Ministry for the Environment
Manatū Mō Te Taiao

Ministry for Primary Industries
Manatū Ahu Matua

FRESHWATER MANAGEMENT GUIDANCE

A Guide to Attributes

In Appendix 2 of the National Policy Statement for Freshwater Management 2014 (as amended 2017)

New Zealand Government

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1 Introduction

The National Policy Statement for Freshwater Management (Freshwater NPS) requires regional councils to identify the 'values' that are associated with the water bodies in their regions. These values must include the two compulsory values in the Freshwater NPS of **ecosystem health** and **human health for recreation**, as well as any other values that are appropriate. Councils must then establish freshwater objectives to achieve those values using a range of attributes, and set limits to meet freshwater objectives.

Freshwater objectives must be established using the freshwater attributes listed in Appendix 2 of the Freshwater NPS. All of the attributes in Appendix 2 are required for the two compulsory values but this is not an exhaustive list. Councils will also need to develop their own attributes to fully achieve the two compulsory values, as well as any other national values (listed in Appendix 1 of the Freshwater NPS) or regional values chosen by the community.

This document provides council staff with guidance on the role and use of the Appendix 2 attributes. It explains the rationale for attributes and how they can be used to set freshwater objectives. It also comments briefly on setting limits to achieve freshwater objectives and how to monitor attributes.

Further relevant guidance documents are available on the Ministry for the Environment website including: guidance on the *policy intent* of setting limits, technical guidance on how to give effect to the Periphyton attribute table 'Note', and the monitoring requirements of the Freshwater NPS

Any future changes to the Freshwater NPS will be reflected in updated guidance.

Give us your feedback

This guide is being released as a draft. We welcome your feedback or suggestions on the content. If you would like to provide feedback, please email freshwater@mfe.govt.nz. A final guide will be published in August 2018.

1.1 Document structure

For the purposes of this guide, the attributes to be managed have been grouped under headings collectively referred to as 'aspects to be managed'. This is not a term used in the Freshwater NPS. Its use is intended to provide structure and clarity to the guidance document and may help councils identify which other attributes need to be identified and managed.

This guide is structured as follows:

- **Section 1** – sets out the rationale for attributes, introduces the concept of 'aspects to be managed', and discusses how attributes provide for values

- **Sections 2–8** – provide detail on each of the attributes in Appendix 2 of the Freshwater NPS grouped under the following aspects: Trophic state, Toxicants, Other stressors, Pathogens, and Toxins.
- **Section 9** – comment on the monitoring requirements in the Freshwater NPS.

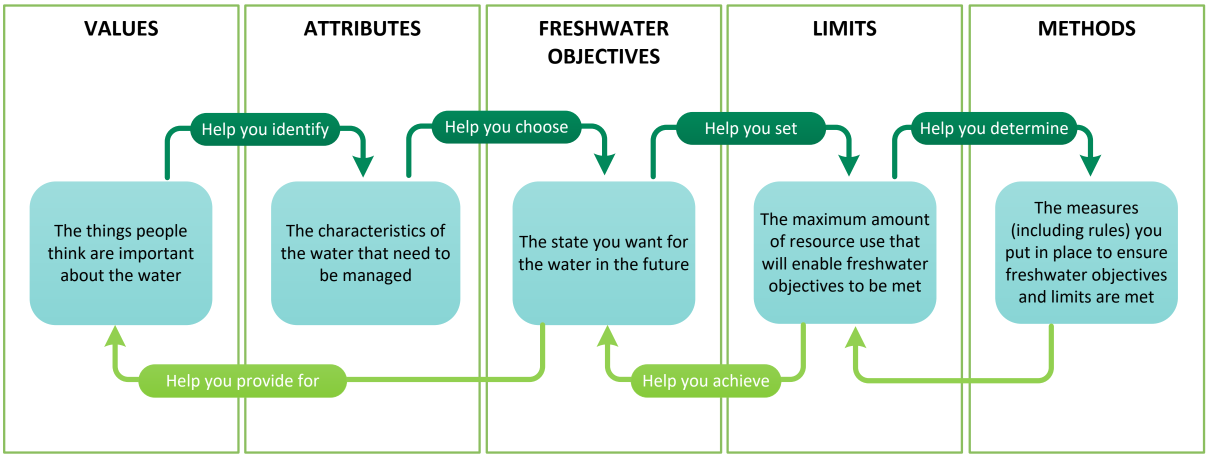
Section 1 includes a diagram showing how attributes fit into the Freshwater NPS framework, and Sections 2–8 use the same diagram format to demonstrate examples of how the different attributes might be used.

1.2 An overview of attributes

An attribute is any measurable characteristic of fresh water, including physical, chemical and biological properties, which supports particular values[1]. The attributes in Appendix 2 represent measurable characteristics relevant to an aspect of the compulsory values. These attributes have been set out in tables with defined 'attribute states' (A–D). The attribute states are to help councils (and communities) set numeric freshwater objectives. Numeric freshwater objectives are the basis for defining limits and management actions. Collectively the freshwater attributes, limits and methods ensure what is valued about a water body is maintained (or improved).

Figure 1 shows this relationship. The subsequent chapters of this document use the same format to show examples of how each attribute could be used.

Figure 1: The Freshwater NPS framework from values to methods



The current Appendix 2 attributes are part of, but not sufficient on their own, to achieve the compulsory values. There are other potential attributes for these values, and councils must identify these and use them to set freshwater objectives for both the compulsory values, and any other values they have identified for their freshwater management units (FMUs). When developing additional attributes, it may be helpful to consider them as the 'aspects that need to be managed' in order to achieve the values.

The National Objectives Framework (NOF) in Part CA of the Freshwater NPS directs the process councils must use to set freshwater objectives (using attributes), to provide for the values that are held for water bodies in a region.

1 Freshwater NPS definition.

1.3 Values and attributes

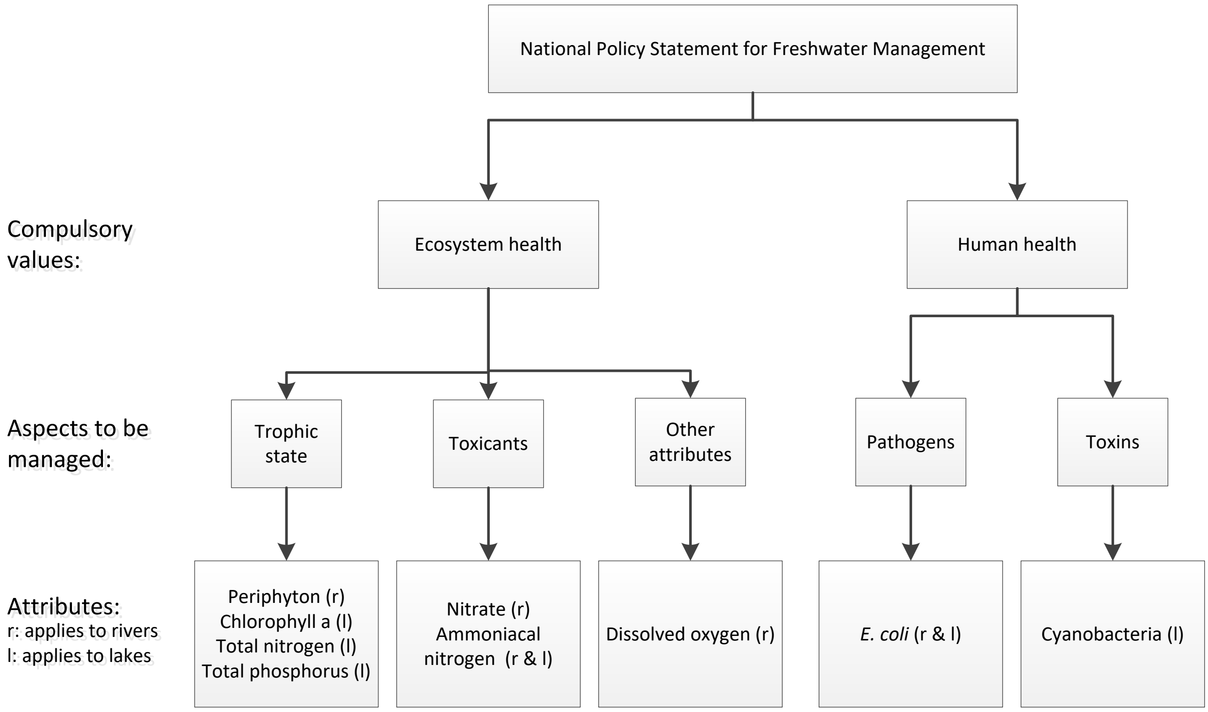
The NPS identifies 13 national values for fresh water. Two of these are compulsory values that apply to all water bodies - ecosystem health and human health for recreation. These must be included in the regional plan (or policy statement) and freshwater attributes developed for them. Councils may also manage for the additional national values contained in Appendix 2, and any other local or regional values.

Each attribute in Appendix 2 applies to a specific freshwater body type (ie, rivers and lakes), and councils must set freshwater objectives using **all** the attributes in Appendix 2 (as relevant to the value and water body type) as each relates to a compulsory value.

Appendix 2 of the Freshwater NPS only provides *some* of the attributes for some of the aspects to be managed to sustain the compulsory and other values. For example, for ecosystem health the Freshwater NPS provides attributes for trophic state, toxicants and other stressors but other aspects such as those relating to habitat quality or extend are not listed. While the provided attributes are necessary to sustain their relevant values in part, they will not be sufficient on their own. Regional councils must manage the values by identifying any other attributes they consider appropriate.

For most values, there will be several 'aspects to be managed'. For example, for human health for recreation in rivers pathogens (eg, *E. coli*) must be managed but councils may also choose to manage amenity aspects such as clarity, sediment and algae cover. These 'aspects' will need to be considered, and one or more attributes will need to be established and used to set freshwater objectives for these so that the value is provided for. Figure 2 below shows the attributes in Appendix 2 which must be used to set freshwater objectives. Note that there may well be other aspects to manage in which case the council will need to develop additional attributes.

Figure 2: Relationship of attributes in Appendix 2 to the compulsory values



There will also be additional attributes which councils identify to provide for the values. These will likely fall within one of the 'aspects to be managed' identified in the figure above. The individual aspects to be managed are described in detail in Sections 1.4–1.8.

1.4 Trophic state (ecosystem health)

The trophic state of a water body is the amount of living material (biomass) that it supports. Healthy freshwater ecosystems have low (oligotrophic) to intermediate (mesotrophic) levels of living material and primary production (growth of plants or algae). High levels of nutrients, primarily nitrogen (nitrate) and phosphorus (phosphate), can cause water bodies to become eutrophic. Eutrophic states are associated with periodic high biomass ('blooms') of plants or algae, including suspended algae (phytoplankton) in lakes and slime and algae on the beds of streams and rivers (periphyton); and in estuaries macro-algae biomass on sub-tidal flats and phytoplankton biomass in the water column. Eutrophic states are associated with poor ecosystem health due to adverse fluctuations in dissolved oxygen and pH, smothering of habitat and alteration of ecological community composition.

The Freshwater NPS specifies attributes for tropic state based on periphyton biomass in rivers, and phytoplankton biomass, total nitrogen, and total phosphorus in lakes. The Freshwater NPS does not specify nutrient concentration criteria for rivers, because the relationship between trophic state and nutrient concentrations varies between rivers even at the regional scale. The nutrient criteria to achieve periphyton biomass objectives in rivers are river specific and must therefore be derived at the local level.

1.5 Toxicants (ecosystem health)

Human activities can result in toxicants being discharged to water bodies at levels that affect ecosystem health. Toxicants can have both lethal and sub-lethal (eg, reducing growth rates or reproductive success) effects. These effects can occur as a result of long- or short-term exposure to toxicants. The Freshwater NPS specifies attributes to manage long-term exposure to two toxicants, nitrate (NO_3N) and ammonia (NH_4N).

Nitrate is also a nutrient and generally impacts on trophic state at much lower concentrations than those that are toxic. Because of this, nitrate will generally be managed well within toxic levels by the requirement to manage trophic state (eg, periphyton). Therefore, the nitrate toxicity attribute is essentially redundant in lakes and many rivers that are managed appropriately for trophic state, and will only be relevant in those rivers that do not naturally support conspicuous periphyton (eg, soft-bottomed streams) and where there are no nutrient sensitive downstream environments present. However, it is still compulsory to set an objective for nitrate toxicity as it is a compulsory attribute for the compulsory value ecosystem health. Councils could set it within the A band and limits set to manage for periphyton will also address the freshwater objective set for nitrate toxicity.

1.6 Other stressors (ecosystem health)

Dissolved oxygen (DO) is the only ‘other stressors’ currently in Appendix 2. Therefore, councils will need to identify their own other relevant stressors – for example heavy metals and sediment.

Dissolved oxygen (DO) is a fundamental aspect of life-supporting capacity, requiring minimum levels to sustain life. The Freshwater NPS specifies DO as an attribute for writing freshwater objectives for rivers downstream of point-source discharges.

1.7 Pathogens (human health for recreation)

Water contaminated by human or animal faeces may contain a range of pathogenic (disease-causing) micro-organisms. Viruses, bacteria, protozoa or intestinal worms can pose a health hazard when the water is used for drinking or recreational activities.

It is difficult and impractical to routinely measure the level of all pathogens that may be present in fresh water. Instead, indicator bacteria are used to indicate the likely presence of untreated sewage and effluent contamination. *Escherichia coli* (*E. coli*) is a bacteria commonly found in the gut of warm blooded organisms and is relatively easy to measure which makes it a useful indicator of faecal presence and therefore of disease-causing organisms that may be present.

E. coli is the attribute for specifying human health for recreation objectives for fresh water because it is moderately well correlated with *Campylobacter* bacteria and numeric health risk levels can be calculated. Campylobacteriosis has the highest reporting rate of all New Zealand’s ‘notifiable’ diseases. See the New Zealand Public Health Observatory.

1.8 Toxins (human health for recreation)

Cyanobacteria (blue-green algae) are common in many terrestrial and aquatic ecosystems where they may grow in the water column (planktonic), aggregated on the water surface (metaphytic), attached to other algae, cyanobacteria or macrophytes (epiphytic), or attached to substrates (benthic).

Under certain conditions, cyanobacteria can produce cyanotoxins, which pose a health threat to humans and animals. The effects of cyanotoxins range from rapid onset of nausea and diarrhoea, to gastroenteritis and other specific effects, such as liver damage (hepatotoxicity), and possibly carcinogenesis.

The Freshwater NPS specifies an attribute for planktonic cyanobacteria in lakes and lake-fed rivers but councils may need to manage other forms as necessary.

2 Trophic state (rivers) – periphyton

2.1 How the attribute is defined

Periphyton biomass is an indicator of the trophic state of rivers and varies considerably over time as a result of processes causing accrual and loss (Biggs, 1996). Accrual depends primarily on nutrient supply, light and temperature, which stimulate algae growth. Biomass loss is driven primarily by high flows, which dislodge periphyton from the stream bed (Biggs, 1996), and grazing by aquatic animals. The time between high flows is the 'accrual period' in which periphyton biomass can increase. Maximum biomass is the product of the accrual rate and the length of the accrual period. High flows periodically flush periphyton from the bed, and biomass then rebuilds throughout the next accrual period.

There is significant temporal variation in the length of accrual periods in any river, including within-year (seasonal) and between-year variation. In unusually dry years, accrual periods can be particularly long in both natural and impacted streams. Because of this, almost any site can be observed to have high periphyton biomass given a long enough period of monitoring (Snelder *et al.,* 2013). However, if nutrient concentrations, light, temperature and flow alteration are managed within limits, the frequency of relevant thresholds being exceeded can be kept within acceptable levels. The periphyton attribute is therefore specified by a combination of biomass thresholds and the percentage of the time the threshold can be exceeded. The attribute requires that periphyton abundance is observed on a monthly basis.

In simple terms, for most rivers in New Zealand, the periphyton criteria restrict the exceedance of specified biomass threshold to once per year, based on monthly sampling (ie, approximately 8 per cent of samples). Inter-annual variation in accrual period length, however, means that a biomass threshold may be exceeded more than once a year over short monitoring periods (eg, periods of one-to-two years) but the site may meet the objective over the longer term (for details, see Snelder *et al*., 2013). The average year is, in fact, notional and no actual year of monitoring data will be 'average'. The Freshwater NPS specifies the frequency criteria, in terms of the long term (ie, multiple years), with thresholds being exceeded on average once each year, or in approximately 8 per cent of samples based on monthly sampling. Objectives are met at a site if the biomass threshold is not exceeded any more frequently than the specified exceedance frequency.

The Freshwater NPS specifies a minimum of three years' sampling to determine the periphyton attribute state at a site. This requirement for long-term sampling allows for inter-annual variation in an accrual period. Confidence in the assessment of state increases with the number of years of data, which is particularly important when the attribute state at a site is close to a threshold. However, less than three years of data may provide reasonable confidence about attribute state in some circumstances. For example, more than three instances of a threshold being exceeded in a single year would mean the threshold is exceeded for more than 8 per cent of samples over three years, even if there are no further exceedances in subsequent years.

The attribute allows for greater exceedances in rivers that tend to have naturally high periphyton biomass due to natural enrichment and naturally long accrual periods. The 'Productive' periphyton class is defined using categories of the River Environment Classification (REC) (Snelder and Biggs, 2002). The Productive periphyton class is defined by the combination of REC 'Dry' Climate categories (ie, Warm-Dry (WD) and Cool-Dry (CD)) and Geology categories that have naturally high levels of nutrient enrichment due to their catchment geology (ie, Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)). The exceedance frequency criteria for sites in the Productive class is twice in the average year (two per year), or approximately 17 per cent of samples over the long term. The majority of New Zealand streams and rivers fall into the 'Default' periphyton class for which the exceedance criterion is one per year, but 3 per cent of rivers fall into the Productive periphyton class (Snelder *et al.,* 2013).

Other attributes may be more useful to express trophic state objectives in some rivers or for some types of periphyton. For example, periphyton might not be a good expression of trophic state in rivers with fine muddy substrates that do not grow conspicuous periphyton; primary production in these rivers is often dominated by macrophytes (rooted plants). Periphyton biomass might not reflect trophic state in rivers dominated by *Didymoshenia geminate* (didymo), especially when measured as chlorophyll *a*. Additional locally derived attributes may be needed to define freshwater objectives for trophic state where these types of issues occur.

2.2 Using the attribute to set freshwater objectives

The periphyton attribute must be used to set freshwater objectives to manage the trophic state aspect of the ecosystem health value in rivers. Two river classes are identified in the periphyton attribute – 'Default' and 'Productive'. Regional councils will need to determine which class a river falls into, using the River Environment Classification (REC), and set freshwater objectives using the appropriate exceedance frequency.

Councils must decide on a trophic state that will support the value. The periphyton attribute table (table 1) provides narrative descriptions of different levels of trophic state and details of the corresponding attribute states.

The Periphyton Attribute table 'Note'[2] also requires councils to set instream concentrations and exceedance criteria for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) in rivers. This will help to achieve the freshwater objective set for periphyton while ensuring the nutrient criteria are also set to achieve outcomes for any nutrient sensitive downstream receiving environments (eg, lakes or estuaries). This Note provides a process which must be followed to determine the nutrient criteria for these requirements. Detailed guidance is being developed on the process contained within the Note and will be available on the Ministry for the Environment's website in 2018.

2 All the wording in the NPS-FM (other than the preamble), including appendices and footnotes, carry the same legal force and obligations.

Setting instream nutrient criteria to help meet the periphyton objective is an intermediate step between setting the freshwater objective and setting catchment nutrient limits. As these instream nutrient criteria are neither 'freshwater objectives' nor 'limits' there is no explicit requirement to put them into a regional plan. However, it could be good practice to do so, to make the linkages between the nutrient criteria and limits clearer, particularly when the criteria are to achieve outcomes in nutrient sensitive downstream environments such as estuaries.[3]

Table 1: Periphyton (Trophic state) attribute table

Value	Ecosystem health		
Freshwater Body Type	Rivers		
Attribute	Periphyton (Trophic state)		
Attribute Unit	mg chl-a/m² (milligrams chlorophyll *a* per square metre)		
Attribute State	**Numeric Attribute State (Default Class)**	**Numeric Attribute State (Productive Class[1])**	**Narrative Attribute State**
	Exceeded no more than 8% of samples[2]	**Exceeded no more than 17% of samples[2]**	
A	≤50	≤50	Rare blooms reflecting negligible nutrient enrichment and/or alteration of the natural flow regime or habitat.
B	>50 and ≤120	>50 and ≤120	Occasional blooms reflecting low nutrient enrichment and/or alteration of the natural flow regime or habitat.
C	>120 and ≤200	>120 and ≤200	Periodic short-duration nuisance blooms reflecting moderate nutrient enrichment and/or alteration of the natural flow regime or habitat.
National Bottom Line	**200**	**200**	
D	>200	>200	Regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat.

1. Classes are streams and rivers defined according to types in the River Environment Classification (REC). The Productive periphyton class is defined by the combination of REC "Dry" Climate categories (i.e. Warm-Dry (WD) and Cool-Dry (CD)) and REC 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)). Therefore the productive category is defined by the following REC defined types: WD/SS, WD/VB, WD/VA, CD/SS, CD/VB, CD/VA. The Default class includes all REC types not in the Productive class.
2. Based on a monthly monitoring regime. The minimum record length for grading a site based on periphyton (chl-a) is 3 years.

[3] The requirement of step (b) in the Periphyton Attribute table Note has direct links to Policy 23(1)(a-c) of the New Zealand Coastal Policy Statement (NZCPS) and may also be relevant to Policy 21(b) of the NZCPS.

Note: To achieve a freshwater objective for periphyton within a freshwater management unit, regional councils must at least set appropriate instream concentrations and exceedance criteria for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP). Where there are nutrient sensitive downstream receiving environments, criteria for nitrogen and phosphorus will also need to be set to achieve the outcomes sought for those environments.

Regional councils must use the following process, in the following order, to determine instream nitrogen and phosphorus criteria in a freshwater management unit:

a) either –

   i) if the freshwater management unit supports, or could support, conspicuous periphyton, derive instream concentrations and exceedance criteria for DIN and DRP to achieve a periphyton objective for the freshwater management unit; or

   ii) if the freshwater management unit does not support, and could not support, conspicuous periphyton, consider the nitrogen and phosphorus criteria (instream concentrations or instream loads) needed to achieve any other freshwater objectives:

b) if there are nutrient sensitive downstream environments, for example, a lake and/or estuary, derive relevant nitrogen and phosphorus criteria (instream concentrations or instream loads) needed to achieve the outcomes sought for those sensitive downstream environments:

c) compare all nitrogen and phosphorus criteria derived in steps (a) – (b) and adopt those necessary to achieve the freshwater objectives for the freshwater management unit and outcomes sought for the nutrient sensitive downstream environments.

The 'Note' to the attribute table refers to the various forms of nitrogen and phosphorus which are relevant to different water bodies. First the Note requires instream concentrations and exceedance criteria for DIN and DRP be set to achieve the periphyton objective for rivers. It then requires criteria for nitrogen and phosphorus be set to achieve the outcomes sought for downstream receiving environments.

DIN and DRP are the dissolved inorganic forms of nitrogen and phosphorus which are available for immediate uptake by plants. Hence DIN and DRP concentrations are relevant in rivers where water tends to be flowing. Total nitrogen (TN) and total phosphorus (TP) are bound forms of the nutrients which are less bio-available, although can be used by plants if there is enough time. Hence TN and TP loads are relevant in receiving environments such as lakes and estuaries where the movement of water is much slower.

The Freshwater NPS requires the improvement of integrated management[4] of freshwater, land, associated ecosystems, and the coastal environments. However, setting only DIN and DRP concentrations to meet a periphyton objective for an upstream water body does not necessarily protect nutrient sensitive downstream environments, so TN and TP must also be managed in FMUs where these environments may be affected.

Essentially the process requires councils to:

1. Set criteria for DIN and DRP if there is (or could be) periphyton biomass present in a FMU.
2. Set criteria for TN and TP if there are nutrient sensitive downstream receiving environments (lakes or estuaries).
3. Set objectives for nitrate and ammonium toxicity, and maybe set objectives for locally derived attributes.
4. If both 1 and 2 occur, limits need to be consistent with the most restrictive criteria.

[4] Freshwater NPS Part C objectives and policies.

5. If neither 1 or 2 occur, limits need to be consistent with the nitrate and ammonium (toxicity) national attributes or any nitrogen and phosphorus criteria for locally derived attributes.

Further technical guidance is available on the process laid out in the Appendix 2 Periphyton Attribute table Note.

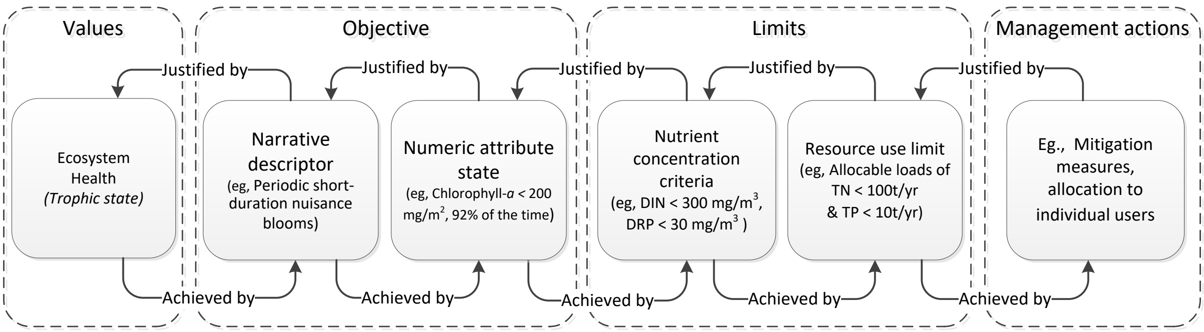
2.3 Defining management actions to achieve freshwater objectives

In general, achieving periphyton objectives will require the management of instream nutrient (nitrogen and phosphorus) concentrations. However, appropriate nutrient criteria will vary spatially with the other factors that determine periphyton biomass in rivers (ie, substrate, time between high flows, and light and temperature regimes) and these will likely also need to be addressed.

The natural frequency of high flows and light regime can be altered by resource use (eg, by flow modification and riparian alteration respectively). This needs to be taken into account when setting nutrient criteria and in considering how periphyton objectives will be achieved. In small streams, periphyton objectives may be able to be met by increased stream shading, which may be achieved by management actions like riparian planting. However, main stems in many catchments cannot be shaded adequately, and ensuring that periphyton objectives are met will generally require managing nutrient concentrations. Where there is significant alteration of flow regimes by large diversions and dams, the change in the frequency of high flows may increase accrual periods and require correspondingly lower nutrient criteria to meet the periphyton objective (Lessard *et al.,* 2012).

The first step in defining management actions to achieve periphyton objectives is to derive instream nutrient concentration criteria as required by the Note. Because flow, light and temperature regimes vary spatially, concentration criteria must be derived that are specific to sites or river types. In defining management actions, the nutrient concentration criteria is a technical step in defining the limits required to meet the freshwater objective (figure 3).

Figure 3: Links between values, objectives, limits and management actions specific to the periphyton attribute



Note: DIN = dissolved inorganic nitrogen; DRP = dissolved reactive phosphorus; TN = total nitrogen; TP = total phosphorus.

Setting nutrient concentration criteria to achieve the freshwater objective requires the use of predictive relationships between periphyton biomass and its key drivers (eg, nutrient concentrations, flows, light). A number of tools for predicting periphyton biomass exist that involve varying levels of complexity, from simple concentration guidelines for the avoidance of excessive growths, to more complicated regression equations (eg, Biggs, 2000a; Biggs, 2000b; Matheson *et al.,* 2012; Snelder *et al.,* 2014; Larned *et al.,* 2015; Matheson *et al.,* 2016). Methods for determining the eutrophic susceptibility of estuaries, assessing their trophic state, and for setting nutrient load limits to achieve outcomes sought for estuaries are also available (Robertson *et al.,* 2016a; Robertson *et al.,* 2016b).

Defining a resource use limit to meet nutrient concentration criteria requires the consideration of point, non-point, natural and anthropogenic sources of nutrients. A catchment model will generally be required to account for the nutrient loads from different sources, their spatial configuration, and to estimate losses through attenuation (the removal of some nutrient load by processes such as assimilation, deposition and denitrification). This will allow a quantitative approach to be taken to defining the resource use limit for the freshwater management unit (FMU).

The resource use limit may be expressed as an allocable nutrient load limit (figure 3), which is the nutrient load that will ensure the nutrient concentration criteria is met.

Defining management actions that will ensure the resource use limit is met is likely to require significant analysis and modelling, including estimating the:

- contributions from different land uses
- impacts of mitigation and good management practice
- biophysical and hydrological capacity and constraints of the landscape.

Deciding on the appropriate mix of management actions will involve considering the economic outcomes of different scenarios and choices (Policy CA(f)(v) of the Freshwater NPS). See also the *Draft Guide to Limits* available on the Ministry for the Environment website.

2.4 Sampling and statistical considerations

Assessing the state of a water body relative to periphyton objectives involves determining how frequently the relevant thresholds are exceeded in the time series of monthly periphyton abundance observations. The recommended minimum record length for reliably assessing a site is three years; further discussion of this can be found in Snelder *et al.* (2013). It may be evident that a site is not achieving an objective based on a shorter time period, if exceedances are higher than specified and high flow frequency has not been unusually low. Equally, it may be evident that a site is highly likely to be achieving an objective based on a shorter time period if maximum biomass is considerably lower than specified during a time with few high flows.

Periphyton abundance is routinely measured and quantified in New Zealand in several ways:

- measurement of chlorophyll *a* concentrations
- ash-free dry mass
- visual observation of percentage cover of different ‘types’ of periphyton.

The periphyton attribute is based on chlorophyll *a*, because this substance is contained in all types of algae and the metric reflects the total algal biomass (ie, the amount of live algae) in a sample. In addition, statistical models relating periphyton abundance to other measures, such as water chemistry, flow regimes, and ecological measures (eg, macroinvertebrate community index (MCI) scores), have been found to be generally stronger for chlorophyll *a* than other measures such as cover.

Estimates of chlorophyll *a* are obtained by quantitative sampling of periphyton at multiple points in a river reach and subsequent laboratory analyses of the samples. The sampling methodology for chlorophyll *a* is specified in Biggs and Kilroy (2000).

Where periphyton biomass is considered likely to meet freshwater objectives, a proportion of monitoring could be carried out using quicker and less costly visual estimate methodologies (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 providing a readily understood estimate of the coverage. Recently developed protocols can be used to estimate chlorophyll *a* from cover data (Kilroy *et al.,* 2013). If monitoring based on visual cover estimates indicates that a site is approaching the maximum periphyton abundance stated in the freshwater objective, monitoring should then be upgraded to include measurement of chlorophyll *a*.

For further discussion on using the visual inspection method and sampling in general (including trend analysis) see A *Draft Guide to Monitoring under the Freshwater NPS* on the Ministry for the Environment website.

For detailed guidance on the role of sampling size and variability when estimating the true 'attribute state' of a monitoring site, interpreting the 'sampling statistics' described in the NOF tables, and burden-of-proof considerations refer to the NIWA publication, *National Objectives Framework - Statistical considerations for design and assessment* (McBride, 2016) on the Ministry for the Environment website.

3 Trophic state (lakes) – phytoplankton, total nitrogen and total phosphorus

3.1 How the attributes are defined

Phytoplankton biomass is the biological expression of the nutrients (nitrogen and phosphorus) in a lake, within the constraints imposed by water clarity, depth of mixing, and residence time. The concentration of chlorophyll *a* in the water column is a measure of the biomass of phytoplankton (algae) in lakes. The annual median and maximum values of chlorophyll *a* are indicators of lake trophic state.

Total nitrogen (TN) and total phosphorus (TP) are also included as attributes for lakes because there are some situations where a lake may be at risk of not achieving a trophic state objective but this is not apparent from the phytoplankton response (Howard-Williams and Hamilton, 2013). The inclusion of TN and TP as attributes helps to define limits for lakes that will ensure trophic state objectives will be met.

The relationship between TN concentration and trophic state in lakes differs according to the stratification regime. For this reason, the nitrogen attribute for lakes specifies thresholds for two classes: Seasonally Stratified and Brackish lakes: and Polymictic lakes.

3.2 Using the attributes to set freshwater objectives

The phytoplankton, TN and TP attributes must be used to set freshwater objectives to manage the trophic state aspect of ecosystem health in all lakes. The lake class, as defined by the Freshwater NPS (Seasonally Stratified and Brackish lakes: and Polymictic lakes), must be used to determine the relevant TN concentration from the attribute tables (table 3). Lakes that are both brackish and polymictic are best managed using the Seasonally Stratified/Brackish classification, but this should be considered on a case-by-case basis.

Councils must decide on a trophic state that will support values and then set objectives accordingly using the three attributes in the Freshwater NPS. The three lake trophic state attribute tables (Phytoplankton (table 2), Total Nitrogen (table 3) and Total Phosporus (table 4)) provide a description of possible trophic state objectives and details of the corresponding attribute states.

Table 2: Phytoplankton (Trophic state) attribute table

Value	Ecosystem health		
Freshwater Body Type	Lakes		
Attribute	Phytoplankton (Trophic state)		
Attribute Unit	mg/m^3 (milligrams chlorophyll *a* per cubic metre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median	**Annual Maximum**	
A	≤2	≤10	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
B	>2 and ≤5	>10 and ≤25	Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrient levels that are elevated above natural reference conditions.
C	>5 and ≤12	>25 and ≤60	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions. Reduced water clarity is likely to affect habitat available for native macrophytes.
National Bottom Line	**12**	**60**	
D	>12	>60	Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes.

Note: For lakes and lagoons that are intermittently open to the sea, monitoring data should be analysed separately for closed periods and open periods.

Table 3: Total Nitrogen (Trophic state) attribute table

Value	Ecosystem health		
Freshwater Body Type	Lakes		
Attribute	Total Nitrogen (Trophic state)		
Attribute Unit	mg/m^3 (milligrams per cubic metre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median	**Annual Median**	
	Seasonally Stratified and Brackish	Polymictic	
A	≤160	≤300	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
B	>160 and ≤350	>300 and ≤500	Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrient levels that are elevated above natural reference conditions.
C	>350 and ≤750	>500 and ≤800	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions.
National Bottom Line	**750**	**800**	
D	>750	>800	Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state, (without native macrophytes/seagrass cover) due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes.

Note**:** For lakes and lagoons that are intermittently open to the sea, monitoring data should be analysed separately for closed periods and open periods.

Table 4: Total Phosphorus (Trophic state) attribute table

Value	Ecosystem health	
Freshwater Body Type	Lakes	
Attribute	Total Phosphorus (Trophic state)	
Attribute Unit	mg/m3 (milligrams per cubic metre)	
Attribute State	**Numeric Attribute State**	**Narrative Attribute State**
	Annual Median	
A	≤10	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
B	>10 and ≤20	Lake ecological communities are slightly impacted by additional algal and plant growth arising from nutrient levels that are elevated above natural reference conditions.
C	>20 and ≤50	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions.
National Bottom Line	**50**	
D	>50	Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes.

Note: For lakes and lagoons that are intermittently open to the sea, monitoring data should be analysed separately for closed periods and open periods.

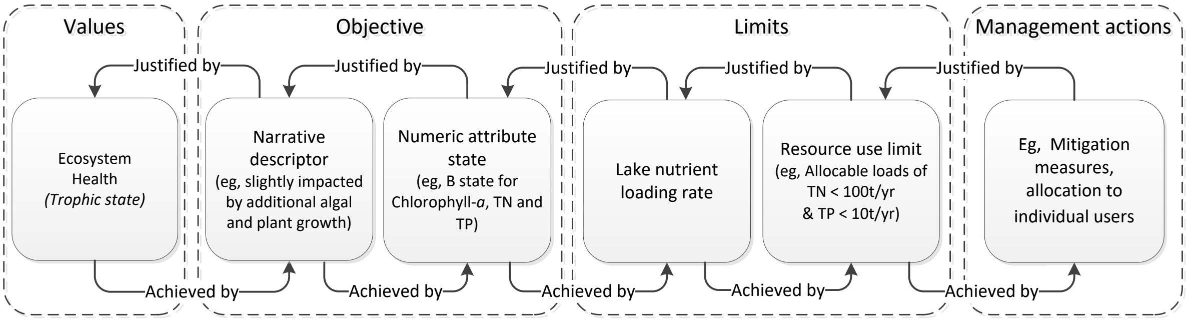
3.3 Defining management actions to achieve freshwater objectives

Ensuring that lakes achieve trophic state objectives will generally require the management of nutrient (nitrogen and phosphorus) loads discharging into lakes from upstream catchments. The first step in defining management actions to achieve lake trophic state objectives is developing a robust understanding of the relationship between trophic state and lake nutrient loading rate.

As well as external (catchment) loads, internal nutrient loads (ie, sources of nutrients within the lake such as those contained with lake bed sediments) can be significant sources of nutrients in lakes.

Defining a resource use limit to achieve nutrient load criteria requires the consideration of internal and external, point, non-point, natural and anthropogenic sources of nutrients. A catchment model will generally be required to account for the nutrient loads from different sources, their spatial configuration, and to estimate losses through attenuation (the removal of some nutrient load by processes such as deposition and denitrification). Defining the lake nutrient loading rate and the relative contributions from the range of sources can be regarded as a technical step in the definition of resource use limits (figure 4). This will allow a quantitative approach to be taken to defining the resource use limit for the freshwater management unit.

Figure 4: Links between values, objectives, limits and management actions specific to the lake trophic state attributes



Note: TN = total nitrogen; TP = total phosphorus.

The approach to expressing resource use limits and defining management actions is likely to be similar to that required for the periphyton attribute (section 2.3).

3.4 Sampling and statistical considerations

The Freshwater NPS is not prescriptive about how to monitor the lake trophic state attributes and councils may employ the protocol already in use or another as they consider appropriate. If a protocol is accepted by the scientific community, and the council, then that is appropriate to use.

See also *A Draft guide to Monitoring under the Freshwater NPS* on the Ministry for the Environment website which includes a case study on selecting representative sites for shallow lakes in the Hawkes' Bay region and a discussion on the frequency of monitoring.

Protocols for monitoring trophic levels of New Zealand lakes and reservoirs are provided by Burns et al., (2000) and are referenced in the Monitoring guide. The Monitoring guide also provides a discussion on the frequency of monitoring and pragmatism when developing a monitoring plan/regime. For detailed guidance on estimating the true 'attribute' state of a monitoring site, the role of sampling size and variability in doing so, and burden-of-proof considerations, refer to *National Objectives Framework - Statistical considerations for design and assessment* (McBride, 2016).

4 Toxicants (rivers) – nitrate

4.1 How the attribute is defined

Nitrate is a toxicant that can cause lethal or sub-lethal (eg, reducing growth rates or reproductive success) effects to aquatic species. These effects can occur as a result of short-term (hours to days) or long-term (weeks, months, years) exposure to nitrate.

The Freshwater NPS defines nitrate toxicity attribute states based on concentrations that protect a specific percentage of test species from long-term exposure to nitrate. The national bottom line is set at nitrate concentrations that provide protection from effects of long-term exposure for 80 per cent of species. The higher attribute states provide for protection from effects of long-term exposure for 95 per cent to 99 per cent of species. All of the Freshwater NPS nitrate toxicity attribute states protect 100 per cent of test species from effects of short-term exposure.

The concentrations for these attributes are linked to observed effects from long-term exposure to nitrate in studies on 22 freshwater aquatic species (Hickey, 2013). The first set of attribute state thresholds (ie, median concentration) are set at the 'No Observed Effect Concentration' (NOEC) for each level of species protection. The second set of attribute state thresholds are set at the 'Threshold Effect Concentration' (TEC) for each level of species protection, which can be interpreted as below the level of an effect.

Each set of thresholds is associated with a particular sample statistic to reflect different timescales of effect. Freshwater objectives set using the:

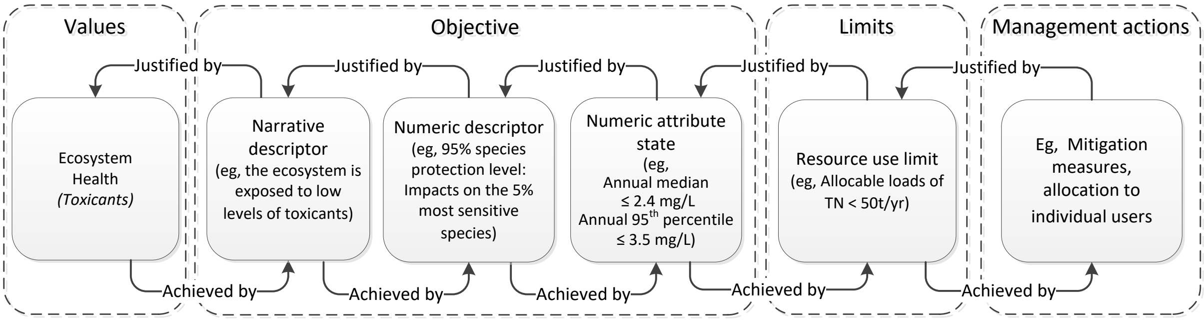
- NOEC and a sample median manages exposure under 'average' conditions
- TEC and a 95th percentile manages exposure during seasonal peaks in nitrate concentrations.

4.2 Using the attribute to set freshwater objectives

The nitrate toxicity attributes must be used to set freshwater objectives in all rivers. **In most situations, however, nitrate concentrations will need to be managed at considerably lower than toxic levels to achieve trophic state objectives eg, Periphyton (section 2).**

Councils must decide on the desired species protection level and define freshwater objectives using the appropriate nitrate concentrations for both sets of thresholds and associated sample statistics (ie, both the median and 95th percentile columns (figure 5 and table 5)). Freshwater objectives should be set in the same attribute state for both sets of thresholds and statistics. Where current conditions are in different attribute states for the different sets, freshwater objectives may be set to bring the lower set into a higher attribute state over time.

Figure 5: Links between values, objectives, limits and management actions specific to the nitrate toxicity attribute



Note: TN = total nitrogen.

Table 5: Nitrate (Toxicity) attribute table

Value	Ecosystem health		
Freshwater Body Type	Rivers		
Attribute	Nitrate (Toxicity)		
Attribute Unit	mg NO_3-N/L (milligrams nitrate-nitrogen per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median	**Annual 95th Percentile**	
A	≤1.0	≤1.5	High conservation value system. Unlikely to be effects even on sensitive species
B	>1.0 and ≤2.4	>1.5 and ≤3.5	Some growth effect on up to 5% of species.
C	>2.4 and ≤6.9	>3.5 and ≤9.8	Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.
National Bottom Line	6.9	9.8	
D	>6.9	>9.8	Impacts on growth of multiple species, and starts approaching acute impact level (ie risk of death) for sensitive species at higher concentrations (>20 mg/L)

Note: This attribute measures the toxic effects of nitrate, not the trophic state. Where other attributes measure trophic state, for example periphyton, freshwater objectives, limits and/or methods for those attributes will be more stringent.

4.3 Defining management actions to achieve freshwater objectives

Defining a resource use limit to meet the freshwater objective requires the consideration of point, non-point, natural and anthropogenic sources of nitrate. A catchment model will generally be required to account for the nitrate loads from different sources, their spatial configuration, and to estimate losses through attenuation (the removal of some nutrient load by processes such as assimilation, deposition or denitrification). This will allow a quantitative approach to be taken to defining the resource use limit for the freshwater management unit. **Where catchment modelling is not possible an estimate is acceptable as a starting point for accounting for nitrate.**

The approach to expressing resource use limits and defining management actions is likely to be similar to that required for nitrogen to meet the periphyton attribute (section 2.3). For additional information on setting and managing to limits see also the *Draft Guide to Limits* on the Ministry for the Environment website.

4.4 Sampling and statistical considerations

Monitoring for nitrate is likely to align well with monthly grab sampling programmes that typically form the core of regional council state-of-environment monitoring programmes.

The recommended number of samples to determine the sample statistics for assessing progress towards freshwater objectives is at least 30 samples over three years. Fewer samples can be used, but confidence in the sample statistics will be lower. More samples will improve the confidence in estimates of sample statistics, however, the marginal improvements in confidence diminish beyond about 20-40 samples (McBride, 2014).

The World Health Organization recommends that percentile based sample statistics should be calculated using the Hazen method rather than the default method in Microsoft Excel (World Health Organization, 2003). The Ministry for the Environment provides a Hazen calculator on our website.

The Ministry for the Environment has commissioned the National Institute of Water and Atmospheric Research (NIWA) to compare nutrient measurements in Wellington rivers by national recommended protocols versus Greater Wellington Regional Council's historical protocols.

The purpose of this work was to look at the impact on regional councils' long-term nutrient measurements if monitoring protocols were changed, using Greater Wellington Regional Council as a case study. The report, *Accounting for changes in method in long-term nutrient data,* is on the Ministry for the Environment website.

5 Toxicants (rivers and lakes) – ammonia

5.1 How the attribute is defined

Ammonia is a toxicant that can cause lethal or sub-lethal (eg, reducing growth rates or reproductive success) effects to aquatic species. These effects can occur as a result of short-term (hours to days) or long-term (weeks, months, years) exposure to ammonia.

The Freshwater NPS defines ammonia toxicity attribute states based on concentrations that protect a specific percentage of test species from long-term exposure to ammonia. The national bottom line is set at ammoniacal nitrogen concentrations that provide protection from effects of long-term exposure for 80 per cent of species. The higher attribute states provide for protection from effects of long-term exposure for 95 per cent to 99 per cent of species.

The toxicant effects of ammonia come from the un-ionised form, while the numeric attribute states are defined for (total) ammoniacal nitrogen. Temperature and pH have a significant effect on the fraction of un-ionised ammonia and its toxicity, so the numeric attribute states, and therefore freshwater objectives, are defined for a pH of 8 and temperature of 20°C.

The ammoniacal nitrogen concentrations that define these attribute states are linked to observed effects from long-term exposure to ammonia in studies on 19 freshwater aquatic species (Hickey, 2014). The first set of attribute state thresholds (ie, median concentration) are set at the No Observed Effect Concentration (NOEC) for each level of species protection. The second set of attribute state thresholds are set at the Threshold Effect Concentration (TEC) for each level of species protection, which can be interpreted as below the level of an effect.

Each set of thresholds is associated with a particular sample statistic to reflect different timescales of effect. Freshwater objectives are set using the:

- NOEC and a sample median manage exposure under average conditions
- TEC and a maximum manage exposure during critical events and daily or seasonal peaks in ammonia concentrations.

5.2 Using the attribute to set freshwater objectives

The Ammonia Toxicity Attribute must be used to set freshwater objectives in all rivers and lakes. Councils must decide on the desired level of species protection and define freshwater objectives using the appropriate ammonia concentrations for both sample statistics (ie, the median and maximum). Freshwater objectives should be set in the same attribute state for both statistics.

Ammonia does not have the same safety 'margin' between concentrations that have lethal and sub-lethal effects that nitrate has. The ammonia concentration that would provide protection for 80 per cent of species with chronic exposure may not protect some sensitive freshwater mussel species from lethal effects. Councils may want to consider setting objectives in the A or B attribute states when species are present that may be at risk of lethal effects (figure 6 and table 6).

Figure 6: Links between values, objectives, limits and management actions specific to the ammonia toxicity attribute

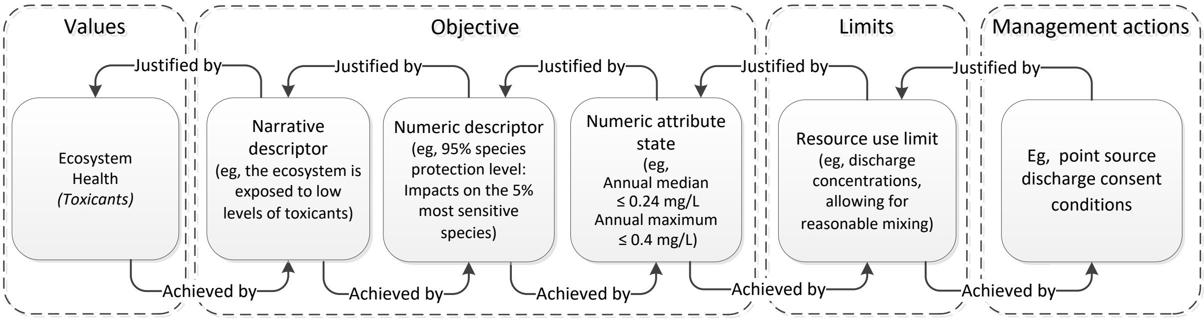


Table 6: Ammonia (Toxicity) attribute table

Value	**Ecosystem health**		
Freshwater Body Type	Lakes and rivers		
Attribute	Ammonia (Toxicity)		
Attribute Unit	mg NH_4-N/L (milligrams ammoniacal-nitrogen per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median*	**Annual Maximum***	
A	≤0.03	≤0.05	99% species protection level: No observed effect on any species tested
B	>0.03 and ≤0.24	>0.05 and ≤0.40	95% species protection level: Starts impacting occasionally on the 5% most sensitive species
C	>0.24 and ≤1.30	>0.40 and ≤2.20	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)
National Bottom Line	1.30	2.20	
D	>1.30	>2.20	Starts approaching acute impact level (ie risk of death) for sensitive species

* Based on pH 8 and temperature of 20°C.

Compliance with the numeric attribute states should be undertaken after pH adjustment.

5.3 Defining management actions to achieve freshwater objectives

Setting limits and management actions to achieve ammonia freshwater objectives is likely to require limits on ammonia concentrations associated with point source discharges. It is likely that management actions will be largely based on setting discharge consent conditions that will ensure the freshwater objective will be met. Existing guidance and case law under the Resource Management Act 1991 should be used to guide decisions about reasonable mixing.

Discharge consent conditions will need to be set at a level that meets both freshwater objectives (ie, those derived in line with the annual median and maximum metrics from the Ammonia Attribute table (Table 6)). The requirement to set a maximum metric for ammonia objectives is also likely to require the management of discharge treatment systems and sites. This will help to manage the risk of accidental or unauthorised discharges, which could create ammonia spikes that may exceed the maximum freshwater objective.

It should be noted that point source discharges may not be the only source of ammonia that needs to managed. For example under some conditions ammonia can be released from the sediments in lakes. For this reason full consideration of all sources of ammonia should be considered when setting limits and choosing management actions.

5.4 Sampling and statistical considerations

Monitoring for ammonia is likely to align well with monthly grab sampling programmes that typically form the core of regional council monitoring, such as for most state-of-environment programmes. McBride (2016) should be used for statistical considerations for design and assessment.

Progress towards, or achievement of, ammonia freshwater objectives must be assessed using both the median and maximum of the observed concentrations. The recommended number of samples to determine the sample statistics for assessing progress towards freshwater objectives is at least 30 samples over three years. Fewer samples can be used, but confidence in the sample statistics will be lower. More samples will improve the confidence in estimates of sample statistics, however, the marginal improvements in confidence diminish beyond about 20–40 samples (McBride 2014, McBride 2016). For detailed guidance on estimating the true 'attribute state' of a monitoring site, the role of sampling size and variability, and burden-of-proof considerations, refer to *the National Objectives Framework - Statistical considerations for design and assessment* guide(McBride,2016).

Because freshwater objectives are defined for a pH of 8 and temperature of 20^{o}C, temperature and pH monitoring data will be required to adjust ammonia sample data to the standard pH and temperature before calculating the relevant sample statistics to assess progress towards freshwater objectives. Each of the measured ammonia concentrations should be adjusted using the corresponding pH result. The median and maximum values of all the adjusted values can then be calculated.

Note that a routine monitoring programme will not necessarily encounter the worst case conditions that will lead to maximum ammonia concentrations. For example, while concentrations of total ammonia may not vary markedly during the day, the same is not the case for pH. As photosynthesis by aquatic plants removes dissolved inorganic carbon from the water as the day proceeds, the pH of the water typically tends to increase (particularly in poorly buffered natural waters). So the maximum value of the 'pH-adjusted' ammonia concentration is likely to occur during the afternoon – particularly in streams that contain many plants. This implies that random or routine sampling is unlikely to identify worst case conditions for the 'annual maximum' attribute, and that a monitoring programme focused on warm, sunny afternoons may be needed instead (see also the Appendix – Ammonia adjustment calculations.

6 Other stressors – dissolved oxygen

6.1 How the attribute is defined

Sufficient dissolved oxygen (DO) is a fundamental requirement for aquatic life.

DO varies diurnally (over the 24-hour day–night cycle), and the minimum DO typically occurs around sunrise. The time of year also affects minimum DO concentrations, with lowest levels typically in summer when:

- temperatures are high (gas solubility declines at higher temperatures), and
- instream plant biomass (including periphyton and macrophytes) is more likely to be high (creating greater respiratory-driven oxygen consumption at night when plant growth is not photosynthesising).

Consequently, the DO attribute states are defined in the Freshwater NPS by two expressions of DO minima; the lowest 7-day mean of daily minima (the '7-day mean minimum') and the lowest daily minimum (the '1-day minimum').

6.2 Using the attribute to set freshwater objectives

The DO attributes must be used to set freshwater objectives for rivers downstream of point sources. Councils must decide on the desired level of protection for the aquatic ecosystem and define freshwater objectives using the appropriate DO concentrations for both sample statistics (ie, 7-day mean minimum and the 1-day minimum) (table 7). Freshwater objectives should be set in the same attribute state for both statistics.

Table 7: Dissolved Oxygen attribute table

Value	Ecosystem health		
Freshwater Body Type	Rivers (below point sources)		
Attribute	Dissolved Oxygen		
Attribute Unit	mg/L (milligrams per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	7-day mean minimum[1] (Summer Period: 1 November to 30th April)	1-day minimum[2] (Summer Period: 1 November to 30th April)	
A	≥8.0	≥7.5	No stress caused by low dissolved oxygen on any aquatic organisms that are present at matched reference (near-pristine) sites.
B	≥7.0 and <8.0	≥5.0 and <7.5	Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance of sensitive fish and macroinvertebrate species.
C	≥5.0 and <7.0	≥4.0 and <5.0	Moderate stress on a number of aquatic organisms caused by dissolved oxygen levels exceeding preference levels for periods of several hours each day. Risk of sensitive fish and macroinvertebrate species being lost.
National Bottom Line	**5.0**	**4.0**	
D	<5.0	<4.0	Significant, persistent stress on a range of aquatic organisms caused by dissolved oxygen exceeding tolerance levels. Likelihood of local extinctions of keystone species and loss of ecological integrity.

1. The mean value of 7 consecutive daily minimum values.
2. The lowest daily minimum across the whole summer period.

6.3 Defining management actions to achieve freshwater objectives

The DO attributes must be used to set freshwater objectives for rivers downstream of point sources, though management may focus on both point and non-point sources to achieve the freshwater objectives. Setting limits and actions requires an understanding of all of the drivers of low DO below point source discharges.

It is likely that point source management actions will be largely based on setting discharge consent conditions so that the freshwater objective will be met, having regard to 'reasonable mixing' zones. Existing guidance and case law under the Resource Management Act 1991 should be used to guide decisions about reasonable mixing. The requirement to achieve the 1-day minimum DO is likely to create requirements for managing discharge treatment systems and sites, to adequately manage the risk of accidental or unauthorised discharges that create short term but severe DO sags.

Managing non-point sources to achieve DO objectives will require the consideration of other freshwater objectives, in particular, trophic state objectives (see section 2), because high plant biomass will contribute to DO depletion. High plant biomass may be driven by diffuse sources of nutrients or high temperature and light, all of which promote high plant (periphyton and macrophyte) biomass.

6.4 Sampling and statistical considerations

Monitoring for DO has traditionally comprised single monthly observations. Monitoring to assess progress towards DO freshwater objectives will likely require an increase in this monitoring frequency.

Monitoring to assess progress towards freshwater objectives will require identifying diurnal minima, which requires continuous DO monitoring. While the metrics in the attribute table (table 7) are defined as DO minima over the six-month summer period from 1 November to 30 April, this does not necessarily imply that the monitoring is required for the full six-month period.[5] It may be sufficient to target monitoring to a small number of high-risk months, or possibly weeks, depending on the understanding of when seasonal minima are likely to occur in the water body. This should be accompanied by a risk assessment outlining when and why this is appropriate and identify triggers that will signal a reassessment.

The DO freshwater objective applies in rivers, downstream of point sources[6], but not every point source discharge would necessarily need to be monitored. The Freshwater NPS requires councils to identify 'representative sites' for monitoring purposes, recognising that it is not practical or feasible to monitor every drop of water everywhere (Part CB of the Freshwater NPS). Representative monitoring sites may prioritise a location based on an understanding of pressures and sensitive locations in terms of DO levels. For example, it would be logical to select locations that have high nutrient and/or biological oxygen demand loadings, particularly where DO at these locations is likely to be sensitive.

See also the National Environmental Monitoring Standard for Dissolved Oxygen and the Freshwater NPS guide on monitoring for a detailed discussion on what is a representative site.

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5 Note that this would have been the case if the average weekly minimum (over the full six-month period) was adopted, but only the minimum weekly and minimum daily metrics form part of the attribute requirements. The 7-day mean minimum is effectively a rolling weekly mean of daily minima, across the monitoring period. The 1-day minimum is simply the lowest daily minimum across the monitoring period.

6 As stated in the attribute table under the freshwater body type.

7 Pathogens (rivers and lakes) – *Escherichia coli*

7.1 How the attribute is defined

The *Escherichia coli* (*E. coli*) attribute states define *E. coli* concentrations where different percentages of the population are at risk of *Campylobacter* infection through ingestion of water during recreation activities The *E. coli* attribute describes different statistical measures of the distribution of *E. coli* concentrations, and the associated risk of *Campylobacter* infection through ingestion of water during recreation activities (McBride, 2012; Ministry for the Environment and Ministry of Health, 2003).

Each of the statistical measure are:

- percentage of exceedances greater than 540 cfu/100mL: This measure indicates how often the level of *E. coli* exceeds the acceptable threshold for swimming
- percentage of exceedances greater than 260 cfu/100mL: This measure indicates how often the *E. coli* exceeds the point where additional monitoring is required
- median: The mid-point of *E. coli* levels
- 95th percentile: an indication of the top of the range of *E. coli* levels within the distribution.

The thresholds of what has been considered an acceptable level of *E. coli* (discussed throughout this document) are based on a 'quantitative microbial health risk assessment' (QMRA) that assessed what the corresponding risk of *Campylobacter* infection would be for different concentrations of *E. coli*.

Infection risk profiles have been developed to relate *E. coli* levels and the proportion of population at risk of *Campylobacter* infection for activities likely to involve full immersion such as swimming or white water rafting (McBride, 2012; Ministry for the Environment and Ministry of Health, 2003).

The *E. coli* attribute table has five categories, or attribute states (ie, A, B, C, D and E) (table 8). Each attribute state has four criteria, or 'statistical tests', that need to be satisfied for water quality to be in that attribute state. Higher attribute states provide lower levels of infection risk for each activity type. All four criteria are necessary to establish an attribute state. If one or more criteria can't be satisfied, a lower attribute state must apply.

For example, for water quality to be in the A state, it must:

- not exceed 540 *cfu*/100ml more than 5% of the time
- not exceed 260 *cfu*/100ml more than 20% of the time
- have a median of ≤130 *cfu*/100ml
- have a 95th percentile of ≤540 *cfu*/100ml.

If any of those criteria are not satisfied, water quality is in a lower state (eg, B, or lower, as long as all criteria can be satisfied). Note there is an overlap in the 'exceedances over 260 *cfu*/100ml' test between states B (20-30% exceedance) and C (20-34%). This overlap occurs because of an overlap in the underlying distribution used to set the attribute states. For example, if a site satisfied all of the other tests for B and had a 260 exceedance of 29% it would still be band B. If one of the other tests did not meet the band B criteria it would drop down to band C.

When categorising individual rivers or lakes using the *E. coli* attribute, the 95th percentile criteria may not apply if the council considers there is insufficient monitoring data to establish a precise 95th percentile. This is to acknowledge that monitoring data at this scale may be limited, and may not be sufficient to model the 95th percentile precisely.

Table 8: *E. coli* attribute table

Value	Human health for recreation				
Freshwater Body Type	Lakes and rivers				
Attribute	*Escherichia coli (E. coli)*				
Attribute Unit	*E. coli*/100 mL (number of *E. coli* per hundred millilitres)				
Attribute State	**Numeric Attribute State**				**Narrative Attribute State**
	% exceedances over 540 cfu/100ml	**% exceedances over 260 cfu/100ml**	**Median concentration (cfu/100ml)**	**95th percentile of *E. coli*/100 mL**	**Description of risk of *Campylobacter* infection (based on *E. coli* indicator)**
A (Blue)	<5%	<20%	≤130	≤540	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 1%
B (Green)	5-10%	20-30%	≤130	≤1000	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 2%*
C (Yellow)	10-20%	20-34%	≤130	≤1200	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 3%*
D (Orange)	20-30%	>34%	>130	>1200	20-30% of the time the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >3%*
E (Red)	>30%	>50%	>260	>1200	For more than 30% of the time the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >7%*

* The predicted average infection risk is the overall average infection to swimmers based on a random exposure on a random day, ignoring any possibility of not swimming during high flows or when a surveillance advisory is in place

(assuming that the *E. coli* concentration follows a lognormal distribution). Actual risk will generally be less if a person does not swim during high flows.

[1] Attribute state should be determined by using a minimum of 60 samples over a maximum of 5 years, collected on a regular basis regardless of weather and flow conditions. However, where a sample has been missed due to adverse weather or error, attribute state may be determined using samples over a longer timeframe.

[2] Attribute state must be determined by satisfying all numeric attribute states.

7.2 Using the attribute to set freshwater objectives

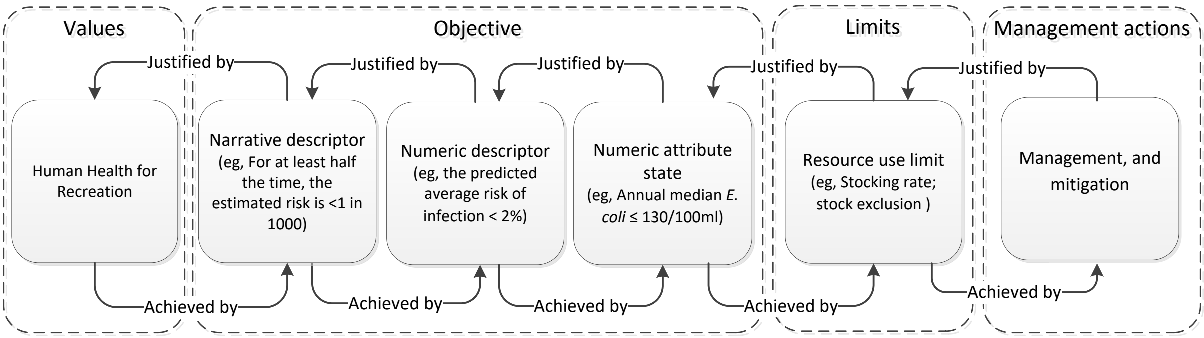
Human health for recreation is a compulsory value, and *E. coli* must be used to set a freshwater objective (or objectives) in each FMU to meet that value (figure 7).

In most cases, freshwater objectives will need be set at a point above current state to give effect to Objective A3. Objective A3 directs the quality of fresh water in a freshwater management unit to improve so it is suitable for primary contact more often, unless regional targets have been achieved or naturally occurring processes prevent further improvement.

This objective seeks relative improvement on the *status quo*. This contrasts with other attributes in the Freshwater NPS for which regional councils are only **required** to set freshwater objectives to improve water quality if the current state is below a national bottom line, or the council decides (after following the process set out in Policy CA2) that water quality must be improved.

For additional guidance on using *E. coli* to set freshwater objectives see *A Draft Guide to Swimming, E. coli and the National Targets under the Freshwater NPS*, available on the Ministry for the Environment website

Figure 7: Links between values, objectives and management actions specific to the *E. coli* attribute



7.3 Defining management actions to achieve freshwater objectives

Defining a resource use limit to meet *E. coli* objectives requires the consideration of all sources of *E. coli* – including point, non-point, natural and anthropogenic sources.

At the property scale, there are significant gaps in our understanding of the yield, fate and transfer of pathogens from land to water (Muirhead *et al.,* 2011), and in our ability to quantify how effective mitigations are in reducing the concentration of pathogens (and indicator bacteria). This means management actions to meet *E. coli* objectives are unlikely to be based on *E. coli* load limits allocated at the property scale. Rather, interventions, such as point-source management and discharge limits, catchment wide stock exclusion and riparian planning as well as improved effluent/sewerage /stormwater management, may be required to meet the freshwater objective and manage *E. coli*.

Methods and tools such as a catchment risk assessments (eg, Ministry for the Environment and Ministry of Health (2003)), Quantitative Microbial Risk Assessment (Till *et al.,* 2008) and faecal source tracking (eg, ESR (2012)) can be useful in identifying *E. coli* sources which may help target effective interventions.

7.4 Sampling and statistical considerations

The recommended number of samples to determine the sample statistics for assessing progress towards freshwater objectives is 60 samples over a maximum of 5 years collected on a regular basis regardless of weather and flow conditions. However, where a sample has been missed due to adverse weather or error, attribute state may be determined using samples over a longer timeframe (see attribute 'Note' in Appendix 2 of the Freshwater NPS). Fewer samples can be used, but confidence in the sample statistics will be lower. More samples will improve the confidence in estimates of sample statistics; however, the marginal improvements in confidence diminish beyond about 20–40 samples (McBride, 2014).

The World Health Organization recommends that percentile based sample statistics should be calculated using the Hazen method rather than the default method in Microsoft Excel (World Health Organization, 2003). The Ministry for the Environment provides a Hazen calculator on our website.

Councils should decide on the frequency and period of monitoring of progress towards any temporally specific freshwater objectives after discussion about what those objectives should be. Monitoring and communications about assessing progress towards freshwater objectives should consider:

- the periods the freshwater objective applies and monitoring is required to represent
- the periods when people might be using the water body for recreational activities and potentially be exposed to health risk
- the periods when pathogens might be expected in the water
- any conditions in which the freshwater objective does/does not apply (eg, flow or rainfall restrictions) and that monitoring is not required to represent
- the desired statistical confidence for concluding that the freshwater objective is achieved

- the timeframe in which the freshwater objective is to be met
- information required for other tools to manage health risks both before and after the freshwater objective is achieved.

Note that there are also 'surveillance' monitoring requirements for *E. coli* which are to assist in monitoring progress toward the national targets. This is covered in *A Draft Guide to Swimming, E. coli and the National Targets under the Freshwater NPS* available on the Ministry for the Environment web site.

8 Toxins (lakes and lake-fed rivers) – planktonic cyanobacteria

8.1 How the attribute is defined

The planktonic cyanobacteria attribute defines levels of toxin-producing cyanobacteria and total cyanobacteria that avoid an appreciable health risk when undertaking recreation activities in water (table 9). These levels were calculated by scaling up the results from tests on exposure to cyanotoxins for pigs and mice (Falconer *et al.,* 1994, and Fawel *et al.,* 1999, cited in Ministry for the Environment and Ministry of Health, 2009).

Planktonic cyanobacteria occur in lakes and lake-fed rivers, so the attribute is only applicable in these water body types. The lake source of flow class of the River Environment Classification could be a useful tool to identify lake-fed rivers.

Freshwater objectives based on planktonic cyanobacteria should be complemented by other health risk-management tools such as surveillance monitoring of both planktonic and benthic cyanobacteria. This provides assessment of risks to human health in both river and lake environments, and provides timely information for authorities to respond to immediate risks (Ministry for the Environment and Ministry of Health, 2009; Wood *et al.,* 2013).

8.2 Using the attribute to set freshwater objectives

Human health for recreation is a compulsory value and planktonic cyanobacteria must be used to set freshwater objectives in all lakes and lake-fed rivers (figure 8)

Changes in 2017 to the Freshwater NPS mean the attribute planktonic cyanobacteria is now also used as a way of achieving and measuring progress toward the national targets for improved swimming quality. Freshwater objectives for this attribute must be set so water quality improves (ie, is not maintained) until regional targets are met so water is suitable for primary contact more often. See *A Draft guide to Swimming, E.coli and the National Targets under the Freshwater NPS* for detail on these requirements for a full description of the policies and monitoring requirements.

While freshwater objectives must be set using the Planktonic Cyanobacteria Attribute, additional attributes may also be relevant to the human health for recreation value in some lakes or lake-fed rivers. The Freshwater NPS enables regional councils to develop freshwater objectives using any other attribute that the council considers appropriate.

Table 9: Cyanobacteria – Planktonic attribute table

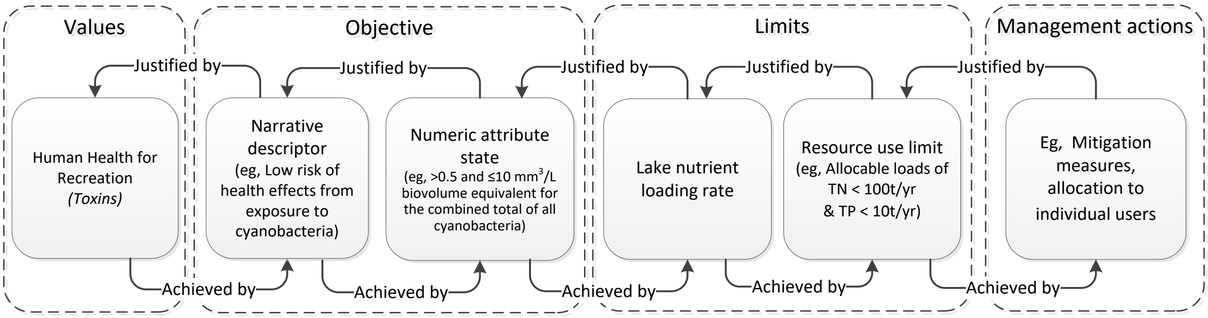
Value	Human health for recreation	
Freshwater Body Type	Lakes and lake fed rivers	
Attribute	Cyanobacteria – Planktonic	
Attribute Unit	Biovolume – mm^3/L (cubic millimetres per litre)	
Attribute State	**Numeric Attribute State**	**Narrative Attribute State**
	80th percentile*	
A (Blue)	≤0.5 mm^3/L biovolume equivalent for the combined total of all cyanobacteria	Risk exposure from cyanobacteria is no different to that in natural conditions (from any contact with fresh water).
B (Green)	>0.5 and ≤1.0 mm^3/L biovolume equivalent for the combined total of all cyanobacteria	Low risk of health effects from exposure to cyanobacteria (from any contact with fresh water).
C (Yellow)	>1.0 and ≤1.8 mm^3/L biovolume equivalent of potentially toxic cyanobacteria OR >1.0 and ≤10 mm^3/L total biovolume of all cyanobacteria	Moderate risk of health effects from exposure to cyanobacteria (from any contact with fresh water).
National Bottom Line	1.8 mm^3/L biovolume equivalent of potentially toxic cyanobacteria OR 10 mm^3/L total biovolume of all cyanobacteria	
D (Orange/Red)	1.8 mm^3/L biovolume equivalent of potentially toxic cyanobacteria OR >10 mm^3/L total biovolume of all cyanobacteria	High health risks (eg, respiratory, irritation and allergy symptoms) exist from exposure to cyanobacteria (from any contact with fresh water).

* The 80th percentile must be calculated using a minimum of 12 samples collected over 3 years. 30 samples collected over 3 years is recommended.

8.3 Defining management actions to achieve freshwater objectives

Ensuring that lakes achieve planktonic cyanobacteria objectives will generally require managing nutrient (nitrogen and phosphorus) loads discharging into lakes from their upstream catchments. The approach to defining a resource use limit and management actions is likely to be similar to that required for the lake trophic state objectives (section 3.3).

Figure 8: Links between values, objectives and management actions specific to the planktonic cyanobacteria attribute



8.4 Sampling and statistical considerations

The *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters* Section 4 (Ministry for the Environment and Ministry of Health 2009) describes sampling procedures for planktonic cyanobacteria. Current council monitoring programmes are likely to provide sufficient information to inform the setting and assessment of freshwater objectives for human health for recreation in many water bodies. Sampling needs to reflect all conditions and at least provide the minimum data required to calculate the sample statistics to assess progress towards freshwater objectives. Such sampling may differ from that required for surveillance monitoring programmes that provide timely information to manage immediate health risks.[7]

The minimum number of samples required to determine the sample 80th percentile for assessing freshwater objectives is 12 samples over three years, though 30 samples over three years are recommended. More samples will improve the confidence in estimates of sample statistics; however, the marginal improvements in confidence diminish beyond about 20–40 samples (McBride, 2014).

The World Health Organization recommends that percentiles should be calculated using the Hazen method rather than the default method in Microsoft Excel (World Health Organization, 2003). The Ministry for the Environment provides a Hazen calculator on our website.

7 See *A Draft guide to Swimming, E.coli and the National Targets under the Freshwater NPS*.

9 Monitoring

The Freshwater NPS requires councils to prepare monitoring plans that describe how they will collect the information they will use to monitor and show progress towards, and the achievement of, freshwater objectives and values (Part CB of the Freshwater NPS).

Monitoring information will be required in both the setting, and assessment of progress towards, freshwater objectives. Councils will need to understand the current state of each attribute as baseline information for setting freshwater objectives; and then be able to demonstrate to their community that they have achieved freshwater objectives over time.

The Freshwater NPS requires councils to detail in the monitoring plan the monitoring methods that will be used and identify the site or sites where monitoring will be undertaken. This leaves councils with flexibility to consider how to generate sufficient monitoring data for setting and assessing progress towards freshwater objectives, as well as generating monitoring data for wider uses (ie, compliance monitoring).

For a full description of the monitoring requirements in the NPS, including a significant reference section on monitoring protocols and guidelines, see *A Draft Guide to Monitoring* available on the Ministry for the Environment website.

Appendix – Ammonia adjustment calculations

ANZECC (2000, Section 8.3.7.2) observes that total ammoniacal nitrogen, NH4-N (often referred to as 'total ammonia'), '*refers to two chemical species that are in equilibrium in water: the un-ionised ammonia, NH_3, and the ionised ammonium ion, NH_4+*.' And, '*The proportion of the two chemical forms varies with the physico-chemical properties of the water, particularly pH and temperature*.'

However, as the name 'total ammonia' implies, the combined amount of these two chemical species is constant, and it does not vary with the physico-chemical properties of the water. That is, 'adjusting' the ammonia concentration for pH does **not** mean that the amount of total ammonia present changes (and in fact the standard laboratory analysis for NH_4-N is successfully carried out at a high pH, e.g. pH 11).

Instead, pH adjustment means calculating the amount of NH_4-N at pH 8 that would have the **equivalent toxicity** to the amount of NH_4-N measured in the sample at the pH of the sample – whatever that may have been. That is, the calculation produces the concentration of NH_4-N which at pH 8 would have the same toxicity as the observed (ie, unadjusted) NH_4-N concentration would have at the observed pH.

The information in table 10 allows the ammonia concentration of a sample to be converted to an equivalent concentration at pH 8 using the following equation:

$$Conc_{pH\ 8} = \frac{Conc_{pH\ sample}}{Ratio} \qquad \text{Equation (1)}$$

Where $Conc_{pH\ sample}$ is the concentration of the sample and $Ratio$ is read from table 10 for the given sample pH.

For example, if a sample was observed with 1.12 mg NH_4-N/L at pH 7.5, the adjusted concentration to use in calculating sample statistics would be 0.63 mg NH_4-N/L at pH 8. This is derived as follows:

Using equation (1) and table 10:

$$Conc_{pH8} = 0.63 = \frac{1.12}{1.79}$$

Where the numerator (1.12) is the observed sample concentration and the denominator (1.79) is the $Ratio$ from table 10 at pH of 7.5.

That is, although there is still 1.12 mg/L of NH_4-N present in the sample, the adjustment process has identified that the toxicity of this sample at pH 7.5 is equivalent to the toxicity associated with a NH_4-N concentration of 0.63 mg/L at pH 8. It's the **equivalent toxicity** that has been adjusted, and not the amount of NH_4-N present in the sample (which remains unchanged).

Note that a method for converting to standard temperature is not currently available.

Table 10: Conversion ratios for pH adjustment of ammonia concentrations

Sample pH	Ratio	Sample pH	Ratio	Sample pH	Ratio
6	2.86	7	2.42	8.1	0.87
6.1	2.84	7.1	2.32	8.2	0.73
6.2	2.82	7.2	2.21	8.3	0.62
6.3	2.80	7.3	2.09	8.4	0.53
6.4	2.77	7.4	1.94	8.5	0.44
6.5	2.73	7.5	1.79	8.6	0.38
6.6	2.70	7.6	1.63	8.7	0.32
6.7	2.64	7.7	1.47	8.8	0.27
6.8	2.59	7.8	1.31	8.9	0.23
6.9	2.51	7.9	1.14	9	0.20
		8	1.00	>9	0.20

Source: Adapted from ANZECC (2000) and Hickey (2014).

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