National Objective Framework for periphyton

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Contents

Tables

Figures

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Executive summary

Periphyton is the name given to the slime and algae found on the bed of streams and rivers. The Ministry for the Environment (MfE) has identified periphyton as a key attribute of ecosystem health for inclusion in the National Objectives Framework (NOF) for freshwater. Periphyton is a relevant attribute because healthy river ecosystems are characterised by the presence of relatively low levels of periphyton, but when thick growths occur they usually reduce the diversity and productivity of invertebrates and fish, and erode recreational values such as swimming and fishing. Maximum abundance of periphyton is mainly determined by the time available for biomass to accrue between floods, and by nutrient concentrations and light. Invertebrate grazing can also significantly reduce biomass accrual, but only where nutrient concentrations are relatively low. Therefore, periphyton abundance in rivers is primarily controlled by factors that are influenced by human activities: flow regimes, nutrient concentrations and light. Consequently, including periphyton abundance as an attribute in the NOF would provide a basis for defining limits for several types of resource use including the discharge of nutrients from point and non-point land-use sources, water uses that alter flow regimes, and land uses impacting on riparian vegetation.

In April 2013 MfE convened the NOF Periphyton Panel of freshwater ecologists (including experts in periphyton) to assist in defining a measurement attribute, thresholds and exceedance frequencies appropriate for periphyton in the context of the NOF. This report documents background information relating to periphyton in the NOF and the conclusions reached by the panel.

Justification for use of chlorophyll *a* as a measure of periphyton abundance rather than periphyton cover is given. Proposed periphyton NOF thresholds and exceedance frequencies for bands A-D are given. The proposed periphyton threshold between the C and D band is a maximum chlorophyll *a* of 200 mg/m^2. The value of 200 mg/m^2 is considered to be a point at which the health of streams is significantly compromised. Given that exceedances do occasionally occur naturally (i.e. even without human influence), an exceedance frequency of once a year on average, based on monthly measurements of periphyton chlorophyll *a*, is proposed (or approximately 8% of the time). It is also proposed that the objective makes an exception to this exceedance frequency for stream types that are naturally productive due to geological enrichment and particularly long accrual periods.

Data collected by four regional councils was used to assess the proportion of observed sites that have exceeded 200 mg/m^2 for 8% of the time. Results showed that sites with a greater proportion of the upstream catchment with pasture land cover were more likely to exceed this criteria. Predictive models were used to estimate the proportions of all rivers in the four regions that would not meet the proposed criteria. Regional patterns resulting from predicted chlorophyll *a* were consistent with prior expectations for all regions. The predictions indicated that the Manawatu had the largest number of river locations (15%) that do not meet the proposed criteria, followed by the Wellington region (10%). The predictions indicate that fewer than 1% of locations do not meet the proposed criteria in the Southland and Canterbury regions.

1 Introduction

The Ministry for the Environment (MfE) has identified periphyton as a key attribute of ecosystem health for inclusion in the National Objectives Framework (NOF) for freshwater. Periphyton is the name given to the slime and algae found on the bed of streams and rivers. Periphyton is a primary source of food for invertebrates, which in turn are food for fish and birds. However, high abundance of periphyton can have negative effects on habitat quality, water chemistry and biodiversity, and can reduce recreation and aesthetic values (Biggs 2000a; Suren et al. 2003; Suplee et al. 2009).

Periphyton is a relevant attribute because healthy river ecosystems are characterised by the presence of periphyton at relatively low levels of abundance (measured as areal cover, biomass or bio-volume; Biggs and Kilroy 2000). Blooms of periphyton can smother habitat, alter invertebrate communities, and produce adverse fluctuations in dissolved oxygen and pH. Periphyton blooms can also cause changes to water colour, odour and the general physical nature of the river bed, which has resultant detrimental effects on values including aesthetics and other human uses (Biggs 2000b). In some conditions, periphyton can become dominated by cyanobacteria which is problematic because of its potential to produce toxins dangerous to both humans and animals. Not all rivers have suitable physical conditions for the growth of conspicuous periphyton. In particular soft (i.e. muddy or sandy) bottomed lowland streams are often not a suitable habitat for periphyton because of the instability of their beds.

The growth rate of periphyton is determined primarily by concentrations of nitrogen and phosphorus, light and temperature. Maximum abundance is determined by the biomass accrual rate (which is controlled by the growth rate and also removal processes such as grazing by invertebrates) and the period of stability available for biomass to accrue (defined as the period between floods that scour and remove periphyton). Therefore, periphyton abundance in rivers is usually controlled by two key factors that are influenced by human activities: flow regimes and nutrient concentrations (Biggs 2000a; Dodds et al. 1997, Biggs, Stevenson et al. 1998). In addition, light can exert a strong influence on periphyton maximum biomass in rivers which, in-turn, is also affected by human activities such as deforestation and management of riparian vegetation (Boothroyd et al. 2004; Davies-Colley and Quinn 1998). Including periphyton abundance as an attribute in the NOF would therefore provide a basis for defining limits for several types of resource use including the discharge of nutrients from point and non-point sources, water uses that alter flow regimes, and activities impacting on riparian vegetation.

In April 2013 MfE convened the NOF Periphyton Panel of freshwater ecologists (including experts in periphyton) to assist in defining a measurement attribute that appropriately indicates the general state of the periphyton community, and thresholds and exceedance criteria appropriate in the context of the NOF. This report documents the background to the conclusions reached by the panel.

2 Measurement of the periphyton attribute

Periphyton abundance is routinely measured and quantified in New Zealand in several ways including measurement of chlorophyll *a* concentrations, ash free dry mass (AFDM) and by visual observation of percentage cover of different 'types' of periphyton. Chlorophyll *a* is considered to be the most commonly recognised standard method (internationally and within NZ) for estimating stream periphyton biomass (e.g. Biggs and Kilroy 2000;Dodds et al. 2002; Hambrook et al. 2007; Kilroy et al. 2013) because all types of algae contain chlorophyll *a* and this metric reflects the total amount of live algae in a sample. Estimates of chlorophyll *a* are obtained by quantitative sampling of periphyton at multiple locations in a river reach and subsequent laboratory analyses of the samples. However, monitoring periphyton based on chlorophyll *a* can be relatively expensive, and there has been increasing use of less costly visual assessment methods (Biggs 2000b, Biggs and Kilroy 2000, Matheson et al. 2012). Visual assessments have the advantage that they indicate the 'type' of periphyton at a river site as well as a readily understood estimate of the coverage.

The panel considered the best measure to use to define the proposed NOF periphyton abundance attribute, and has recommended that chlorophyll *a* be used. The key reason for this is that chlorophyll *a* is a single and relevant variable representing periphyton abundance that has been used extensively in New Zealand for many years and has been used as the main guideline measure of periphyton abundance to date. In addition, statistical models relating periphyton abundance to other measures such as water chemistry, flow regimes and ecological measures such as ecosystem 'health' scores have been found to be generally stronger for chlorophyll *a* than other measures, such as cover. Chlorophyll *a* is also the standard metric for measuring periphyton abundance internationally so that advances made overseas in understanding factors controlling periphyton growth can be applied in New Zealand.

Although the proposed objective is specified in terms of chlorophyll *a*, a significant proportion of monitoring could be carried out for low risk systems using the quicker and less costly visual estimate methodologies. Recently developed protocols can be used to estimate chlorophyll *a* from cover data (Kilroy et al. 2013). Should monitoring based on visual cover estimates indicate that a site is approaching the relevant periphyton abundance threshold, monitoring could then be upgraded to include measurement of chlorophyll *a*.

3 Factors affecting periphyton abundance

Periphyton abundance varies considerably over space and time as a result of natural processes and human causes. The factors controlling periphyton can be summarised simply as a balance of processes causing biomass accrual versus processes causing biomass loss (Biggs 1996). Accrual is controlled by the rate of growth of algae, which depends primarily on nutrient supply, light and temperature, all of which vary from river to river, and over time. Periphyton loss is determined primarily by high flows, which tear or abrade periphyton from the stream bed (Biggs 1996). The time between high flows is the ‘accrual period’ in which periphyton abundance can increase, and maximum abundance is the product of the length of the accrual period accrual rate. Variability in peaks of periphyton abundance over time therefore depends on variation in the average period between high flows as well as the factors that control the accrual rate. Additional variation between sites may be due to factors such as light intensity, local substrate stability and the intensity of periphyton grazing by invertebrates (Doyle and Stanley 2006; Uehlinger 1991).

Management of periphyton abundance is concerned with not only the maximum periphyton abundance, but also the percentage of the time that abundance exceeds a given threshold. Because accrual periods between high flows are subject to wide variation through time, there is a probability that periphyton at almost any site may exceed a given threshold at some time over many years (see Appendix 2 for a more detailed discussion). However, if nutrient concentrations, light, temperatures and flow alteration due to abstraction are managed within limits, the frequency that relevant thresholds are exceeded can often be kept within at acceptable levels. For this reason, the proposed NOF periphyton objective is defined in terms of an abundance threshold and a maximum exceedance frequency.

The frequency that a threshold is exceeded is affected by natural drivers which need to be taken into account when setting thresholds and assessing monitoring data to determine if objectives are being met. Two factors that are relevant to setting the acceptable frequency that thresholds are exceeded are the degree of natural nutrient enrichment and the length of the accrual period. Streams and rivers whose catchments are dominated by soft sedimentary mudstones and volcanic rock geologies tend to have naturally more nutrient-enriched waters and tend to have higher periphyton abundance than sites dominated by other geologies (Biggs and Gerbeaux 1993, Biggs 1996). The large variation in climate in New Zealand also naturally drives wide variation in the length of the period between high flows (i.e. the accrual period) (Snelder and Booker 2012). In particular, the low rainfall climate on the eastern aspects of the North and South Islands means that accrual periods tend to be longer in summer, which can be exacerbated in drought years. When streams and rivers in these areas have a combination of natural enrichment and long accrual periods they will naturally be more productive and will tend to exceed any given periphyton abundance threshold more frequently than other locations.

There is also significant year-to-year variability in the length of accrual periods at a site (see Appendix 2 for a detailed analysis). This means that average periphyton abundance and the frequency that any given abundance threshold is exceeded is variable among years. This needs to be taken into account when monitoring data are used to assess whether objectives are being met.

Ideally, periphyton is monitored by taking monthly measurements of abundance. Objectives are met at a site if the abundance threshold is exceeded less frequently than the specified exceedance frequency. However, because of the significant inter-annual variation in the frequency of floods, the abundance threshold may be exceeded more frequently than specified by the objective for short monitoring periods (e.g., over periods of 1 to 2 years) but the site may meet the objective over the longer term (e.g., over periods of more than 3 years).

4 Abundance thresholds and exceedance criteria for the NOF

The NOF Periphyton Panel have proposed four bands (A to D) for periphyton and have associated these with a narrative description of the ecological health that can be expected within these bands (Table 4-1). The NOF D-band represents conditions that fail to meet the national bottom line meaning that regional management objectives for periphyton abundance cannot be set in the D-band. Bands A-C may apply where council, iwi and community deem that lower levels of periphyton growth are desirable due to a need to manage for higher levels of ecosystem health or to support other values.

The proposed periphyton NOF D-band threshold is a chlorophyll *a* of 200 mg/m^2. Periphyton biomass in excess of 200 mg/m^2 can be termed a 'bloom' (see Fig 28 of Biggs 2000b) and is likely to be associated with compromised ecological health due to effects on habitat quality and water chemistry (e.g. dissolved oxygen may be low during night-time). Studies have shown that chlorophyll *a* in excess of 200 mg/m^2 are consistent with invertebrate communities that are dominated by stream invertebrates that are dominated by taxa that are tolerant of poor water quality such as snails, worms and midges (e.g. Matheson et al. 2012[1], Biggs 2000b). Chlorophyll *a* in exceess of 200 mg/m^2 is also the point that the majority of people consider is undesirable for recreation (Biggs 2000b, Fig. 28; Suplee et al., 2009).

The A-band is defined by a maximum chlorophyll *a* less than 50 mg/m^2. Sites with a chlorophyll *a* of less than this value are characterised by invertebrate taxa that are sensitive to water quality and habitat disturbance such as stone flies, mayflies, and caddis flies (Biggs 2000b). A transition from invertebrate communities dominated by sensitive taxa to tolerant taxa occurs as site maximum chlorophyll *a* concentrations increase from 50 to 200 mg/m^2. Subdividing this gradient to define the threshold between the B and C bands is somewhat subjective. It must first be acknowledged that increased primary production at sites having maximum periphyton biomass greater than 50 mg/m^2 may increase the productivity of salmonid fisheries, with only small reductions in the occurrence of sensitive invertebrate taxa. The MFE guidelines (Biggs 2000b) suggest productive trout fisheries are maintained at maximum chlorophyll *a* values up to 120 mg/m^2 (for filamentous periphyton taxa) and 200 mg/m^2 (for diatom taxa).

There are practical difficulties associated with the measurement of chlorophyll *a* in terms of the type of periphyton. For example, both filamentous and diatom types often co-occur in close proximity. We therefore propose the B/C boundary is 120 mg/m^2 regardless of periphyton type. We note that the MFE guideline also proposed a threshold of 120 mg/m^2 of filamentous periphyton taxa during summer months for maintaining aesthetic and recreation values. We consider that this guideline is reasonable and strengthens the justification for adopting 120 mg/m^2 as the NOF threshold between the B and C bands. For the remainder of this report we concentrate on discussion of the NOF D-band because this band is considered to be a point at which ecological health is significantly compromised and because this band defines the bottom line that will apply everywhere in New Zealand.

In addition to a threshold for chlorophyll *a*, it is proposed that each NOF band includes an exceedance frequency. It is proposed that each band is defined such that periphyton is

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[1] Relationships between periphyton abundance and macro-invertebrate communities, based on work by Matheson et al. (2012), are described in Appendix C.

generally less than the thresholds. However, natural variability in the frequency of floods, and therefore biomass accrual period, means that some naturally occurring excursions beyond each threshold can be expected occasionally, even in relatively non-enriched systems. Streams and rivers are resilient and ecological health will usually recover quickly from such excursions if they are infrequent and of a short duration. Therefore, an exceedance frequency of once in the average year, based on monthly measurements of periphyton chlorophyll *a*, is proposed. Because of variation in the length of accrual periods between years, a site that is considered to be within a given NOF band may have more than one exceedance of the relevant threshold in some years, but no exceedance in other years. The average year is in fact notional and no actual year of monitoring data will be ‘average’. A more robust way to express the frequency criteria, therefore, is in terms of the long run (i.e. multiple years) exceedance frequency, which is 1 per year (or approximately 8% of the time) based on monthly sampling.

It is proposed that the objective makes an exception to this exceedance frequency for sites that are productive due to natural enrichment and long accrual periods. It is proposed that a “Productive” periphyton class is nominally discriminated using categories of the River Environment Classification (REC; Snelder and Biggs, 2002). The Productive periphyton class is defined by REC “Dry” Climate categories (i.e. Warm-Dry (WD) and Cool-Dry (CD) and Geology categories that have naturally high levels of nutrient enrichment due to their catchment geology (i.e. Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)). An exceedance frequency of twice in the average year (2 per year), or approximately 17% over the long run, is proposed as the upper D-band threshold for these productive sites. The majority of New Zealand streams and rivers fall into the “Default” periphyton class for which the exceedance criterion is 1 per year but 3% of sites are classified as Productive (Figure 4-1).

Another important consideration in applying the proposed objective is that some streams and rivers can have fine bed material that does not support much periphyton and thus where high abundance may not be an issue. If these sites are dominated by aquatic macrophytes (rooted plants) there could, however, be abundant periphyton attached to the stems and leaves or to other debris. It is likely that up to 26% of New Zealand’s streams and rivers by length will not support conspicuous amounts of periphyton (Figure 4-1). In addition, many streams and small rivers are sufficiently shaded by riparian vegetation which will also prevent conspicuous periphyton development.

Table 4-1: Proposed NOF bands for periphyton and corresponding narrative descriptions of the levels of support for ecosystem health.

	Band			
Attribute / value	**A**	**B**	**C**	**D**
Chlorophyll *a* (mg/m^2)	<50	50-120	120-200	>200
Frequency: Default class	1 per year	1 per year	1 per year	>1 per year
Frequency: Productive class	2 per year	2 per year	2 per year	>2 per year
Ecosystem Health	Rare blooms reflecting negligible nutrient enrichment and/or alteration of the natural flow regime or habitat.	Occasional blooms reflecting low - moderate nutrient enrichment and/or alteration of the natural flow regime.	Periodic short-duration nuisance blooms reflecting moderate - high nutrient enrichment and/or alteration of the natural flow regime.	Regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime.
Invertebrate community	Strong predominance of pollution sensitive invertebrates	Mostly pollution sensitive invertebrates.	Mix of pollution sensitive and tolerant invertebrates.	Strong predominance of pollution tolerant invertebrates.

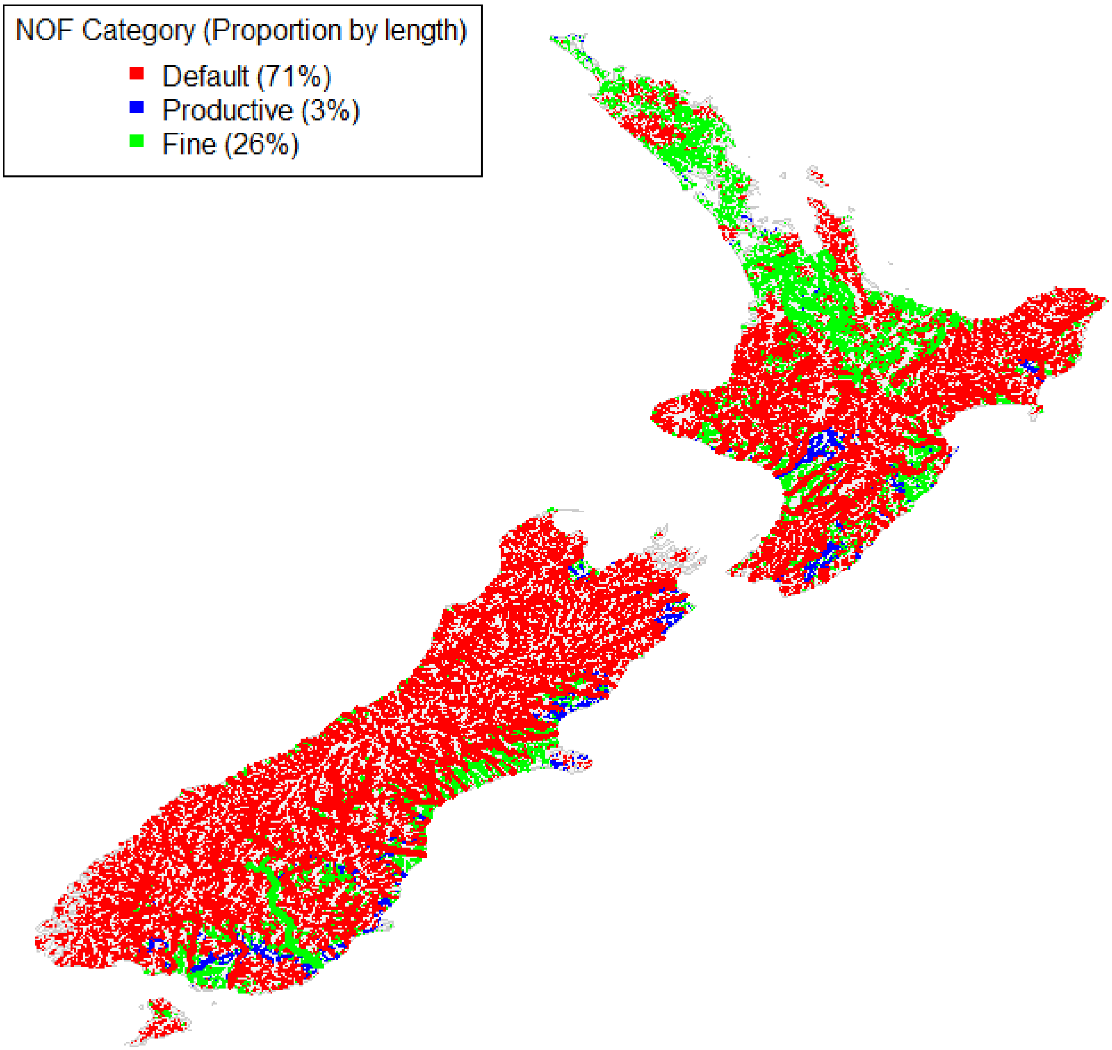

Figure 4-1: Classification of rivers and streams for NOF periphyton attribute. The Default class (red) has a proposed exceedance frequency of 1 per year; the Productive class (blue) has a proposed exceedance frequency of 2 per year. Locations that are likely to have fine substrates, which will not support conspicuous amounts of periphyton, are shown in green.

5 Assessment of the current state of New Zealand rivers in terms of the proposed periphyton attribute

Two types of analysis have been undertaken to evaluate the extent to which the proposed criteria might be currently met in New Zealand; comparison of monitoring data with proposed NOF criteria, and spatial modelling in regions where sufficient data occurred to adequately calibrate the models. The robustness of both of these analyses was limited by the availability of chlorophyll *a* time-series data. However, there has been significant research on periphyton in New Zealand for over two decades. The NOF Periphyton Panel consider the results from these analyses are reasonable and are also consistent with the expert knowledge and experience gained from this research.

5.1 Available data

Chlorophyll *a* time series data were available for the Manawatu-Whanganui, Canterbury, Wellington and Southland regions. The time series for Manawatu-Whanganui was based on monthly samples taken over a four-year period (ending May 2013) at 42 sites. The data for Canterbury were also monthly samples taken over a two-year period (ending June 2013) at 24 sites.

The chlorophyll *a* data for Wellington and Southland were not based on monthly sampling. The Wellington data were based on annual samples taken between 2004 and 2010 at 46 sites, during summer. The Southland data were based on sample occasions between 2002 and 2011 at 60 sites. Most samples were taken during summer months (December to April) although there were samples from other seasons. In the following analyses we made the assumption that mean chlorophyll *a* calculated from time series with more than five sample occasions could be used to represent the long run mean of chlorophyll *a*. We removed sites with fewer than five samples, resulting in 179 sites.

5.2 Comparison of monitoring data with proposed NOF criteria

We compared the monitoring data with the proposed NOF criteria by evaluating the proportion of sites that exceeded 200 mg/m^2 chlorophyll *a* more than 8% of the time (sites in the default class) or 17% of the time (sites in the ‘Productive’ class) and evaluating the proportion of samples that exceeded 200 mg/m^2 chlorophyll *a* for each site. We also assigned each site into one of five Pasture categories based on the proportion of the upstream catchment that was occupied by Pasture land cover according to the Land Cover Data Base (LCDB version 2). The categories were defined with the following break points for the proportion of the catchment occupied by Pasture: 20%, 40%, 60%, 80%, and 100%.

The proportion of sites that would fail to meet the proposed objectives are indicated by the red and blue lines on Figure 5-1. The proportion of sites that exceeded 200 mg/m^2 chlorophyll *a* more than the proposed exceedance frequencies was generally higher as the proportion of the catchment occupied by Pasture land cover increased (Figure 5-1). The plot also indicates that the frequency that the 200 mg/m^2 chlorophyll *a* threshold is exceeded is higher in the ’Productive’ compared to the default class Table 5-1). This supports the proposal to have a less stringent criterion (i.e. allowable average exceedance frequency of 2 per year) for the Productive class.

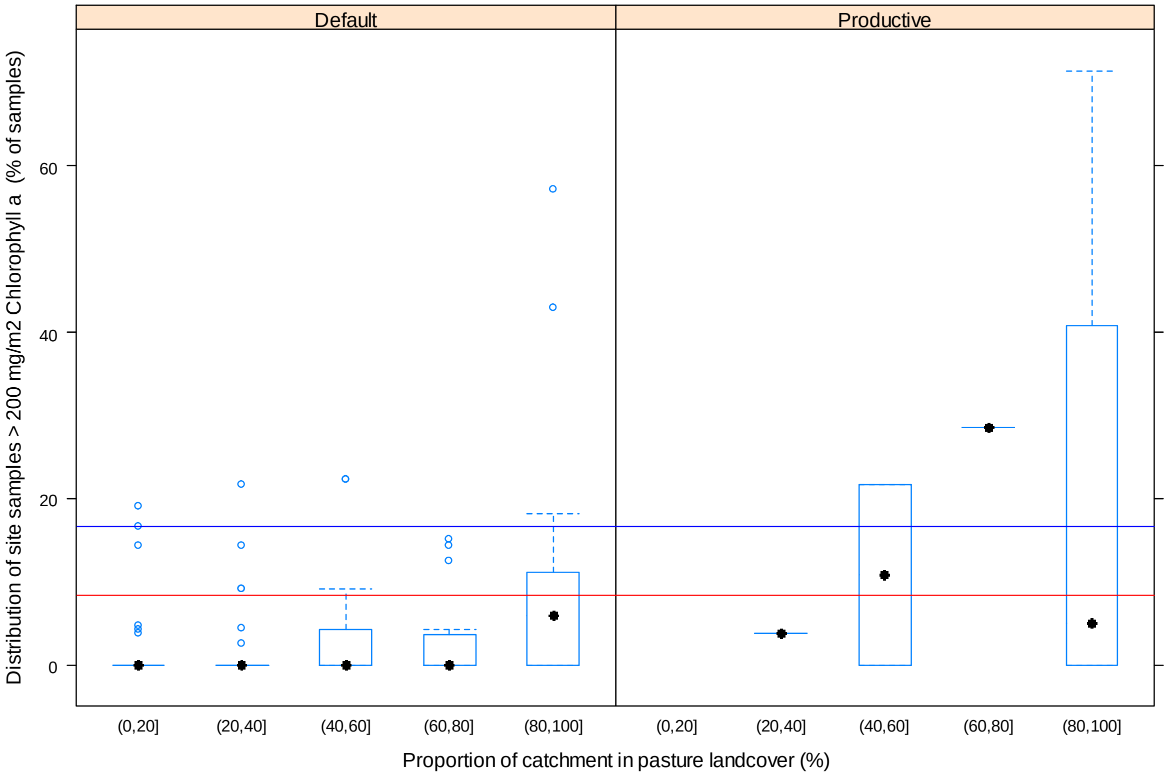

Figure 5-1: Distribution of the proportion of samples for individual sites that exceeded the 200 mg/m2 chlorophyll *a* threshold. The sites are grouped by proportion of the catchment in pasture land cover and subdivided by Default (left panel) and Productive (right panel) categories. The horizontal red and blue lines indicate the proposed exceedance frequencies (1 per year and 2 per year) which are represented by these data as sites exceeding the threshold of 200 mg/m^2 chlorophyll *a* more than 8% and 17% of the time for the Default and Productive classes respectively. The box contains the inter-quartile range, the dot shows the median value, whiskers indicate 1.5 times interquartile range and the circles indicate outliers.

Table 5-1: Proportion of samples and sites that exceeded 200 mg/m^2 chlorophyll *a*.

NOF periphyton class	Proportion of catchment in pasture land cover (%)	Number of monitored sites	Proportion of all samples that exceeded 200 mg/m^2 chlorophyll *a* (%)	Proportion of sites that exceeded 200 mg/m^2 chlorophyll *a* more than 8% of the time (%)	Proportion of sites that exceeded 200 mg/m^2 chlorophyll *a* more than 17% of the time (%).
Default	0 to 20	76	0.8	4	1
	20 to 40	28	1.9	14	4
	40 to 60	27	3.1	22	7
	60 to 80	22	2.2	14	0
	80 to 100	17	5.9	35	18
Productive	0 to 20	0	NA	NA	NA
	20 to 40	1	3.7	0	0
	40 to 60	2	15.6	50	50
	60 to 80	2	28.6	100	100
	80 to 100	4	20	50	25

5.3 Spatial modelling

We used the available data to make predictions of the proportion of the regional river networks that are likely to exceed the proposed criteria. We assumed that the observed data were reasonable approximations of the long run chlorophyll *a* distributions derived from monthly samples at all sites despite the variation in sampling procedures among regions. We assumed that the distribution of monthly chlorophyll *a* samples at sites follows the exponential distribution at most sites based on findings by Snelder et al. (in press). The exponential distribution has the mean as its only parameter allowing the frequency that any value is exceeded to be estimated from the mean of observations based on the quantile function:

$$Chlorophyll\ a\ =\ -\ln(Pr)\ \times\ \mu$$

where *Pr* ($0 \leq Pr < 1$) is the probability that abundance is exceeded given the mean chlorophyll *a* at the site ($\mu > 0$). If the mean is derived from monthly observations, the quantile function can be used to estimate the expected value of the abundance exceeded for 1 month of the year by setting probability to 1/12.

At the first step in our analysis we tested the assumption that monthly chlorophyll *a* samples at sites are exponentially distributed using the available data. First, we computed the overall mean chlorophyll *a* and the value exceeded for 8% of the records for each site. We then predicted the value exceeded for 8% of the time using the estimated mean and the quantile function. There were strong relationships between the observed and estimated chlorophyll *a* exceeded for 8% of the time indicating that the exponential distribution assumption was reasonable (Figure 5-2). At the second step of the analysis we fitted four regression models (one for each region) to the site mean chlorophyll *a* values (see Appendix A for details) and used these models to make predictions for the entire region.

The regional regression models explained between 44% and 64% of the variation in mean site chlorophyll *a* (see Appendix 1 for details). Regional patterns resulting from predicted chlorophyll *a* were consistent with prior expectations for all regions (Figure 5-3). The predictions indicated that the Manawatu had the largest number of segments (15%) that were predicted to not meet the proposed criteria. The Southland and Canterbury regions had the fewest segments (>1%) that were predicted to not meet the proposed criteria. Approximately 10% of the segments in the Wellington region were predicted to not meet the proposed criteria. The number of segments predicted to not meet the proposed criteria, accounting for Default and Productive classes, is given in Table 5-2.

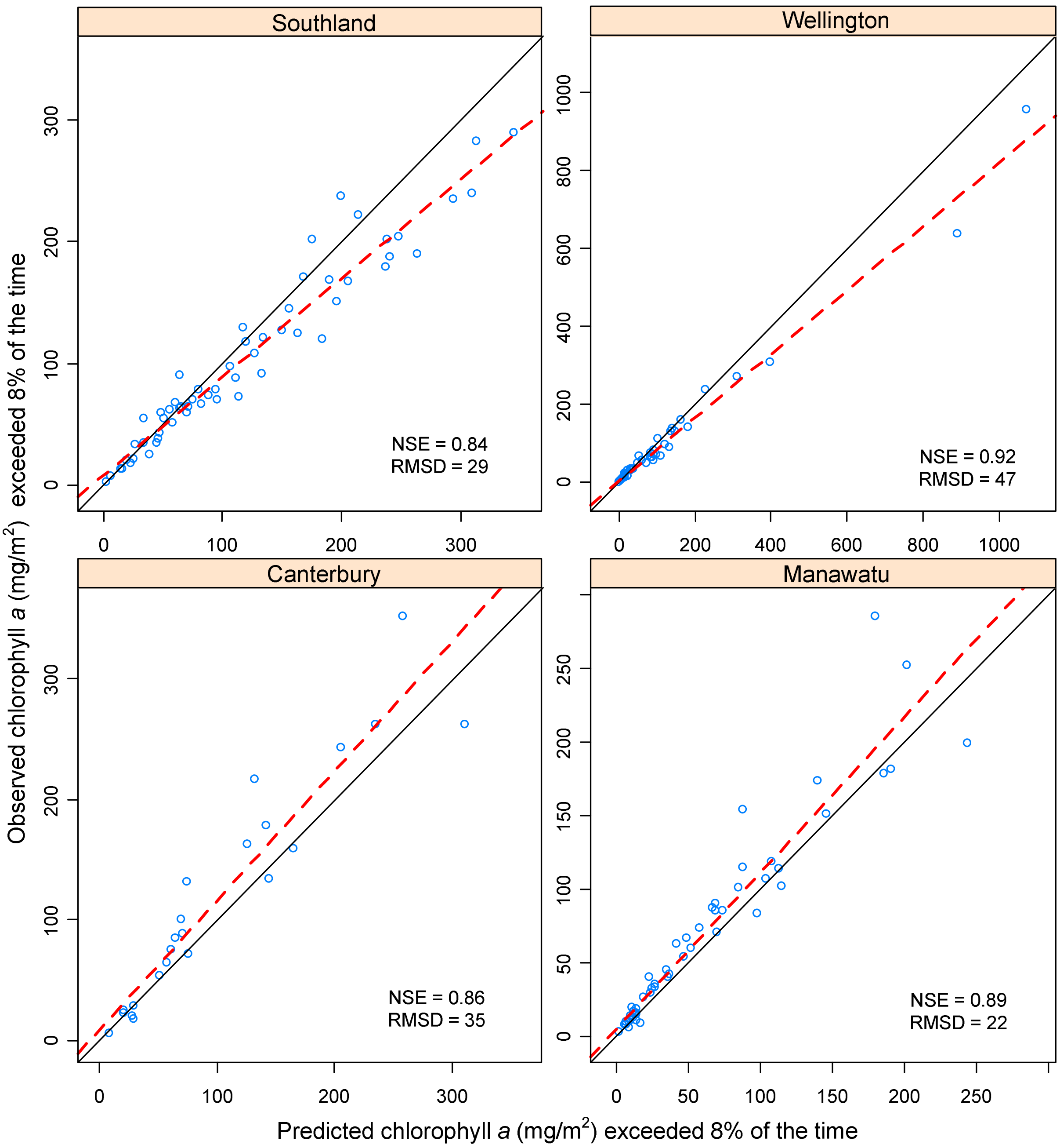

Figure 5-2: Relationships between the observed and predicted chlorophyll *a* exceeded for 8% of the time. The predictions were made using the estimated mean and the quantile function for the exponential distribution. Nash-Sutcliffe Efficiency (NSE) is a measure of the performance of a model that indicates the agreement between observed and predicted (Nash and Sutcliffe, 1970). NSE values can range from 1 (a perfect fit) to negative infinity and values over 0.8 suggest excellent performance. Root mean square deviation (RMSD) indicates the mean prediction error as chlorophyll *a* (mg m^{-2}).

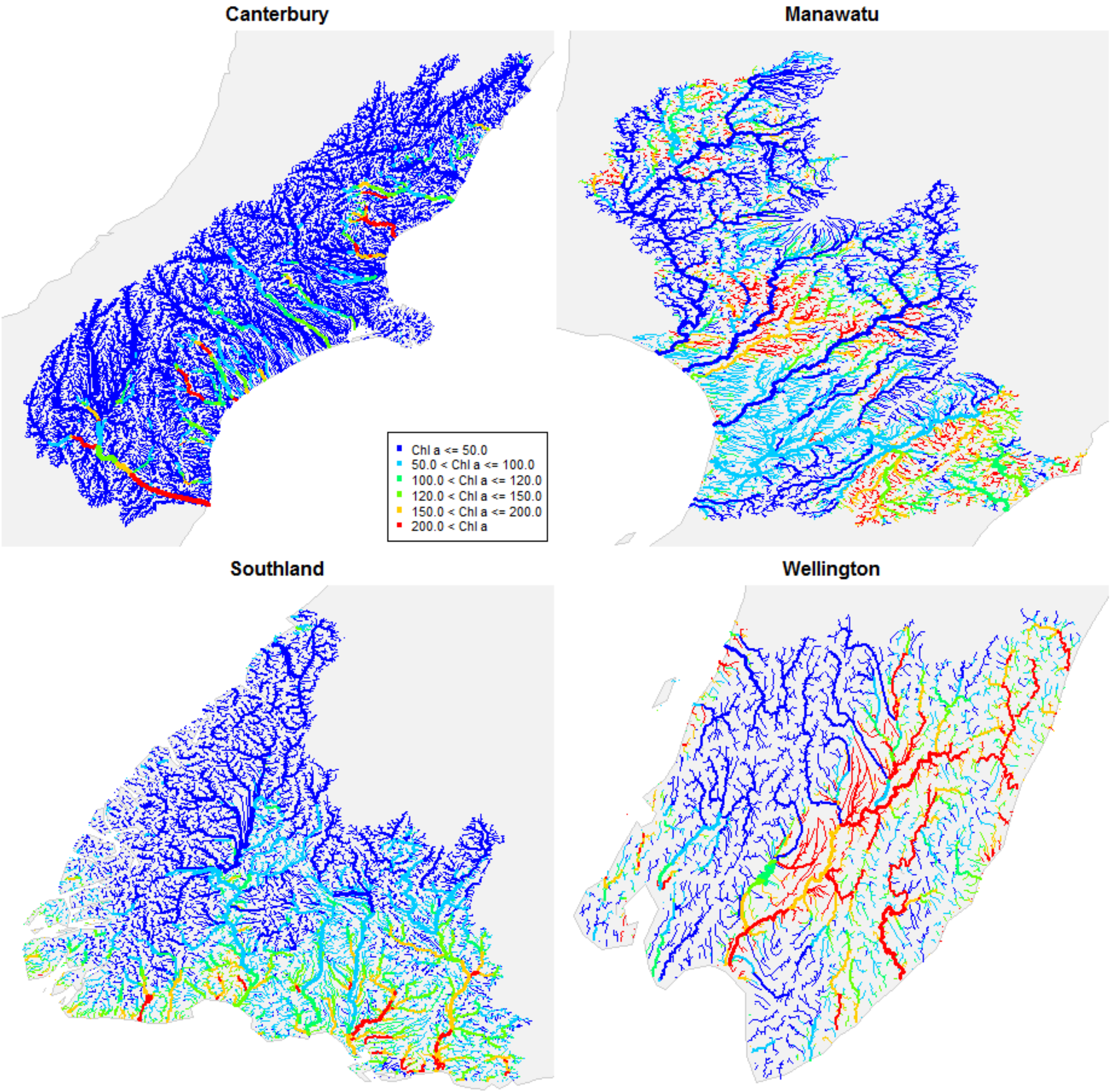

Figure 5-3: Predicted regional patterns of the chlorophyll *a* (mg/m^2) that is exceeded 8% of the time.

Table 5-2: Predicted proportion of segments not meeting the proposed periphyton criteria for the four regions and for the Default and Productive periphyton class.

Region and Periphyton Class	Proportion of regional network segments in class (%)	Proportion of segments exceeding 200 mg/m^2 more than 8% of the time (%)	Proportion of segments exceeding 200 mg/m^2 more than 17% of the time (%)
Canterbury Default	92.4	0.4	0.1
Canterbury Productive	7.6	0.1	0.1
Manawatu Default	89.9	13.2	6.1
Manawatu Productive	10.1	34.7	20.8
Southland Default	92.9	0.3	0
Southland Productive	7.1	1.9	0
Wellington Default	85.3	8.4	3.3
Wellington Productive	14.7	18.8	4.6

6 Conclusions

This document sets out proposed NOF criteria for management of periphyton abundance in rivers and streams. We consider that, given the available data and knowledge, these criteria are robust and that they represent achievable and reasonable expectations of the ecosystem health of New Zealand rivers. We caution however that fluctuations in periphyton abundance is a natural process and our ability to precisely predict the frequency of high abundance is low.

We emphasise in particular that considerable care must be taken in assessing whether locations are meeting periphyton objectives using monitoring data. The considerable inter-annual variation in the drivers of periphyton, high flows in particular, mean that short periods of monitoring data (e.g. one to two years) will be insufficient to determine if a site meets the objective over the long run. If the proposed periphyton objective does become part of the NOF it will be important to provide guidelines for monitoring and evaluation.

7 Acknowledgements

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8 References

Biggs, B.J.F. (1996) Patterns in benthic algae of streams. Pp. 31-56 in Stevenson, R.J., Bothwell, M.L., Lowe, R.L. (eds) Algal Ecology: Freshwater benthic ecosystems. Academic Press, San Diego.

Biggs, B.J.F. (2000a) Eutrophication of streams and rivers: dissolved nutrient chlorophyll relationships for benthic algae. Journal of the North American Benthological Society 19, 17–31.

Biggs, B.J.F. (2000b) New Zealand Periphyton Guideline: detecting, monitoring and managing enrichment of streams. Ministry for the Environment, Wellington.

Biggs, B.J.F., Gerbeaux, P.J. (1993) Periphyton development in relation to macro-scale (geology) and microscale (velocity) limiters in two gravel-bed rivers, New Zealand. New Zealand Journal of Marine and Freshwater Research, 27: 39-53.

Biggs, B.J.F., Kilroy, C. (2000) Stream periphyton monitoring manual. Published by NIWA for MfE.

Biggs, B.J.F., Stevenson, R.J., Lowe, R.L. (1998) A habitat matrix conceptual model for stream periphyton. Archiv Fur Hydrobiologie, 143(1): 21 - 56.

Booker, D.J. (2013) Spatial and temporal patterns in the frequency of events exceeding three times the median flow (FRE3) across New Zealand. Journal of Hydrology (NZ) 52, 15–40.

Boothroyd, I.K.G., Quinn, J.M., Langer, E.R., Costley, K.J., Steward, G. (2004) Riparian buffers mitigate effects of pine plantation logging on New Zealand streams - 1. Riparian vegetation structure, stream geomorphology and periphyton. Forest Ecology and Management, 194(1-3): 199-213. 10.1016/j.foreco.2004.02.018

Davies-Colley, R.J., Quinn, J. (1998) Stream lighting in five regions of North Island, New Zealand: control by channel size and riparian vegetation. New Zealand Journal of Marine and Freshwater Research, 32: 591-605.

Dodds, W.K., Jones, J.R., Welch, E.B. (1998) Suggested classification of stream trophic state: Distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Water Research, 32(5): 1455-1462. 10.1016/s0043-1354(97)00370-9

Dodds, W.K., Smith, V.H., Lohman, K. (2002) Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Canadian Journal of Fisheries and Aquatic Sciences, 59(5): 865-874. 10.1139/f02-063

Doyle, M.W., Stanley, E.H. (2006) Exploring potential spatial-temporal links between fluvial geomorphology and nutrient-periphyton dynamics in streams using simulation models. Annals of the Association of American Geographers, 96(4): 687-698. 10.1111/j.1467-8306.2006.00511.x

Hambrook, B.J., Frey, J.W., Sullivan, D.J., Carpenter, K.D., Mabe, J.A. (2007) Role of algae in assessing aquatic ecological conditions of wadeable streams for USGS NAWQA surface water status and trends. Journal of Phycology, 43: 31-32. <Go to ISI>://WOS:000253474200103

Kilroy, C., Booker, D.J., Drummond, L., Wech, J.A., Snelder, T.H. (2013) Estimating periphyton standing crop in streams: a comparison of chlorophyll *a* sampling and visual assessments. New Zealand Journal of Marine and Freshwater Research, 47(2): 208-224. 10.1080/00288330.2013.772526

Matheson, F., Quinn, J., Hickey, C. (2012) Review of the New Zealand instream plant and nutrient guidelines and development of an extended decision making framework: Phases 1 and 2 final report. Prepared for the Ministry of Science & Innovation Envirolink Fund. NIWA Client Report No: HAM2012-081.

McGill, R., Tukey, J. W. and Larsen, W. A. (1978) Variations of box plots. The American Statistician 32, 12–16.

Nash, J.E., Sutcliffe, J.V. (1970) River flow forecasting through conceptual models: Part 1. A discussion of principles. Journal of Hydrology 10, 282–290.

Snelder, T.H., Biggs, B.J.F. (2002) Multi-scale river environment classification for water resources management. Journal of the American Water Resources Association 38, 1225–1240.

Snelder, T.H., Booker, D.J. (2012) Natural flow regime classifications are sensitive to definition procedures. River Research and Applications. DOI: 10.1002/rra.2581.

Snelder, T.H., Booker, D.J. Quinn, J. Kilroy, C. (in press) Predicting periphyton cover frequency distributions for New Zealand rivers. Journal of the American Water Resources Association.

Snelder, T.H., Woods, R., Biggs, B.J.F. (2005) Improved eco-hydrological classification of rivers. River Research and Applications 21, 609–628.

Suplee, M.W., Watson, V., Teply, M., McKee, H. (2009) How green is too grees? Public opinion of what constitutes undesirable algae levels in streams. Journal of the American Water Resources Association, 45(1): 123-140. 10.1111/j.1752-1688.2008.00265.x

Suren, A., Biggs, B., Kilroy, C., Bergey, E. (2003) Benthic community dynamics during summer low-flows in two rivers of contrasting enrichment 1. Periphyton. New Zealand Journal of Marine and Freshwater Research 37: 53-70.

Uehlinger, U. (1991) Spatial and temporal variability of the periphyton biomass in a prealpine river (Necker, Switzerland). Archiv Fur Hydrobiologie, 123: 219-237.

Unwin, M., Snelder, T.H., Booker, D.J., Ballantine, D., Lessard, J. (2010) Predicting water quality in New Zealand rivers from catchment-scale physical, hydrological and land cover descriptors using random forest models. NIWA client report prepared for Ministry for the Environment, CHC2010-037, p58.

Appendix A Details of the four regional mean chlorophyll models

Multiple linear regression models using the same method as Snelder *et al*. (in press) were used to relate observed chlorophyll *a* to predictor variables. Predictor variables were as for Snelder et al. (in press) and are available for all segments of the national river network (REC, Snelder and Biggs 2002). Estimates of nutrient concentrations were derived from predictions to the national river network by Unwin et al. (2010). We used the fitted models to predict mean chlorophyll *a* for all segments of the regional river networks and to predict the chlorophyll *a* concentration having a probability of occurrence of not more than 8 and 17% (i.e. 1 and 2 per year for monthly monitoring) using the quantile function. We then evaluated the proportion of segments in each region that were predicted to exceed the 200 mg/m^2 threshold either 8% or 17% of the time depending on whether these belonged to the Default or Productive periphyton class.

Table A-1. Predictor variables used in the regional regression models of mean chlorophyll *a* concentrations. Predictor variables are available for all segments of the national digital river network (REC, Snelder and Biggs 2002). Estimates of nutrient concentrations were derived from predictions to the national river network by Unwin et al (2010). Variables marked by an asterisk were themselves modelled based on data provided by the National Water Quality Network.

Variable	Description
DRP	Dissolved reactive phosphorus (mg m^{-3})
DIN	Dissolved inorganic nitrogen (mg m^{-3})
TP	Total nitrogen (mg m^{-3})
TN	Total phosphorus (mg m^{-3})
TN:TP	Ratio of Total nitrogen to total phosphorus
DIN:DRP	Ratio of DIN to DRP.
Clarity	Black disk clarity (γBD, m)
Absorbance	Light absorption coefficient at 340 nm (g340; m^{-1})
Solar radiation	Mean daily solar radiation (R, MJ m^{-2})
Shade	Site shade (%)
Substrate	Average areal proportion of bed sediment using categories: 1-mud, 2-sand, 3-fine gravel, 4-coarse gravel, 5-cobble, 6-boulder, 7-bedrock.
T95*	Ninety fifth percentile of water temperature (^{o}C)
PAR*	Photo-synthetically active radiation at riverbed (µmol m^{-2} s^{-1})
FRE2	Frequency of floods of two times the median flow (year^{-1})
FRE3	Frequency of floods of three times the median flow (year^{-1})
FRE4	Frequency of floods of four times the median flow (year^{-1})
LowFlow	Mean annual seven day low flow divided by mean flow.
nNeg	Mean days that flow was less than previous day (days year^{-1})
Reversals	Number of occasions on which the direction of daily change in flows reverses (year^{-1}).

Table A-2. Details of the regional mean site chlorophyll *a* models including the r^2 values, the variables included and their coefficients standard errors and *p*-values.

	Estimate	Std.Error	t value	*p*-value
Canterbury (r^2=73%)				
(Intercept)	-220.6	63.4	-3.5	0.00
Substrate	4.1	2.4	1.7	0.11
T95	1.7	0.5	3.6	0.00
FRE2	-1.5	0.4	-3.6	0.00
log10(DRP)	-16.9	3.9	-4.3	0.00
Reversals	0.4	0.1	3.2	0.01
nNeg	0.4	0.1	2.8	0.01
CV_Flow	17.6	7.3	2.4	0.03
Manawatu (r^2=52%)				
(Intercept)	22.5	3.2	7.1	0.00
Substrate	-3.3	0.6	-5.4	0.00
log10(TN)	3.5	0.7	5.2	0.00
Southland (r^2=49%)				
(Intercept)	2.4	12.9	0.2	0.86
Substrate	1.9	0.9	2.1	0.05
T95	1.2	0.4	2.9	0.01
log10(TN)	-4.1	1.6	-2.6	0.01
log10(TP)	5.6	1.6	3.5	0.00
Reversals	-0.1	0.1	-2.1	0.04
Wellington (r^2=69%)				
(Intercept)	3.4	16.5	0.2	0.84
T95	1.7	0.4	4.2	0.00
DINDRP	0.1	0.0	3.2	0.00
log10(TN)	-8.6	4.4	-2.0	0.06
log10(TP)	8.9	4.7	1.9	0.07
nNeg	-0.1	0.1	-2.1	0.04
CV_Flow	21.9	7.0	3.1	0.00

Appendix B Considerations for periphyton monitoring based on an assessment of the variability of high flows from hydrological data

B1 Rationale

It is important to consider inter-annual variability in periphyton abundance in relation to both setting of periphyton objectives and monitoring for comparison with objectives. Periphyton abundance is strongly influenced by variability in flows. In particular the length of accrual periods is directly related to the frequency of floods, because the accrual period is the period between floods. Significant year to year variation in flood frequency means that the average length of the accrual period varies between years and that robust objectives can only be defined for "average" hydrological conditions. It also means that the abundance thresholds will be more frequently exceeded in some years than in others, even when a site meets the objective overall. This complication requires guidance on what time period should be used when using monitoring data to assess whether periphyton objectives are being met.

FRE3 is an index of hydrological variability that has been related to periphyton biomass (e.g. the MfE periphyton guidelines; Biggs 2000b). FRE3 is the frequency of events exceeding three times the long-term median flow. The index is inversely related to the average growth period between floods. This is the same as days of accrual of biomass (Biggs 2000b). FRE3 is highly correlated with similar indices used to represent hydrological variability such as FRE2 or FRE4.

Periphyton biomass is expected to be higher than average in years with lower FRE3 because there are more days of accrual. Thus, an assessment of whether periphyton objectives are met at a site requires a sufficiently long monitoring period that observed FRE3 is close to its long-term value. The following analysis provides guidance on the level of confidence that a specified period of hydrological record is likely to have an observed FRE3 value within various deviations below the long-term FRE3. The deviation below the long term mean FRE3 value is of interest because these represent periods with more days of accrual and therefore higher probability of exceeding biomass periphyton thresholds.

The data and analysis presented here are intended to provide information for deciding the time-period over which compliance with periphyton objectives should be assessed. The analysis also considers whether the length of the appropriate time period varies between river classes. Guidance for interpreting periphyton monitoring data gathered over short time periods is given based on the analysis.

B2 Data

A flow time-series database was collated that comprised mean daily flows observed at 312 gauging stations with available records of 15 full years or longer after having removed any years with more than 30 days of missing data. Available mean daily flow time-series from the National Institute of Water and Atmospheric Research's (NIWA) national database were collated alongside data supplied by some regional councils (Northland Regional Council, Auckland Council, Waikato Regional Council, Greater Wellington Regional Council, and

Environment Canterbury). The time-series database contained only sites that were not affected by large engineering projects such as dams, diversions or substantial abstractions, according to information given by each data provider. See Snelder et al. (2005) and Booker (2013) for further details on gauging station selection. The gauging stations were located throughout New Zealand and represented a wide range of hydrological conditions (Figure B-1).

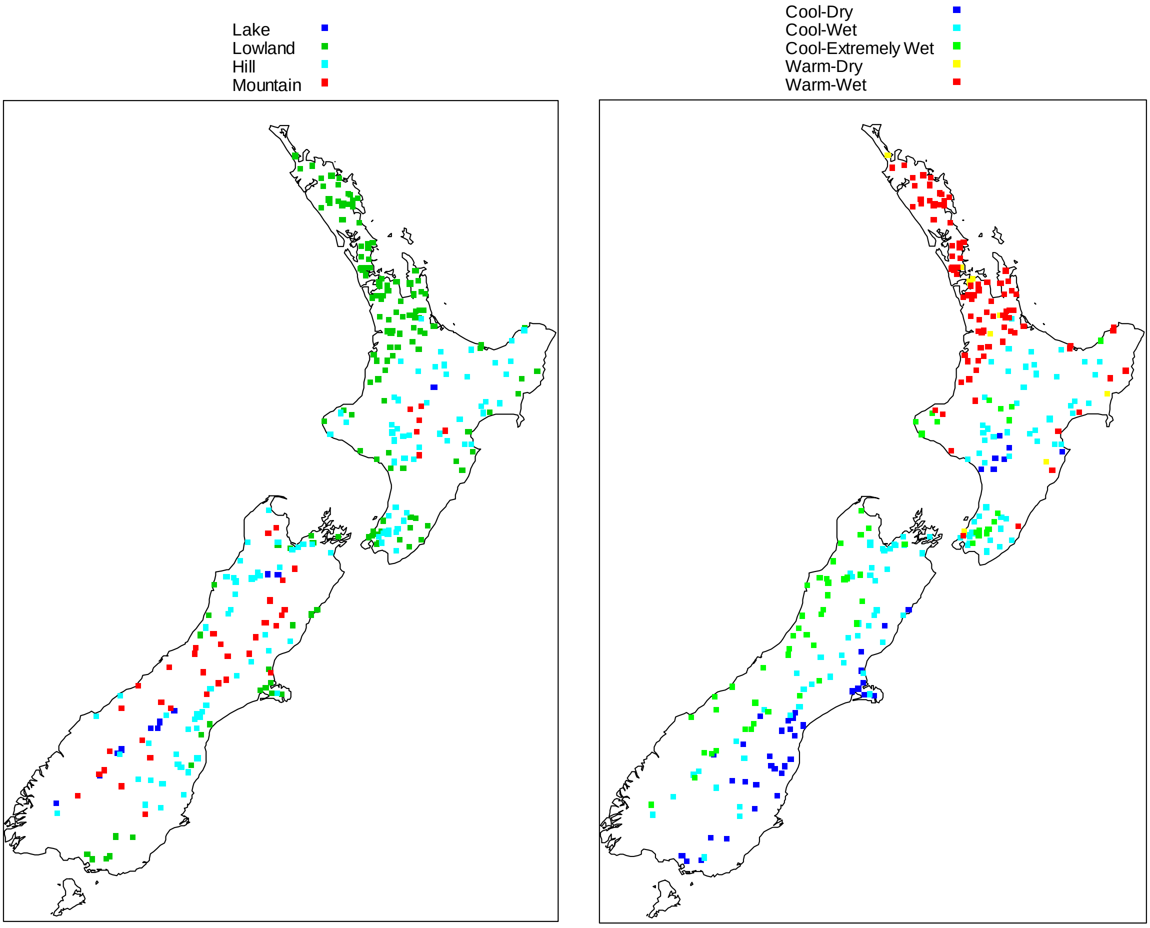

Figure B-1: Maps showing locations of gauging stations and REC Climate and Topography categories.

B3 Methods

The procedure of Booker (2013) for calculating the number of events that exceeded three times the long-term median flow (FRE3) was followed. FRE3 was expressed in units of number of events per year throughout. A 5-day window was used in all cases such that events occurring within 5 days of a previous event did not contribute to FRE3. This window is applied on the basis that a 5 day period is too short for significant periphyton growth to occur. See Booker (2013) for a method that allows conversion between FRE3 calculated with and without a 5-day window.

Three times the long-term median flow was used to set the reference flow for calculating FRE3 in all cases. The long-term FRE3 was calculated as the number of events exceeding three times the median for all days of record (divided by the number of years of record). At this stage 14 sites were removed from the analysis because their long-term FRE3 was less than 1.

For each hydrological record we simulated monitoring periods by calculating FRE3 over time periods of various lengths, and which started at various locations throughout the flow records. FRE3 was calculated for time periods of 1, 2, 3, 4 and 5 years in length for moving windows starting every 73 days throughout each record. Moving windows starting every 73 days meant that FRE3 was calculated 5 times a year for each length of time period.

We then compared FRE3 calculated in each time period (y) at each start point (i) for each gauging station (j) with the long-term FRE3 for that gauging station. The precentage difference in FRE3 was calculated as $(FRE3_{yij}/FRE3_{j})*100$. The probability of each $FRE3_{yij}$ being less than 100, 90, 80, 70, 60 and 50% of the long term $FRE3_{j}$ was then calculated.

The results for individual gauging stations were grouped into classes defined by the River Environment Classification (REC; Snelder and Biggs 2002). Classes at the Climate and Source of Flow levels of the REC were used as these explain significant hydrological variability (Snelder et al. 2005). These classes differentiate river segments based on the climate and topography of the upstream catchment. Only 4 of the gauging stations were classified as Warm-Extremely Wet and were therefore merged with the Warm-Wet class. Only 9 of the 312 gauging stations belonged to the Glacial Mountain category and were therefore merged with the REC Mountain category to form one “Mountain” category.

For all box and whisker plots: boxes represent the first and third quartile; whiskers represent the 95% percentile; solids dots are the median; and open dots are outliers. See McGill et al. (1978, p16) for further details and mathematical explanation of box and whisker plots.

B4 Results

Of the 312 gauging stations, there were at least 10 in each Climate category and at least 11 in each Topography category (Table B-1). However, some Source-of-flow classes were represented by a small number of gauges and some Source-of-flow classes were not represented by any gauges.

Variation in long-term FRE3 was differentiated by both REC Climate and Source-of-flow classes (Figure B-1). The strongest patterns were associated with Climate categories. FRE3 tended to be higher for gauging stations with wetter catchments and tended to be lower for Lake-fed topography categories.

Table B-1: Mean and range of long-term FRE3 together with number of catchments by REC Climate, Topography and Source-of-flow categories. Note that FRE3 is calculated with a 5-day window between events.

Classification	Class	Min	Mean	Max	n
Climate	Cool-Dry	1.38	6.24	10.97	45
	Cool-Wet	1.24	7.94	15.24	104
	Cool-Extremely Wet	1.04	11.7	17.33	59
	Warm-Dry	5.36	9.52	14.82	10
	Warm-Wet	1.69	8.86	14.3	94
Topography	Lake	1.04	6.27	13.07	11
	Lowland	1.24	8.77	17.25	152
	Hill	1.24	9.05	16.74	108
	Mountain	3.19	8.41	17.33	41
Source-of-flow	Cool-Wet Lake	4.49	5.8	7.11	2
	Cool-Extremely Wet Lake	1.04	6.37	13.07	9
	Cool-Dry Lowland	2.25	6.3	10.14	20
	Cool-Wet Lowland	1.24	9.31	12.65	24
	Cool-Extremely Wet Lowland	11.29	13.94	17.25	5
	Warm-Dry Lowland	5.36	9.52	14.82	10
	Warm-Wet Lowland	1.69	8.81	14.3	93
	Cool-Dry Hill	1.38	6.19	10.97	25
	Cool-Wet Hill	1.24	7.97	15.24	55
	Cool-Extremely Wet Hill	7.89	13.74	16.74	27
	Warm-Wet Hill	13.63	13.63	13.63	1
	Cool-Wet Mountain	3.32	6.61	13.23	23
	Cool-Extremely Wet Mountain	3.19	10.7	17.33	18

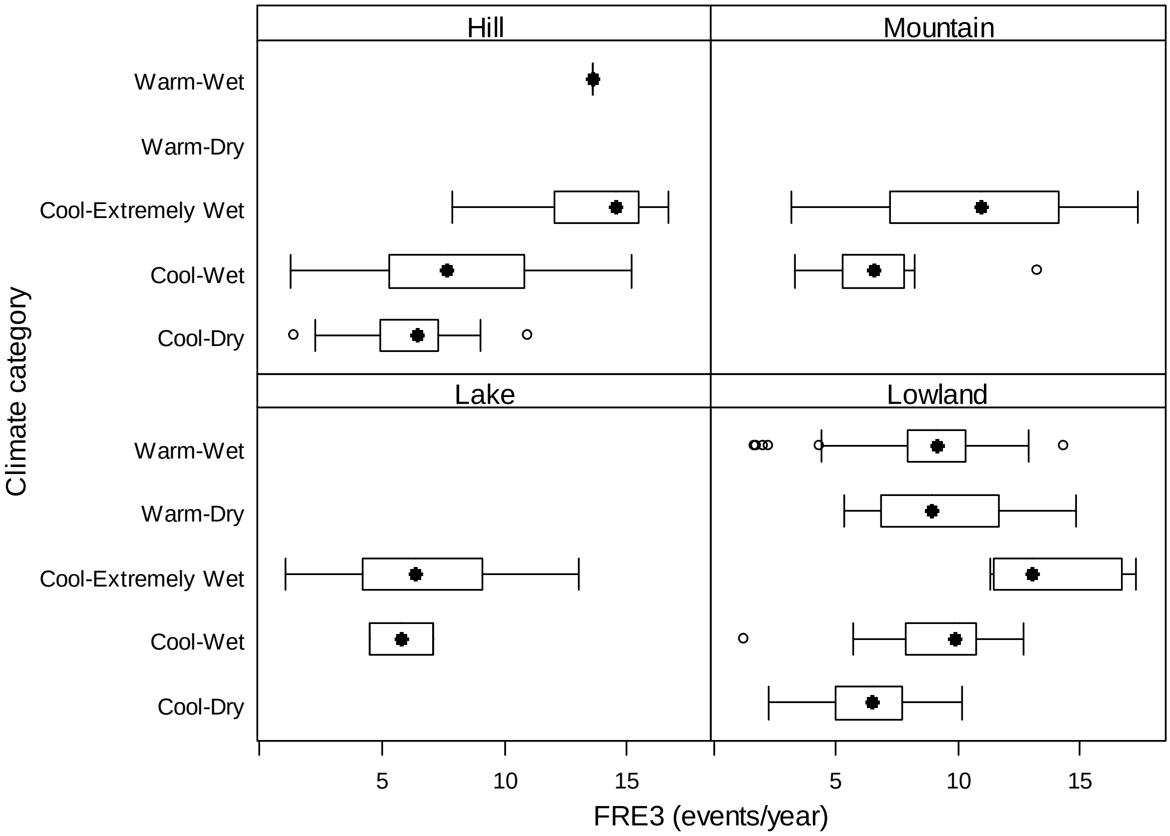

Figure B-1: Long-term FRE3 values observed at gauging stations grouped by REC Climate and Topography classes. Note that FRE3 is calculated with a 5-day window between events.

In a recent paper, Booker (2013) showed patterns in FRE3 through time exist for hydrological records across New Zealand. Annual values of FRE3 cannot therefore be considered to be stationary (i.e., constant mean and variance through time). Patterns in FRE3 include trends (long term increases or decreases with time) and temporal auto-correlations (cyclical patterns). Results shown here support these findings, with cyclical patterns apparent even when FRE3 was calculated over relatively long periods (e.g., 5 years) (Figure B-2). This meant that observed values from discrete time periods deviated from the long-term FRE3 even when FRE3 was calculated over these relatively long periods (Figure B-3).

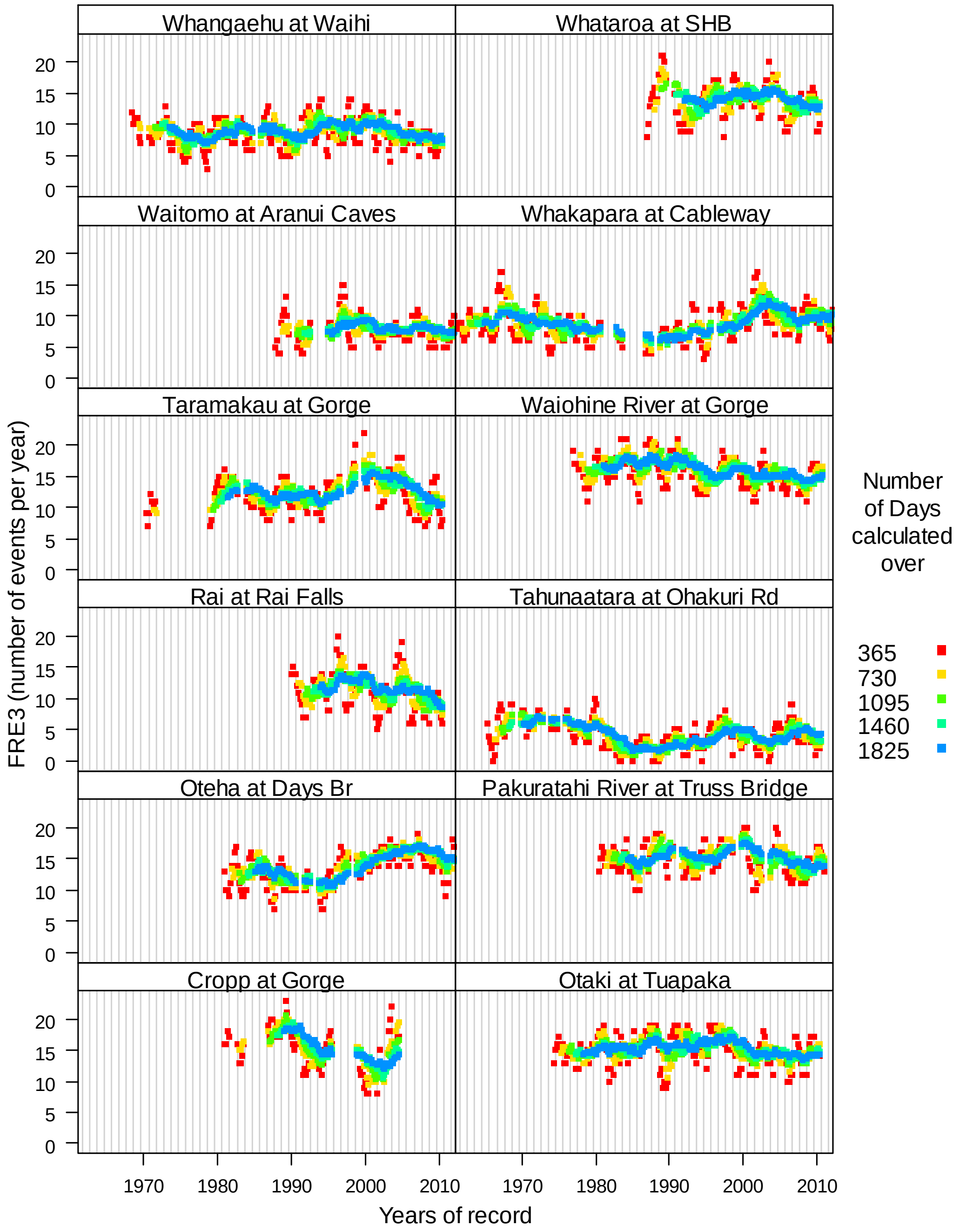

Figure B-2: FRE3 calculated over 1, 2, 3, 4 and 5 years starting every 73 days for 12 randomly selected gauging stations.

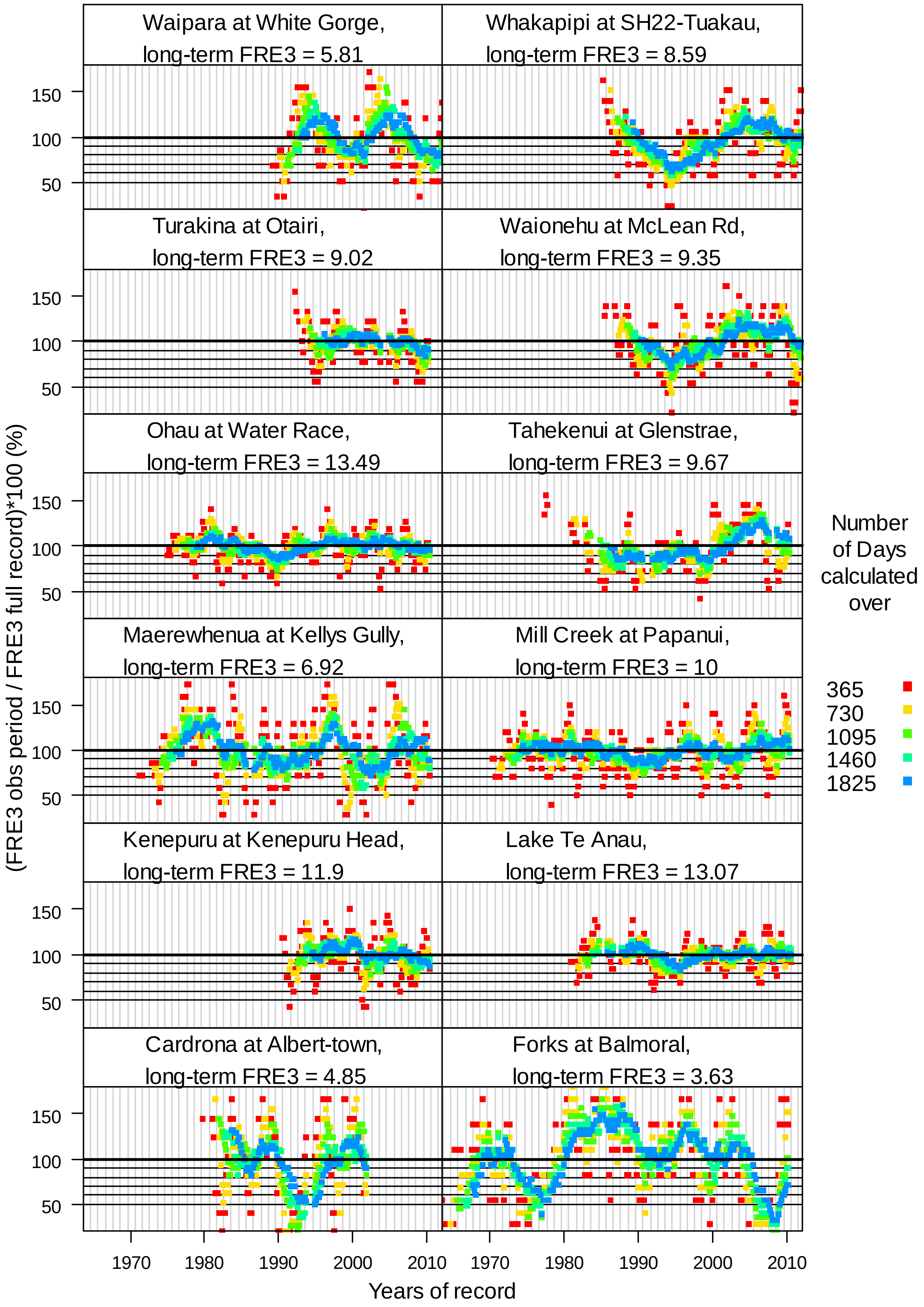

Figure B-3: Difference between long-term FRE3 and FRE3 calculated over 1, 2, 3, 4 and 5 years starting every 73 days for 12 randomly selected gauging stations. Horizontal black lines represent deviations below the long-term FRE3.

The results were summarised for each gauging station by calculating the percentage of time periods for which the observed FRE3 was within various deviations below the long-term FRE3 (Figure B-4). For example, Figure B-4 shows that when a 3 year (1095 day) period was used, observed FRE3 was not less than 50% of the long-term FRE3 for the majority of sites. However, for the 3 year period, two sites had around 40% of their observed FRE3 values that were less than 50% of the long-term FRE3.

Results for all gauging stations together showed the overall relationships between the probability of observing a deviation away from long-term FRE3 and the period over which FRE3 was observed. As the observation time period increased there was greater probability of observed values of FRE3 being nearer to the long-term FRE3. Observed values of FRE3 less than 50% of the long-term FRE3 were rare, especially when observation periods were greater than 2 years. However, observed values of FRE3 less than 90% of the long-term FRE3 were very common, especially when observation periods were short.

Similar results were seen when the same analysis was conducted after having grouped the gauging stations by Climate classes (Figure B-5), Topography classes (Figure B-6) and Source-of-flow classes (Figure B-7). The chance of observing a deviation away from long-term FRE3 still decreased as the period over which FRE3 was observed increased. However, the exact pattern to this relationship differed between types of catchment.

Large deviations below the long-term FRE3 were less likely in the Warm-dry and Cool-Extremely Wet climate classes. This indicates there is less temporal variations in FRE3 for these classes. Observed FRE3 from Lake catchments were most likely to deviate from the long-term FRE3. A larger proportion of Lake catchments had a relatively high probability of observed FRE3, being considerably less than the long-term FRE3 in comparison to other types of catchments. Results indicated that, for a 3-year observation period, 95% of Lowland catchments had all observations of FRE3 that were more than 60% of the long-term FRE3. However, for the same observation period, only 50% of Lake catchments had all observations of FRE3 that were more than 60% of the long-term FRE3.

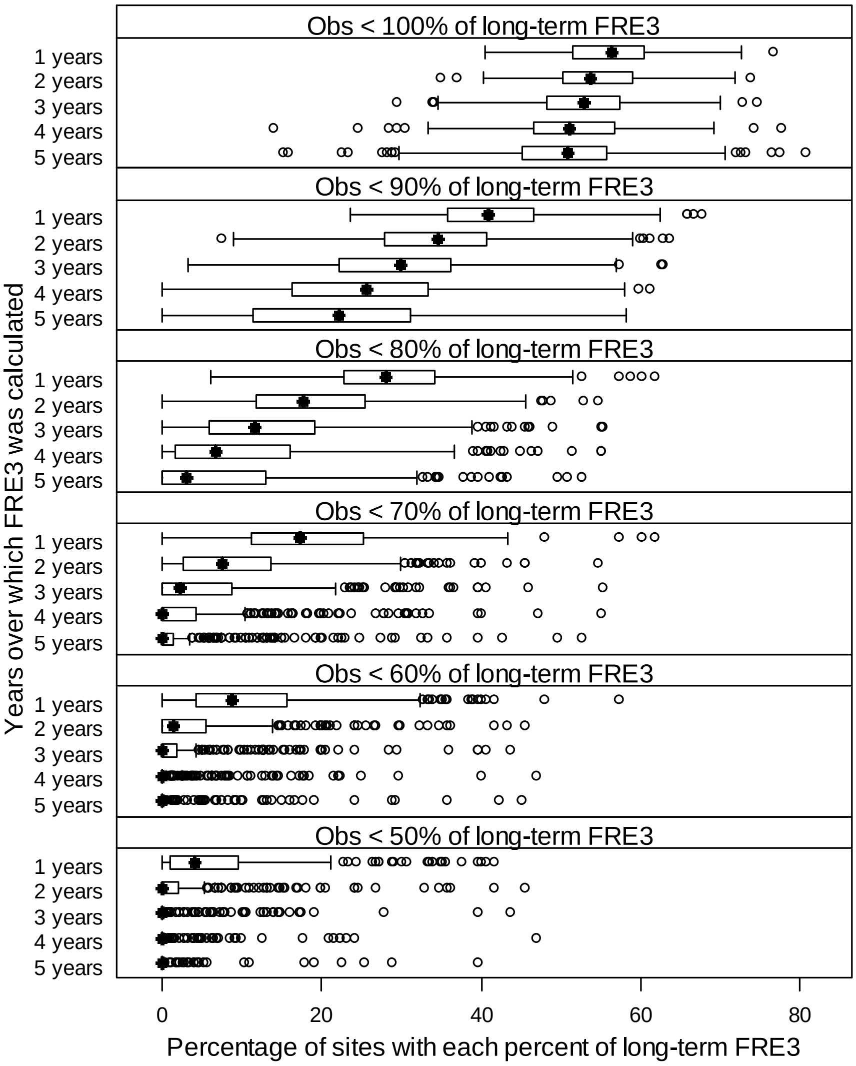

Figure B-4: Percentage of sites where observations of FRE3 were less than the observed long-term FRE3. For various lengths of period and various magnitudes of difference from the long-term FRE3.

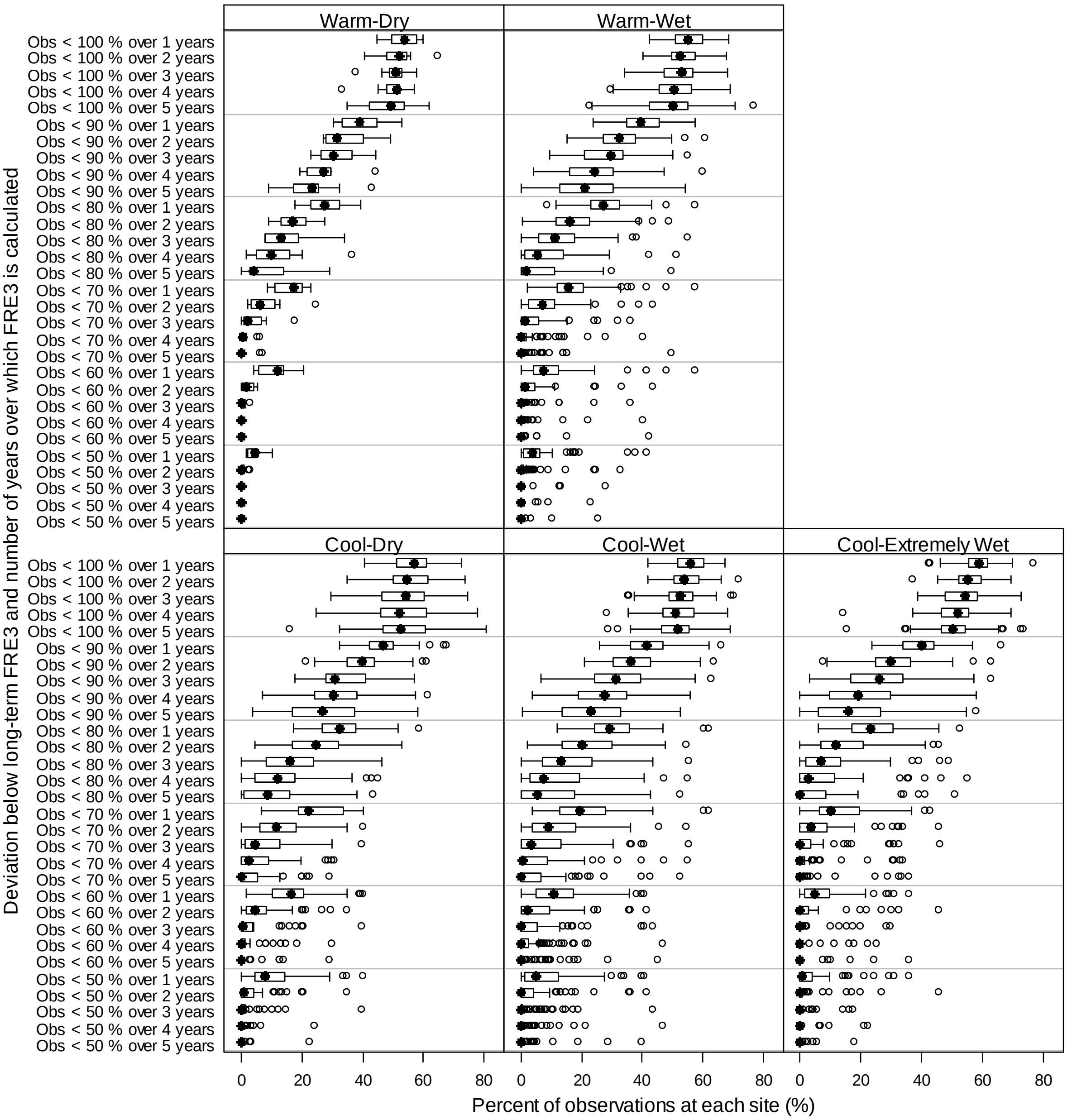

Figure B-5: Percentage of sites where observations of FRE3 were less than the observed long-term FRE3 by Climate class. For various lengths of period which FRE3 was calculated over and various magnitudes of difference from the long-term FRE3 for rivers in different REC Climate classes.

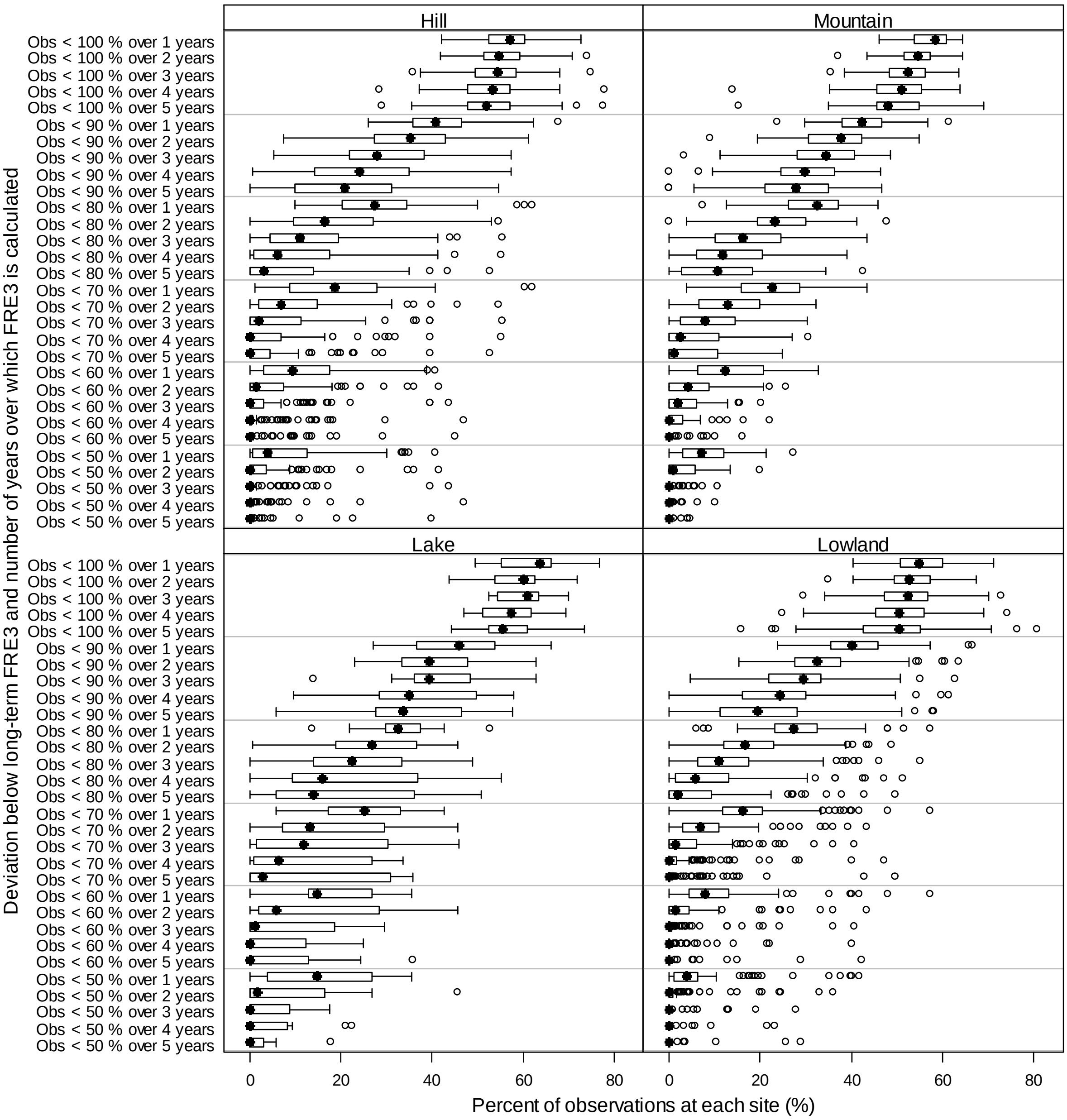

Figure B-6: Percentage of sites where observations of FRE3 were less than the observed long-term FRE3 by Topography class. For various lengths of period which FRE3 was calculated over and various magnitudes of difference from the long-term FRE3 for rivers in different REC Topography classes.

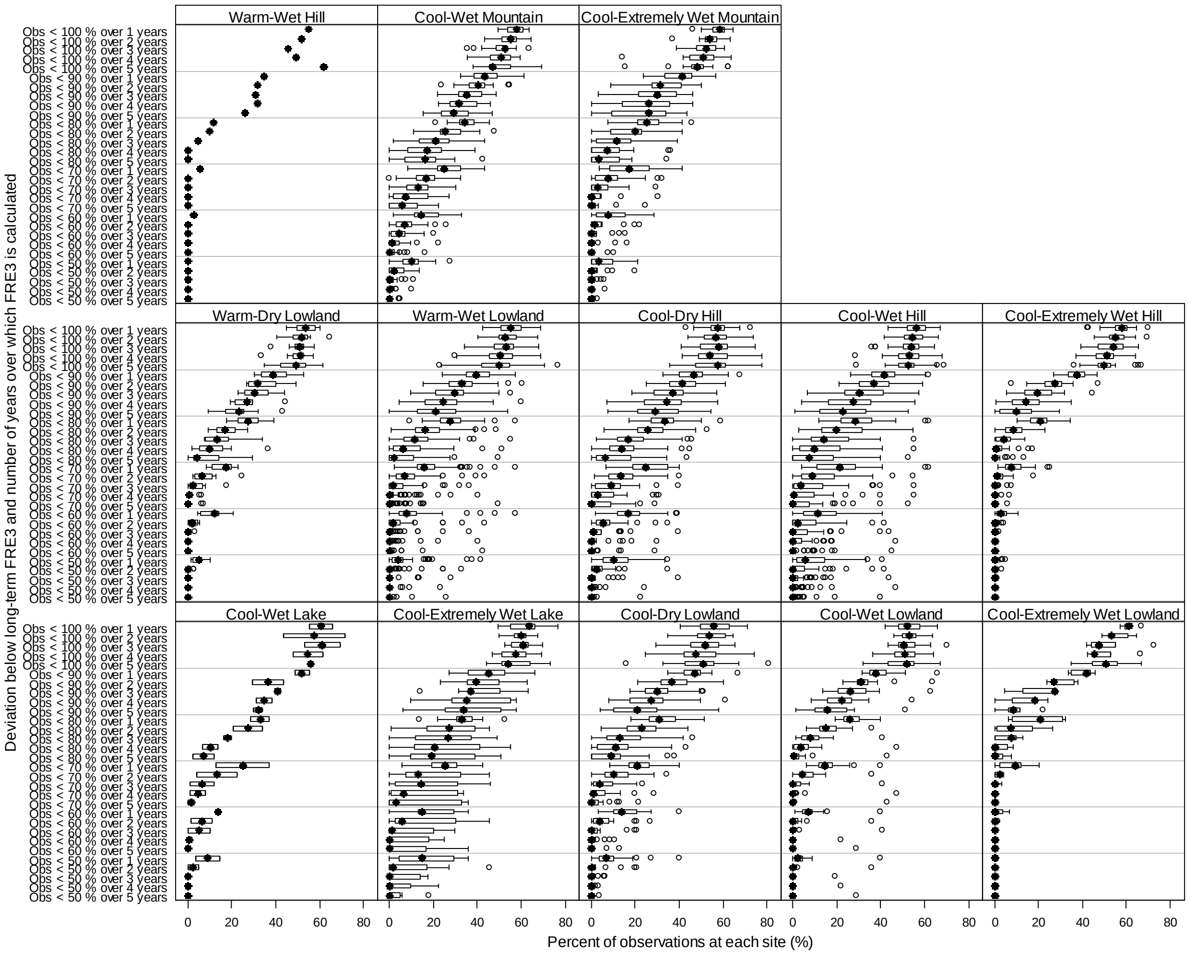

Figure B-7: Percentage of sites where observations of FRE3 were less than the observed long-term FRE3 by Source-of-flow class. For various lengths of period which FRE3 was calculated over and various magnitudes of difference from the long-term FRE3 for rivers in different REC Source-of-flow classes.

B5 Discussion

This method assumed that the long-term median flow was known and was stationary. Hydrological records with reasonably long periods (15 years) were used in this analysis. The median flow can be calculated with a high degree of confidence for records of this length. However, when calculating FRE3 from hydrological records covering shorter periods one needs to consider that uncertainties in calculated FRE3 arise from both uncertainty in the calculated median as well as inter-annual variability in the frequency of floods. For example, for a new gauging station the long-term median flow may be unknown.

Here we evaluated deviation below the long-term FRE3 expressed as percentages. We did not consider absolute values of FRE3. The absolute values of FRE3 may be important in the case of extreme hydrological regimes (very flashy and very stable). In very flashy catchments the long-term FRE3 will be high (e.g. 20 events per year). A particular period may have a FRE3 of only 16 events per year (20% deviation below the long-term FRE3), but this still includes sufficient flood events to ensure that periphyton biomass may never breach thresholds. On the other hand, in catchments with very stable flow regimes, long-term FRE3 will be low (e.g. 4 events per year). A particular period may have only one fewer events per year, representing a 20% deviation below the long-term FRE3, but this represents a considerable increase in the days of accrual in absolute terms and may produce significantly more exceedance of the thresholds.

From this analysis it is clear that confidence that a monitoring represents the long-term average hydrological conditions increases as the monitoring period increases. There is a trade-off between the need for immediate results and confidence that the observations represent the long-term state. It is clear that it is not possible to assess whether objectives are met from short periods of monitoring (e.g. < 3 years). However, short periods of record may provide useful insights into the likelihood that objectives are being met if these are combined with detailed analysis and modelling of both hydrological data (actual accrual rates) and periphyton biomass data. In addition, if periphyton biomass thresholds are breached more frequently than specified by an objective during periods in which deviations are above the long-term value of FRE3, there is a likelihood that the objective is not being met.

These results indicate that confidence that a specific monitoring period represents the long-term average hydrological conditions varies by REC class. For example, shorter observations periods are needed to represents the long-term average FRE3 in Lowland catchments than in Lake catchments. This is because, for the same time period, observed FRE3 for Lowland catchments is more likely to be near to the long-term FRE3 than is the case for Lake catchments. Results by Topography classes showed that Hill and Mountain catchments lie somewhere between the Lake and Lowland catchments.

Appendix C Relationships between invertebrate community metrics and periphyton abundance

Weighted Composite Cover (WCC) is a measure of periphyton abundance in terms of the stream bed covered (%) by two forms of periphyton; mats and filaments (Matheson et al. 2012). Matheson et al. (2012) used WCC to examine relationships between periphyton abundance and invertebrate community metrics (macro-Invertebrate Community Index; MCI and the proportion of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichopera (caddisfly) taxa; EPT). These relationships were used by the NOF Periphyton Panel of experts to assist in defining the proposed NOF periphyton bands for ecological health based on the invertebrate metrics (Table 2).

The WCC metric used by Matheson et al. (2012) was converted to an estimate of chlorophyll *a* so that periphyton abundance was measured in the same units as the proposed NOF thresholds. To derive a relationship between WCC and chlorophyll *a* we used available data from the Manawatu-Whanganui and Canterbury regions for sites at which both measures of periphyton abundance had been used on the same sampling occasions (see section 5.1). A regression of $\log_{10}$ of the site mean chlorophyll *a* against square-root transformed site mean WCC (n = 66) explained 59% of the variation in log mean chlorophyll *a*:

$$\text{Log}_{10}\text{ chlorophyll } a = 0.291 + 0.307\,(\sqrt{\text{WCC}})$$

We then calculated 95% confidence intervals for chlorophyll *a* at WCC values used as thresholds in the study by Matheson et al. (2012). The estimated chlorophyll *a* values for the three thresholds by Matheson et al. (2012) contain the three proposed NOF thresholds (50, 120, and 200 mg/m^2; Table 2). The two higher NOF thresholds (120 and 200 mg/m^2) are towards the lower end of the range for equivalence to WCC.

Table C-1: Invertebrate community metrics in relation to periphyton abundance levels derived by Matheson et al. (2012). Chlorophyll *a* (95% confidence interval) concentrations were derived using the above relationship to convert from WCC thresholds used by Matheson et al. (2012). The relationships are based on the assumption that stressors other than periphyton abundance (e.g., deposited fine sediment, metals, pesticides, high temperature) have minimal direct influence on ecosystem health).

WCC (%)	95% CI for chlorophyll *a* (mg/m^2)		Proposed NOF band	Invertebrate community metrics		
	lower	upper		MCI	QMCI	EPT abund
20	35	62	A	> 125	>6	>70
40	102	285	B	110-125	5-6	>50
55	191	714	C	90-110	4-5	>25