Guidance on look-up tables for setting nutrient targets for periphyton

Second edition

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Contents

Figures

Tables

Purpose and scope of this document

This document provides guidance on the interpretation and use of look-up tables of *in-stream nutrient concentrations and exceedance criteria* (*nutrient criteria*) for achieving periphyton target attribute states as required by the National Policy Statement for Freshwater Management (NPS-FM) 2020, clause 3.13: *Special provision for attributes affected by nutrients.* Derivation of the generalised nutrient concentrations and exceedance criteria is described by Snelder et al (2021) and was commissioned by the Ministry for the Environment. This guidance should be read together with the NPS-FM and other guidance (see the More information section).

The *nutrient criteria* in the look-up tables apply to all hard-bottomed (ie, cobble- or gravel-bed) streams and rivers, because such streams support, or could support, conspicuous periphyton (see NPS-FM, clause 3.13(3)(a)(i)). The criteria were developed using data from hard-bottomed stream sites. This guidance does not apply to soft-bottomed streams as these streams do not normally support conspicuous periphyton. Refer to Ministry for the Environment (2021) for further background on hard-bottomed versus soft-bottomed streams and rivers.

The nutrient concentrations and exceedance criteria apply to river segments with stream order ≥ 3 as defined by the digital river network associated with the River Environment Classification (REC, Snelder and Biggs, 2002). The *nutrient criteria* were developed using data from monitoring sites located on river segments with stream order ≥ 3. The nutrient concentrations and exceedance criteria are most applicable to river segments of stream order ≥ 3 because they were developed from a dataset in which >98 per cent of monitoring sites were order 3 or greater. The nutrient concentrations and exceedance criteria can be used in lower-order streams; however, their applicability will decrease in situations where characteristics of low-order streams diverge from those of higher-order streams. Relevant characteristics to consider when judging whether the nutrient concentrations and exceedance criteria are applicable at sites on river segments of order < 3 are the type of bed substrate, and flow, temperature and light regimes.

A note on terminology used in this Guidance: '*Nutrient criteria*' and its relationship to ‘instream concentration and exceedance criteria’ in the NPS-FM 2020

For avoidance of doubt, the term ‘*nutrient criteria*’ in this document refers to the concentrations of nutrients (ie, nitrogen and phosphorus) and their temporal exceedances (ie, a specified percentage of sampling occasions where a concentration is exceeded). Note in this document and as it refers to the policy, the objective is to achieve a defined periphyton biomass (chlorophyll-a) target state 92 per cent of the time by meeting nutrient concentration criteria that are based on medians of monitored data. Those nutrient concentration criteria have been modelled incorporating variable levels of under-protection risk (5–20 per cent).

Nutrient criteria and its derivatives (eg, generalised criteria, criteria, criterion etc) refer to the NPS-FM 2020 requirement in clause 3.13 to set ‘in-stream concentrations and exceedance criteria’ for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP). This should not be confused with ‘exceedance criteria’ for other NPS-FM 2020 attributes, which are defined by different percentiles (eg, periphyton is defined by the 92nd percentile).

Introduction

Periphyton objectives and nutrient criteria

Periphyton (a complex mix of algae, cyanobacteria and other microbes growing on the substrate of rivers) is an important component of healthy river ecosystems, but excessive biomass can:

- smother habitat
- cause significant daily fluctuations in dissolved oxygen in the water (including periods of low dissolved oxygen, which can significantly impact ecosystem health)
- change the appearance of the water and people's ability to fish, swim or carry out other activities.

The National Policy Statement for Freshwater Management 2020 (NPS-FM) includes periphyton biomass (measured by the algal component of periphyton as chlorophyll *a*, mg m^{-2}) as a compulsory attribute (a measurable characteristic) that contributes to ecosystem health values. The NPS-FM requires regional councils and unitary authorities (referred to as 'councils') to set target attribute states[1] and restrict maximum periphyton biomass in rivers.

For most rivers in New Zealand, target attribute states aim to restrict the exceedance of a specified maximum biomass threshold. As high biomass occurs occasionally, even in rivers draining natural areas, the target attribute state allows the threshold to be occasionally exceeded. Exceedances of the maximum biomass threshold are allowed in no more than 8 per cent of samples, which is the 92nd percentile of the distribution of monthly periphyton biomass observations over at least three years of data. The 92nd percentile is equivalent to an allowed exceedance of the biomass in one of 12-monthly observations, on average.

As maximum periphyton biomass is influenced by the concentration of nutrients in the water column, the NPS-FM also requires councils to set appropriate in-stream concentrations and exceedance criteria for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) to achieve periphyton biomass target attribute states. In addition, councils are required to set in-stream nutrient concentrations and exceedance criteria for DIN and DRP for other nutrient-affected attributes (refer to NPS-FM clause 3.13: *Special provision for attributes affected by nutrients*).

It is well understood that several processes influence maximum periphyton biomass in rivers. A simple conceptual model characterises these processes as accrual and loss (Biggs, 1996). Accrual (ie, accumulation of biomass over time) is influenced by factors that affect algal growth rates, such as temperature, light and nutrient concentrations. Loss is strongly controlled in many rivers by disturbance (removal by abrasion and scouring), which is driven by the interaction between flow regime (eg, frequency of high-flow events) and substrate stability. Biomass loss can also be caused by grazing, by invertebrates and fish. The factors controlling accrual and loss vary between rivers because they depend on environmental characteristics such as the climate and topography of the upstream catchment. Therefore, appropriate in-stream concentrations not only depend on the periphyton biomass target attribute states, but also the environmental characteristics of the river to which they apply.

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[1] Note that this guidance refers to periphyton target attribute states in the NPS-FM 2020. Target attribute states are defined by a maximum biomass threshold, which can be referred to by the NOF bands (ie, A, B or C bands) and an exceedance criterion, which is set at the 92nd percentile. In past NPSs, target attribute states were referred to as numeric objectives or objectives.

Deriving robust and justifiable *criteria* for nitrogen and phosphorus to achieve periphyton target attribute states is a significant technical challenge for at least these two reasons:

1. Data that can be used to relate periphyton biomass to nutrient concentrations is limited due to the resources required to collect it and the requirement to collect it consistently over several years (with the minimum record length of three years being required to grade a site for periphyton) before there is sufficient data.
2. The links between nutrient concentrations and periphyton abundance are complex. Collected data and current modelling methods used to quantify these links are simplifications of reality. This means there is uncertainty associated with any attempt to derive *nutrient criteria*. Appreciable uncertainty with respect to appropriate nutrient concentrations and exceedance criteria exists for sites that are represented by data. However, the uncertainty is even higher when models are used to derive generalised nutrient concentrations which are intended to be applied at sites with no data.

Because of the challenges associated with deriving robust and justifiable *nutrient criteria*, appropriate in-stream nutrient concentrations need to be set by considering locally relevant data and conditions as well as existing generalised *nutrient criteria*. This guidance describes how recently produced generalised nutrient concentrations can be used alongside other considerations to set in-stream concentrations of nitrogen and phosphorus to achieve periphyton target attribute states.

Following this introduction, the guidance is presented in four parts:

- **Section 1** summarises milestones in developing *nutrient criteria* for managing periphyton in New Zealand rivers. This section also provides an explanation of the risk-based approach to setting *nutrient criteria*, which is the basis for the criteria provided in these guidelines.
- **Section 2** describes key findings of a recent study that developed look-up tables of new *nutrient criteria* to achieve target attribute states for periphyton biomass. An understanding of these findings is important to correctly interpret and use the look-up tables.
- **Section 3** contains the look-up tables for *nutrient criteria* to achieve specified periphyton biomass target attribute states. The tables are provided for shaded and unshaded sites and for two forms of nitrogen and phosphorus:
  - Total Nitrogen (TN)
  - Dissolved Inorganic Nitrogen (DIN)
  - Total Phosphorus (TP)
  - Dissolved Reactive Phosphorus (DRP).[2]
- **Section 4** provides guidance for using the look-up tables to derive *nutrient criteria* to achieve periphyton biomass target attribute states.

Go to the end of the document for references, a glossary of terms, links to further information and an appendix describing how to determine River Environment Classification classes.

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[2] NPS-FM 2020, Clause 3.13(1): *Special provision for attributes affected by nutrients* requires councils set appropriate in-stream concentrations and exceedance criteria for DIN and DRP, as a minimum requirement. Refer to Section 4 for discussion on background to TN and TP.

1: Nutrient criteria for managing periphyton

Background

The first New Zealand-specific guidelines related to periphyton in rivers were published by the Ministry for the Environment in 1992: *Water Quality Guidelines No 1: Guidelines for the control of undesirable growths in water* (Ministry for Environment, 1992). The 1992 Guidelines covered sewage fungus, phytoplankton, periphyton and macrophytes. The guidelines for periphyton were based on limited research.

Research interest in periphyton expanded during the 1990s (Larned, 2010) and led to a significant update of the guidelines in 2000: *New Zealand Periphyton Guideline: detecting, monitoring and managing enrichment of streams* (Biggs, 2000a). The 2000 guideline included criteria for DIN and DRP (annual mean values from monthly observations) predicted to prevent maximum periphyton biomass from exceeding given levels. The concentrations were derived from relationships based on data from 30 river sites throughout New Zealand. All the sites were hill-fed, cobble-bed rivers, with no spring or lake influence, no point source pollution discharges upstream, and no shading. The limitations of the dataset were clearly stated by Biggs (2000b).

A later analysis showed that, based on River Environment Classification (REC) classes, at least 30 per cent of river segments in New Zealand were not represented by the model underlying the DIN and DRP criteria in the 2000 guideline (Matheson et al, 2012). With insufficient data available in 2012 to develop new data-driven national models for predicting periphyton biomass Matheson et al (2012) proposed the use of Bayesian Belief Networks to assess the risk of development of nuisance periphyton growth at river sites.

Periphyton was included as an attribute in the first version of the National Objectives Framework (NOF) in the updated NPS-FM (New Zealand Government, 2014). Background and rationale to the periphyton attribute was set out by Snelder et al (2013). After establishing the periphyton attribute in the NPS-FM 2014, there was renewed interest in *nutrient criteria* (Larned et al, 2015). The requirement for councils to set appropriate in-stream concentrations and exceedance criteria for DIN and DRP to achieve a 'freshwater objective' for periphyton was first introduced in the amended version of the NPS-FM 2014, released in 2017. This initial requirement (set out as a note under the attribute table for periphyton) was transferred to clause 3.13 of the NPS-FM in 2020 (New Zealand Government, 2020) (*Special provision for attributes affected by nutrients*) in an expanded form.

Since 2017, regional councils have been required to make two sets of decisions related to the NOF's periphyton attribute: set target attribute states for maximum periphyton biomass in rivers and having done so, set appropriate in-stream concentrations and exceedance criteria of nitrogen and phosphorus that will achieve those targets. The NOF indicates that maximum periphyton biomass thresholds can be set within a range that is nominally described by bands:

- the A band is the most stringent objective (ie, lowest biomass ≤ 50 mg chlorophyll m^{-2})
- the B band is defined as 50 mg chlorophyll m^{-2} < maximum biomass ≤ 120 mg chlorophyll m^{-2}
- the C band is defined as 120 mg chlorophyll m^{-2} < maximum biomass ≤ 200 mg chlorophyll m^{-2}.

The D band is defined as a maximum biomass of > 200 mg chlorophyll m^{-2}, which is a NOF bottom line (ie, an unacceptable state). (Note that an exceedance criterion, which is set at the 92nd percentile, applies to all NOF bands for periphyton).

A study by Snelder et al (2019) provided a set of *criteria* for two nutrients, total nitrogen (TN) and dissolved reactive phosphorus (DRP) that were derived to achieve maximum periphyton biomass thresholds defined by the NOF A, B and C bands. The two models underlying these *criteria* — one including TN and the second DRP as the nutrient — accounted for differences between rivers in the factors that influence periphyton accrual and loss. The resulting spatially variable *nutrient criteria* were defined for 21 river classes defined by the source-of-flow level of the REC (Snelder and Biggs, 2002).

The Snelder et al (2019) study used data obtained from the National Rivers Water Quality Network (NRWQN), which contains 77 sites from 48 large rivers across New Zealand. Limitations of this dataset included the relatively small number of sites, with most sites on large rivers, and periphyton abundance observations as percentage cover of the stream bed rather than the chlorophyll measurement prescribed by the NPS-FM.

Snelder *et al* (2019) tested their TN and DRP criteria using a limited set of periphyton biomass (measured as chlorophyll) and nutrient concentration observations collected by regional councils at ~170 sites across NZ. The test indicated the criteria performed reasonably well but that the testing data could be used to re-calibrate (ie, adjust) the derived TN and DRP concentration criteria to better match the biomass observations at the regional council sites.

The recalibrated Snelder et al (2019) criteria for TN and DRP were provided as tables with REC classes as rows, and maximum periphyton biomass thresholds (defined by the NOF A, B and C bands) as columns. (Note, hereafter, the Snelder et al (2019) outputs are referred to as the original look-up tables.) The original look-up tables were promoted as guidance for setting in-stream concentrations of nitrogen and phosphorus to achieve periphyton target attribute states (Ministry for the Environment, 2020). However, because of the limitations of the original Snelder et al (2019) study, and the improved availability of data collected by regional councils, the Ministry for the Environment undertook a project to derive new criteria.

The look-up tables in this document are based on a new study (Snelder et al, 2021) that derived in-stream nutrient concentrations and exceedance criteria for periphyton biomass objectives using regional council monitoring data. The study aimed to improve on the original look-up tables through:

a) the use of new data from regional council periphyton monitoring programmes

b) the use of periphyton measured as chlorophyll, as specified in the NOF periphyton biomass attribute, rather than data on cover, which needed to be converted to chlorophyll

c) application of a range of statistical methods using the larger dataset.

Under protection risk

The criteria based on the Snelder et al (2019) study, and the new study by Snelder et al (2021), use the concept of under-protection risk.[3]

Under-protection risk (which was referred to in Snelder et al (2019) as 'spatial exceedance criteria' was not a feature of nutrient concentrations and exceedance criteria (*nutrient criteria*) before the 2019 study and is not mentioned by the NPS-FM 2020.

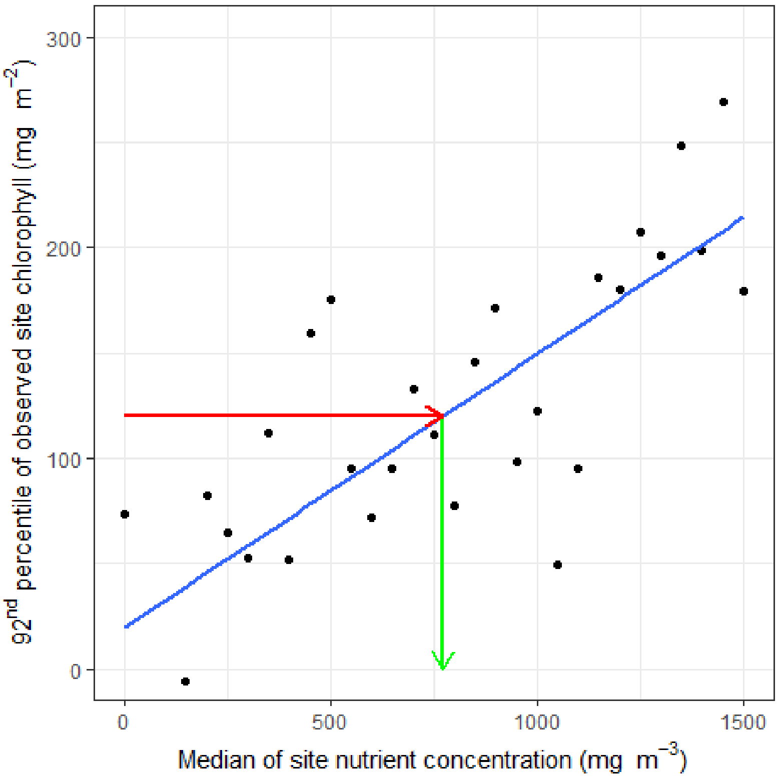
The under-protection risk concept is based on the uncertainty associated with the statistical models underlying the *nutrient criteria* in the look-up tables. In both studies, *nutrient criteria* were defined by inverting periphyton biomass models, that is rearranging the model equation to find the nutrient concentration which is consistent with a defined biomass threshold.

Both studies describe periphyton biomass at different sites as a function of environmental characteristics of those sites, including nutrient concentrations. In both studies, the fitted statistical models were consistent with our general understanding of the accrual and loss processes that determine maximum periphyton biomass in rivers. However, not unexpectedly, the models had large uncertainties. The practical importance of this uncertainty is that when the model is inverted and used to define *nutrient criteria* for sites, those criteria are themselves uncertain. Both the earlier and new *nutrient criteria* are therefore based on a risk-based (or probabilistic) approach rather than relying on biomass predictions in absolute terms. The under-protection risk can be understood as the probability that a randomly chosen site will exceed the designated maximum biomass threshold when it is compliant with the specified nutrient concentration criterion.

The model inversion, criteria uncertainty and probabilistic approach, can be understood conceptually using a graphical representation of nutrient–biomass relationship. Figure 1 is a simple hypothetical statistical regression model in which site biomass is modelled as a function of site nutrient concentration. Each black point represents a pair of observations at a site. The blue line represents the model of the nutrient–biomass relationship that is fitted to the observations. The inversion of the nutrient–biomass model to derive criteria is indicated by the arrows. The horizontal red arrow represents a specified biomass threshold of 120 mg chlorophyll m^{-2}. The nutrient concentration corresponding to this biomass is shown by the vertical green line, which defines the criterion as 772 mg m^{-3}.

[3] Snelder et al (2019) and the previous Ministry for the Environment guidance document use the term 'spatial exceedance criteria' but this has been replaced by 'under-protection risk'. The new term is equivalent to the old term but is intended to emphasise that the risk is the probability that a randomly chosen site will exceed the stated biomass threshold (ie, the site is 'under-protected'). The term 'risk' was introduced because it better conveys there is a subjective choice that needs to be made when choosing the criteria.

Figure 1 **Schematic representation of the derivation of nutrient criteria based on a hypothetical biomass–nutrient model**



Note: The blue line represents a statistical regression model fitted to the data. See text for further explanation.

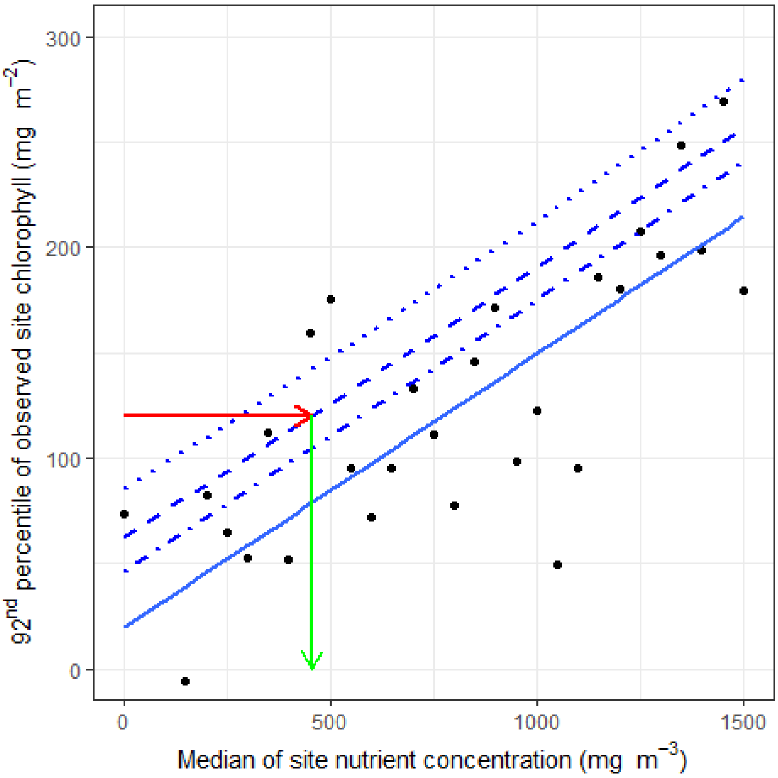
Figure 1 also illustrates uncertainty is associated with the derived nutrient criteria, which is shown by the scatter of observations around the regression line. Uncertainty — due to sampling error and uncontrolled sources of variation — means there is a risk the specified biomass threshold will be exceeded even if the nutrient concentration is held at or below the derived criterion.

Assuming the model errors are normally distributed, uncertainty in the nutrient–biomass model means 50 per cent of sites will exceed the specified biomass threshold at the stated criterion. These sites will be under-protected. In addition, 50 per cent of sites will be below the specified biomass threshold even when the nutrient concentration is higher than the stated criteria. These sites will be over-protected.

A subjective decision might be made that the uncertainty is acceptable because the amount by which the biomass threshold is exceeded at the 50 per cent of under-protected sites is 'small' or ecologically unimportant. However, uncertainties associated with nutrient–periphyton biomass relationships are generally too large to be ignored.

Accounting for under-protection risk is shown in figure 2. The main idea is that a regression model is not simply a single regression line; the model describes the range of values covered by future, or unobserved, cases. This range is described by a probability distribution that is centred on the regression line in figure 1. The probability distribution around the line is determined by the model's residual error. If the model residuals are normally distributed, the probability distribution is symmetrical (the regression line represents the mean of the distribution), and its width (ie, the spread of values either side of the regression line) is related to the model variation explained (figure 2). Therefore, a regression model can be used to predict the entire probability distribution for a specified nutrient concentration.

Figure 2 **Graphical representation of the derivation of hypothetical nutrient criteria showing the fitted statistical regression line (solid blue) and the predicted cumulative probability distribution**



Note: The blue lines (dot-dash, dashed and dotted) above the solid blue line represent the 70th, 80th and 90th percentiles of the predicted response distribution. These lines are used to define nutrient criteria having under-protection risks of 30 per cent, 20 per cent and 10 per cent, respectively. If the acceptable level of under-protection risk is 20 per cent, then the sites above and below the dashed line represent the under-protected and over-protected sites, respectively. See text for further explanation.

The predicted probability distribution can be used to define maximum periphyton biomass thresholds that are not exceeded with specified probabilities. For example, the dot-dash, dashed, and dotted lines shown in figure 2 indicate maximum periphyton biomass levels not exceeded by 70 per cent, 80 per cent and 90 per cent of cases, respectively; in other words, the lines show biomass thresholds at the 70th, 80th and 90th percentiles of the predicted distribution. The probability the biomass thresholds are exceeded is defined by the complement of these percentiles (ie, there are under-protection risks of 30 per cent, 20 per cent and 10 per cent). As an example, the top blue (dotted) line shown in figure 2 represents the 90th percentile of the distribution and defines *nutrient criteria* having an under-protection risk of 10 per cent (ie, a probability that the biomass threshold is exceeded of 10 per cent).

For the hypothetical biomass–nutrient model discussed here, if the under-protection risk is to be 20 per cent, and the acceptable response is 120 mg chlorophyll m^{-2}, the corresponding criterion is defined by the point at which the red arrow shown in figure 2 intersects the line representing the 80th percentile of the predicted distribution (dashed blue line in figure 2). This point is shown in figure 2 by the green arrow, which indicates a criterion of 455 mg m^{-3}.

Note that the nutrient criterion for the under-protection risk of 20 per cent is lower (more stringent) than that defined by the regression line (ie, the solid blue line shown in figure 1) because the tolerance of risk of under-protection is lower. It is noted the risk of over-protection is the complement of the risk of under-protection (ie, over-protection risk = 100 per cent — under-protection risk).

In the probabilistic approach, the *nutrient criteria* are defined so periphyton biomass in excess of a given threshold is restricted to a specified (ie, chosen) probability. For example, for the new *nutrient criteria,* the nutrient concentrations can be chosen so that biomass in excess of the A, B or C band thresholds have probabilities (under-protection risks) of 5 per cent, 10 per cent, 15 per cent and 20 per cent.[4]

It is important to note the locations where biomass will exceed the threshold are not predicted by the *nutrient criteria*. Rather, the probability choices (eg, 5 per cent, 10 per cent, 15 per cent or 20 per cent) indicate that, on average, if nutrient concentrations are kept within the criteria across an area of interest, it can be expected that biomass will exceed the threshold at, respectively, 5 per cent, 10 per cent, 15 per cent or 20 per cent of sites.

The level of under-protection risk that is used to define *nutrient criteria* is not a scientific decision. It is a subjective ('normative') choice for the decision-maker about the level of precaution needed. The NPS-FM is clear that regional councils must decide both the target attribute states for periphyton biomass, and the associated nitrogen and phosphorus criteria to achieve these. **However, the NPS-FM does not mention the additional decision around the 'under-protection risk'. Rather, it directs regional councils to set 'appropriate' concentrations for nutrients.**[5] The use of 'under-protection risk' is currently the best technical solution for defining appropriate nutrient concentrations for rivers because it addresses the problem that *nutrient criteria* cannot be specified such that there is no risk that the biomass threshold will be exceeded. (Refer to section 4 on steps to using the tables.)

This guidance document provides look-up tables for different periphyton under-protection risks of 5 per cent, 10 per cent, 15 per cent and 20 per cent, and for different river types as described by the River Environment Classification (REC).[6]

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4 The Technical Report (Snelder et al 2021) covers under-protection risk down to 30 per cent noting that this entails greater risk to the environment.

5 Section 3.13 NPS-FM (NZ Government 2020).

6 For instructions about looking up REC segment information see Appendix 1.

2: Findings of the 2021 study

This guidance is based on appropriate in-stream nutrient concentrations and exceedance criteria *(nutrient criteria)* produced by the new study (ie, Snelder et al, 2021) because the underlying models were based on the most recent, relevant and comprehensive data, and the models and derived criteria appear to be reasonably robust.

This section summarises findings of the new study that are important in the context of using the look-up tables provided by this guidance including:

- validation of the approach
- saturating concentration and biomass ceiling
- shaded sites.

Approach

The new study developed multi-variable, ordinary, least squares regression (OLS) models (Snelder et al, 2021). These models explained between-site variation in observed maximum periphyton biomass as a function of several environmental variables at the sites, including measures of nutrient concentration, flow regime (hydrological indices), shading, electrical conductivity and temperature. The input data for the models was derived from monitoring at 251 sites from 9 regions across New Zealand. Four models were defined, each with a single and different nutrient form (TN, DIN, TP, DRP).

The relationships represented by the models were consistent with expectations based on a conceptual understanding of the processes of accrual and loss of periphyton. The relationships represented by the models were also consistent with previous modelling studies (eg, Biggs, 2000b; Snelder et al, 2014, 2019).

The four models were inverted and used to derive probabilistic criteria for each of the four nutrient forms as described above. The new study investigated alternative approaches to fitting models and defining *nutrient criteria* for periphyton. However, the study ultimately recommended the use of OLS models and the probabilistic approach that underlies the criteria provided by the original look-up tables.

The new study validated the *nutrient criteria* provided by the new look-up tables by using the National Rivers Water Quality Network (NRWQN) data used by the Snelder et al (2019) study as an independent test dataset. The validation provided confidence the *nutrient criteria* perform well.

Saturating nutrient concentration and biomass ceiling

The new study indicated that, at low concentrations, there is a large increase in periphyton biomass with each unit increase in N and P concentration (blue line, figure 3). However, at higher concentrations, the same unit increase in N and P concentration causes a smaller increase in periphyton biomass. Furthermore, the study indicated a point is reached where the biomass response reaches a ‘ceiling’ (grey dashed line, figure 3) beyond which there is no evidence for any further biomass response to increasing nutrient concentrations.

The new study refers to the nutrient concentration beyond which there is no biomass response as the 'saturating concentration'.[7] Note that Figure 3 is based on the model that had DIN as the nutrient, and the saturating concentration (as site median values) was assessed to be approximately 1000 mg m^{-3} (=1 mg L^{-1}). Approximate saturating concentrations (as site median values) were assessed to be 1000 mg m^{-3} (=1 mg L^{-1}) for TN, 25 mg m^{-3} (=0.025 mg L^{-1}) for DRP and 50 mg m^{-3} (=0.05 mg L^{-1}) for TP. The grey vertical line in Figure 3 indicates the approximate saturating concentration.

The saturating concentration for each nutrient was assessed subjectively taking into account the amount of available data and the predicted response. Note that the data that was used to define the model is indicated by the red 'rugs' on the x and y axis of figure 3. Each vertical or horizontal red line in the rugs represents one of the 251 sites in the fitting dataset.

The rugs on figure 3 indicate most of the data was for sites at which the 92nd percentile of chlorophyll was less than the biomass ceiling and nutrient concentrations were less than the saturating concentration. This pattern was similar across all four nutrients. The relatively low proportion of data points with chlorophyll and nutrient concentrations higher than the ceiling and saturating concentration, respectively, means considerable uncertainty exists regarding their precise values. Note also the blue line in Figure 3 represents the predictions made by the model for one site but the location of the ceiling and saturating concentrations will differ between sites. For example, for a given nutrient concentration, the predicted biomass, and therefore biomass ceilings, will increase with increasing site temperatures and decreasing site frequency of high flows.

The modelled response (blue line) continues to increase with increasing nutrient concentration after the biomass threshold is reached (Figure 3). This is because nutrients are represented in the models by the log (base 10)-transformed site median nutrient concentrations (ie, one of DIN, TN, DRP or TP in each model). The $\log_{10}$ transformation was used because it linearised the relationship between nutrient concentration and biomass. However, this mathematical representation is a simplification that cannot represent the biomass ceiling (ie, the model predictions cannot become constant to represent the nutrient saturation). The model predictions therefore continue to increase after the saturating concentration even though this is likely to be unrealistic.

The new study indicates that, in some REC source-of-flow classes, the biomass ceiling, even at high percentiles of the predicted cumulative probability distribution (eg, the 80th percentile which corresponds to the 20 per cent under-protection risk) may be lower than the NOF B and C band thresholds of 120 mg chlorophyll m^{-2} and 200 mg chlorophyll m^{-2}**. In other words, the models indicate factors other than nutrient concentration limit the maximum biomass in these REC classes so that thresholds will not be reached, no matter how high the nutrient concentration**. This is shown in Figure 3 by the grey, dashed horizontal line being below the 200 mg chlorophyll m^{-2} threshold (red line). This indicates that, in some REC source-of-flow classes, it is unlikely some thresholds (B or C) will be exceeded because of nutrient enrichment.

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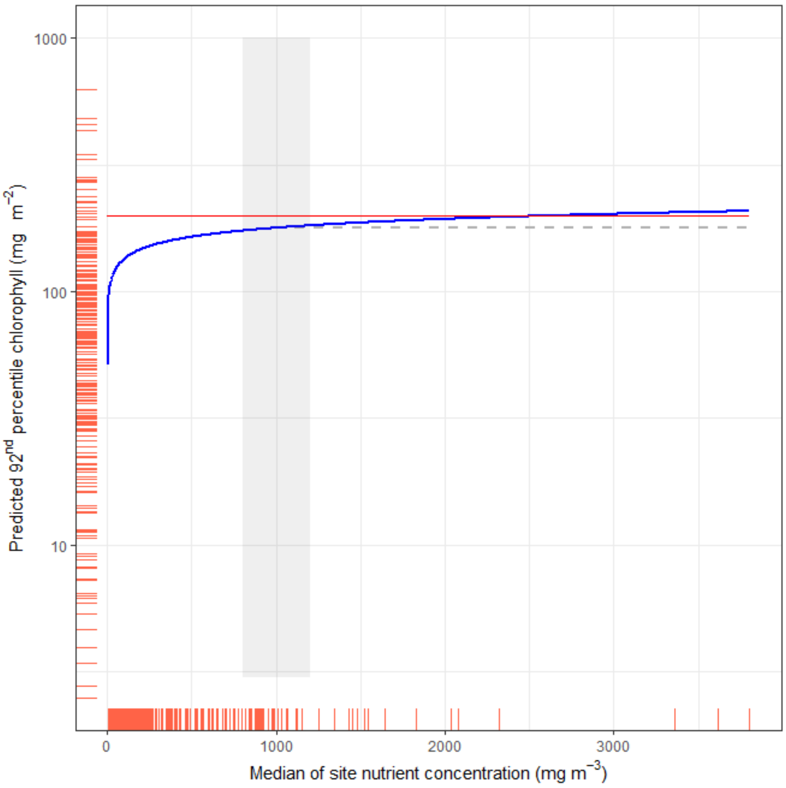
7 Saturation of periphyton growth occurs when a nutrient concentration increases to a point at which another growth-critical factor becomes limiting and growth rates no longer respond to further increases in nutrient concentration. This phenomenon is well established, in particular for nitrogen (Earl et al, 2006; Mulholland et al, 2008), as is the associated maximum biomass (ie, the 'ceiling') (eg, Dodds et al, 2006, reported average maximum chlorophyll at saturating concentrations for TN of 150 mg m^{-2}). In the Snelder et al (2021) study, the saturating concentrations were subjectively assessed and are uncertain. However, the assessed saturating concentrations are reasonably consistent with values reported in the literature (eg, Dodds, 2006; Keck and Lepori, 2012).

Figure 3 **Example of the predicted 92nd percentile chlorophyll for a single site based on the regression model as a function of nutrient concentration (blue line)**



Note: The predictions and nutrient concentrations in this figure pertain to the model that used DIN as the nutrient. The predictions represent the 80th percentile of the predicted probability distribution for a site having the mean value of each predictor from the fitting data set. Similar responses were produced by the TN, DRP and TP models. The grey vertical line indicates the subjectively assessed approximate saturating concentration. The red horizontal line indicates a biomass of 200 mg m^{-2}. The dashed grey line represents the subjectively assessed biomass ceiling (where the dose-response relationship between periphyton biomass and nutrient concentration slows down). The red 'rug' indicates the density of the data that was used to define the model on both axes. An important point is that the saturating concentration is defined where the nutrient concentration axis is well-informed by the data and where the response curve is flattening.

When the models were inverted and used to derive the *nutrient criteria* in the new study, predictions of biomass were obtained for the observed range of site median values for each nutrient form. Therefore, for each nutrient, the maximum possible value for a criterion is the maximum observed site median nutrient concentration, which was 4500, 3800, 300 and 230 mg m^{-3} for TN, DIN, TP and DRP, respectively.

The combination of the maximum of the observed site median nutrient concentrations and biomass ceiling produced three types of outcomes when the models were inverted to derive *nutrient criteria*. These cases are shown schematically on figure 4 as cases A, B and C.

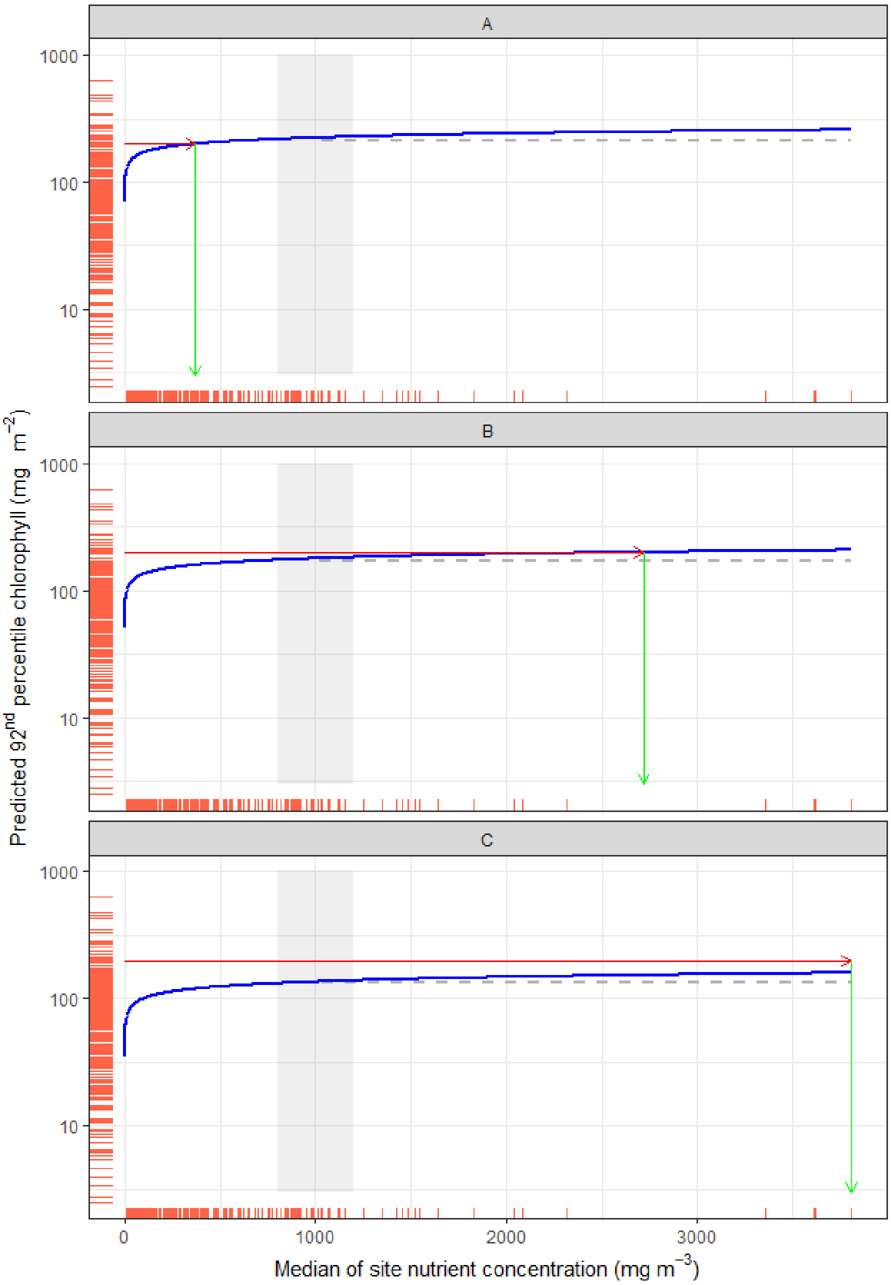
- For case A, the biomass threshold is less than the biomass ceiling and therefore the assessed criterion is less than the saturating concentration. Confidence in the criterion is highest for case A because it is associated with model predictions that are well represented by the data, the biomass threshold is lower than the assessed biomass ceiling, and the nutrient exceedance criterion is less than the saturating concentration.
- For case B, the biomass threshold is greater than the biomass ceiling but is predicted by the model to occur at a nutrient concentration that is less than the maximum observed site median.

- For case C, the biomass threshold is greater than the biomass ceiling but is not reached by the model predictions even at a nutrient concentration equal to the maximum observed site median.

Cases B and C mean the look-up tables have *nutrient criteria* that are greater than the saturating concentration, and care is needed in interpreting these. Confidence in the criteria is low for case B, and particularly case C, because the model predictions are poorly represented by the data. (Note the criteria for these cases are informed by few data points as indicated by the rugs on the x axes in figure 4.) In addition, there is low confidence the model predictions beyond the saturating concentration reflect the likely biomass response because these are greater than the biomass ceiling (ie, the prediction is the consequence of the mathematical representation that is a simplification that cannot represent the biomass ceiling).

The complication is that the exact saturating concentration and biomass ceiling cannot be known with certainty and can be expected to be variable across sites. The *nutrient criteria* based on the models (ie, the numbers in the look-up tables) are therefore the best indication that is achievable but confidence in these decreases the greater the amount these values exceed the approximately assessed, saturating concentrations.

Figure 4 **Schematic representation of the three possible outcomes for nutrient criteria produced by the Snelder et al (2021) study**



Note: See figure 3 caption for explanation of the features on the plots. For case A, a nominated biomass threshold of 200 mg m^{-2} is less than the biomass ceiling and therefore the assessed nutrient criteria is less than the saturating concentration. For case B, the biomass threshold of 200 mg m^{-2} is greater than the estimated biomass ceiling, but the model predicts that this biomass threshold is reached within the range of the modelled nutrient concentrations, but greater than the saturating concentration. For case C, the model predicts that the biomass threshold of 200 mg m^{-2} is not reached within the range of the modelled nutrient concentrations.

The effect of shading

The data used in the new study made it possible to define *nutrient criteria* for ‘shaded’ and ‘unshaded’ locations. The *nutrient criteria* are always higher for shaded sites as this reflects the importance of light and temperature in the growth of periphyton. This means the new *nutrient criteria* could be used to investigate the use of shading to achieve target attribute states (ie, riparian planting). The use of shade to achieve periphyton target attribute states is limited because wide rivers, lakes and estuaries cannot be shaded.

The new study used a range of methods to evaluate shade at the monitoring sites so it was not possible to include shade as a continuous variable (ie, per cent shade, as described by Harding et al, 2009). Instead, the available data were reduced to a binary variable: shaded sites (> 20 per cent shade) and unshaded sites (< 20 per cent shade). In this study, the shaded category includes sites shaded by varying amounts of overhanging riparian vegetation and by topographic features (eg, steep valley sides, especially for streams-oriented east to west). Examples of such sites are illustrated in figure 19 in Harding et al (2009). Unshaded sites are therefore restricted to largely open sites, including sites in large rivers.

3: Look-up tables of nutrient criteria for managing periphyton

Tables 1 to 4 below provide the *nutrient criteria* to achieve maximum biomass thresholds specified by NOF A, B and C bands. The criteria are provided for TN, DIN, TP and DRP for shaded and unshaded rivers belonging to 21 River Environment Classification (REC) source-of-flow classes. Note the model outputs for some source of flow classes at some under-protection risks have output values below reference state conditions. These values are shown by grey cells in the tables below. See 'resolution of *nutrient criteria*' in Section 4: *How to use the look-up tables* for information on how to interpret these values and set *nutrient criteria* for those specific under-protection risk and periphyton biomass combinations.

Table 1 **TN criteria as median concentrations (mg m^{-3}) to achieve the NOF A, B and C bands (chlorophyll thresholds of 50, 120 and 200 mg m^{-2}, respectively) at under-protection risks of 5 per cent, 10 per cent, 15 per cent and 20 per cent, for unshaded and shaded sites**

Table 1.1 Unshaded sites												
	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	6	570	4176	27	2089	4490	70	3498	4500	146	4153	4500
CX/M	4	382	3599	18	1416	4432	46	2639	4498	97	3554	4500
CX/H	3	252	3047	12	978	3980	30	2113	4303	64	3026	4454
CX/L	2	195	3127	9	774	4215	23	1894	4368	50	3205	4447
CX/Lk	2	219	2799	10	834	3998	25	1846	4327	52	2749	4457
CW/GM	1	66	1390	2	254	4115	7	623	4500	14	1269	4500
CW/M	2	154	2135	6	568	4090	17	1175	4457	35	2017	4499
CW/H	1	47	885	2	183	2419	5	420	3512	11	809	4044
CW/L	1	28	625	1	112	1833	3	278	2936	6	563	3527
CW/Lk	1	56	1183	2	221	3142	6	545	4170	12	1088	4326
CD/M	1	121	1934	5	466	4006	13	1057	4442	27	1819	4497
CD/H	1	57	910	3	223	2155	6	497	3054	13	858	3668
CD/L	1	7	182	1	31	694	1	79	1480	2	164	2252
CD/Lk	1	61	1272	3	241	2765	6	600	3812	14	1202	4184
WX/L	1	33	749	1	134	2476	3	335	3722	7	680	4273
WX/H	1	45	1009	2	179	2926	5	441	3732	10	899	4250
WW/H	1	26	609	1	105	2109	3	263	3517	6	538	4007
WW/L	1	23	541	1	95	1786	3	245	3071	5	505	3642
WW/Lk	1	36	868	2	162	2573	4	434	3790	10	912	4218
WD/L	1	13	312	1	61	976	2	173	1654	4	359	2154
WD/Lk	1	27	662	2	121	1805	3	323	2869	7	694	3527

Table 1.2 Shaded sites												
	5%			10%			15%			20%		
REC class	**A band**	**B band**	**C band**	**A band**	**B band**	**C band**	**A band**	**B band**	**C band**	**A band**	**B band**	**C band**
CX/GM	32	2335	4496	130	4072	4500	327	4420	4500	678	4495	4500
CX/M	21	1599	4457	86	3426	4500	217	4188	4500	451	4449	4500
CX/H	14	1120	4050	57	2888	4436	145	3626	4499	302	4019	4500
CX/L	10	891	4254	43	2938	4432	112	3994	4496	237	4236	4500
CX/Lk	11	975	4055	47	2595	4436	118	3599	4500	244	4033	4500
CW/GM	3	303	4342	13	1137	4500	33	2580	4500	68	4271	4500
CW/M	8	657	4200	32	1867	4496	80	3255	4500	165	4155	4500
CW/H	2	216	2632	9	735	3975	24	1587	4356	50	2517	4459
CW/L	2	134	2034	6	512	3460	14	1162	3924	30	1917	4192
CW/Lk	3	263	3400	11	981	4306	28	2045	4437	59	3284	4490
CD/M	6	545	4127	24	1682	4495	62	3120	4500	130	4073	4500
CD/H	3	258	2315	12	787	3576	30	1486	4128	63	2239	4365
CD/L	1	36	806	2	147	2136	4	368	2964	8	744	3529
CD/Lk	3	283	2972	12	1073	4134	31	2038	4401	66	2864	4468
WX/L	2	159	2753	6	614	4209	17	1447	4491	36	2611	4500
WX/H	2	216	3116	9	819	4167	22	1946	4500	47	3016	4500
WW/H	1	127	2383	5	489	3953	13	1198	4379	27	2225	4495
WW/L	1	110	2006	4	444	3580	12	1048	3937	26	1892	4132
WW/Lk	2	176	2752	7	750	4143	21	1645	4362	47	2807	4433
WD/L	1	62	1048	3	285	2051	8	633	2633	20	1063	3089
WD/Lk	2	132	1947	6	570	3447	15	1237	3941	35	1901	4146

Note: All values are specified in terms of median concentrations.

Table 2 DIN criteria as median concentrations (mg m^{-3}) to achieve the NOF A, B and C bands (chlorophyll thresholds of 50, 120 and 200 mg m^{-2}, respectively) at under-protection risks of 5 per cent, 10 per cent, 15 per cent and 20 per cent, for unshaded and shaded sites

Table 2.2: Unshaded sites

	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	2	514	3674	8	2254	3800	30	3296	3800	83	3655	3800
CX/M	1	323	3380	5	1508	3787	19	2681	3800	52	3334	3800
CX/H	1	186	2836	3	1067	3465	11	2199	3700	30	2798	3784
CX/L	1	112	3077	2	709	3612	6	2039	3713	18	3079	3784
CX/Lk	1	156	2759	3	894	3520	8	1911	3738	23	2689	3799
CW/GM	1	27	1536	1	170	3787	1	573	3800	3	1372	3800
CW/M	1	93	2217	2	477	3646	5	1148	3793	13	2078	3800
CW/H	1	21	845	1	118	2322	2	337	3149	3	762	3510
CW/L	1	9	543	1	58	1677	1	196	2602	2	483	3008
CW/Lk	1	23	1161	1	146	3150	2	486	3597	3	1058	3702
CD/M	1	58	1923	1	347	3563	3	940	3788	8	1782	3800
CD/H	1	26	754	1	148	1882	2	375	2651	4	705	3155
CD/L	1	2	87	1	8	497	1	28	1214	1	76	1893
CD/Lk	1	21	1150	1	138	2533	2	470	3307	3	1077	3588
WX/L	1	9	611	1	62	2385	1	214	3312	2	541	3701
WX/H	1	14	938	1	91	2672	1	310	3284	2	810	3729
WW/H	1	7	466	1	44	2095	1	150	3114	1	397	3439
WW/L	1	5	346	1	34	1545	1	120	2655	1	318	3075
WW/Lk	1	8	600	1	61	2297	1	231	3244	2	631	3622
WD/L	1	3	155	1	18	666	1	73	1244	1	200	1678
WD/Lk	1	5	366	1	38	1311	1	143	2272	1	405	2916

Table 2.2: Shaded sites												
	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	12	2563	3800	77	3638	3800	267	3788	3800	719	3800	3800
CX/M	7	1782	3793	48	3296	3800	167	3725	3800	451	3792	3800
CX/H	4	1310	3532	27	2765	3781	97	3254	3800	264	3506	3800
CX/L	2	918	3643	16	3005	3781	58	3487	3800	160	3632	3800
CX/Lk	3	1128	3590	21	2638	3797	75	3315	3800	200	3571	3800
CW/GM	1	233	3796	3	1297	3800	11	3279	3800	31	3793	3800
CW/M	2	600	3715	12	2005	3800	43	3304	3800	114	3691	3800
CW/H	1	155	2572	3	725	3490	9	1641	3719	25	2470	3777
CW/L	1	80	1941	2	461	2987	4	1085	3335	11	1827	3561
CW/Lk	1	201	3356	3	1008	3688	10	2259	3790	27	3295	3800
CD/M	2	452	3652	7	1701	3800	26	3134	3800	71	3618	3800
CD/H	1	188	2070	4	671	3124	12	1361	3544	32	2004	3706
CD/L	1	11	636	1	71	1846	1	242	2544	2	580	3006
CD/Lk	1	185	2784	3	1012	3569	10	1894	3734	26	2682	3782
WX/L	1	86	2655	2	510	3688	4	1481	3800	12	2556	3800
WX/H	1	128	2851	2	774	3711	6	2039	3800	16	2783	3800
WW/H	1	61	2437	1	377	3412	3	1186	3768	8	2294	3798
WW/L	1	45	1840	1	289	3050	2	866	3336	6	1732	3494
WW/Lk	1	75	2495	1	529	3538	4	1463	3721	12	2529	3757
WD/L	1	19	759	1	151	1619	2	421	2141	5	774	2550
WD/Lk	1	45	1494	1	330	2882	3	872	3320	8	1456	3492

Note: All values are specified in terms of median concentrations.

Table 3 TP criteria as median concentrations (mg m^{-3}) to achieve the NOF A, B and C bands (chlorophyll thresholds of 50, 120 and 200 mg m^{-2}, respectively) at under-protection risks of 5 per cent, 10 per cent, 15 per cent and 20 per cent, for unshaded and shaded sites

Table 3.1 Unshaded sites

	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	0	53	283	1	186	300	3	256	300	9	287	300
CX/M	0	41	281	0	161	300	2	246	300	7	284	300
CX/H	0	26	244	0	132	289	1	208	298	4	247	300
CX/L	0	17	268	0	120	293	1	234	299	2	270	300
CX/Lk	0	14	202	0	81	276	1	157	292	2	207	297
CW/GM	0	3	161	0	22	299	0	75	300	0	173	300
CW/M	0	8	206	0	46	296	0	122	300	1	216	300
CW/H	0	2	101	0	15	219	0	48	267	0	104	286
CW/L	0	1	58	0	6	158	0	24	216	0	58	242
CW/Lk	0	1	87	0	10	221	0	38	281	0	91	295
CD/M	0	3	124	0	21	277	0	64	299	0	132	300
CD/H	0	1	46	0	9	132	0	24	195	0	48	237
CD/L	0	0	6	0	0	39	0	2	93	0	6	139
CD/Lk	0	0	55	0	5	185	0	21	254	0	61	277
WX/L	0	1	104	0	10	233	0	41	287	0	105	299
WX/H	0	1	142	0	15	243	0	58	290	0	144	300
WW/H	0	1	73	0	6	223	0	26	256	0	73	285
WW/L	0	0	44	0	4	159	0	16	222	0	45	247
WW/Lk	0	0	56	0	5	171	0	23	233	0	63	271
WD/L	0	0	12	0	1	50	0	7	91	0	17	120
WD/Lk	0	0	27	0	2	99	0	11	176	0	33	220

Table 3.2 Shaded sites												
	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	0	184	300	6	277	300	25	298	300	72	300	300
CX/M	0	161	300	4	273	300	18	298	300	53	300	300
CX/H	0	131	289	2	234	300	11	273	300	35	290	300
CX/L	0	118	293	1	261	300	7	285	300	23	293	300
CX/Lk	0	82	275	1	188	295	6	245	299	18	279	300
CW/GM	0	23	299	0	127	300	1	295	300	3	300	300
CW/M	0	48	296	1	181	300	3	276	300	9	297	300
CW/H	0	16	221	0	83	281	1	165	294	2	223	298
CW/L	0	7	160	0	45	234	0	104	259	1	162	277
CW/Lk	0	10	220	0	69	291	0	151	299	1	227	300
CD/M	0	22	277	0	103	300	1	222	300	3	280	300
CD/H	0	9	132	0	38	221	0	85	265	1	138	286
CD/L	0	0	40	0	4	123	0	16	175	0	41	215
CD/Lk	0	5	186	0	41	272	0	123	288	1	190	297
WX/L	0	11	235	0	80	296	0	180	300	1	237	300
WX/H	0	16	245	0	114	299	0	205	300	2	246	300
WW/H	0	7	225	0	53	273	0	152	299	1	227	300
WW/L	0	4	161	0	32	239	0	96	261	0	164	273
WW/Lk	0	4	169	0	43	247	0	117	291	1	177	296
WD/L	0	1	49	0	10	108	0	29	147	0	53	176
WD/Lk	0	2	99	0	21	208	0	60	246	0	103	263

Note: All values are specified in terms of median concentrations.

Table 4 DRP criteria as median concentrations (mg m^{-3}) to achieve the NOF A, B and C bands (chlorophyll thresholds of 50, 120 and 200 mg m–2, respectively) at under-protection risks of 5 per cent, 10 per cent, 15 per cent and 20 per cent, for unshaded and shaded sites

Table 4.1 Unshaded sites

	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	0	7	104	0	31	181	1	76	214	2	121	225
CX/M	0	10	129	0	41	210	1	92	227	3	148	230
CX/H	0	9	126	0	41	196	1	94	217	3	142	226
CX/L	0	9	144	0	42	212	1	105	225	3	166	229
CX/Lk	0	4	75	0	20	137	1	51	174	1	86	198
CW/GM	0	1	34	0	7	114	0	18	214	0	40	229
CW/M	0	2	44	0	10	134	0	25	194	1	51	216
CW/H	0	1	32	0	6	99	0	17	154	0	37	189
CW/L	0	1	15	0	3	53	0	8	97	0	17	135
CW/Lk	0	1	18	0	3	65	0	9	114	0	21	153
CD/M	0	0	9	0	2	38	0	5	87	0	11	145
CD/H	0	0	4	0	1	15	0	2	37	0	4	65
CD/L	0	0	2	0	0	7	0	1	19	0	2	40
CD/Lk	0	0	4	0	1	16	0	2	43	0	4	81
WX/L	0	1	30	0	6	101	0	16	156	0	35	188
WX/H	0	1	32	0	6	121	0	16	181	0	36	210
WW/H	0	1	16	0	3	69	0	8	138	0	19	178
WW/L	0	0	8	0	2	35	0	4	73	0	10	112
WW/Lk	0	0	7	0	1	30	0	4	62	0	8	93
WD/L	0	0	1	0	0	3	0	0	9	0	1	18
WD/Lk	0	0	1	0	0	5	0	0	13	0	1	29

Table 4.2 Shaded sites												
	5%			10%			15%			20%		
REC class	A band	B band	C band	A band	B band	C band	A band	B band	C band	A band	B band	C band
CX/GM	0	22	167	1	85	217	3	141	228	7	179	230
CX/M	0	31	200	2	104	228	4	173	230	10	208	230
CX/H	0	30	186	1	104	220	4	162	227	10	194	229
CX/L	0	30	204	1	118	227	4	186	230	10	210	230
CX/Lk	0	15	126	1	58	180	2	103	206	5	134	218
CW/GM	0	5	91	0	22	223	1	57	230	1	104	230
CW/M	0	7	114	0	30	201	1	73	222	2	128	229
CW/H	0	5	83	0	21	164	1	53	201	1	93	217
CW/L	0	2	43	0	9	107	0	25	152	1	49	178
CW/Lk	0	2	52	0	11	123	0	30	173	1	60	206
CD/M	0	1	29	0	6	100	0	16	172	0	34	214
CD/H	0	0	12	0	2	43	0	6	83	0	14	123
CD/L	0	0	5	0	1	23	0	3	57	0	6	99
CD/Lk	0	0	12	0	2	50	0	6	103	0	14	151
WX/L	0	4	84	0	20	164	0	51	203	1	94	218
WX/H	0	4	98	0	20	189	0	54	221	1	111	230
WW/H	0	2	53	0	10	150	0	28	189	1	61	207
WW/L	0	1	27	0	5	82	0	15	131	0	31	167
WW/Lk	0	1	23	0	4	69	0	12	110	0	27	138
WD/L	0	0	2	0	0	10	0	1	26	0	3	46
WD/Lk	0	0	3	0	1	16	0	2	43	0	4	89

Note: All values are specified in terms of median concentrations.

4: How to use the look-up tables

This section describes the use of the look-up tables to derive *nutrient criteria* for managing target periphyton attribute states.

Tables 1 to 4 in Section 3 contain the *nutrient criteria* that correspond to the periphyton thresholds which define the three NOF bands. These are taken directly from Snelder et al (2021).

The table columns refer to the biomass threshold as NOF bands A, B and C (ie, 50 mg chlorophyll m^{-2}, 120 mg chlorophyll m^{-2}, 200 mg chlorophyll m^{-2}) for four sets of under-protection risk (5 per cent, 10 per cent, 15 per cent and 20 per cent). The rows refer to the 21 River Environment Classification (REC) source-of-flow classes. Separate tables are provided for shaded and unshaded river sites.

The following principles should be understood before using the tables:

- The look-up tables are intended to be starting points for defining nutrient concentration criteria, not as a mandated method for setting *nutrient criteria,* and are uncertain.
- The *nutrient criteria* should be interpreted as applying to a population of sites – they cannot be meaningfully interpreted for individual sites in isolation.
- The criteria are provided for two forms of nitrogen and phosphorus. The NPS-FM requires, at a minimum, in-stream nutrient concentrations and exceedance criteria for DIN and DRP. However, the criteria for TN and TP may be useful for analyses supporting other parts of the NOF process.
- The resolution of the look-up tables is set by the NOF bands and REC source-of-flow classes. When deriving *nutrient criteria*, measured values of current state for periphyton should be rounded to the closest band.
- The criteria do not account for growth limitation by nitrogen or phosphorus; therefore, it should be assumed compliance with criteria for both nitrogen and phosphorus is required to achieve the target periphyton attribute state.
- *Nutrient criteria* much higher than the saturating concentrations need to be treated cautiously.

The following sub-sections expand on the above points and then provide guidance for using the tables, and assessing confidence in the obtained *nutrient criteria* and their application.

Purpose of the look-up tables

The look-up tables are intended to be starting points for defining *nutrient criteria* for managing target periphyton attribute states. They should not be considered as definitive or a mandated method for setting *nutrient criteria* for at least two reasons:

1. While the look-up tables are based on the most recent and complete data and modelling, the derived *nutrient criteria* are uncertain. This means, for a stated under-protection risk, the proportion of sites that will exceed the biomass threshold when concentrations are held to the criteria is uncertain.
2. There are other ways *nutrient criteria* could be derived and, in some circumstances, those alternatives would be justifiable and sensible. For example, alternative *nutrient criteria* may be justified where managing periphyton involves interventions other than nutrient or shade management. Thus, in rivers with regulated flows it may be possible to manage

maximum biomass by releasing high flows from a reservoir. In this type of situation, bespoke *nutrient criteria* would be required.

Interpreting the nutrient criteria

It is important to interpret the *nutrient criteria* and the associated under-protection risk as applying to populations of sites. The *nutrient criteria* ensure the proportion of a population of sites that exceeds the nominated biomass threshold is equal to the nominated under-protection risk. Hypothetically, if a population of sites had nutrient concentrations equal to the criterion for a nominated biomass threshold, a proportion of those sites would be expected to have biomass greater than the threshold with the remaining sites expected to have biomass lower than threshold. The proportion expected to have biomass greater than the threshold is defined by the under-protection risk and the remainder is the complement of this (ie, 100 minus under-protection risk).

Because the *nutrient criteria* apply to populations of sites, they cannot be meaningfully interpreted based on observations of biomass and nutrient concentrations at individual sites. Two scenarios illustrate this point.

1. If a site has a nutrient concentration equal to the look-up table's nutrient criterion but a biomass higher than the threshold, it is incorrect to infer the criterion is inaccurate. This outcome is expected to occur because the look-up table's *nutrient criteria* allow a proportion of sites in the population to exceed the threshold (ie, these sites are under-protected).
2. If a site has a biomass lower than the threshold but a concentration higher than the look-up table's nutrient criterion, it is also incorrect to infer the criterion is inaccurate. This outcome is expected to occur because the *nutrient criteria* assume that a proportion of sites in the population will not exceed the threshold (ie, these sites are over-protected).

Only monitoring of periphyton can confirm the actual biomass at a site and therefore the site's grading relative to the periphyton attribute.

If a nutrient concentration at an individual site exceeds a nutrient criterion in the tables, the correct interpretation is that the risk of the nominated biomass threshold being exceeded at that site (ie, the risk of the site failing to achieve the target attribute state) is higher than the nominated under-protection risk. However, exceeding the nutrient criterion does not mean the site will exceed the biomass threshold. Hypothetically, if a group of sites had nutrient concentrations equal to the nutrient criterion for a nominated biomass threshold, a proportion of those sites would be expected to have biomass greater than the threshold with the remaining sites having biomass lower than the threshold. The proportion expected to have biomass greater than the threshold is defined by the under-protection risk and the remainder is the complement of this (ie, 100 minus under-protection risk).

Form of nutrient

Section 3.13 in the NPS-FM specifies that: "To achieve a target attribute state for periphyton … every regional council must, at a minimum, set appropriate instream concentrations and exceedance criteria for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP)."

Although *nutrient criteria* for only DIN and DRP are mandated by the NPS-FM, Snelder et al (2021) also provide look-up tables for TN and TP for two main reasons. First, models describing maximum periphyton biomass based on the total forms of N and P often have better performance than the dissolved forms of the nutrients. Where models have better performance, this gives more confidence in the derived *nutrient criteria*. In the Snelder et al (2021) study the models for TN and DIN had similar performance but the TP model performed significantly better than the DRP model.

Second, water quality modelling is often carried out as part of the development actions and limits to achieve target attribute states for periphyton, and other attributes. Water quality models account for the generation, transport and transformation of nitrogen and phosphorus in catchments and generally account for total nitrogen and phosphorus (ie, the sum of all forms). It can be useful therefore to have *nutrient criteria* defined in terms of TN and TP because this is consistent with the modelled loads and concentrations.

Resolution of the nutrient criteria

The look-up tables provide a realistic level of resolution by restricting the target attribute states to the NOF A, B and C bands, and by restricting discrimination of spatial variation in relevant environmental characteristics of New Zealand's rivers to that described by 21 REC source-of-flow classes. Uncertainties associated with the derivation of the look-up tables mean that increasing the resolution of the target attribute states, or spatial variation in river character, is unlikely to be statistically justifiable.

Limits to resolution of the data and models underlying the look-up tables also means that *nutrient criteria* given by some cells in the look-up tables for DRP and TP are zero. The zero values occur because the underlying models predict that the biomass threshold is exceeded even when the nutrient concentration is zero. **The look-up table cells with zero values should be interpreted as being combinations of biomass threshold and under-protection risk that are unrealistic even when rivers are in a natural or reference state**. Therefore, in-stream nutrient concentrations and exceedance criteria cannot be set in this case using the national look-up tables. Councils must derive their own *nutrient criteria* for DIN and DRP using best available information (refer to NPS-FM, Clause 1.6). A suggestion is to set *nutrient criteria* based on estimated reference state. Estimates of reference state for REC source-of-flow classes are provided by (McDowell et al, 2013.)

NOF bands are communication shorthand to convey the idea the decision-maker must choose a target attribute state within a range of possible options. Conceptually, however, target attribute states can be set at a single numeric level, rather than a NOF band. For example, a target attribute state could be set at 70 mg m^{-2} (which falls within the range of the B band). In addition, the requirement to maintain and improve (policy 5 of the NPS-FM) means that target attribute states cannot be set to be worse than current state. Therefore, conceptually, a site cannot have a target attribute state of the B band (which is between 50 and 120 mg chlorophyll m^{-2}) if its measured state is currently 70 mg m^{-2}. However, due to the uncertainty inherent in measuring current state and setting *nutrient criteria*, it is not realistic to expect criteria in the look-up table can be provided at a level of precision greater than that defined by the NOF bands.

In situations where the current state for periphyton is measured and *nutrient criteria* are required, it is suggested the current state is rounded to the closest band. For example, if a *nutrient criterion* is needed for a site with a measured current state of 70 mg m^{-2}, the closest band boundary is the bottom of the A band (50 mg m^{-2}); *nutrient criteria* for the A band would therefore be appropriate. In cases where the *current state is to be maintained,* the *nutrient criteria* may need to be adjusted from the nearest band to fit the periphyton biomass objectives measured at site. This may be done at local scale using the same methodology in Snelder et al (2021) and the dataset of all regional council data, or other appropriate local data.

Limiting nutrient

Growth rates in the algae in periphyton – and, consequently, accrual rates of periphyton biomass – depend on the interaction between multiple resources, each of which can limit growth when in short supply. In particular, the two major nutrients, N and P, interact. If concentrations of one (eg, P) are low enough to limit algal growth, increasing concentrations of the other (ie, N) may not cause growth rates (and therefore biomass) to increase.

Patterns of nutrient limitation in rivers are complex and typically vary over time (following seasonal and flow-driven fluctuations in nutrient concentrations) and space (following variability of nutrient concentrations along rivers). Robust determination of N or P limitation of periphyton biomass generally requires field experiments. Such experiments can identify whether N and/or P are limiting periphyton growth (and biomass) but the result applies only to the time of the experiment and the particular environmental conditions.

Because of this complexity, the *nutrient criteria* do not account for any interaction between N and P. The possibility that low (ie, growth-limiting) concentrations of N or P at a site might lead to lower maximum biomass than expected (given the concentration of the other nutrient) is part of the uncertainty seen in the four relationships (ie, between chlorophyll and each of DIN, TN, DRP and TP, along with other covariates that affect chlorophyll). **Therefore, it should be assumed that compliance with criteria for both nitrogen and phosphorus is required to achieve the target periphyton attribute state.**

Nutrient criteria greater than the saturating concentration

The look-up tables contain criteria for all nutrient forms that are greater than the assessed saturating concentrations of approximately 1000 mg m^{-3} for TN and DIN, 25 mg m^{-3} for DRP and 50 mg m^{-3} for TP. While these saturating concentrations are uncertain, some *nutrient criteria* are considerably higher than these approximate values.

From a practical perspective, a nutrient criterion much higher than the saturating concentration indicates that nutrient enrichment may not cause the biomass threshold to be reached or exceeded because of physical controls on biomass. However, the outcome of nutrient enrichment is highly uncertain in these situations and care is needed in interpreting the *nutrient criteria* in the look-up tables.

Where biomass is subject to physical controls (like low-temperature and high-flow variability), it is also likely the *nutrient criteria* are much higher than current state. In addition, high *nutrient criteria* may also exceed acceptable levels to achieve other attribute states, either at the site being considered or in downstream receiving environments. These situations are discussed below in the sub-section: *Applying the nutrient criteria*.

In situations where current periphyton biomass is unacceptably high, it is likely reduction in biomass will not be achieved unless current nutrient concentrations are reduced below the saturating levels. This means where current maximum periphyton biomass is unacceptably high and the look-up tables indicate that *nutrient criteria* are considerably higher than the saturating concentration, the desired maximum periphyton biomass is unlikely to be achieved by the criterion in the look-up table (ie, concentrations would need to be lowered to the saturating level).

Nutrient criteria for shaded sites

The *nutrient criteria* for shaded sites might be selected for sites that have existing shade, or in situations where riparian management to provide shade is planned. Davies-Colley et al (2009) provide useful information on whether it is feasible for riparian shading to limit periphyton.

Steps to using the tables

1: Select an appropriate periphyton biomass threshold and under-protection risk for a site

The first steps in deciding on *nutrient criteria* are to nominate a biomass threshold and under-protection risk.

The biomass threshold adopted is a management decision based on the NOF process. An adopted biomass threshold in a regional plan is referred to by the NPS-FM as the target attribute state. However, during the development of a regional plan, a range of choices of thresholds may be considered (eg, from A through to C band), depending on the baseline or current state (noting the NPS-FM requirement to at least maintain current state), and the impact of each choice then evaluated.

The NPS-FM does not mention under-protection risk, but regional councils are directed to set 'appropriate' nutrient concentrations to achieve target attribute states. The under-protection risk is a pragmatic technical solution to uncertainty inherent in the statistical models underlying the *nutrient criteria* and therefore that there is no single 'appropriate nutrient concentration and exceedance criteria'. Rather, the models describe the probability that a maximum biomass threshold will be exceeded along a range of nutrient concentrations. Selection of an under-protection risk is a way of defining an appropriate (and absolute) *nutrient criterion* by fixing the probability that the threshold will be exceeded. Fixing the probability requires making a choice about the risk that the target attribute state will not be achieved. The under-protection risk does not affect the adopted target attribute state for periphyton biomass itself, or requirements to achieve it (ie, limiting resource use and responding to degradation); it only affects the requirement to set *nutrient criteria* to achieve that target periphyton biomass.

Precise guidance on selecting the under-protection risk cannot be given, however councils should provide the demonstrable process that sets out how and why they made their under-protection risk decision. In broad terms, the risk a council adopts should be linked to the environmental outcomes it requires, and the values of the resources it is managing, with lower under-protection risk being adopted in places with higher value and vice versa. As for the biomass threshold, during the development of a regional plan, councils may consider a range of choices of under-protection risk and evaluate the impact of each choice.

The choice of biomass threshold and under-protection risk will be site specific. At the completion of this step, you will have a set of biomass thresholds and under-protection risks pertaining to the sites under consideration.

2: Obtain nutrient criteria from the tables

The *nutrient criteria* are obtained in two further steps:

1. Obtain the REC source-of-flow class for the site using a geographic information system (GIS). Online instructions for how to do this are set out in appendix 1. Other methods

based on GIS analysis and the REC spatial dataset are available and often used in technical processes such as those the support regional plan development.

2. Assign the site a shade status using the definition set out in the Section 2: The effect of shading, then refer to the unshaded sites or shaded sites tables as appropriate.

The *nutrient criteria* corresponding to each biomass threshold and under-protection risk of interest for each nutrient (DIN, TN, DRP and TP) can now be looked up in the tables. At the completion of this step, you will have a set of *nutrient criteria* pertaining to the sites and associated choices of biomass threshold and under-protection risk being considered as a basis for step 3.

3: Assess confidence in the nutrient criteria

It is good practice to have a demonstrable process which performs some checks and verification of the *nutrient criteria* obtained by the above steps. Although there are limited ways to assess confidence in the criteria, where a monitoring network for periphyton and nutrients exists, a useful validation analysis is outlined below. This allows you to determine whether the *nutrient criteria* across all the sites collectively (ie, the population) are consistent with each selected under-protection risk.

Care with the validation analysis is required. It is not simply a matter of comparing observed nutrient concentrations and biomass with the *nutrient criteria* in the look-up tables as the criteria in the tables are risk-based and apply to populations of sites. This means you cannot interpret the look-up table criterion for a site as a prediction of the associated biomass threshold. Instead, you need to assess the *nutrient criteria* by determining how well they predict the proportion of sites in a population that would exceed a nominated biomass threshold.

To carry out the validation, the criteria are inverted and used to predict the biomass at all sites. The proportion of sites for which the observed biomass exceeds the predicted biomass is then the verification statistic of interest. The following steps are required:

1. Obtain the median concentration of each nutrient and 92nd percentile biomass from the observations at each monitoring site.
2. Obtain the REC source-of-flow class and shade status for each site.
3. For a fixed nutrient and level of under-protection risk, obtain the criteria for the A, B and C bands for each site based on the site’s REC source-of-flow class and shade status.
4. For each nutrient and site, interpolate the biomass from the criteria by:
    a) treating the biomass thresholds for A, B and C bands of 50, 120 and 200 mg m^{-2} as the variable Y and *nutrient criteria* from the look-up tables for each band as the variable X
    b) interpolating the biomass from the above Y values for the value of X defined by the observed site nutrient concentration
    c) treating the interpolated biomass as a prediction.
5. Calculate, over all sites, the proportion of observed values that exceed the above predicted values.
6. Repeat this process for each nutrient and level of under-protection risk.
7. If the *nutrient criteria* are consistent with the observations at the monitoring sites, the proportion of sites for which observations exceed the predictions should approximately match the levels of under-protection risk. You would interpret reasonable agreement as

verification the *nutrient criteria* are valid for the sites represented by the monitoring network. You should not expect perfect agreement. Divergence between the proportion of observations that exceed the predictions and the under-protection risk can be expected to decrease as the sample size increases. An example of this analysis is shown in Snelder et al (2021) associated with the validation of the criteria using the National Water Quality Monitoring Network (NRWQN) dataset.

Applying the nutrient criteria

Once you have identified *nutrient criteria* from the look-up tables (hereafter referred to as the 'identified criteria'), you need to decide whether to apply the identified criteria or alternative criteria.

These are the three situations in which alternative criteria should apply:

8. Where the current nutrient concentrations are less than the *nutrient criteria,* including where the nutrient exceedance criteria for DRP or TP are zero (see above), the requirement to at least maintain water quality applies. In this situation, replace an identified criterion by the current measured and/or modelled concentration. Note that current nutrient concentrations can be obtained for monitoring sites and have also been estimated for all rivers in New Zealand based on statistical modelling (Whitehead et al, 2022) and the data can be accessed from Rivermaps.
9. Where the identified criteria are higher than levels to achieve other attribute states at the site (eg, the nitrate toxicity target attribute). More guidance on this situation will be provided in upcoming Ministry for the Environment guidance on setting in-stream nutrient concentrations for other nutrient-affected attributes.
10. Where there are sensitive downstream receiving environments that require nutrient concentrations or loads that imply the identified criterion is too high. More guidance for setting in-stream nutrient concentrations in this situation is provided by the Ministry for the Environment (2021).

5: More information

Action for healthy waterways and changes to the NPS-FM

More information about the National Policy Statement for Freshwater Management is provided on the Ministry for the Environment's website on the page About NPS.

Information about attributes in NPS freshwater management under the Action for health waterways programme is also available on the Ministry's website.

Periphyton under protection risk

This approach is based on peer-reviewed, published science and more information can be found in the publications below, as well as the publications in the References section.

These publications constitute the most up-to-date work on national scale periphyton modelling.

- Snelder, Kilroy and Booker. 2021. *Derivation of nutrient criteria for periphyton biomass objectives using regional council monitoring data*. Ministry for the Environment
- *Action for healthy waterways: Summary of modelling to inform environmental impact assessment of nutrient proposals*. Ministry for the Environment. 2020.
- *Nutrient Concentration Targets to Achieve Periphyton Biomass Objectives Incorporating Uncertainties*. Snelder et al. 2019. Journal of the American Water Resources Association.

Datasets

The complete dataset used in the production of Snelder et al (2021) can be found on the Ministry for the Environment data service.

This contains regional council monitoring data with direct observations of periphyton biomass.

How to set nutrient targets in catchments

Guidance on setting nutrient targets including those for downstream, receiving environments under the NPS-FM 2020 is available on the Ministry for the Environment's website:

- *Guide to setting in-stream nutrient concentrations under Clause 3.13.* Ministry for the Environment. 2021.

This guidance has useful information that was relevant to the 2017 NPS-FM and has subsequently been updated to reflect the policy settings in the 2020 NPS-FM.

Glossary

The table below defines the terms that are used in this guidance.

Term	Definition
Biomass	A level of periphyton abundance measured as mg chlorophyll *a* m^{-2}. Note that chlorophyll *a* is generally referred to in this guidance as chlorophyll.
Biomass thresholds	Levels of periphyton biomass that denote the ends of the NOF periphyton attribute bands. The ranges within which councils must manage periphyton in their areas. The periphyton NOF attribute is divided into A, B and C bands with 92nd percentile chlorophyll-a boundaries being 50 mg m^{-2}, 120 mg m^{-2} and 200 mg m^{-2} respectively. All periphyton abundances above 200 mg m^{-2} chl-a are considered to be in the D band and below the national bottom line for periphyton.
Environmental manager	Persons or organisations with authority to manage environmental outcomes and implement the NPS-FM 2020.
Maximum biomass	In this guidance, maximum biomass means the 92nd percentile of the distribution of monthly periphyton biomass observations. The term 'maximum' is used to clarify that healthy rivers support some periphyton biomass, but excessive biomass causes adverse effects. The 92nd percentile of the observations is close to the maximum observed value.
NOF	National Objectives Framework. A step-by-step approach to freshwater management in the NPS-FM 2020, requiring councils to set environmental objectives for freshwater and achieve them via the management of attributes (such as those found in appendices 2A and 2B of the NPS-FM 2020).
Target/nutrient target	The in-stream nutrient concentrations derived in Snelder (2019) and subsequently updated in Snelder, Kilroy and Booker (2021). These represent the nutrient concentrations at specific sites and have 5 per cent, 10 per cent, 15 per cent and 20 per cent risks of exceeding a nominated periphyton biomass threshold. They are found in each cell of the look-up tables in section 3. This is a distinct concept from 'target attribute states'.
DIN	Dissolved Inorganic Nitrogen — one form of the two periphyton nutrients that must be managed under the NPS-FM 2020, clause 3.13. Under this clause, in-stream nutrient concentrations and exceedance criteria for DIN to be determined as part of achieving the periphyton target attribute states in rivers. It does not have a NOF target attribute state in the NPS-FM 2020.
DRP	Dissolved Reactive Phosphorus — one form of the two periphyton nutrients that must be managed under the NPS-FM 2020, clause 3.13. Under this clause, in-stream nutrient concentrations and exceedance criteria for DRP must be determined as part of achieving the periphyton target attribute states in rivers. DRP attribute bands are found in appendix 2B, table 20 of the NPS-FM 2020.
TN	Total Nitrogen — one form of the two periphyton nutrients that must be managed under the NPS-FM 2020. This is the form of nitrogen that is used to

	manage the trophic state in lakes. TN attribute bands are found in appendix 2A, table 3 of the NPS-FM 2020.
TP	Total Phosphorus — one form of the two periphyton nutrients that must be managed under the NPS-FM 2020. This is the form of phosphorus that is used to manage the trophic state in lakes. TP attribute bands are found in appendix 2A, table 4 of the NPS-FM 2020.
REC	River Environment Classification — a system of classes that discriminates individual segments of New Zealand's rivers and streams into a number of hierarchical levels. The first hierarchical level represents the climate category (eg, CX, meaning cool extremely wet) and source-of-flow category (eg, Lk, meaning lake-fed).
Under-protection risk	The risk, expressed as percentage, that a randomly chosen location will exceed a specified biomass threshold despite nutrient concentrations being compliant with the specified nutrient concentration and exceedance criteria. This was referred to previously as 'spatial exceedance criteria', which is an unrelated term to 'exceedance criteria' in the NPS-FM 2020.

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Appendix 1: How do I work out the REC class of a particular site?

The River Environment Classification (REC) System groups rivers and parts of river networks that share similar characteristics, including physical and biological. Rivers that share the same class can be treated as similar to one another and different to rivers in other classes. The REC system groups rivers according to several environmental factors that strongly influence or cause the rivers' physical and ecological characteristics (climate, topography, geology and land cover).

1. To view the REC dataset, go to https://data.mfe.govt.nz/data/category/fresh-water/
2. Click on the + symbol for 'River Environment Classification New Zealand (2010)'.
3. Navigate to your stream or river using the zoom.
4. Click on the stream or river of interest to bring up a data table.
5. Look under 'Climate'. The codes used are as follows:

Climate category	Notation
Warm-Extremely-Wet	WX
Warm-Wet	WW
Warm-Dry	WD
Cool-Extremely-Wet	CX
Cool-Wet	CW
Cool-Dry	CD

6. Next, look under 'SRC_OF_FLW' (source-of-flow). The codes used are:

Source-of-flow	Notation
Glacial-Mountain	GM
Mountain	M
Hill	H
Low-Elevation	L
Lake	Lk
Spring	Sp
Wetland	W
Regulated	R