a REC class; and that water quality at the sites was not unduly influenced by variables that were not included in the model. To check the validity of these assumptions, verification of the estimated values were made by comparing them with independent reference conditions and trigger values that were derived from individual sites that were *a priori* classified as minimally disturbed (i.e. < 5% heavy pasture land cover). The reference conditions and trigger values derived from the minimally disturbed sites were generally within the confidence limits of the modelled estimates validation providing confidence in the modelled estimates. Finally, the use of regression models to estimate reference conditions and trigger values assumes that there is little or no effect of temporal variation in water quality. The conventions used for filtering the data meant that sites had been sampled at regular intervals and therefore seasonal bias was unlikely. There is potential for water quality data to be affected by long term trends. However, more than five years of monthly monitoring data is generally required to detect significant trends. Because the datasets used were no longer than five years, trends were unlikely to have influenced the results. In general terms, the uncertainties that these limitations induce are reflected by the magnitude of the confidence intervals and this allows users to assess the quality of the estimated values.

In addition to deriving reference conditions and trigger values, this study enables the identification of river and stream environments (REC classes) with high anthropogenic input relative to reference conditions. Metrics describing 1) the anthropogenic contribution to indicator values and 2) the degree of enrichment beyond the reference conditions, showed that lowland sites classified as warm-wet, warm-dry or cool-dry exhibited the greatest anthropogenic input and enrichment. Knowledge of reference conditions helps avoid setting water quality limits or targets that are either too high that they may have little ecological benefit or too restrictive, and impossible to meet (e.g., < reference conditions). It is recommended that this approach be considered by regulatory authorities during the process of setting water quality objectives and limits.

1 Introduction

A key issue in the management of freshwater aquatic systems is the establishment of reference conditions and trigger values. Reference conditions are defined as the chemical, physical or biological conditions that can be expected in streams and rivers with minimal or no anthropogenic influence (Soranno et al., 2011). Reference conditions provide an indication of the maximum obtainable water quality and are the basis for estimating the component of the contaminant load that is attributable to human activities. Trigger values indicate that there is a 'potential risk' of adverse effects, and management action or site-specific investigations may be needed. Trigger values are intended to be used "…in conjunction with professional judgement, to provide an initial assessment of the state of a water body regarding the issue in question" (ANZECC, 2000). Furthermore "Trigger values are concentrations that, if exceeded, would indicate a potential environmental problem, and so 'trigger' a management response, e.g., further investigation and subsequent refinement of the guidelines according to local conditions" (ANZECC, 2000). There is a need to establish the reference condition and trigger values because there is always some natural level of contaminant input to aquatic systems, and few catchments are minimally affected by human activities. Furthermore, at a regional scale, reference sites are seldom available for many stream types.

1.1 Trigger values

While the terms reference condition and trigger value ostensibly refer to specific and separate ideas, they are strongly linked because of the manner in which 'trigger values' have been defined in the ANZECC (2000) framework. The 2000 ANZECC Guidelines (ANZECC 2000; Table 1) were intended to provide guidance in the development of locally applicable, up-to-date water quality guidelines, and in the absence of those, to provide trigger-values. The ANZECC (2000) approaches are ranked from most- to least-preferred (ANZECC 2000; Figure 3.1.2). The most-preferred guidelines are effects-based; that link environmental values (e.g., suitability for use) and issues (e.g., algal proliferations) to recognised indicators (e.g., nutrients). The New Zealand periphyton guidelines are an example of an effects-based guideline (MFE 2000). The second-most preferred approach is to define trigger values for indicators using a reference condition-based method. In this approach, ANZECC (2000) proposes a 'rule' to establish trigger values based on the distribution of observed concentrations at pre-identified local reference sites. The rule defines trigger values as the 80th percentile of a distribution of observed concentrations of indicators that are harmful at high values (e.g., nitrate) and/or the 20^{th} percentile of indicators that cause problems at low values (e.g, clarity and dissolved oxygen). It is presumed that a test[1] site for which the median of a series of measurements of water quality is below the trigger value has a low risk of environmental impairment (ANZECC 2000). Thus, trigger values are derived from reference sites, but are somewhat more lenient than (say) the median of values measured at a reference site.

Table 1. Example of ANZECC (2000) trigger values for physiochemical stressors in New Zealand upland and lowland rivers. See Table 2 for description of the indicators.

Indicator	Upland river	Lowland river
FRP (µg L^{-1})	9	10
TP (µg L^{-1})	26	33
NO_x (µg L^{-1})	167	444
NH_4 (µg L^{-1})	10	21
TN (µg L^{-1})	295	614
pH upper limit	8.0	7.8
DO (% saturation) lower limit	99	98

The least-preferred method ANZECC (2000) provided was 'default trigger-values' that were to be used *only* in the absence of reliable local data (Section 3.3.2.5, ANZECC 2000). Default trigger-values are derived from an analysis of available data from sites that were assessed to be in a reference state. The $20^{th}/80^{th}$ percentile values of indicators observed at the reference sites were used to define the default trigger values. Default trigger values are derived for sites within defined ecoregions[2] or other types of environmental classifications. Default trigger values are then only used for test sites that belong to the same ecoregion or class. Despite the caution that default trigger values should only be applied in the absence of reliable local data, the ANZECC 2000 default water quality guidelines are used very widely in New Zealand and Australia, because, at least in part, they are obtained with minimum effort, and because reference sites are generally scarce (Larned and Snelder 2011).

[1] The term 'test site' is used by ANZECC (2000). This means the site at which the water quality assessment is to be made.
[2] An ecoregion is a spatially contiguous region whose boundaries are derived by considering a combination of factors that influence stream water quality, often including climate, topography, geology and land cover.

The ANZECC (2000) guidelines (Table 1) provide default trigger values for New Zealand that were derived from distributions of values measured at reference and pseudo-reference sites within the National River Water Quality Network (Smith and McBride, 1990). Distributions were obtained from data measured at sites in large streams and rivers in 18 upland (> 150 m elevation and with glacial and lake-fed sites removed) and 3 lowland (< 150 m elevation and with one site with alpine headwaters removed) locations. It has been argued that the current (ANZECC 2000) default trigger values have limited accuracy because they are based on too few classes and too few data , especially for smaller streams that are likely to be more impacted by anthropogenic inputs (Larned and Snelder 2011).

1.2 Reference conditions

It is important that reference conditions and trigger values are estimated as accurately as possible. Accurate estimation of reference conditions avoids prescribing expectations or guidelines that are not achievable because background levels (e.g., concentrations) are naturally high, or alternatively, that are insufficiently protective of values. Accurate estimation of reference conditions also aids in the identification of the manageable portion of anthropogenic losses, and to identify those catchments where there is significant potential for restoration of environmental conditions or intensification of human activities. Accurate estimation of trigger values reduces the likelihood of committing both type I (inferring impairment when it does not exist) and type II (not detecting impairment when it does exists) statistical errors (Hawkins et al. 2000).

There are a range of methods that are used to estimate reference conditions and that are, therefore, potentially useful for assisting with the development of trigger values and default trigger values. Statistically, the simplest is the “minimally disturbed condition” (Lewis et al., 1999). The minimally disturbed condition approach utilises data from a stream or river that is not subject to anthropogenic disturbance now or in the past (Stoddard et al., 2006). However, such reference sites are uncommon, particularly in most agriculturally productive landscapes (Larned et al., 2003). Their rarity often means that a reference site may only be representative of a few catchments in the area due to differing climate or soil factors. Another approach for estimating reference conditions, known as the “historical condition”, uses data from before a stream or river became degraded (Stoddard et al. 2006). However, this approach may be unreliable because there is often little historical data and because of time lags between losses from agricultural land and the effects on rivers and streams (Cooper and Thomsen, 1988; Vant and Huser, 2000). Another approach to the estimation of reference conditions is to combine sample data from reference sites in groups defined by a classification system and use a percentile of the distribution of values as the reference condition estimate (e.g., the median or 80% percentile of large-undisturbed river as per ANZECC, 2000). The quality of the estimate in this approach is limited by the ability of the classification system to group reference sites that are representative of the impact site. In this method a reference site determined at the 80th percentile would be analogous to the default trigger values determined in the ANZECC (2000) approach. Alternatively, the “least disturbed condition” also groups sample data for sites according to a classification and then nominates sites that have the least anthropogenic input (Stoddard et al., 2006). A reference condition is then estimated as a percentile at the lower end of the distribution of values for the least impacted sites (e.g., 5th percentile). Ideally, all approaches are combined with an assessment of ecological conditions (e.g., including biological indicators). However, congruent ecological and water quality data are often lacking. Therefore all approaches, especially the least disturbed condition, run the risk of estimating a reference condition that is too high.

1.3 Other approaches to estimating reference conditions

All of the above approaches to estimation of reference conditions are limited by both a lack of sampling sites that represent reference conditions, and a paucity of data. This lack of data reduces the specificity and confidence of the estimates of the reference condition and of trigger values. Specificity refers to the environmental specificity of guidelines, i.e. the extent to which guidelines discriminate sites according to the factors that control water quality. Confidence refers to statistical uncertainty of the estimates.

An alternative approach that both increases and quantifies confidence and increases specificity is to statistically model data from all available sites, regardless of whether they are judged to be in a reference condition. Dodds and Oakes (2004) developed a statistical model approach that estimates the influence of anthropogenic land uses on nutrient concentrations in lotic systems. The approach of Dodds and Oakes (2004) utilised an analysis of covariance and linear regression to assess the relationship between the median values of observed indicators at many sites and the percentage of anthropogenic land use for a range of sites that exhibit no significant regional effect (i.e. enabling sites to be aggregated between ecoregions, thereby maximising the value of the data). The ordinate intercept of these regression relationships is the estimated value of the indicator in the absence of anthropogenic influence, or a reference value.

2 Aims and scope

The aim of this report is to provide estimates of physical, chemical and microbiological indicators of water quality under reference conditions and to provide default trigger values that if exceeded require “further investigation and subsequent refinement of the guidelines according to local conditions” as per ANZECC (2000).

The scope of the report was to discuss the relative merits of different approaches for estimating reference conditions and trigger values and use the best approach to define reference conditions and trigger values for the first three levels of the hierarchical River Environment Classification (REC; Snelder and Biggs, 2002: climate, topography and geology) for the following indicators: clarity, electrical conductivity, suspended solids, ammoniacal nitrogen, oxidised nitrogen, filterable reactive phosphorus, total phosphorus and *Escherichia coli*. The data was to be provided in the form of tables of reference conditions and trigger values (with confidence intervals), of sites defined as being in a minimally disturbed condition, and as two metrics: 1) the percentage of anthropogenic contribution to the current value of an indicator, and 2) the degree of enrichment of the current indicator’s value beyond reference conditions.

Reference conditions, as defined in this report, were estimated and modelled as the median value of water quality variables that represent water quality indicators in the absence of anthropogenic influence. The preferred approach (mixed effects models) had three advantages: it utilised all data within a REC class thereby avoiding the calculation of reference conditions based on only a few (or no) minimally disturbed sites, avoids the need for long historical datasets associated with the use of sites in the “historical condition”, and reduces the potential inaccuracy involved with categorising sites as being in the “least disturbed condition”.

Trigger values were defined as an estimate of the relevant percentile under reference conditions for a REC class. As per ANZECC (2000), the 80th percentile was used for all indicators except clarity pH and dissolved oxygen saturation which were also presented as 20th percentiles (if appropriate). For *E. coli* a 95th percentile was used as per MfE & MoH (2003). The difference to the ANZECC (2000) trigger value approach is that we utilised the relevant percentile of data from all suitable sites (not just those under, or near to, minimally disturbed condition) in our approach to estimate a reference or trigger value as opposed to a percentile of a pooled dataset of a few rivers that were judged to be reference sites. Due to the much larger number of sites, the classification system and the method of analysis, the approach yields robust estimates for REC classes and therefore maximised the potential to account for natural variation factors that influence water quality (i.e. catchment climate, topography and geology).

3 Methodology

3.1 Data

A database containing water quality data representing several indicators (Table 2) was collated from McDowell et al. (2009) and the National River Water Quality Network (NRWQN; for description see Smith and McBride, 1990). This database included about 1000 sites that are routinely sampled by Regional Authorities and 77 sampled by the National Institute of Water and Atmospheric Research, respectively. The database contains records from as early as the late 1980s but we used on data from the period 2007 to 2011 to reduce issues related to changes in water quality analyses and temporal trends.

The data sets that are collated in the database varied widely in reporting formats, reporting conventions, variable names, units of measurement, and sampling frequency or flows. For example, electrical conductivity was provided as a field measurement (labelled "Conductivity" or some near equivalent), as a laboratory measurement (typically labelled EC25, i.e., conductivity at 25°C), and sometimes as both within a single region. Units of measurement (most notably for conductivity) varied between regions, and (less commonly) for a single variable within a region. To consolidate these data into a uniform structure and minimise the potential for error, we used a modified version of a MS-Access database developed for a previous MfE water quality review (Ballantine, et al., 2010). When retrieving data for subsequent analyses, we adopted the following filtering conventions:

1. field conductivity (COND) was used where available, otherwise EC25 (which was highly correlated (r^2 = 0.85) with COND for sites where both variables were reported) was used as a surrogate;
2. total nitrogen (TN) for regions which did not specifically report this variable was calculated (where possible) as the sum of Nitrate+Nitrite Nitrogen (NNN) plus Total Kjeldahl Nitrogen (TKN);
3. only total nitrogen and phosphorus that were derived from unfiltered samples were used; and
4. sites in estuarine waters were flagged so as to avoid skewing data for variables (such as conductivity) which are likely to be highly elevated in such environments.

The frequency of sampling varied across the sites represented in the dataset from fortnightly to bimonthly. In addition, constraints and objectives associated with the design of regional sampling programmes mean that geographical and environmental coverage of the sites is uneven and variable (Figure 1). The sites in our dataset therefore tended to represent locations where there is a known or predicted change in water quality.

We used the New Zealand River Environment Classification (REC; Snelder and Biggs, 2002) to classify the sites according to the environmental conditions that are strong determinants of their reference water quality. Building on experience gained in earlier attempts (e.g., Biggs et al., 1990), the REC categorizes rivers and streams according to overarching factors that are likely to influence biological and physical processes. The spatial framework for the REC is a digital representation of the New Zealand river network comprising 560,000 segments (between confluences) with a mean length of ~700m that is contained within a Geographic Information System (GIS). The first three levels of the REC focus on climate, topography, and geology of the catchment upstream of all network segments. Subsequent work has validated the REC in relation to flow (Snelder et al., 2005), nutrients (Snelder et al., 2004a), water quality (Larned et al. 2003), and invertebrate community composition (Snelder et al., 2004b). Being hierarchical, the REC enables the classification of all streams and rivers in New Zealand at varying levels of classification detail, from general to specific.

Table 2. Indicators analysed by this study including description and units.

Indicator type	Indicator name	Description	Units
Physical	Clarity	Black disc visibility	m^{-1}
	Conductivity	Electrical conductivity	$\mu S\ cm^{-1}$
	SS	Suspended solids	$mg\ L^{-1}$
	pH	Hydrogen ion concentration	
	DO	Dissolved oxygen	%
	Turbidity	Turbidity	NTU
	Temperature	Water temperature	^{o}C
Nutrients	NH_4-N	Ammoniacal nitrogen	$\mu g\ L^{-1}$
	NO_3-N	Nitrate	$\mu g\ L^{-1}$
	TN	Total nitrogen	$\mu g\ L^{-1}$
	FRP	Filterable reactive phosphorus	$\mu g\ L^{-1}$
	TP	Total phosphorus	$\mu g\ L^{-1}$
Faecal indicator bacteria count	*E. coli*	*Escherichia coli*	MPN 100 mL^{-1}

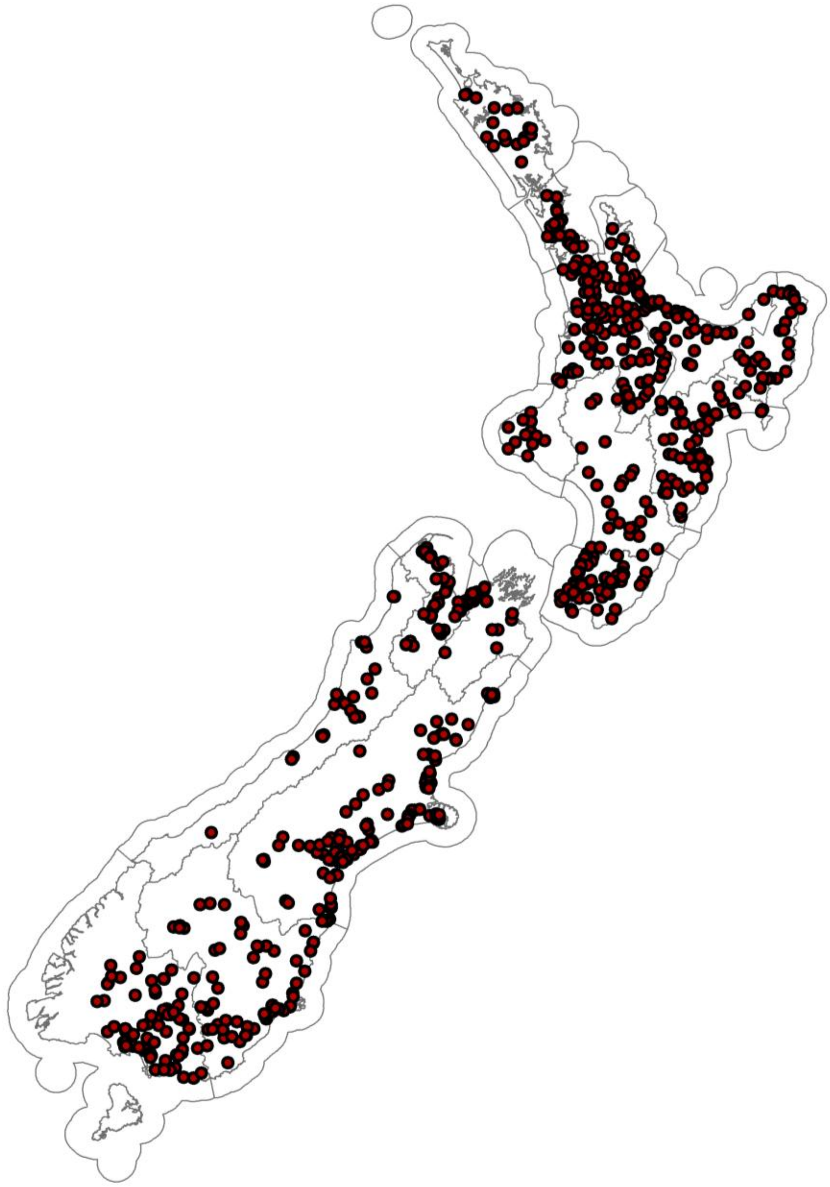

Figure 1. Location of "filtered" sampling sites within New Zealand by region.

Site geographic co-ordinates and names were used to identify the REC class at the first three levels (climate, topography, and geology) for the segments on which each site was located (Table 3). The proportion of the area contributing catchment in categories defined by the New Zealand Land Cover Database (MFE 2004) was also obtained for each segment from the REC database. Previous work by Unwin et al. (2010) identified the percentage of heavy pasture (defined as the sum of cropland, vineyards, orchards and high producing exotic grassland) or urban land cover as the dominant signal of anthropogenic influence on water quality at the national scale.

Table 3. Defining characteristics, categories, and membership criteria of the River Environment Classifications at each level used in this analysis.

Level	Defining characteristic (level)	Categories	Notation	Category membership criteria
Level 1	Climate	Warm-extremely-wet	WX	Warm: mean annual temperature ≥ 12°C
		Warm-wet	WW	Cool: mean annual temperature < 12°C
		Warm-dry	WD	Extremely Wet: mean annual effective precipitation[1] ≥ 1500 mm
		Cool-extremely-wet	CX	
		Cool-wet	CW	Wet: mean annual effective precipitation > 500 and < 1500 mm
		Cool-dry	CD	Dry: mean annual effective precipitation ≤ 500mm
Level 2	Topography[2]	Glacial-mountain	GM	GM: M and % permanent ice > 1.5%
		Mountain	M	M: > 50% annual rainfall volume above 1000m ASL
		Hill	H	H: 50% rainfall volume between 400 and 1000m ASL
		Low-elevation	L	L: 50% rainfall below 400 m ASL
		Lake	Lk	Lk: Lake influence index[3] > 0.033
Level 3	Geology	Alluvium	Al	Category = the spatially dominant geology category unless combined Soft-Sedimentary geological categories exceed 25% of catchment area, in which case class = SS.
		Hard sedimentary	HS	
		Soft sedimentary	SS	
		Volcanic acidic	VA	

[1] Effective precipitation = annual rainfall – annual potential evapotranspiration

[2] Called "source of flow" in Snelder and Biggs (2002)

[3] See Snelder and Biggs (2002) for a description.

3.2 Data processing

Indicators included in the analysis were clarity (m), conductivity (µS cm^{-1}), dissolved oxygen (DO, reported as a percentage saturation), *E. coli* (measured as most probable number $100mL^{-1}$), pH, turbidity (nephelometric turbidity units, NTU), temperature (^{o}C), and suspended solids, filterable (also called dissolved) reactive phosphorus (FRP), total phosphorus (TP), nitrate-nitrogen (NO_3-N), ammoniacal-nitrogen (NH_4-N), and total nitrogen (TN) (all reported in g m^{-3}). The following conventions were used to filter data:

1. Sites were only included in the database if there were 15 or more measurements of an indicator during the period of record, to ensure accurate estimates of median values for each indicator at each site;
2. Indicator values below the indicated detection limit were set at half the detection limit. At some sites the median value was below the stated detection limit for that observation. The percentage of sites less than the detection was generally <1% except for suspended solids (3.4%), FRP (4.3%) and NH_4-N (17.4%). For indicator values marked as in-excess of a specified level, such as *E. coli* (>20000 MPN $100mL^{-1}$), the numerical value for the maximum level was used;
3. After inspecting scatter plots of values, sites with > 50% urban deviated significantly from the general relationship between percent heavy pasture and indicator values. All sites with >50% urban land use were excluded from further analysis. This was because these sites had the potential to bias the relationship between water quality parameters and heavy pasture.

The data represented many sites, but not all indicators were observed, or were above the detection limit on all occasions at all sites. Furthermore, sites were not equally distributed amongst REC classes (Figure 2). To decrease this imbalance, we amalgamated the sites in the glacial mountain topography category of the REC into the mountain category. There were relatively few sites in these categories (commonly < 10 and 20, respectively) and because these two categories represent similar environmental mountainous catchment conditions, water quality can be expected to be similar (Larned et al., 2003).

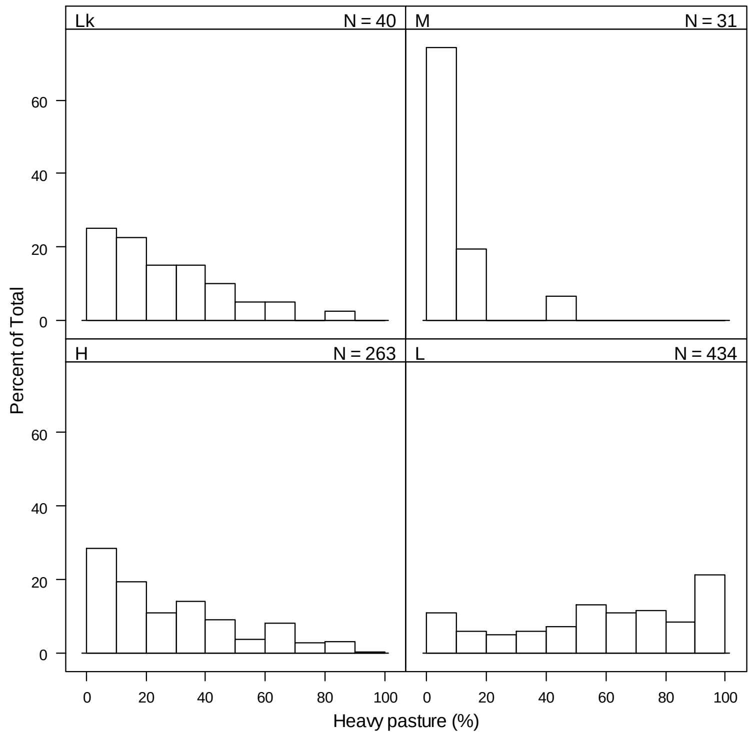

Figure 2. Histogram of the percentage of TN sites with a catchment with heavy pasture (10% increments) land use by REC topography class (M is Mountain and Glacial Mountain, H is Hill, Lk is Lake, L is Low-elevation).

3.3 Data analysis

Sites were treated as independent points, and values at each site were represented by medians and the relevant percentile for a trigger value for each indicator (at each site the 80th percentile was used for all indicators except for clarity and dissolved oxygen saturation which used 20th percentile at each site and *E. coli* which was represented by the 95th percentile). We note that 20 out of the 693 sites used in the analysis were located on the same river segment, but as this represents only 3% of sites it is not expected to bias the analysis. We log (base 10) transformed the median and trigger values for each indicator before analysis to approximate normality and confirmed this with a Shapiro-Wilk test.

The analysis of covariance (ANCOVA), used in other studies (e.g., Dodds and Oakes, 2004), determines if there is a linear relationship between the response (log_{10} median and trigger values of the indicators) and the explanatory variable (percentage of heavy pasture) and whether this relationship differs between groupings of the data based on a factor (i.e. the REC classes). The statistical significance of the factor within an ANCOVA model may justify the amalgamation or separation of data based on REC class. However, if relationships are non-linear, especially where the percentage of heavy pasture is low, ANCOVA models may poorly estimate the intercept (the value of interest representing the reference condition or trigger value).

In addition to an ANCOVA analysis, we used a mixed-effects model with random slopes and intercepts, and with a smoothing spline (Verbyla et al., 1999), to model the relationship between the logged median and trigger values for each indicator and the percent heavy pasture. The benefit of including a spline in the mixed-effects model is that it accounts for non-linearity in the relationship between the indicator and heavy pasture if it exists. In addition, the benefit of mixed-effects models is that some information gleaned from the data as a whole is used to fit relationships to each class. Where a class has little data, the data from the other classes becomes more important and pulls the individual class estimate towards the mean of the other classes. However, a class with sufficient data for estimating the intercept will not be noticeably influenced by the data from the other classes. Hence a mixed-effects model means that data from classes with few data are not discarded and all classes are represented in the final model. Tests for the significance of the variation between REC (2^{nd} level) classes for slope and intercept estimates as fitted as random effects used the likelihood ratio test (Verbyla et al., 1999). The models were fitted in Genstat 12 (Genstat committee, 2010) using residual maximum likelihood (REML).

Geology influences the concentration of certain indicators in water (e.g., Phosphorus; Dillon and Kirchner, 1975). To determine variation in reference conditions and trigger values due to geology we took those REC classes at the second level with the largest number of sites (i.e. CDH, CDL, CWH, CWL, CXH, CXL, WDL and WWL) and further analysed (as above) sites grouped at the third (geology) level of the REC provided there were 5 or more sites within each geology class.

The uncertainty of estimated reference conditions and trigger values is a reflection of the strength of the relationship between the indicator and percent heavy pasture and the number of contributing sites. This was determined by the width of the 95% confidence intervals of the intercept terms in the models. We also assessed the reliability of the estimates of reference condition by comparing, where possible, the regression intercepts of the ANCOVA and mixed-effects models with concentrations at sites that were nominated as being in a minimally disturbed condition. For this comparison, we used the median value of sites with < 5% heavy pasture as minimally disturbed condition reference sites. Herlihy and Sifneos (2008) highlighted some of the disadvantages with this definition of a minimally disturbed condition reference site. For example, indicator values may be compromised if the 5% of heavy pasture included in the definition is near to or surrounds the sampling site. Suplee et al. (2007) provided additional criteria to defend their selection of minimally disturbed condition reference sites for nutrients. This included the enrichment of other indicators such as heavy metals (or Al), in the presence of abandoned mines, and the use of best professional judgement to account for the presence of point sources or grazing impacts. Our criteria for sites categorised as minimally disturbed condition does not guarantee that sampling points were not near to intensive agriculture. However, we added to the stringency our minimally disturbed condition categorisation with an additional test. For all sites, we considered whether indicators exceeded ANZECC (2000) trigger values for in upland and lowland rivers (not those defined here). Sites were discarded from the set of nominated ‘minimally disturbed sites’ if they exceeded the ANZECC (2000) trigger value for any indicator.

The derived trigger values were also compared to observed values at minimally disturbed sites. However, selected sites were not restricted to those that met current guidelines for good water quality in upland and lowland rivers in Australia and New Zealand (ANZECC, 2000).

Estimates of the reference condition can be used to determine the degree of anthropogenic influence on water quality (e.g., McDowell et al. 2011). We used the reference condition estimates to define two metrics that quantify the degree of anthropogenic influence on streams and rivers. The first metric was the anthropogenic contribution to the indicator values. This metric was calculated by subtracting the estimated reference condition value from the median value at each site and expressing the remainder as a percentage of the site median value. We grouped these site indices by REC classes (2^{nd} level) and reported the median values by indicator. The REC class values by indicator were compared by ranking and a one-way analysis of variance with pair-wise tests of the two most enriched classes with the remaining classes. The second metric was the degree of enrichment and was calculated by expressing the site median indicator value as a proportion of the estimated reference value of the indicator for the site. We reported the median values of these site indices by indicator in REC classes (2^{nd} level) and the median values of each indicator across all sites. Due to the method of calculation, metrics could not be expressed for some indicators (e.g., DO as a proportion of a percentage) or are unsuitable (e.g., conductivity or spot measurements of DO may not reflect anthropogenic inputs). Hence, the analysis was restricted to clarity, nutrients, *E. coli* and suspended solids. An assessment of the number of sites exceeding trigger values was also made for each indicator.

4 Results

There were generally differences between linear (ANCOVA) and non-linear (mixed-effects) fits to the relationship between indicators and percent heavy pasture (Figure 3). There tended to be a large number of sites with high percent heavy pasture and few with low values of percent heavy pasture (Figure 3). This increased the possibility that linear regressions would be affected by a “pan handle” effect, i.e. insufficient leverage of sites with low percent heavy pasture so that the value of the intercept is overestimated. The non-linear spline fits reduced the possibility of insufficient leverage towards the intercept and underestimation of reference conditions and trigger values.

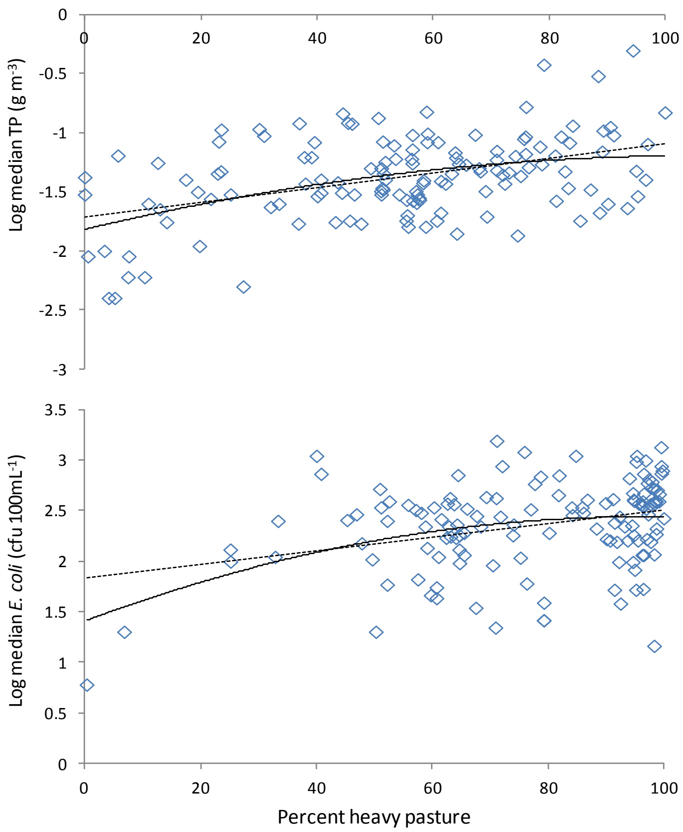

Figure 3. Example of the fits of a linear regression (ANCOVA, dashed line) and a regression using a mixed-effects model with random slopes and intercepts and with a common spline to model any non-linearity between log median TP and *E. coli* and the percentage heavy pasture for the River Environment Classes warm-wet lowland cool-dry lowland, top and bottom, respectively.

Using the mixed-effects model there were significant differences between classes at the 2nd level of the REC (Table 4) in the intercept estimates for median and trigger values, therefore justifying the generation of separate estimates for each class. The relationship between percent heavy pasture and each indicator (which also incorporated a spline) was also often significantly different between classes, but in some cases like turbidity, was not, meaning that while different intercept values were justified, the predictive relationship did not exhibit significant slope (or curvature) differences between classes. Of the possible 228 REC class by indicator combinations, 167 were represented by at least one minimally disturbed condition site (i.e. < 5% heavy pasture). Of these 167 sites, 142 (85%) lay within the 95% confidence intervals for the estimated median reference value calculated using the mixed-effects models and a spline, but 68% fell within the confidence intervals when the linear regression ANCOVA approach was used.

Table 4. Tests for the significance of the variation between REC (2nd level) classes of median reference and trigger values for slope and intercept estimates as random (*viz*. including splines) effects using the likelihood ratio test (Verbyla et al., 1999).

Indicator	Median reference values		Trigger values	
	Slope	Intercept	Slope	Intercept
Clarity	0.001	<0.001	0.002	<0.001
Conductivity	0.050	<0.001	0.040	<0.001
Suspended solids	0.115	<0.001	0.027	<0.001
Turbidity	0.087	<0.001	0.121	<0.001
E. coli	<0.001	<0.001	<0.001	<0.001
FRP	0.005	<0.001	0.017	<0.001
TP	0.251	<0.001	0.500	<0.001
NO_3-N	0.001	<0.001	<0.001	<0.001
NH_4-N	0.117	<0.001	0.177	<0.001
TN	0.008	<0.001	<0.001	<0.001
Temperature	0.021	<0.001	0.022	<0.001
Dissolved oxygen[1]	<0.001	<0.001	0.002	<0.001
pH[2]	0.500	0.010	0.500	0.077

[1] Slope and intercept significance at the 80th percentile were 0.048 and <0.001, respectively.
[2] Slope and intercept were not significant for pH at the 20th percentile.

In general, confidence intervals for median reference and trigger values were wider for warm REC climate level classes than cool classes (Figures 4-10; Appendix I and II). Often this was a reflection of a paucity of data (*viz*. < 10 sites), but some indicators such as *E. coli* and suspended solids had wide confidence intervals despite being represented by as many as 110 sites (Figure 4). Across all classes, confidence intervals were widest for clarity, *E. coli*, suspended solids and ammoniacal-N (Figures 4, 5, 8 and 9). One reason for wide confidence intervals may be the number of sites with median concentrations that are at or below the detection limit (*viz*. ammoniacal-N), especially if these occur across a wide span of percentage of heavy pasture.

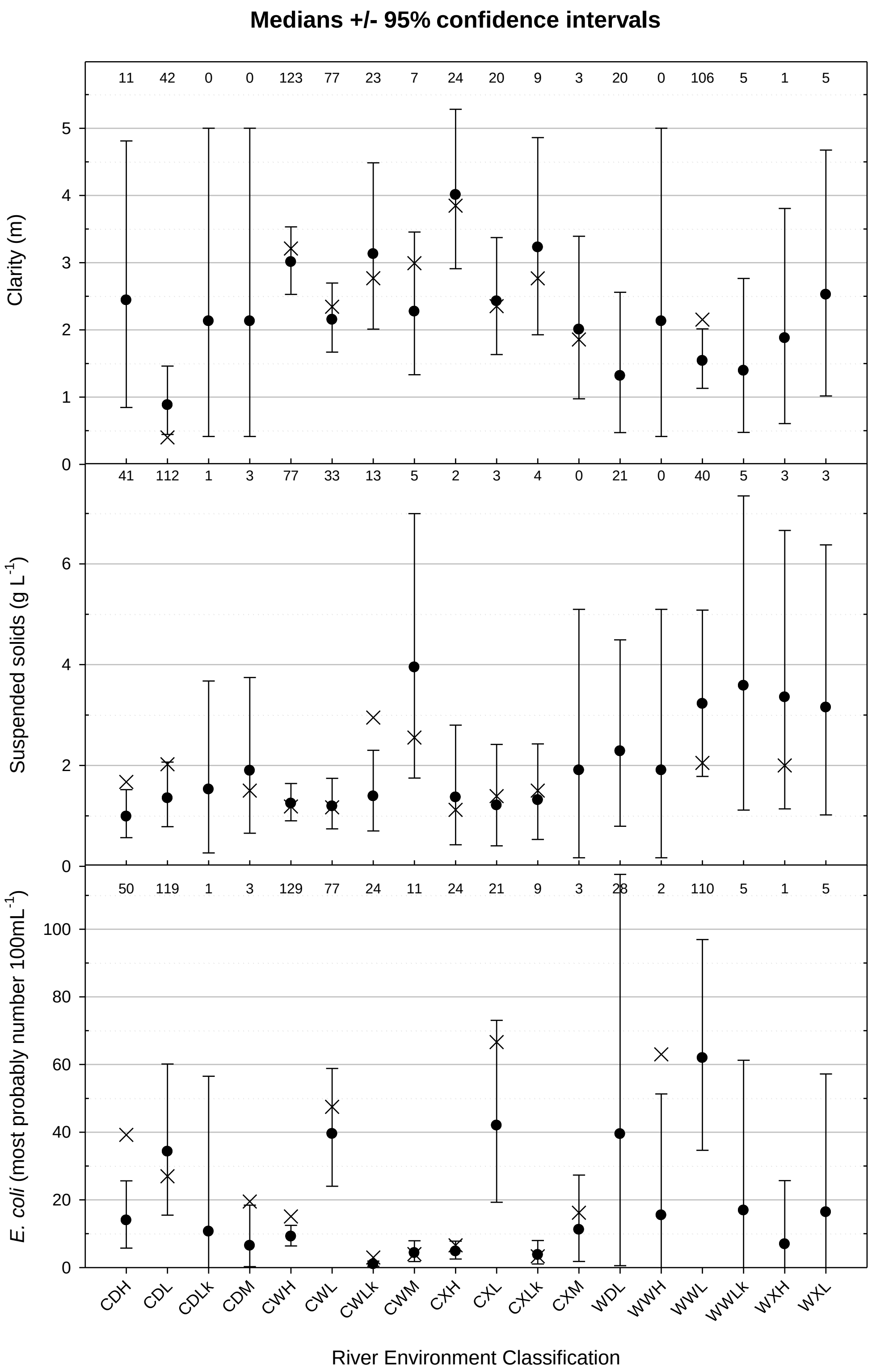

Figure 4. Estimated (circles ± 95% confidence intervals) reference median *E. coli*, suspended solids concentrations and clarity for sites grouped by REC (2nd level) classes. The cross indicates the median for a known minimally disturbed condition-reference site within a class. Numbers at the top of each plot refer to the count of sites within a class. Absolute values are given in Appendix I.

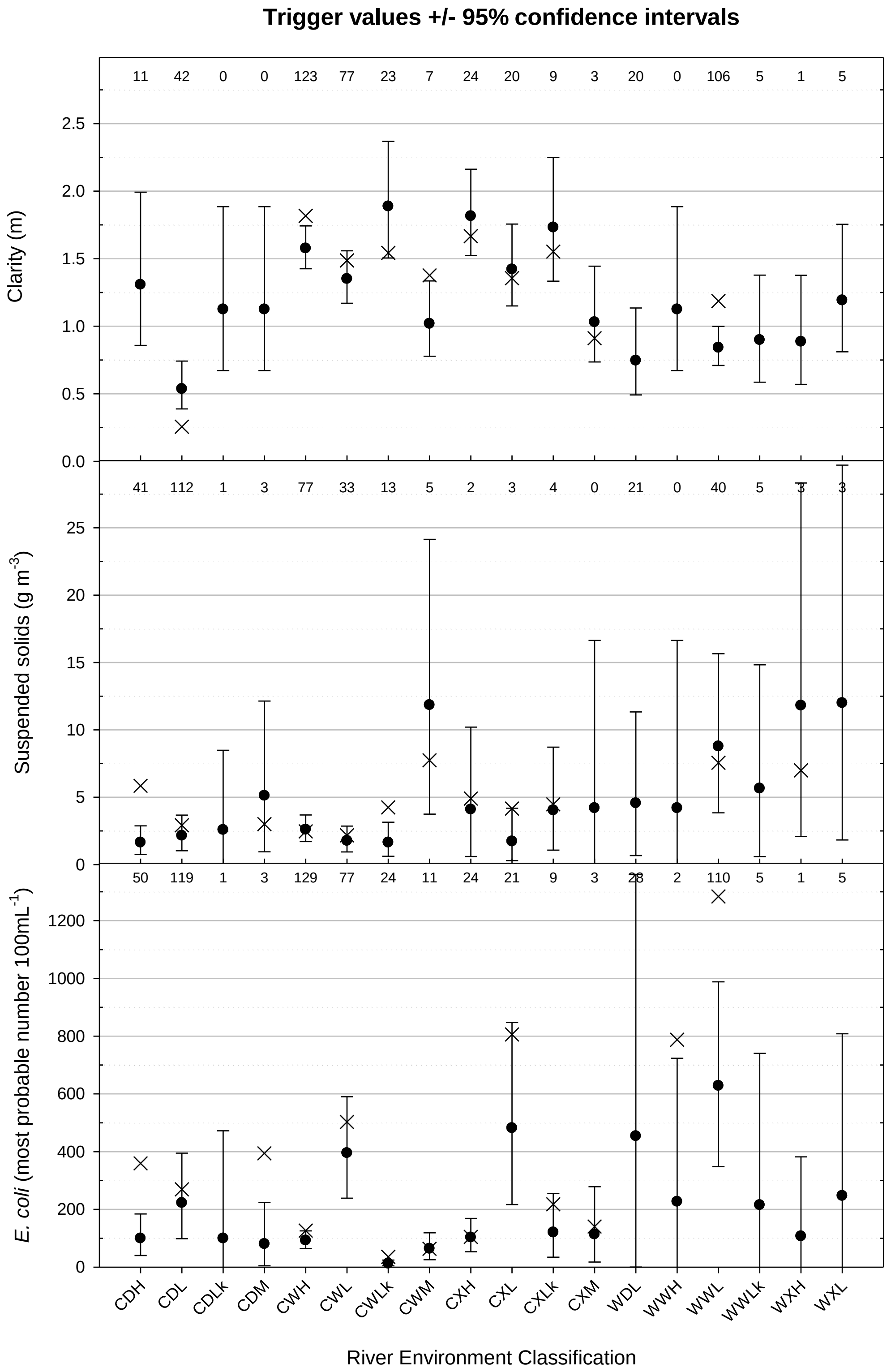

Figure 5. Estimated (circles ± 95% confidence intervals) trigger values for *E. coli* (95th percentile), suspended solids (80th percentile) concentrations and clarity (20th percentile) for sites grouped by REC (2nd level) classes. The cross indicates the trigger value for a known minimally disturbed condition trigger site within a class. Numbers at the top of each plot refer to the count of sites within a class. Absolute values are given in Appendix I.

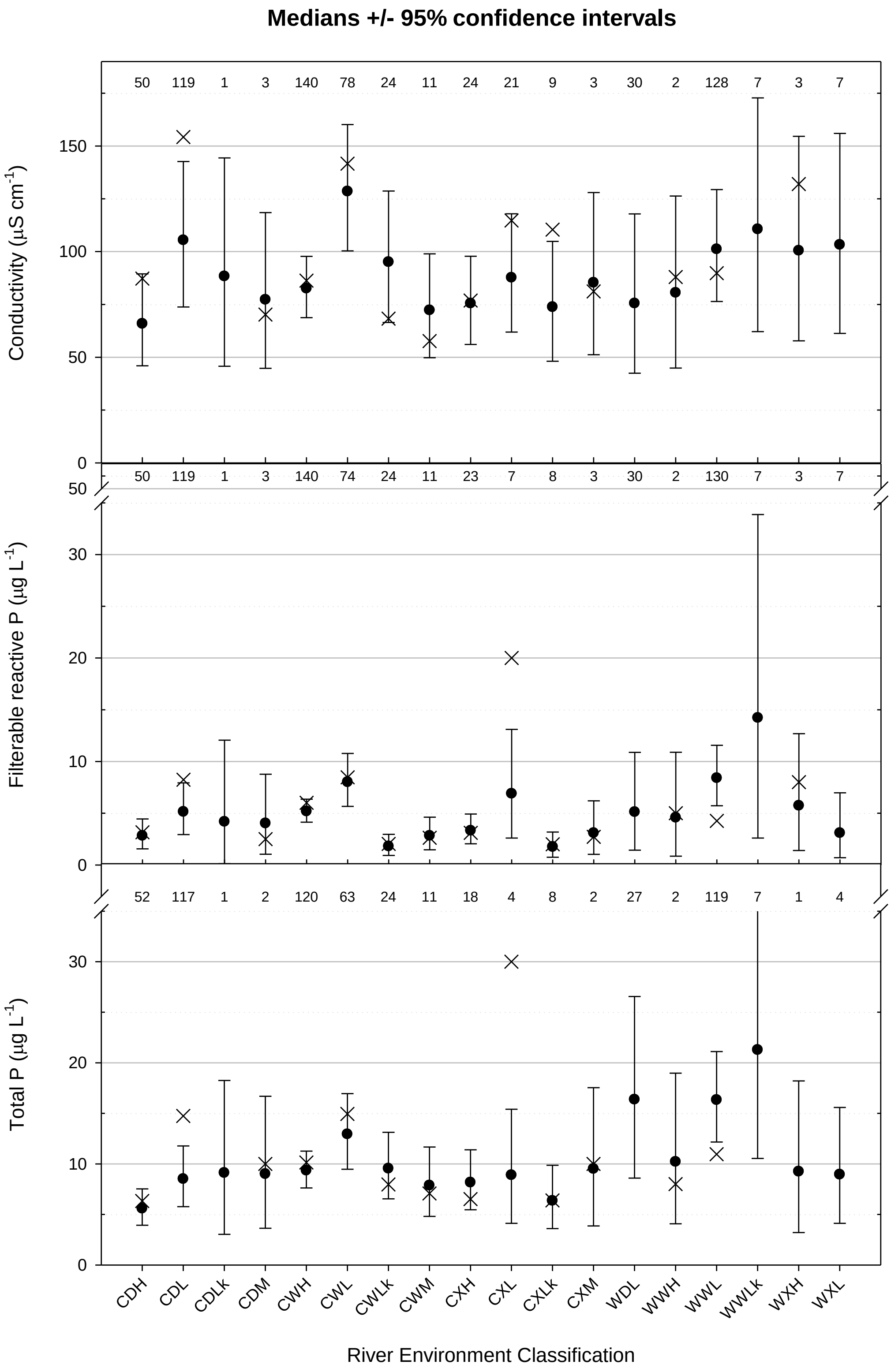

Figure 6. Estimated (circles ± 95% confidence intervals) reference median conductivity, and filterable reactive and total phosphorus concentrations for sites grouped by REC (2nd level) classes. The cross indicates the median for a known minimally disturbed condition-reference site within a class. Numbers at the top of each plot refer to the count of sites within a class. Absolute values are given in Appendix I.

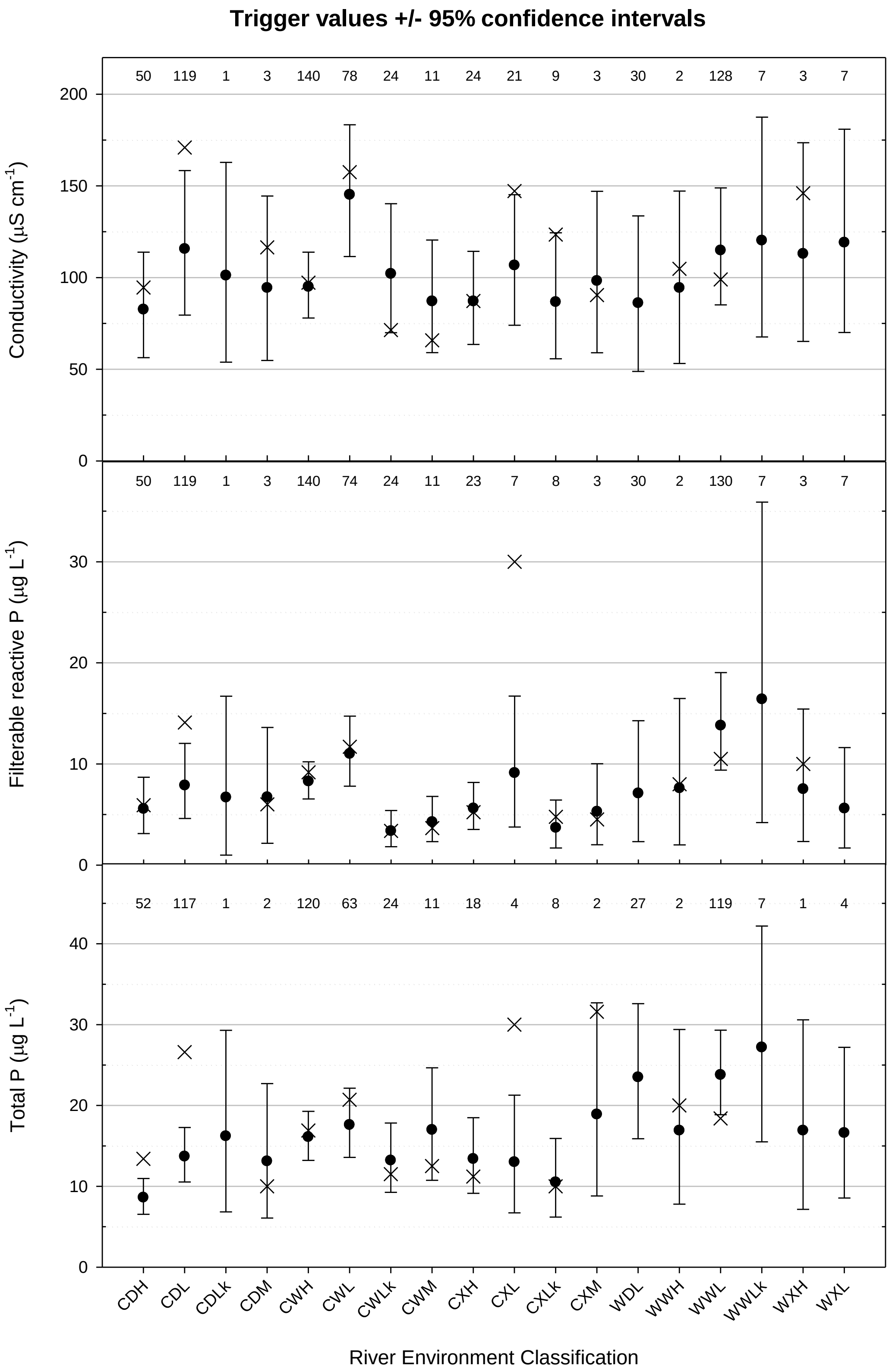

Figure 7. Estimated (circles ± 95% confidence intervals) 80th percentile trigger values for conductivity, and filterable reactive and total phosphorus concentrations for sites grouped by REC (2nd level) classes. The cross indicates the trigger value for a known minimally disturbed condition trigger site within a class. Numbers at the top of each plot refer to the count of sites within a class. Absolute values are given in Appendix I.

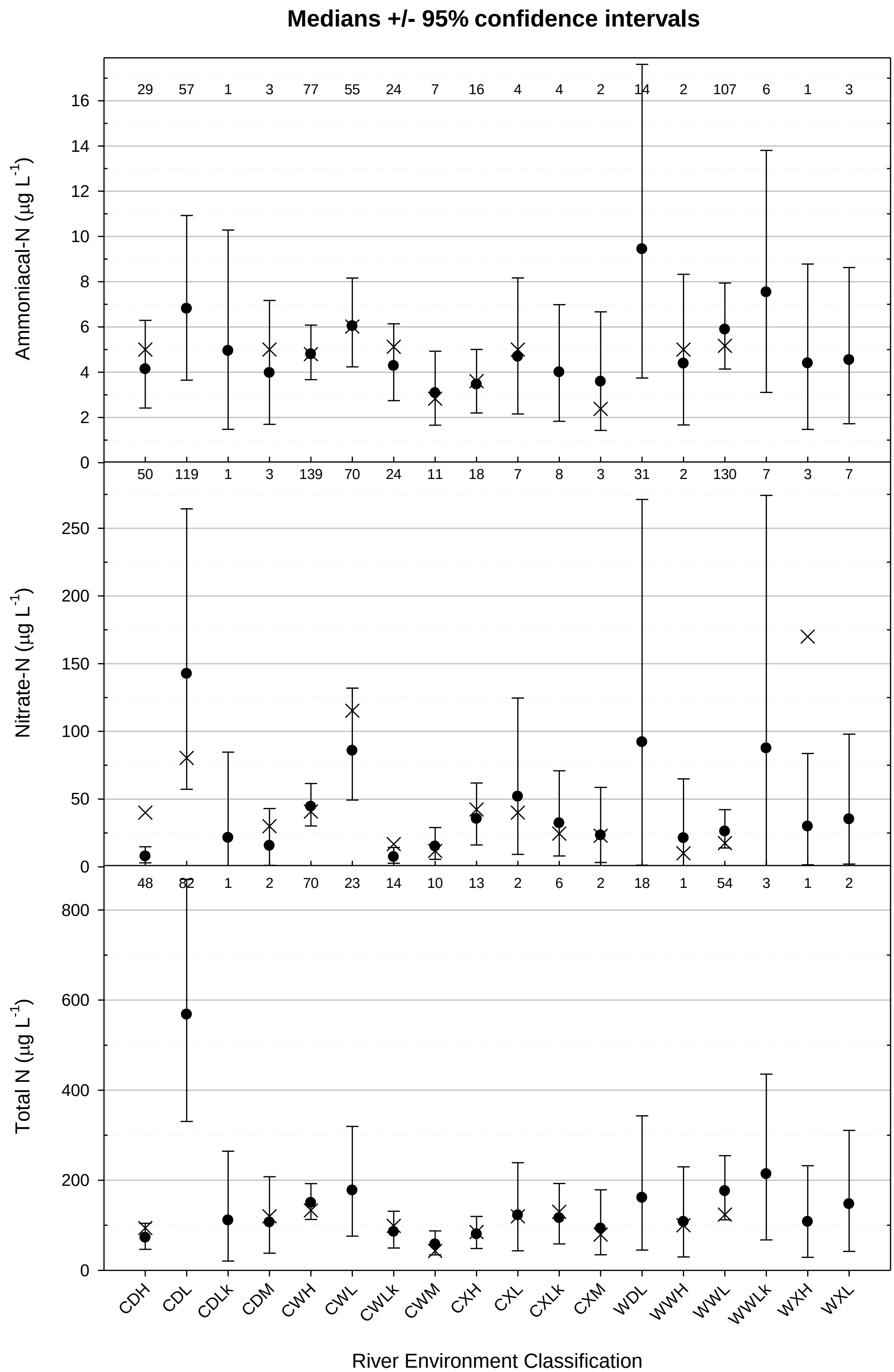

Figure 8. Estimated (circles ± 95 confidence intervals) reference median ammoniacal-, nitrate- and total-N concentrations for sites grouped by REC (2nd level) classes. The cross indicates the median for a known minimally disturbed condition-reference site within a class. Numbers at the top of each plot refer to the count of sites within a class. Absolute values are given in Appendix I.

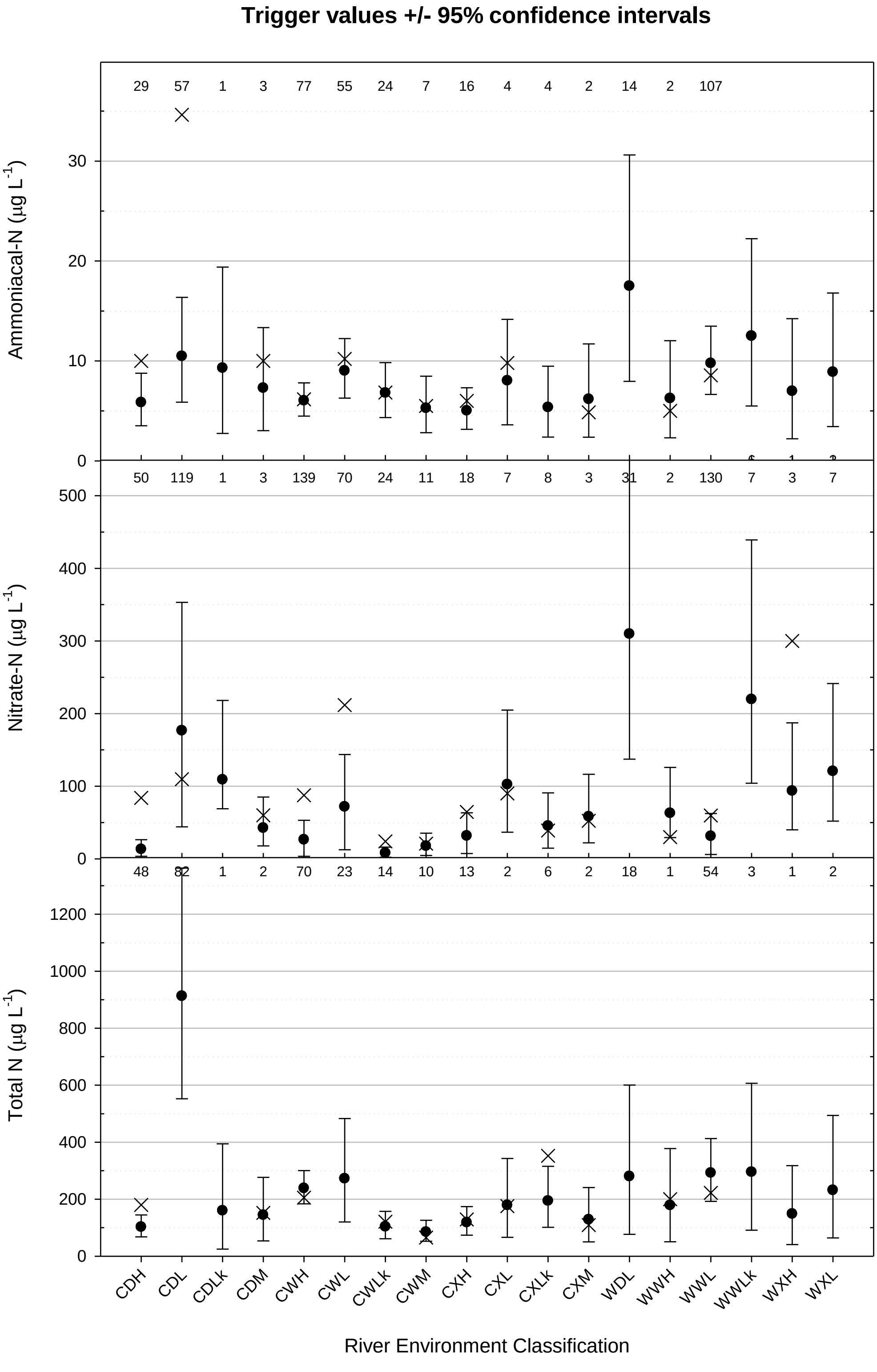

Figure 9. Estimated (circles ± 95% confidence intervals) 80th percentile trigger values of ammoniacal-, nitrate- and total-N concentrations for sites grouped by REC (2nd level) classes. The cross indicates the trigger value for a known minimally disturbed condition trigger site within a class. Numbers at the top of each plot refer to the count of sites within a class. Absolute values are given in Appendix I.

Reference conditions and trigger values were also estimated for up to four of the 3rd (geology) level REC classes within each 2nd level REC class that conformed to data requirements (see Section 2: methodology) (Figures 10 and 11). Differences among geological classes appeared most likely for CDL and CWL sites (i.e. minimal or no overlap of some confidence intervals). Most of the other classes exhibited either too few sites to yield more than one or two geological classes, or had widely overlapping confidence intervals. The CWL sites exhibited greater FRP and TP for sites categorised as VA (volcanic acid) than sites of other geology categories, but this was not true of other indicators.

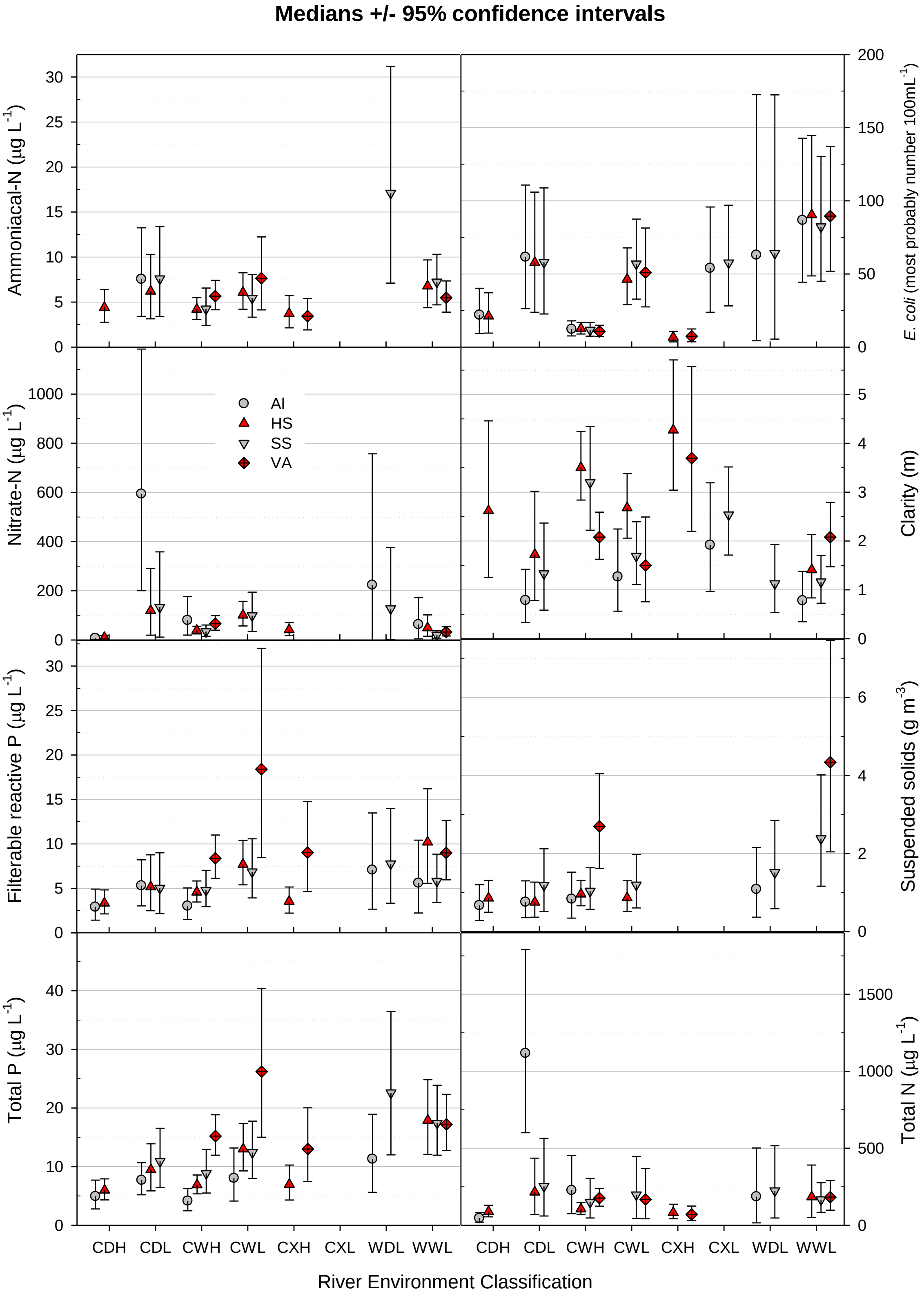

Figure 10. Estimated (circles ± 95% confidence intervals) reference median ammoniacal-nitrogen, nitrate-nitrogen, total-nitrogen, filterable reactive phosphorus, total phosphorus, suspended solids, and *E. coli* concentrations and clarity for sites grouped by REC (climate by tpography by geology) classes. Al, HS, SS and VA = Alluvial, Hard sedimentary, Soft sedimentary, and Volcanic acid geologies, respectively. Absolute values are given in Appendix II.

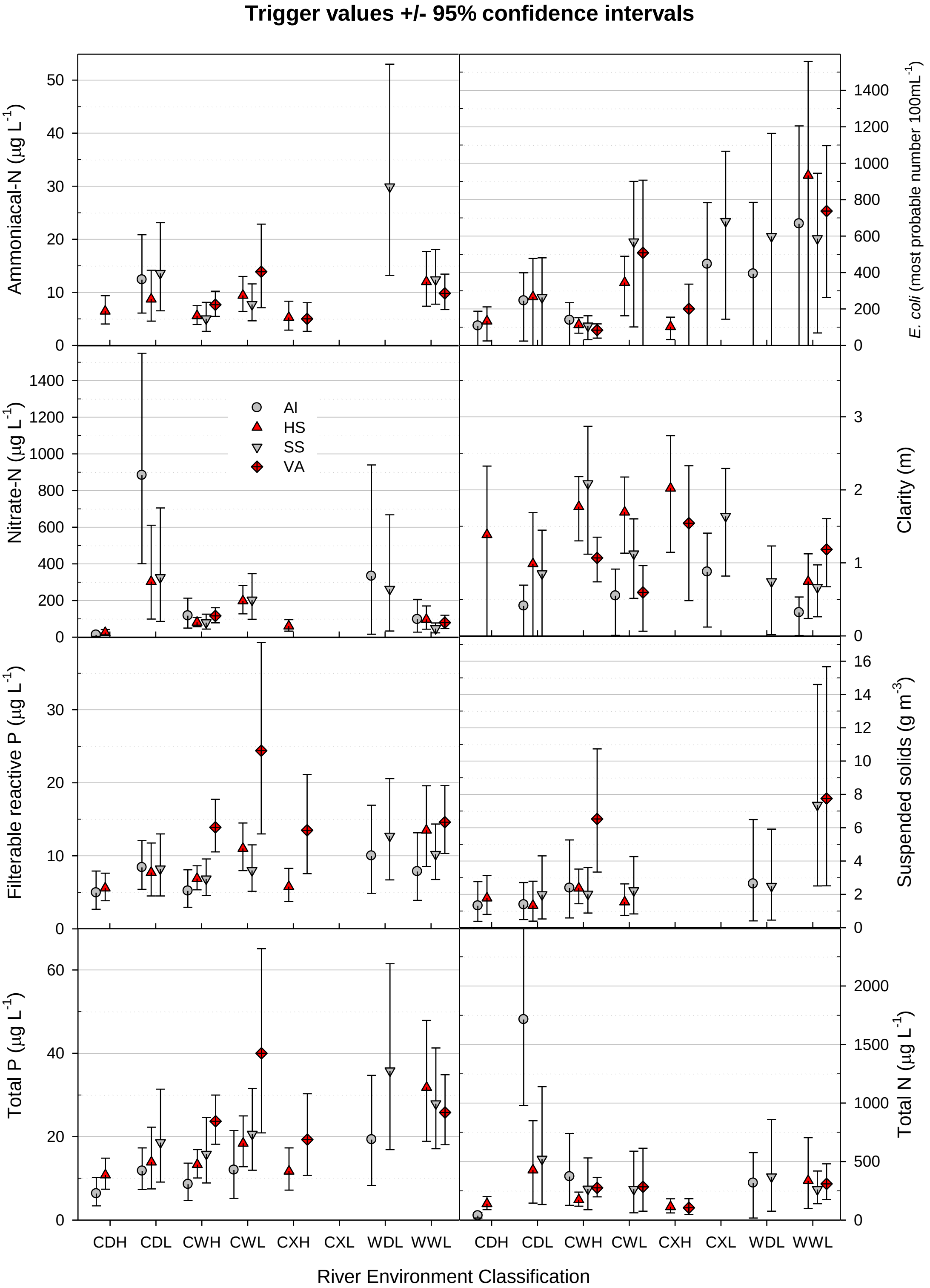

Figure 11. Estimated (circles ± 95% confidence intervals) 80th percentile trigger values for ammoniacal-nitrogen, nitrate-nitrogen, total-nitrogen, filterable reactive phosphorus, total phosphorus, suspended solids, and *E. coli* (95th percentile) concentrations and clarity (20th percentile) for sites grouped by REC (climate by topography by geology) classes. Al, HS, SS and VA = Alluvial, Hard sedimentary, Soft sedimentary, and Volcanic acid geologies, respectively. Absolute values are given in Appendix II.

4.1 Analysis of anthropogenic influence

Compared to other REC classes, the anthropogenic contribution to FRP, *E. coli*, suspended solids, TN and TP were large in the CDL and WDL classes (Table 5). The anthropogenic contributions to TN and NO_3-N were also larger in the WWL class than other classes (Table 5). Due to the large median concentration exhibited by most sites relative to their estimated reference condition, there were similar differences between classes for the degree of enrichment (Figure 12). Across all sites the median values for the degree of enrichment ranged from 19% for clarity to 335% for NO_3-N (Table 6).

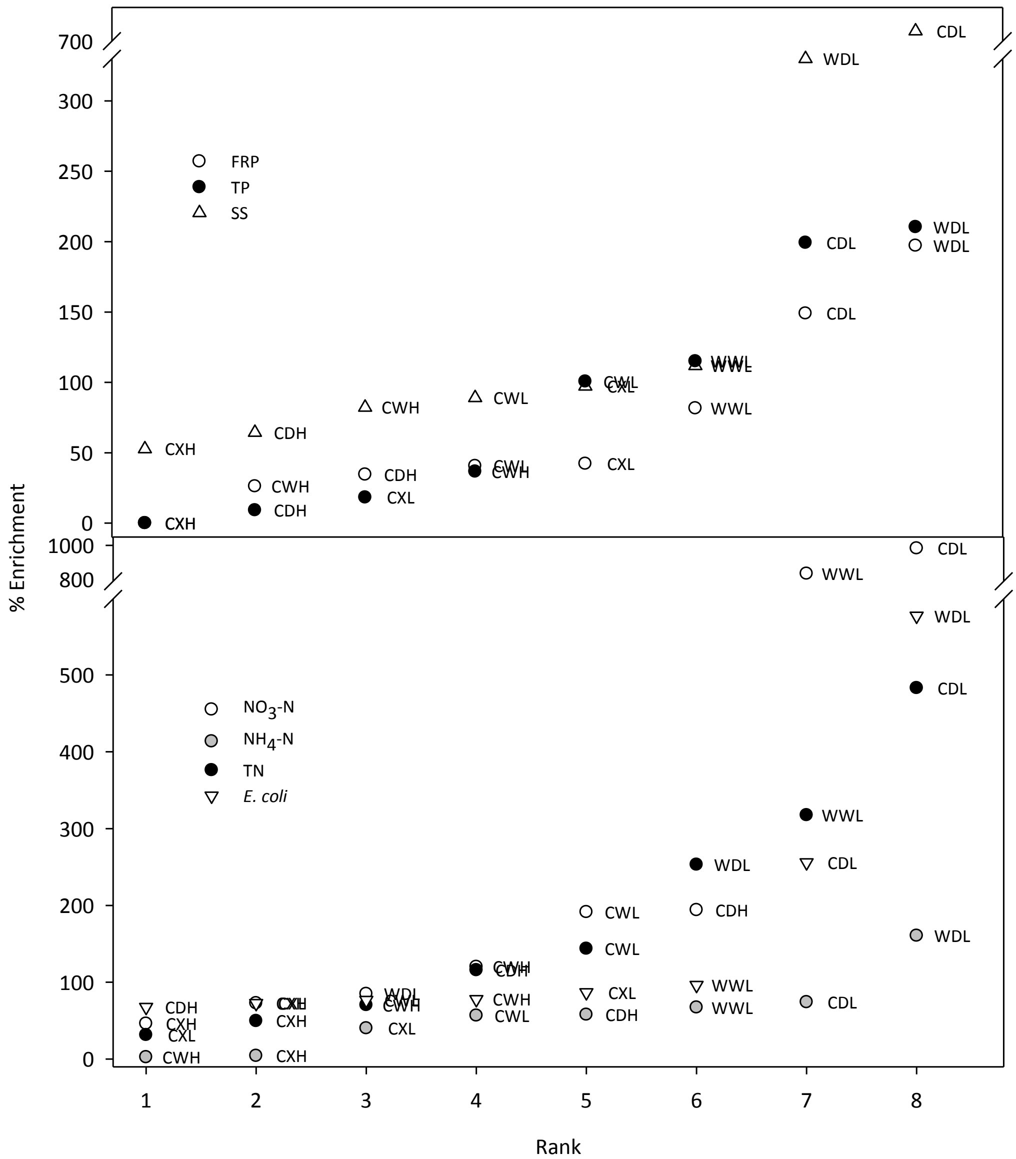

Figure 12. Ranking of the median value for sites grouped by REC class (2nd level) for each indicator. Class median value was calculated only from sites with > 15 observations and had < 50% urban land use.

Table 5. Mean percentage anthropogenic contribution to indicator values by classes at the second (climate by topography) level of the River Environment Classification. The number in parentheses refers to the number of sites that met the requirements of the data filter (i.e. median value generated from sites with > 15 data points and < 50% urban land use).

REC	Suspended solids	Clarity	*E. coli*	Filterable reactive P	Total P	Nitrate-N	Total N
CDH	39 (46)	32 (32)	40 (59)	26 (59)	8 (58)	66 (59)	54 (57)
CDL	88 (85)	32 (59)	72 (125)	60 (124)	67 (124)	91 (124)	83 (122)
CWH	45 (75)	26 (127)	44 (126)	21 (156)	27 (134)	55 (154)	41 (133)
CWL	46 (28)	28 (78)	43 (82)	29 (79)	50 (63)	66 (79)	59 (62)
CXH	26 (2)	11 (19)	42 (22)	0[1] (19)	0 (19)	32 (19)	33 (19)
CXL	49 (3)	6 (7)	46 (21)	28 (6)	15 (6)	41 (6)	24 (5)
WDL	77 (23)	35 (18)	85 (18)	66 (31)	68 (29)	46 (31)	72 (28)
WWL	53 (55)	33 (119)	49 (98)	45 (138)	53 (128)	89 (134)	76 (126)

[1] Median for REC class was at, or less than, the estimated reference condition value.

Table 6. Median degree of enrichment of all sites as a percentage of the reference condition. The number in parentheses refers to the number of sites used to generate a median value (sites with > 15 data points and had < 50% urban land use).

Indicator	% degree of enrichment relative to reference condition
Suspended solids	181 (364)
Clarity	19 (500)
E. coli	118 (616)
Filterable reactive P	62 (634)
Total P	90 (597)
Nitrate-N	335 (631)
Total N	182 (588)

The median value for each site was compared to the suggested trigger value for each indicator. Uncertainty in trigger values was included via a 95% confidence interval – using the same logic as the comparison of minimally disturbed sites to reference estimates. Although the sum of a trigger value and a confidence interval represents a more lenient "yardstick' than the trigger value alone, it gives the user a 95% probability that the true trigger is within this estimate. Trigger values (with confidence intervals included) were exceeded at or around 30% of sites for most indicators except for nitrate, total N and total P which exhibited a greater proportion of sites exceeding their trigger value (with confidence interval), and conductivity, *E. coli*, pH and dissolved oxygen that commonly had <20% of sites exceeding their respective trigger value (Table 7). Previous national water quality analyses estimated that for most indicators a much greater proportion of sites exceeded their respective ANZECC (2000) trigger values (Larned et al., 2003). For example, FRP, *E. coli*, ammonical-N, and clarity exceeded their trigger values in 61, 72, 58, and 40% of sites, respectively. This reflects the ability of the current scheme to account for natural variation according to the REC.

Table 7. Percentage frequency of sites that exceed their respective indicator trigger value (80th percentile unless otherwise indicated) plus 95% confidence interval for sites within selected REC classes at the second level (climate by topography) and all classes.

Indicator	Exceeding trigger value + CI	CDH	CDL	CWH	CWL	CXH	CXL	WDL	WWL	All classes
Conductivity	% > trigger value	48%	78%	41%	44%	33%	29%	84%	61%	55%
	% > trigger value + CI	26%	55%	29%	27%	13%	19%	84%	42%	38%
pH	% > trigger value	16%	14%	29%	18%	5%	10%	27%	20%	21%
	% > trigger value + CI	8%	11%	22%	12%	5%	10%	13%	18%	15%
Suspended solids	% > trigger value	51%	72%	39%	61%	0%	33%	62%	30%	53%
	% > trigger value + CI	20%	45%	34%	48%	0%	0%	0%	10%	31%
Turbidity	% > trigger value	44%	72%	28%	58%	11%	30%	57%	49%	47%
	% > trigger value + CI	32%	50%	19%	36%	11%	15%	23%	28%	29%
Clarity	% > trigger value	64%	12%	29%	45%	13%	5%	50%	39%	34%
	% > trigger value + CI	0%	0%	20%	23%	4%	0%	20%	17%	16%
FRP	% > trigger value	34%	76%	41%	22%	35%	57%	87%	39%	47%
	% > trigger value + CI	20%	34%	20%	22%	30%	14%	57%	39%	28%
Total P	% > trigger value	58%	73%	46%	76%	33%	25%	85%	72%	61%
	% > trigger value + CI	35%	72%	46%	54%	33%	25%	81%	72%	56%
Ammoniacal-N	% > trigger value	66%	63%	30%	65%	25%	0%	86%	72%	55%

Indicator	Exceeding trigger value + CI	CDH	CDL	CWH	CWL	CXH	CXL	WDL	WWL	All classes
	% > trigger value + CI	41%	61%	25%	24%	13%	0%	64%	50%	36%
Nitrate-N	% > trigger value	68%	85%	65%	70%	56%	71%	77%	84%	73%
	% > trigger value + CI	50%	73%	53%	61%	33%	14%	58%	78%	60%
Total N	% > trigger value	84%	66%	54%	100%	46%	50%	100%	78%	68%
	% > trigger value + CI	73%	48%	40%	70%	15%	0%	67%	67%	50%
Diss. oxygen saturation[1]	% > trigger value	17%	4%	16%	7%	15%	0%	14%	45%	32%
	% > trigger value + CI	9%	0%	11%	6%	15%	0%	0%	28%	16%
Temperature	% > trigger value	4%	14%	18%	25%	11%	0%	3%	6%	14%
	% > trigger value + CI	4%	9%	12%	5%	0%	0%	0%	0%	5%
E. coli[3]	% > trigger value	24%	55%	21%	14%	13%	5%	50%	5%	24%
	% > trigger value + CI	6%	20%	16%	6%	8%	5%	0%	4%	11%

[1] Taken as the lower limit (20th percentile)
[2] Taken as 95th percentile.

5 Discussion

5.1 Model validity

Our use of regression models to estimate median reference conditions and trigger values make several high level assumptions, particularly that: (1) the proportion of the catchment area occupied by intensive agricultural land (as represented by heavy pasture) is a good surrogate of the anthropogenic influence on water quality indicators; (2) the span of the independent variable, percent heavy pasture, is wide enough and encompasses enough points at low percent heavy pasture to yield a good prediction of the dependent variable at no heavy pasture, (i.e. the intercept); (3) the number of sites used to fit the model are a representative, unbiased sample of the population of sites within a class; (4) where there is no check via a nominated reference site, the estimate can be relied on and was not unduly influenced by other variables not included in the model; and (5) there is little or no effect or temporal variation.

Prior to the present work, Unwin et al. (2010) explored a similar dataset using Random Forests, a powerful regression technique, and identified several predictors that together accounted for between 39.7 to 77.8% of variance in 11 water quality indicators, and >60% for 8 of these indicators. The most important predictor was percent heavy pasture. Variation in other important factors such as the catchment characteristics: slope, elevation, climatic and geological features are discriminated by classes at the first three levels of the REC in our analysis. Use of the REC has also been found to explain variation in a variety of biological, chemical and hydrological variables in other studies (e.g., Snelder et al., 2004a,b; Booker and Snelder 2012). Although many other studies have emphasized either the percentage of cropland (Dodds and Oakes, 2004) or the total percentage of agriculture within a catchment as explanatory variables (Chambers et al., 2012), our focus on heavy pasture, as a surrogate for anthropogenic activity, reflects the domination of New Zealand agriculture by the pastoral sector (Larned et al., 2003).

During analysis the relative anthropogenic influence amongst catchments was accounted for using the percentage of land in heavy pasture. However, while the success of the regression is determined by the spread in the data, accurate estimation of the intercept was dependent on having sufficient data of low percent heavy pasture to “anchor” the prediction. There is potential that too few minimally-disturbed sites will lead to insufficient leverage towards reference conditions or trigger values at the intercept. However, we included a spline within the mixed-effects models to account for this possibility, which we showed to be a significant advantage over the linear ANCOVA model (Figure 3).

Although we had a large number of sites in our analysis, as the level of classification detail of the REC classification increased, the number of sites available for analysis decreased. Sites within the national network of water quality monitoring sites tend to be defined by those that were accessible and or of concern; that is exhibiting, or under threat of exhibiting, poor water quality. Inspection of Figure 1 indicates that there are large areas of New Zealand that are also under-represented, such as the West Coast, where additional data may improve model predictions. Hence, there is a possibility that data does not represent the wider population or spatial representation of sites within a class.

Although our model accounted for many natural factors (e.g., geology) and anthropogenic factors there is still a possibility that estimates may be influenced by other factors. Such factors include, but are not limited to, temporal (not static as classified in the REC) climate variation including the frequency of extreme events (Scarsbrook et al., 2003). For example, severe storms caused mass movement erosion during February, 2004 in the Manawatu-Wanganui region (e.g., Dymond et al., 2006). There is a possibility that this could have increased observed values of indicators at sites with low percentage of catchment in heavy pasture land cover, and hence increased the value of the estimated intercept. However, the number of sites likely to be affected (n = 7) were few compared to those within the wider class (e.g., cool-wet lowland; n = 85).

A further consideration is the potential for temporal trends to influence estimates. However, significant trends are generally only detectable for datasets longer than 5 years (i.e. trends at sites in our datasets were unlikely to be significant). Our conventions for filtering the data did not exclude the potential for seasonal variation or different flow rates to affect the distribution of values for each site but in general the sites had been sampled at regular intervals and therefore seasonal bias is unlikely for most sites. In general terms the limitations of our analysis is minimised by the use of median and trigger values and the uncertainties that these limitations induce are also accounted for by the magnitude of the confidence intervals.

5.2 Comparison to other methods and potential use

Our approach to estimating reference and trigger values maximises the use of available data and should result in fewer errors than other methods. For instance, using the lower quartile of all data for an area to estimate of the reference condition risks including few unimpacted sites and is likely to be biased towards enrichment (USEPA, 1998). Similarly, using a percentile based on only a few reference sites means that the estimates are likely to have limited geographical spread, which will limit the representativeness of the derived trigger values. For example, current ANZECC (2000) trigger values are derived from data representing large rivers that are often in areas (e.g., national parks) with different climate and soils to agricultural catchments.

Our method is a modification of the method based on the linear ANCOVA model that has been used in other countries (e.g., Dodds and Oakes 2004). We showed that the mixed-effects models, which included a smoothing spline, were better than ANCOVA models for estimating reference and trigger values in our dataset. More minimally disturbed condition reference values fell within the confidence intervals of the mixed-effects models than the ANCOVA method suggesting that not accounting for a “pan handle” effect may result in reference values being overestimated by linear ANCOVA models.

Our trigger value estimates have significantly more spatial specificity than the current ANZECC (2000) default trigger values and can be used to evaluate and interpret water quality data representing test locations. We suggest that users locate test sites on the REC river network to determine the site classification at the second (topography) and third (geology) levels of the REC. The relevant trigger values can then be obtained from the Appended Tables I and II. Where the third (geology) level class of the test site is represented in Appended Table II, we recommend that the 95% confidence interval of the trigger value should be considered. For third (geology) level classes that are not represented in Table II we recommend that the 95% confidence interval of the trigger value for the second (topography) level class should be considered. There is a 95% probability that the ‘true’ trigger value is within these recommended values. Thus, users can be confident that should a median value for a test site be less (for Clarity and DO) or more than (for all other indicators) this value, then further investigation is required. We recommend that trigger values derived using our method are checked against any other relevant guidelines (e.g., toxicity guidelines) before being adopted and in general effects based guidelines should be used where available. We note that if the estimated trigger values presented here are used to revise the ANZECC guidelines (i.e. to become the default trigger values), our recommendations about how to handle the uncertainties will need to be ratified. Default trigger values could be made more or less conservative by taking into account the uncertainty in the estimated value (e.g., a more conservative value for indicators that are harmful at high values would utilise a lower percentile and confidence interval for the estimate).

Knowledge of reference conditions should enable substantial gains in managing water quality by accounting for natural variation in water quality. The difference between current concentrations of indicators and those likely at reference sites represents the anthropogenic contribution. However, only a portion of this contribution will be manageable (Figure 13). We propose that the manageable load represent that part of the anthropogenic load which is easily mitigated without causing financial hardship: and thus it would depend on the profitability of the enterprise and the propensity for contaminant loss relative to natural losses. Recognising that reference conditions vary spatially helps to avoid setting limits that are too high and produce little benefit for environmental values or are so low that they are impossible to meet.

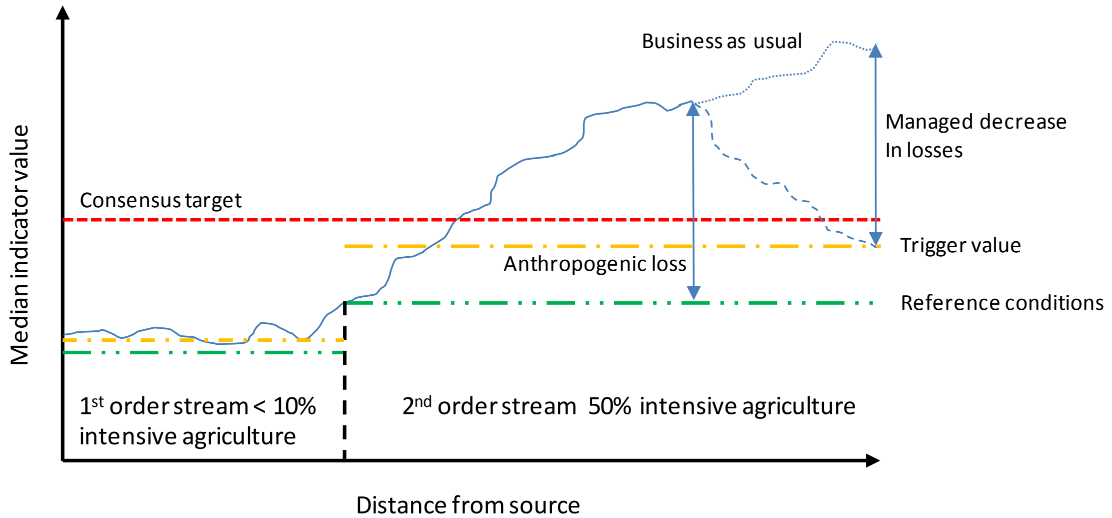

Figure 13. Conceptual diagram of indicator values in two streams varying in % heavy pasture with distance from the stream's source. Determination of the anthropogenic and manageable losses will help a consensus on a realistic target.

Research has revealed many of the edaphic (e.g., soil and climatic) factors and management (e.g., the placement and timing of P inputs) practices that result in water quality deterioration (e.g., McDowell et al., 2011). Estimates of the anthropogenic contribution means it is possible to determine the manageable loss and set a catchment target following an assessment of how low (on the contamination scale) it is possible to go with current mitigation technologies *viz.* better management of land in percentage of intensive agriculture. For example, a recent assessment was made of water quality, and anthropogenic and manageable inputs of indicators (or contaminants) into the tributaries and main stem of the Pomahaka River, Otago (McDowell et al., 2011). Table 8 shows the median concentrations of several indicators in the Heriot Burn, subject to intensive dairying and tile drainage, were well in excess of the estimated trigger value warranting further investigation. Relative to the estimated median reference condition, concentrations were enriched by 300-700%. Additional analysis of inputs in the Heriot Burn found there to be considerable diffuse input of water quality contaminants derived from effluent. A test was derived and a formula derived that would detect "effluent contamination":

$$\ln(\text{contamination}) = 0.13\times\ln(\textit{E. coli} + 1) + 0.14\times\ln(NH_4\text{-N} + 0.005) + 0.57\times\ln(TP + 0.0025)$$

If a sample had a "contamination" value in excess of 1.554 the sample was deemed to contain effluent. As part of an assessment of the manageable load the formula was applied to all samples collected from tile drainage into the Heriot Burn. Discharges relating to poor effluent practice (e.g., application on wet soils) accounted for 33% of NH_4-N, 30% of *E. coli* and 9% of total P loads. Assuming that this was prevented by better effluent practice (larger ponds or low rate application) and translated into changes in the stream, NH_4-N, *E. coli* and total P concentrations would decrease to 14 μg L^{-1}, 308 MPN 100mL^{-1} and 53 μg L^{-1}. Restricting access to streams would decrease this loss by a further 5-20% for *E. coli* (Muirhead et al., 2011) and 14-50% for total P (McDowell and Nash, 2012). With two simple mitigation strategies, concentrations would be near (e.g., total P = 26 μg L^{-1}) or within the trigger value (e.g., *E. coli* = 246 MPN 100mL^{-1}). If the trigger value was set as a consensus target as per Figure 13, the objective could be achieved with little cost and thus conform to a manageable load.

Table 8. Median concentrations in the Heriot Burn 2009-2010 in Otago and the corresponding median reference and trigger values from Appendix II. The anthropogenic input represents the difference between the median and estimated median reference concentrations.

Indicator	Median concentration	Trigger value	Estimated reference median concentration	Anthropogenic input
NH_4-N (μg L^{-1})	20	9	6	14
E. coli (MPN 100 mL^{-1})	460	267	58	402
Total P (μg L^{-1})	58	14	9	49

6 Conclusions and recommendations

Within the limits of the available data, median values for water quality indicators under reference conditions and trigger values for streams and rivers were estimated for classes at the second and third levels of the River Environment Classification. Comparing the mixed effects models incorporating a spline to a simpler linear ANCOVA approach, we have confidence that our mixed effects models better estimated reference conditions and trigger values because more sites, classified as minimally disturbed (i.e. < 5% heavy pasture land cover), were generally within the confidence limits of the reference estimate.

The establishment of default trigger values for classes at the second and third levels of the REC is a significant advance on the current ANZECC (2000) guidelines in three respects. First, the environmental specificity of the reference and default trigger values is greatly increased from two classes provided by the ANZECC (2000) guidelines to at least 18 classes at the second (topography) level of the REC. Second, confidence intervals are provided for both reference and trigger values. Third, the methods used in the current study use all the relevant available data on water quality that is available, including many regional council datasets.

The establishment of reference condition estimates enables the identification of river and stream environments (REC classes) with high anthropogenic input and the indicators that are have high levels of enrichment relative to reference conditions within a REC class. The REC classes also means that natural variation in reference conditions is accounted for, thereby decreasing the risk that targets that are either too restrictive, and impossible to meet (e.g., if below reference conditions), or too high that they have little ecological effect. It is recommended that this approach be considered by regulatory authorities during the process of setting water quality objectives.

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Appendix I: Table (I) of estimated median and trigger values (20 and 80th percentiles) along with the 95% confidence interval (CI) of the estimates at the 2nd level (climate by topography) of the REC. Values for minimally disturbed condition (MDC)-reference sites are also given for the respective percentile.

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
Clarity	CDH	1.3	0.4	2.7	[2]	2.4	0.8	4.8		3.7	1.3	7.1		
(m)	CDL	0.5	0.2	0.9	0.3	0.9	0.4	1.5	0.4	1.2	0.7	2.0	0.6	2
	CDLk	1.1	0.2	2.6		2.1	0.4	5.0		3.3	0.5	7.9		
	CDM	1.1	0.2	2.6		2.1	0.4	5.0		3.3	0.5	7.9		
	CWH	1.6	1.3	1.9	1.8	3.0	2.5	3.5	3.2	4.6	3.9	5.3	4.7	44
	CWL	1.4	1.0	1.8	1.5	2.2	1.7	2.7	2.3	3.0	2.4	3.7	3.1	20
	CWLk	1.9	1.1	2.8	1.5	3.1	2.0	4.5	2.8	4.5	3.0	6.2	4.0	5
	CWM	1.0	0.5	1.7	1.4	2.3	1.3	3.5	3.0	4.2	2.6	6.2	5.0	5
	CXH	1.8	1.2	2.5	1.7	4.0	2.9	5.3	3.8	6.2	4.7	8.0	6.0	13
	CXL	1.4	0.9	2.1	1.4	2.4	1.6	3.4	2.4	3.4	2.4	4.6	3.2	7
	CXLk	1.7	0.9	2.8	1.6	3.2	1.9	4.9	2.8	4.7	2.9	6.8	4.0	2
	CXM	1.0	0.4	1.9	0.9	2.0	1.0	3.4	1.9	3.6	1.8	5.9	3.6	3
	WDL	0.7	0.2	1.5		1.3	0.5	2.6		1.6	0.6	3.0		
	WWH	1.1	0.2	2.6		2.1	0.4	5.0		3.3	0.5	7.9		
	WWL	0.8	0.6	1.2	1.2	1.5	1.1	2.0	2.2	2.4	1.8	3.0	3.2	8
	WWLk	0.9	0.3	1.9		1.4	0.5	2.8		1.7	0.6	3.4		
	WXH	0.9	0.3	1.9		1.9	0.6	3.8		3.2	1.1	6.4		
	WXL	1.2	0.4	2.3		2.5	1.0	4.7		4.2	1.8	7.6		
Conductivity	CDH					66	46	89	87	83	56	114	95	2
($\mu S\ cm^{-1}$)	CDL					105	74	143	154	116	80	158	171	3
	CDLk					88	46	144		101	54	163		
	CDM					77	45	118	70	94	55	144	117	1
	CWH					83	69	98	86	95	78	114	97	46
	CWL					129	100	160	142	145	111	183	158	21
	CWLk					95	66	129	68	102	70	140	71	5
	CWM					72	50	99	58	87	59	120	66	7

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	CXH					76	56	98	77	87	64	114	87	13
	CXL					88	62	118	115	107	74	145	147	7
	CXLk					74	48	105	110	87	56	124	123	2
	CXM					85	51	128	81	98	59	147	90	3
	WDL					76	42	118		86	49	134		
	WWH					81	45	126	88	94	53	147	105	1
	WWL					101	76	129	90	115	85	149	99	9
	WWLk					111	62	173		120	68	188		
	WXH					100	58	155	132	113	65	174	146	1
	WXL					103	61	156		119	70	181		
E. coli	CDH					14	6	26	39	100	40	184	360	2
(MPN 100 mL^{-1})	CDL					34	15	60	27	223	99	395	269	3
	CDLk					11	4	57		100	0	472		
	CDM					6	0	18	20	81	5	224	394	1
	CWH					9	6	12	15	92	64	126	127	43
	CWL					40	24	59	47	395	239	590	503	20
	CWLk					1	0	2	3	13	5	25	36	5
	CWM					4	2	8	4	64	26	119	64	7
	CXH					5	2	8	7	103	53	169	105	13
	CXL					42	19	73	67	482	217	847	806	7
	CXLk					4	1	8	3	121	35	255	218	2
	CXM					11	2	27	16	114	18	279	141	3
	WDL					39	1	116		454	0	1360		
	WWH					15	0	51	63	227	0	723	788	1
	WWL					62	35	97	119	628	348	988	1284	9
	WWLk					17	0	61		215	0	741		
	WXH					7	0	26		107	0	382		
	WXL					16	0	57		247	0	808		
NH4-N	CDH					4	2	6	5	6	4	9	10	1
(µg L^{-1})	CDL					7	4	11	20	10	6	16	35	2

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	CDLk					5	1	10		9	3	19		
	CDM					4	2	7	5	7	3	13	10	1
	CWH					5	4	6	5	6	4	8	6	20
	CWL					6	4	8	6	9	6	12	10	15
	CWLk					4	3	6	5	7	4	10	7	5
	CWM					3	2	5	3	5	3	8	5	5
	CXH					3	2	5	4	5	3	7	6	8
	CXL					5	2	8	5	8	4	14	10	1
	CXLk					4	2	7		5	2	9		
	CXM					4	1	7	2	6	2	12	5	2
	WDL					9	4	18		17	8	31		
	WWH					4	2	8	5	6	2	12	5	1
	WWL					6	4	8	5	10	7	13	9	8
	WWLk					8	3	14		13	5	22		
	WXH					4	1	9		7	2	14		
	WXL					5	2	9		9	3	17		
NO3-N	CDH					8	3	15	40	18	9	32	84	2
($\mu g\ L^{-1}$)	CDL					143	57	264	80	265	133	442	110	3
	CDLk					21	0	85		40	0	149		
	CDM					16	1	43	30	30	5	72	60	1
	CWH					44	30	62	41	87	64	114	87	42
	CWL					86	49	132	115	170	111	242	212	21
	CWLk					7	3	14	17	11	5	19	24	5
	CWM					15	5	29	12	24	11	42	21	7
	CXH					35	16	62	42	54	29	85	65	11
	CXL					52	9	125	40	92	26	194	90	1
	CXLk					32	8	71	24	47	17	93	39	2
	CXM					23	3	59	23	48	12	106	52	3
	WDL					92	1	271		195	22	504		
	WWH					21	0	65	10	36	3	99	30	1
	WWL					26	14	42	17	65	40	96	60	9

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	WWLk					87	0	274		122	6	341		
	WXH					30	1	84	170	63	9	157	300	1
	WXL					35	2	98		80	11	201		
Total N ($\mu g\ L^{-1}$)	CDH					73	47	104	94	103	68	145	180	2
	CDL					568	331	868	2800	913	552	1362	3500	1
	CDLk					111	20	264		160	25	395		
	CDM					107	38	208	120	144	54	277	152	1
	CWH					150	113	193	133	238	184	300	205	14
	CWL					178	76	320		272	120	483		
	CWLk					86	50	131	99	104	61	157	121	4
	CWM					58	34	87	43	85	52	126	66	6
	CXH					80	48	120	85	119	74	174	129	6
	CXL					122	43	239	120	179	66	343	176	1
	CXLk					116	59	193	130	194	102	316	352	2
	CXM					93	34	179	79	128	50	241	110	2
	WDL					161	45	343		281	77	601		
	WWH					108	30	230	100	179	51	378	200	1
	WWL					176	112	255	124	292	192	413	222	4
	WWLk					214	68	436		295	91	607		
	WXH					108	29	232		148	41	318		
	WXL					147	42	311		232	64	494		
FRP ($\mu g\ L^{-1}$)	CDH					3	2	4	3	6	3	9	6	2
	CDL					5	3	8	8	8	5	12	14	3
	CDLk					4	0	12		7	1	17		
	CDM					4	1	9	3	7	2	14	6	1
	CWH					5	4	6	6	8	7	10	9	43
	CWL					8	6	11	8	11	8	15	12	21
	CWLk					2	1	3	2	3	2	5	3	5
	CWM					3	1	5	3	4	2	7	4	7
	CXH					3	2	5	3	6	4	8	5	12

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	CXL					7	3	13	20	9	4	17	30	1
	CXLk					2	1	3	2	4	2	6	5	2
	CXM					3	1	6	3	5	2	10	5	3
	WDL					5	1	11		7	2	14		
	WWH					5	1	11	5	8	2	16	8	1
	WWL					8	6	12	4	14	9	19	10	9
	WWLk					14	3	34		16	4	36		
	WXH					6	1	13	8	8	2	15	10	1
	WXL					3	1	7		6	2	12		
Total P ($\mu g\ L^{-1}$)	CDH					6	4	8	6	9	7	11	13	2
	CDL					9	6	12	15	14	11	17	27	3
	CDLk					9	3	18		16	7	29		
	CDM					9	4	17	10	13	6	23	10	1
	CWH					9	8	11	10	16	13	19	17	29
	CWL					13	9	17	15	18	14	22	21	15
	CWLk					10	7	13	8	13	9	18	12	5
	CWM					8	5	12	7	17	11	25	12	7
	CXH					8	5	11	7	13	9	19	11	9
	CXL					9	4	15	30	13	7	21	30	1
	CXLk					6	4	10	6	10	6	16	10	2
	CXM					10	4	18	10	19	9	33	32	2
	WDL					16	9	27		23	16	33		
	WWH					10	4	19	8	17	8	29	20	1
	WWL					16	12	21	11	24	19	29	18	9
	WWLk					21	11	36		27	15	42		
	WXH					9	3	18		17	7	31		
	WXL					9	4	16		17	9	27		
Turbidity (NTU)	CDH					0.5	0.3	0.8	0.7	0.9	0.5	1.5	1.8	2
	CDL					0.7	0.4	1.1	1.1	1.3	0.7	2.1	1.6	3
	CDLk					0.9	0.1	2.3		1.9	0.2	5.0		

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	CDM					1.4	0.4	2.8	1.0	2.9	0.8	6.2	1.6	1
	CWH					1.0	0.8	1.3	1.0	2.4	1.8	3.1	2.3	45
	CWL					1.2	0.8	1.7	1.2	2.3	1.5	3.3	2.4	21
	CWLk					0.8	0.5	1.3	1.3	1.3	0.7	2.0	2.4	5
	CWM					1.6	0.9	2.6	1.1	4.6	2.3	7.7	3.0	7
	CXH					0.7	0.4	1.1	0.8	2.1	1.2	3.2	2.5	12
	CXL					1.3	0.7	2.1	2.5	2.6	1.4	4.2	5.6	6
	CXLk					0.7	0.4	1.2	0.8	2.0	0.9	3.6	2.1	2
	CXM					1.3	0.5	2.6	1.5	3.5	1.0	7.4	4.9	3
	WDL					2.5	0.8	5.2		4.2	1.4	8.5		
	WWH					1.5	0.4	3.2	2.2	2.7	0.6	6.2	3.4	1
	WWL					2.3	1.6	3.3	1.9	5.2	3.3	7.5	4.7	9
	WWLk					2.1	0.6	4.3		3.9	1.2	8.0		
	WXH					1.9	0.6	3.8	0.9	6.9	1.9	14.9	5.8	1
	WXL					1.2	0.4	2.2		4.0	1.4	7.8		
Suspended solids (mg L^{-1})	CDH					1.0	0.6	1.5	1.7	1.6	0.8	2.9	5.8	2
	CDL					1.4	0.8	2.1	2.0	2.1	1.0	3.7	2.9	3
	CDLk					1.5	0.3	3.7		2.6	0.0	8.5		
	CDM					1.9	0.7	3.7	1.5	5.1	0.9	12.1	3.0	1
	CWH					1.2	0.9	1.6	1.2	2.6	1.7	3.7	2.5	26
	CWL					1.2	0.7	1.7	1.2	1.8	0.9	2.9	2.2	10
	CWLk					1.4	0.7	2.3	2.9	1.6	0.6	3.1	4.2	2
	CWM					3.9	1.7	7.0	2.6	11.8	3.7	24.1	7.7	3
	CXH					1.4	0.4	2.8	1.1	4.1	0.6	10.2	4.9	2
	CXL					1.2	0.4	2.4	1.4	1.7	0.3	4.2	4.2	1
	CXLk					1.3	0.5	2.4	1.5	4.0	1.1	8.7	4.5	2
	CXM					1.9	0.2	5.1		4.2	0.0	16.6		
	WDL					2.3	0.8	4.5		4.6	0.7	11.3		
	WWH					1.9	0.2	5.1		4.2	0.0	16.6		
	WWL					3.2	1.8	5.1	2.0	8.8	3.8	15.7	7.6	2

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	WWLk					3.6	1.1	7.3		5.7	0.6	14.8		
	WXH					3.4	1.1	6.7	2.0	11.8	2.1	28.3	7.0	1
	WXL					3.2	1.0	6.4		12.0	1.8	29.7		
Dissolved														
oxygen	CDH	84	76	92	89	95	90	100	98	104	100	108	105	2
(%)	CDL	81	72	89	80	91	85	97	84	101	96	105	90	1
	CDLk	89	74	103		96	87	106		105	98	113		
	CDM	89	77	101	93	95	87	103	98	104	97	110	106	1
	CWH	86	82	90	84	94	92	97	93	105	103	107	105	45
	CWL	80	74	86	75	91	87	95	87	105	101	108	102	19
	CWLk	94	86	102	95	98	93	104	98	105	100	109	101	5
	CWM	93	85	102	96	98	93	104	100	103	98	108	102	7
	CXH	95	88	102	98	100	95	104	102	107	103	110	107	12
	CXL	93	86	101	96	100	94	105	103	110	105	114	113	7
	CXLk	90	81	99	87	96	90	102	95	104	99	110	105	2
	CXM	93	82	104	100	98	90	106	102	105	98	111	105	3
	WDL	82	70	95		90	82	98		100	94	107		
	WWH	90	77	103	99	96	88	105	102	104	97	110	105	1
	WWL	92	86	98	97	97	93	101	100	103	99	106	103	9
	WWLk	85	72	97		91	83	99		101	94	107		
	WXH	90	76	103		97	88	106		105	97	112		
	WXL	90	78	102		98	90	106		107	100	113		
pH[3]	CDH					7.6	7.4	7.7	7.7	7.7	7.6	7.9	7.9	2
	CDL					7.5	7.4	7.6	7.2	7.8	7.7	7.9	7.4	1
	CDLk					7.6	7.4	7.8		7.8	7.7	7.9		
	CDM					7.6	7.4	7.7	7.4	7.8	7.6	7.9	7.6	1
	CWH					7.6	7.5	7.7	7.6	7.8	7.7	7.9	7.9	46
	CWL					7.6	7.5	7.7	7.5	7.8	7.7	7.9	7.8	21
	CWLk					7.6	7.4	7.7	7.5	7.7	7.6	7.9	7.7	5
	CWM					7.6	7.5	7.8	7.7	7.8	7.7	7.9	7.8	7

Indicator	REC	20%ile	20%ile - CI	20%ile + CI	MDC 20%ile	Median	Median - CI	Median + CI	MDC Median	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI	MDC 80%ile	Num sites for MDC
	CXH					7.5	7.4	7.7	7.5	7.8	7.6	7.9	7.7	12
	CXL					7.4	7.3	7.5	7.4	7.7	7.6	7.8	7.7	7
	CXLk					7.6	7.4	7.7	8.0	7.8	7.6	7.9	8.2	2
	CXM					7.6	7.4	7.7	7.7	7.8	7.6	7.9	7.8	3
	WDL					7.5	7.4	7.7		7.8	7.6	7.9		
	WWH					7.5	7.4	7.7	7.4	7.8	7.6	7.9	7.6	1
	WWL					7.5	7.4	7.6	7.5	7.7	7.6	7.8	7.7	9
	WWLk					7.5	7.4	7.7		7.8	7.6	7.9		
	WXH					7.6	7.4	7.8	7.5	7.8	7.6	7.9	7.6	1
	WXL					7.6	7.4	7.7		7.8	7.7	7.9		
Temperature (^oC)	CDH					9.2	8.4	10.0	9.4	13.6	12.6	14.7	13.7	2
	CDL					10.0	9.2	10.8	10.2	12.9	11.9	13.9	12.9	3
	CDLk					10.8	8.3	13.6		14.6	11.6	17.9		
	CDM					9.4	8.0	10.9	10.4	13.3	11.5	15.2	14.3	1
	CWH					10.4	10.0	10.9	10.6	13.9	13.4	14.5	14.0	39
	CWL					10.5	9.9	11.2	10.6	13.4	12.7	14.2	13.5	15
	CWLk					12.0	11.0	13.1	11.6	15.6	14.4	16.9	15.2	5
	CWM					8.6	7.9	9.4	7.9	12.5	11.5	13.5	11.9	7
	CXH					10.2	9.5	10.9	10.3	13.3	12.4	14.1	13.3	12
	CXL					11.7	10.8	12.7	12.5	15.0	13.9	16.2	15.9	7
	CXLk					10.7	9.6	11.8	11.4	13.9	12.6	15.3	15.2	2
	CXM					10.2	8.8	11.7	10.2	13.2	11.6	14.9	13.1	3
	WDL					13.2	11.1	15.4		16.6	14.2	19.3		
	WWH					10.9	9.1	12.9	13.3	13.6	11.6	15.9	16.0	1
	WWL					13.1	12.3	14.0	14.3	16.2	15.3	17.2	18.2	9
	WWLk					13.5	11.3	15.9		16.4	13.9	19.1		
	WXH					12.5	10.6	14.5	13.9	15.3	13.3	17.6	16.7	1
	WXL					12.0	10.3	13.7		15.5	13.5	17.6		

[1] = 80th percentile for all data except *E. coli* which is a 95th percentile.
[2] = no suitable MDC-reference sites (and data) available
[3] = mixed effects model only established separate values for the median of reference conditions not lower trigger value.

Appendix II: Table (II) of estimated median and 20 and 80th percentiles along with the 95% confidence interval (CI) of the estimates at the 3rd level (climate by topography by geology) of the REC.

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
Clarity	**CDH[2]**	Al	0.6	0.2	1.4	1.4	0.5	2.6	2.3	1.0	4.0
(m)	CDL	Al	0.4	0.1	0.8	0.8	0.3	1.4	1.1	0.6	1.8
	CWH	Al	0.7	0.3	1.5	1.7	0.8	2.9	2.9	1.6	4.5
	CWL	Al	0.6	0.2	1.1	1.3	0.6	2.2	2.2	1.2	3.4
	CXH	Al	0.8	0.2	1.8	2.1	0.8	3.8	3.3	1.6	5.6
	CXL	Al	0.9	0.3	1.6	1.9	1.0	3.2	3.2	1.9	4.9
	WDL	Al	0.4	0.1	0.9	0.8	0.3	1.5	1.1	0.6	1.8
	WWL	Al	0.3	0.1	0.6	0.8	0.3	1.4	1.7	0.9	2.7
	CDH	HS	1.4	0.4	2.8	2.6	1.3	4.5	4.3	2.9	6.1
	CDL	HS	1.0	0.3	2.1	1.7	0.8	3.0	2.6	1.7	3.6
	CWH	HS	1.8	1.4	2.2	3.5	2.8	4.2	5.4	4.5	6.4
	CWL	HS	1.7	1.2	2.3	2.7	2.1	3.4	3.6	2.9	4.4
	CXH	HS	2.0	1.3	2.9	4.3	3.0	5.7	6.7	5.0	8.6
	CXL	HS	1.8	0.8	3.1	3.5	1.9	5.5	5.3	3.3	7.7
	WDL	HS	0.8	0.2	1.8	1.5	0.6	2.8	2.7	1.5	4.2
	WWL	HS	0.7	0.4	1.3	1.4	0.8	2.1	2.4	1.7	3.1
	CDH	SS	1.3	0.4	2.9	2.2	0.9	4.0	3.1	1.5	5.1
	CDL	SS	0.9	0.3	1.8	1.3	0.6	2.4	1.9	1.2	2.6
	CWH	SS	2.1	1.3	3.1	3.2	2.2	4.3	3.9	3.0	5.0
	CWL	SS	1.1	0.6	1.7	1.7	1.1	2.4	2.4	1.8	3.0
	CXH	SS	2.0	0.9	3.5	3.4	1.9	5.5	4.6	2.8	6.8
	CXL	SS	1.6	1.0	2.5	2.5	1.7	3.5	3.5	2.5	4.6
	WDL	SS	0.7	0.3	1.5	1.1	0.5	1.9	1.5	1.0	2.2
	WWL	SS	0.7	0.4	1.1	1.2	0.7	1.7	1.9	1.4	2.5
	CDH	VA	1.1	0.3	2.3	2.2	0.9	4.1	3.5	1.8	5.7
	CDL	VA	0.7	0.2	1.6	1.4	0.6	2.5	2.1	1.2	3.4
	CWH	VA	1.1	0.8	1.4	2.1	1.6	2.6	3.4	2.8	4.1

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CWL	VA	0.6	0.2	1.1	1.5	0.8	2.5	3.1	2.0	4.3
	CXH	VA	1.5	0.8	2.6	3.7	2.2	5.6	5.4	3.7	7.4
	CXL	VA	1.5	0.4	3.1	3.0	1.3	5.4	4.5	2.4	7.2
	WDL	VA	0.7	0.2	1.4	1.3	0.5	2.4	2.1	1.2	3.3
	WWL	VA	1.2	0.8	1.7	2.1	1.5	2.8	2.9	2.2	3.6
Conductivity	CDH	Al				53	31	81	70	41	108
(µS cm^{-1})	CDL	Al				106	67	153	119	75	174
	CWH	Al				68	44	97	80	52	114
	CWL	Al				112	66	172	128	75	194
	CXH	Al				73	40	115	85	47	133
	CXL	Al				79	46	120	93	54	142
	WDL	Al				66	31	114	77	37	131
	WWL	Al				97	57	149	110	64	167
	CDH	HS				76	51	106	94	63	133
	CDL	HS				100	61	150	111	67	166
	CWH	HS				88	70	108	102	81	126
	CWL	HS				145	109	186	161	119	208
	CXH	HS				82	57	110	94	65	128
	CXL	HS				97	59	143	111	68	165
	WDL	HS				93	44	159	100	50	167
	WWL	HS				110	74	154	121	80	170
	CDH	SS				71	38	113	98	54	155
	CDL	SS				120	69	185	141	81	216
	CWH	SS				82	59	109	105	75	141
	CWL	SS				124	86	169	151	103	207
	CXH	SS				87	53	129	108	66	161
	CXL	SS				94	63	131	121	80	170
	WDL	SS				74	38	123	91	47	150
	WWL	SS				127	87	176	151	102	210

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CDH	VA				67	36	107	83	45	133
	CDL	VA				101	54	163	110	60	176
	CWH	VA				86	67	109	96	73	122
	CWL	VA				115	72	167	128	80	187
	CXH	VA				77	49	112	88	55	128
	CXL	VA				88	48	139	102	57	160
	WDL	VA				72	33	125	80	38	136
	WWL	VA				91	65	121	103	73	138
E. coli	CDH	Al				22	9	40	108	27	236
(MPN $100ml^{-1}$)	CDL	Al				62	26	111	246	93	468
	CWH	Al				12	8	18	139	43	285
	CWL	Al				45	24	72	525	104	1228
	CXH	Al				7	3	12	145	24	350
	CXL	Al				54	24	96	447	110	988
	WDL	Al				63	4	173	394	2	1173
	WWL	Al				87	44	143	668	132	1565
	CDH	HS				21	10	37	134	56	243
	CDL	HS				58	24	106	267	56	616
	CWH	HS				13	9	17	114	75	160
	CWL	HS				46	29	68	345	201	527
	CXH	HS				7	4	11	103	50	173
	CXL	HS				52	24	92	377	107	797
	WDL	HS				60	4	164	443	0	1376
	WWL	HS				90	49	145	933	308	1874
	CDH	SS				22	9	41	136	17	347
	CDL	SS				58	23	109	264	46	633
	CWH	SS				12	7	17	107	51	183
	CWL	SS				57	33	87	569	238	1036
	CXH	SS				7	3	12	114	33	239

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CXL	SS				58	28	97	681	296	1217
	WDL	SS				64	5	172	598	33	1670
	WWL	SS				82	45	130	586	227	1104
	CDH	VA				22	9	41	136	17	347
	CDL	VA				59	22	111	261	31	671
	CWH	VA				11	7	15	84	49	127
	CWL	VA				51	27	81	508	109	1165
	CXH	VA				7	4	12	201	65	405
	CXL	VA				54	24	97	459	69	1136
	WDL	VA				62	4	172	435	0	1350
	WWL	VA				90	52	137	738	379	1213
pH[3]	CDH	Al				7.4	7.1	7.6	7.5	7.2	7.7
	CDL	Al				7.4	7.1	7.6	7.5	7.3	7.7
	CWH	Al				7.5	7.3	7.7	7.5	7.3	7.7
	CWL	Al				7.4	7.2	7.7	7.5	7.3	7.7
	CXH	Al				7.4	7.1	7.7	7.4	7.2	7.7
	CXL	Al				7.3	7.0	7.5	7.4	7.2	7.6
	WDL	Al				7.4	7.1	7.7	7.5	7.2	7.7
	WWL	Al				7.4	7.1	7.6	7.4	7.2	7.6
	CDH	HS				7.6	7.4	7.8	7.8	7.7	8.0
	CDL	HS				7.5	7.3	7.8	7.8	7.7	8.0
	CWH	HS				7.7	7.5	7.8	7.9	7.8	8.0
	CWL	HS				7.6	7.4	7.7	7.8	7.7	7.9
	CXH	HS				7.5	7.3	7.7	7.8	7.6	7.9
	CXL	HS				7.4	7.1	7.6	7.7	7.6	7.9
	WDL	HS				7.5	7.2	7.8	7.8	7.6	8.0
	WWL	HS				7.4	7.2	7.6	7.8	7.6	7.9
	CDH	SS				7.6	7.3	7.9	7.8	7.7	8.0
	CDL	SS				7.7	7.4	7.9	7.8	7.7	8.0

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CWH	SS				7.6	7.4	7.8	7.9	7.7	8.1
	CWL	SS				7.5	7.3	7.7	7.8	7.7	8.0
	CXH	SS				7.5	7.3	7.8	7.8	7.6	8.0
	CXL	SS				7.4	7.2	7.6	7.7	7.6	7.9
	WDL	SS				7.5	7.3	7.8	7.8	7.6	8.0
	WWL	SS				7.7	7.5	7.9	7.8	7.6	8.0
	CDH	VA				7.5	7.2	7.7	7.6	7.5	7.8
	CDL	VA				7.5	7.2	7.7	7.7	7.5	7.8
	CWH	VA				7.6	7.4	7.7	7.7	7.6	7.8
	CWL	VA				7.4	7.2	7.7	7.7	7.5	7.8
	CXH	VA				7.4	7.2	7.7	7.6	7.4	7.8
	CXL	VA				7.3	7.0	7.6	7.6	7.4	7.7
	WDL	VA				7.5	7.2	7.8	7.6	7.5	7.8
	WWL	VA				7.4	7.2	7.5	7.6	7.5	7.7
NH_4-N ($\mu g\ L^{-1}$)	**CDH**	Al				5	2	9	7	2	15
	CDL	Al				8	3	13	12	6	21
	CWH	Al				5	2	8	5	2	10
	CWL	Al				5	2	9	7	3	14
	CXH	Al				4	1	7	6	2	12
	CXL	Al				5	2	10	9	3	18
	WDL	Al				8	3	16	12	5	23
	WWL	Al				9	4	15	17	7	32
	CDH	HS				4	3	6	6	4	9
	CDL	HS				6	3	10	9	5	14
	CWH	HS				4	3	5	6	4	7
	CWL	HS				6	4	8	9	6	13
	CXH	HS				4	2	6	5	3	8
	CXL	HS				5	2	9	9	4	17
	WDL	HS				10	3	22	17	4	38

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	WWL	HS				7	4	10	12	7	18
	CDH	SS				5	2	9	7	2	16
	CDL	SS				8	3	13	14	7	23
	CWH	SS				4	2	7	5	3	8
	CWL	SS				5	3	8	8	5	12
	CXH	SS				4	1	7	6	2	12
	CXL	SS				5	2	11	9	2	20
	WDL	SS				17	7	31	30	13	53
	WWL	SS				7	5	10	12	8	18
	CDH	VA				5	2	9	7	2	16
	CDL	VA				7	2	14	11	3	23
	CWH	VA				6	4	7	8	5	10
	CWL	VA				8	4	12	14	7	23
	CXH	VA				3	2	5	5	3	8
	CXL	VA				5	2	11	9	2	20
	WDL	VA				11	3	22	18	5	39
	WWL	VA				5	4	7	10	7	13
NO_3-N	CDH	Al				7	1	16	12	4	24
(µg L^{-1})	CDL	Al				594	200	1183	884	401	1549
	CWH	Al				80	20	176	117	50	213
	CWL	Al				202	13	556	294	79	632
	CXH	Al				67	0	207	73	12	176
	CXL	Al				74	1	220	102	16	250
	WDL	Al				223	0	757	333	16	940
	WWL	Al				63	4	172	97	27	206
	CDH	HS				10	4	18	25	12	42
	CDL	HS				119	19	291	303	99	610
	CWH	HS				39	25	56	80	57	108
	CWL	HS				101	57	157	197	127	282

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CXH	HS				41	19	72	60	33	95
	CXL	HS				62	11	149	111	33	231
	WDL	HS				108	0	383	246	2	732
	WWL	HS				49	15	102	96	43	170
	CDH	SS				8	0	23	17	3	43
	CDL	SS				133	11	358	325	86	705
	CWH	SS				34	15	61	79	44	125
	CWL	SS				99	34	194	203	97	346
	CXH	SS				35	3	93	54	14	118
	CXL	SS				50	0	150	93	15	228
	WDL	SS				127	1	376	262	33	668
	WWL	SS				20	7	37	47	23	78
	CDH	VA				11	0	35	22	3	55
	CDL	VA				209	0	660	456	68	1133
	CWH	VA				66	40	100	116	78	160
	CWL	VA				167	30	397	287	100	566
	CXH	VA				51	6	130	74	21	158
	CXL	VA				69	0	230	116	10	312
	WDL	VA				155	0	570	310	0	945
	WWL	VA				32	16	54	79	47	120
Total N	CDH	Al				46	19	83	37	17	65
(µg L^{-1})	CDL	Al				1117	601	1790	1714	979	2651
	CWH	Al				226	75	453	371	125	739
	CWL	Al				204	20	538	271	24	726
	CXH	Al				122	11	325	142	14	373
	CXL	Al				154	36	347	204	50	452
	WDL	Al				186	15	501	317	17	886
	WWL	Al				189	20	495	283	34	729
	CDH	HS				88	55	129	139	89	200

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CDL	HS				215	69	436	427	144	849
	CWH	HS				105	70	148	173	118	238
	CWL	HS				192	49	420	293	78	634
	CXH	HS				82	42	136	113	61	182
	CXL	HS				124	32	269	184	51	392
	WDL	HS				168	13	456	301	8	870
	WWL	HS				184	51	391	336	99	704
	CDH	SS				108	11	286	106	11	279
	CDL	SS				252	59	564	521	133	1140
	CWH	SS				149	47	305	265	88	531
	CWL	SS				197	45	447	263	62	589
	CXH	SS				129	12	342	142	14	373
	CXL	SS				167	11	460	208	13	574
	WDL	SS				224	47	516	370	75	859
	WWL	SS				166	83	276	261	140	419
	CDH	VA				77	8	200	104	11	272
	CDL	VA				235	24	620	546	59	1424
	CWH	VA				177	124	239	275	198	365
	CWL	VA				167	42	368	284	75	614
	CXH	VA				70	31	124	105	48	183
	CXL	VA				127	9	350	208	13	574
	WDL	VA				150	9	416	302	8	876
	WWL	VA				182	98	291	309	175	480
FRP	CDH	Al				3	1	5	5	3	8
(μg L^{-1})	CDL	Al				5	3	8	8	5	12
	CWH	Al				3	2	5	5	3	8
	CWL	Al				6	2	11	8	4	14
	CXH	Al				4	1	7	5	2	10
	CXL	Al				4	2	8	6	3	11

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	WDL	Al				7	3	13	10	5	17
	WWL	Al				6	2	10	8	4	13
	CDH	HS				3	2	5	6	4	8
	CDL	HS				5	2	9	8	5	12
	CWH	HS				5	3	6	7	5	9
	CWL	HS				8	5	10	11	8	14
	CXH	HS				4	2	5	6	4	8
	CXL	HS				8	3	13	10	5	16
	WDL	HS				11	4	21	18	8	34
	WWL	HS				10	6	16	13	8	20
	CDH	SS				4	1	7	6	2	11
	CDL	SS				5	2	9	8	4	13
	CWH	SS				5	3	7	7	5	10
	CWL	SS				7	4	11	8	5	11
	CXH	SS				4	2	8	6	3	11
	CXL	SS				6	2	12	8	3	15
	WDL	SS				8	3	14	13	7	21
	WWL	SS				6	3	9	10	7	14
	CDH	VA				8	3	16	12	4	23
	CDL	VA				11	4	23	17	6	31
	CWH	VA				8	6	11	14	11	18
	CWL	VA				18	8	32	24	13	39
	CXH	VA				9	5	15	13	8	21
	CXL	VA				12	4	25	16	5	31
	WDL	VA				18	6	37	28	11	54
	WWL	VA				9	6	13	15	10	20
Total P	CDH	Al				5	3	8	6	3	10
(μg L^{-1})	CDL	Al				8	5	11	12	7	17
	CWH	Al				4	2	6	9	5	14

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CWL	Al				8	4	13	12	5	21
	CXH	Al				5	2	10	9	3	18
	CXL	Al				7	3	12	10	4	19
	WDL	Al				11	6	19	19	8	35
	WWL	Al				12	6	21	19	8	33
	CDH	HS				6	4	8	11	7	15
	CDL	HS				9	6	14	14	7	22
	CWH	HS				7	5	9	13	10	17
	CWL	HS				13	9	17	18	13	25
	CXH	HS				7	4	10	12	7	17
	CXL	HS				11	5	21	17	7	30
	WDL	HS				23	10	42	32	13	59
	WWL	HS				18	12	25	32	19	48
	CDH	SS				8	3	15	13	5	24
	CDL	SS				11	6	17	19	9	31
	CWH	SS				9	5	13	16	9	25
	CWL	SS				12	8	18	21	12	32
	CXH	SS				9	3	17	15	5	30
	CXL	SS				12	4	24	18	5	37
	WDL	SS				23	12	36	36	17	61
	WWL	SS				17	12	24	28	17	41
	CDH	VA				13	5	23	17	6	32
	CDL	VA				17	6	32	25	10	48
	CWH	VA				15	12	19	24	18	30
	CWL	VA				26	15	40	40	21	65
	CXH	VA				13	7	20	19	11	30
	CXL	VA				17	5	36	23	7	48
	WDL	VA				34	13	66	45	16	86
	WWL	VA				17	13	22	26	18	35

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
Suspended solids (mg L^{-1})	CDH	Al				0.7	0.3	1.2	1.3	0.4	2.8
	CDL	Al				0.8	0.4	1.3	1.4	0.5	2.7
	CWH	Al				0.8	0.3	1.5	2.4	0.6	5.3
	CWL	Al				1.0	0.4	1.9	1.9	0.3	4.5
	CXH	Al				0.9	0.2	2.0	2.5	0.1	7.1
	CXL	Al				0.9	0.2	1.8	1.6	0.1	4.5
	WDL	Al				1.1	0.4	2.2	2.6	0.4	6.5
	WWL	Al				1.4	0.5	2.7	3.6	0.6	8.7
	CDH	HS				0.9	0.5	1.3	1.8	0.8	3.1
	CDL	HS				0.8	0.4	1.3	1.3	0.4	2.8
	CWH	HS				1.0	0.7	1.3	2.4	1.4	3.5
	CWL	HS				0.9	0.5	1.3	1.5	0.7	2.6
	CXH	HS				1.0	0.4	1.8	3.0	0.7	6.7
	CXL	HS				0.9	0.4	1.7	1.7	0.4	3.7
	WDL	HS				1.2	0.5	2.2	2.7	0.5	6.3
	WWL	HS				1.7	0.8	3.0	4.7	1.2	10.3
	CDH	SS				0.9	0.4	1.7	1.5	0.3	3.5
	CDL	SS				1.2	0.5	2.1	2.0	0.5	4.3
	CWH	SS				1.0	0.6	1.6	2.0	0.9	3.6
	CWL	SS				1.2	0.6	2.0	2.2	0.8	4.3
	CXH	SS				1.3	0.4	2.7	3.2	0.2	8.7
	CXL	SS				1.2	0.4	2.5	2.0	0.2	5.5
	WDL	SS				1.5	0.6	2.8	2.5	0.5	5.9
	WWL	SS				2.4	1.2	4.0	7.4	2.5	14.6
	CDH	VA				1.8	0.7	3.3	2.0	0.4	4.9
	CDL	VA				2.1	0.8	4.0	2.6	0.5	6.1
	CWH	VA				2.7	1.6	4.0	6.5	3.3	10.7
	CWL	VA				2.5	0.9	4.6	3.2	0.6	7.7
	CXH	VA				2.5	0.7	5.3	4.3	0.2	12.1
	CXL	VA				2.4	0.7	4.9	2.8	0.2	7.7

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	WDL	VA				3.0	1.1	5.8	4.2	0.6	10.4
	WWL	VA				4.3	2.0	7.5	7.8	2.5	15.7
Turbidity	CDH	Al				0.3	0.2	0.6	0.6	0.2	1.0
(NTU)	CDL	Al				0.6	0.3	0.9	1.0	0.5	1.7
	CWH	Al				0.6	0.3	1.0	1.5	0.7	2.7
	CWL	Al				0.6	0.3	1.1	1.4	0.5	2.7
	CXH	Al				0.4	0.2	0.8	1.1	0.3	2.3
	CXL	Al				0.6	0.3	1.0	1.5	0.6	2.8
	WDL	Al				0.9	0.4	1.6	1.8	0.6	3.7
	WWL	Al				1.2	0.5	2.0	3.0	1.1	5.8
	CDH	HS				0.6	0.4	0.9	1.2	0.7	1.9
	CDL	HS				1.1	0.6	1.8	2.1	0.8	3.8
	CWH	HS				1.0	0.8	1.4	2.7	1.9	3.7
	CWL	HS				1.1	0.7	1.4	2.2	1.4	3.1
	CXH	HS				0.7	0.4	1.0	2.2	1.2	3.4
	CXL	HS				1.0	0.5	1.7	2.4	1.0	4.4
	WDL	HS				1.6	0.6	2.9	3.5	1.1	7.2
	WWL	HS				2.8	1.6	4.4	6.3	3.0	10.9
	CDH	SS				1.0	0.4	1.8	1.8	0.6	3.6
	CDL	SS				1.4	0.7	2.4	3.0	1.1	5.7
	CWH	SS				1.2	0.7	1.7	2.7	1.5	4.3
	CWL	SS				1.9	1.1	2.8	3.6	1.8	5.9
	CXH	SS				1.2	0.5	2.1	3.3	1.3	6.1
	CXL	SS				1.7	0.9	2.6	3.9	2.0	6.5
	WDL	SS				2.9	1.4	5.0	5.1	1.8	9.9
	WWL	SS				3.2	1.9	4.9	8.8	4.5	14.4
	CDH	VA				0.7	0.3	1.3	1.0	0.3	1.9
	CDL	VA				1.1	0.4	2.1	1.6	0.6	3.2
	CWH	VA				1.3	0.9	1.7	2.8	1.9	4.0

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CWL	VA				1.1	0.5	1.9	2.0	0.8	3.6
	CXH	VA				0.8	0.3	1.4	1.6	0.6	3.1
	CXL	VA				1.1	0.4	2.0	1.9	0.6	3.9
	WDL	VA				1.7	0.6	3.2	2.5	0.7	5.2
	WWL	VA				1.8	1.2	2.6	3.4	2.0	5.1
Dissolved oxygen saturation[3] (%)	CDH	Al	78	66	91	92	84	101	97	90	104
	CDL	Al	73	63	83	85	78	91	92	86	98
	CWH	Al	84	71	96	94	85	103	98	92	104
	CWL	Al	84	69	99	97	87	108	99	92	107
	CXH	Al	88	72	104	97	85	109	99	91	107
	CXL	Al	89	76	103	97	87	106	103	96	110
	WDL	Al	70	54	87	82	71	93	94	84	103
	WWL	Al	81	66	96	90	79	100	95	87	102
	CDH	HS	85	76	94	96	90	102	106	101	111
	CDL	HS	83	69	97	94	84	104	105	98	113
	CWH	HS	82	77	87	93	89	96	105	103	108
	CWL	HS	76	70	83	89	84	93	106	102	110
	CXH	HS	95	87	103	100	95	106	108	104	113
	CXL	HS	94	82	106	99	91	108	110	104	117
	WDL	HS	80	63	97	86	75	98	101	91	110
	WWL	HS	90	79	101	96	88	104	105	99	110
	CDH	SS	85	70	101	96	84	107	106	98	114
	CDL	SS	85	71	100	96	86	106	106	99	114
	CWH	SS	91	83	99	98	92	104	108	103	112
	CWL	SS	88	78	97	97	90	103	105	99	110
	CXH	SS	95	82	107	102	93	111	108	101	115
	CXL	SS	95	86	104	102	95	108	112	106	117
	WDL	SS	80	64	95	88	77	98	103	94	112

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	WWL	SS	90	80	100	96	89	103	102	96	107
	CDH	VA	87	72	103	94	83	105	103	95	111
	CDL	VA	86	70	102	93	82	104	101	93	110
	CWH	VA	93	87	99	98	94	102	104	100	107
	CWL	VA	88	75	101	94	85	103	102	95	109
	CXH	VA	96	82	110	99	89	108	104	97	112
	CXL	VA	96	80	112	99	87	110	108	100	115
	WDL	VA	81	63	98	85	73	97	100	90	109
	WWL	VA	94	86	101	98	92	103	102	98	106
Temperature[3] (^{O}C)	CDH	Al				9.3	8.4	10.2	12.8	11.6	14.0
	CDL	Al				10.7	9.9	11.6	12.7	11.7	13.8
	CWH	Al				10.3	9.4	11.2	13.3	12.2	14.5
	CWL	Al				11.3	10.1	12.5	13.3	12.0	14.8
	CXH	Al				10.3	9.0	11.7	12.7	11.3	14.3
	CXL	Al				11.6	10.5	12.8	13.9	12.6	15.3
	WDL	Al				12.2	10.7	13.7	14.6	12.9	16.4
	WWL	Al				12.8	11.5	14.1	15.1	13.6	16.7
	CDH	HS				9.7	9.0	10.4	14.0	13.0	15.0
	CDL	HS				10.0	9.2	11.0	13.7	12.4	15.1
	CWH	HS				10.3	9.8	10.8	13.9	13.3	14.6
	CWL	HS				11.3	10.6	12.0	14.3	13.4	15.1
	CXH	HS				10.4	9.7	11.2	13.5	12.6	14.4
	CXL	HS				12.0	10.8	13.3	14.9	13.6	16.4
	WDL	HS				12.6	11.0	14.5	15.5	13.7	17.4
	WWL	HS				13.2	12.2	14.2	16.0	14.7	17.4
	CDH	SS				9.5	8.3	10.8	13.9	12.4	15.5
	CDL	SS				10.4	9.4	11.5	14.1	12.7	15.6
	CWH	SS				10.4	9.8	11.1	13.8	12.9	14.8
	CWL	SS				10.3	9.5	11.0	13.6	12.6	14.6

Indicator	Topography	Geology	20%ile	20%ile - CI	20%ile + CI	Median	Median - CI	Median + CI	80%ile[1]	80%ile[1] - CI	80%ile[1] + CI
	CXH	SS				10.2	9.1	11.3	13.6	12.3	15.0
	CXL	SS				11.8	10.8	12.7	14.9	13.8	16.0
	WDL	SS				12.9	11.5	14.4	16.0	14.3	17.7
	WWL	SS				13.1	12.2	14.0	16.3	15.1	17.6
	CDH	VA				9.9	8.6	11.2	13.8	12.3	15.4
	CDL	VA				10.7	9.4	12.2	13.7	12.2	15.3
	CWH	VA				11.4	10.8	12.0	14.5	13.8	15.3
	CWL	VA				11.7	10.5	12.9	14.1	12.8	15.5
	CXH	VA				10.6	9.4	11.8	13.5	12.1	14.9
	CXL	VA				12.1	10.6	13.7	14.7	13.1	16.4
	WDL	VA				13.0	11.2	15.0	15.5	13.7	17.4
	WWL	VA				13.4	12.6	14.2	16.2	15.2	17.3

[1] = 80th percentile for all data except *E. coli* which is a 95th percentile.

[2] = indicator classes in bold do not meet the requirements of the filter at the geology level of the REC.

[3] = less data is available for most of these indicators and hence is not discussed in this report. However, the mixed effects model produced significant slopes and intercepts