Development of a periphyton monitoring programme within the Bay of Plenty

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		Name	Signature	Name	Signature	Date
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Executive summary

1 Under the National Policy Statement for Freshwater Management (NPS-FM), a number of National Objective Frameworks (NOF) have been identified to ensure the maintenance of healthy ecosystems. One of the NOF attributes includes measurement of periphyton (algal) biomass (expressed as chlorophyll *a*, the dominant pigment of algae). Periphyton is a natural component of rivers, and provides an important food source for invertebrates. However, periphyton blooms can have detrimental impacts on not only the ecological value of rivers, but also their recreational, aesthetic and cultural values.

2 The NOF has proposed four bands (A to D) for periphyton biomass, with the D band representing conditions that fail to meet the National "bottom line". This band occurs when chlorophyll *a* biomass exceeds 200 mg/m². At this level, stream health can decline, and invertebrate communities become dominated by taxa such as snails, worms and midges. In contrast, the A band has a maximum chlorophyll biomass < 50 mg/m². Sites within this band are characterised by “sensitive” invertebrates such as mayflies, caddis flies and stoneflies.

3 The NOF chlorophyll *a* bands also recognise that streams flowing through unmodified catchments can sometimes experience short-lived algal blooms, especially in catchments dominated by nutrient bearing rocks, or during times of very stable (but infrequent) times of low flow. Stream ecosystems are highly resilient to short term algal blooms, so a frequency of exceedance is also considered. Thus streams flowing through catchments dominated by nutrient rich rocks have an acceptable exceedance frequency of 2/12 months, whilst streams flowing through catchments dominated by nutrient poor rocks have an acceptable exceedance frequency of 1/12 months.

4 Implementation of the NPS-FM requires the Bay of Plenty Regional Council (BOPRC) to commence a periphyton monitoring program to:

- determine the current state of periphyton biomass in waterways,
- help set periphyton biomass limits according to established NOF bands,
- determine whether periphyton biomass is increasing or decreasing over time as a result of land use change, and implementation of council policies and plans,
- generate data to be used to investigate linkages between a stream’s nutrient and flow regime in order to help set nutrient limits according to the NOF bands.

BOPRC has divided the region into nine Water Management Areas (WMAs) to allow prioritisation of targeted work for each area. Two of these WMAs, the Rangitaiki and the Kaituna-Maketu, have been identified as the first priority.

5 A high degree of natural variability occurs within each WMA, meaning that NOF attributes such as periphyton will vary greatly throughout the region. This natural variability makes it difficult to accurately describe the current state of all waterways, or set meaningful nutrient limits to minimise the chance of periphyton blooms. This means that a waterway classification is needed throughout the region. This waterway classification forms Freshwater Management Units, that reflects the fact that periphyton is influenced by many environmental factors such as a stream’s flow regime, substrate nature, nutrients, and light regime. Having an appropriate spatial classification ensures that different stream types are adequately represented in a monitoring programme. A FMU framework based on geology and substrate size was subsequently used to classify waterways into three stream types. Sites within these stream types were then selected within the different WMAs.

6 Choice of sites should also be made with a clear understanding of the required outcomes of the monitoring. Fundamental to this decision was to have a clear understanding of the objectives of a monitoring program set to “determine the current state of periphyton biomass in waterways”, as this was open to interpretation. For example, major differences would occur in site selection procedures between a programme designed to describe “*the extent to which waterways throughout the region experience excessive periphyton blooms*” and another programme designed to describe “*the extent to which excessive periphyton blooms occur in waterways throughout the region, where such blooms are not limited by shade or physical habitat”.* The former programme would randomly select sites throughout the region (partitioned amongst different defined classes), whilst the second program would select sites only where periphyton blooms are expected to occur (within the different REC classes). For the NPS implementation work, it was recommended that the second objective was more relevant, so all sites were restricted to unshaded, hard-bottomed streams. This meant that we restricted our sites to either Volcanic or non-volcanic Hard-bottomed streams.

7 A rules-based approach to site selection was developed that selected potential sites for a periphyton monitoring programme. A number of steps were implemented using GIS to select waterways. Firstly, all waterways in the region were assigned to discrete nutrient and flood frequency classes. All sites dominated by soft-substrates and heavily shaded were omitted, as periphyton blooms were unlikely to occur in these streams. Small headwater streams that may be ephemeral, and large rivers where sampling would be difficult were also omitted. Remaining reaches were selected that crossed roads, and these were then allocated to discrete nutrient/flood frequency classes in each of the three Geology/substrate size stream types. Only the most common nutrient/flood frequency classes were chosen for field visits, where a GIS analyses was used to select a random subset of samples for field inspections.

8 A total of 95 randomly selected sites in different nutrient/flood frequency classes in the two FMU classes were assessed for their suitability as periphyton monitoring sites. This suitability was based on attributes such as substrate size, amount of shade, being the wadeable, physical and legal access, and being able to easily gauge a site. A total of 30 streams were finally selected from the sixth most common nutrient/flood frequency classes.

9 At each site, periphyton communities will be sampled in runs, as this hydraulic habitat type is found most commonly in a wide range of rivers. Periphyton biomass (as chlorophyll *a*) will be estimated using standard quantitative procedures, based on scraping material from a fixed area of 10 randomly selected stones within each sampling site. Chlorophyll *a* will be measured by extraction using hot ethanol. In addition to quantitative sampling, periphyton cover will also be visually estimated at each site, with periphyton groups being classified into defined classes (e.g., filaments, mats, cyanobacteria). These visual estimates will be used to calculate composite cover metrics, to compare to chlorophyll data. Nutrient samples will also be collected from each site, and flows measured using standard gauging techniques.

10 Monthly monitoring of periphyton biomass for a period of at least three years from selected sites will provide important information to categorise the current state of sites into one of the four chlorophyll *a* biomass categories outlined in the NOF. This information will feed into the council's public consultation process required under the NPS-FW. Furthermore, data generated from this monitoring programme may allow regionally based predictive models to be developed that explain the interaction of parameters such as nutrients and flow on the periphyton biomass. These models could be used to help BOPRC set nutrient limits as part of its obligations under the NPS-FW

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Part 1: Introduction

1.1 Factors controlling periphyton

"Periphyton" is the term used to describe the slime that grows attached to rocks, stumps, and other stable substrates in rivers and streams. It is composed mostly of algae, although it can also contain fungi and bacteria. It is a natural component of rivers, and provides an important food source for invertebrates. Periphyton can also be an important indicator of changes of water quality because increases in the concentrations of dissolved nutrients may lead to excessive cover and biomass of periphyton (i.e., a bloom or proliferation). Periphyton blooms have detrimental impacts on not only the ecological value of rivers but also their recreational, aesthetic and cultural values.

The amount of periphyton in a stream is dictated by many variables operating at different spatial and temporal scales. Large-scale factors such as climate and source of flow (e.g., mountain, hill, lowland, or spring-fed sources) interact to determine a stream's natural flow regime (Figure 1). Streams that flood frequently will generally support less periphyton than streams that rarely flood. The time between high flows is termed the accrual period, during which periphyton biomass can increase. Consequently, maximum biomass is often observed after lengthy periods of low, stable flows (Biggs, 1988; Biggs, 2000b; Suren et al., 2003b). A common method of quantifying flood frequency is to calculate the hydrological statistic FRE3, which is the mean annual frequency of flows greater than three times the long-term median flow (Booker 2013). In an comparison of relationships between multiple flow indices and biotic variables, FRE3 explained most variability in river biota, including periphyton (Clausen and Biggs, 1997).

The nutrient status of a stream is also an important influence on periphyton biomass. All other things being equal, streams with high nutrient levels generally support more periphyton than streams with low nutrient levels. Nutrient concentrations are determined by a mixture of natural factors such as geology and anthropogenic factors such as agricultural land use. Nutrient levels are often higher in catchments dominated by soft sediment or volcanic material than in catchments dominated by hard sedimentary rock (Biggs and Gerbeaux, 1993). Changes to land use can lead to increased nutrient inputs into streams (Figure 1), with streams draining intensively farmed catchments having higher nutrient concentrations that streams draining plantation forest or native bush.

Periphyton can be controlled by factors operating at smaller spatial scales. For example, substrate composition can play an important role in determining overall periphyton biomass. Stream beds dominated by highly mobile fine sediments will support less periphyton than streams with larger, stable substrates such as cobbles and gravels (Figure 1). Velocity is also a major factor affecting periphyton biomass. Streams with steep gradients (which usually also have larger substrates) generally have high instream velocities that can scour periphyton from boulders, especially during floods. Low gradient streams, in contrast, have slower velocities, which may result in higher periphyton cover and biomass. However, high instream velocities do not always result in lower periphyton biomass. In low nutrient streams, higher water velocity can actually increase periphyton biomass because of more rapid delivery of nutrients to the cell surfaces, especially if they are taxa with can hold on firmly to stable substrates (and therefore withstand some floods). What appears to be the most important factor is the average velocity that periphyton communities are gown under, and have adapted to (Biggs and Thomsen, 1995). Increases in water velocity above this will, however, usually result in a loss of biomass if this increase exceeds the ability of the periphyton to stay attached to rocks.

This would explain the findings of (Biggs and Close, 1989) who observed a variable response of periphyton biomass to increases in flow unless that flow was increased by more than six times the preceding seven day flow. Under these circumstances, biomass was always reduced.

Periphyton consists mainly of autotrophic organisms (i.e., obtaining energy from the sun via photosynthesis); therefore the amount of light reaching a stream is a further important factor influencing biomass. Streams flowing through forested catchments will generally have lower periphyton biomass than streams flowing through open catchments such as tussock or pasture. Low periphyton biomass is typically associated with approximately 80% or more shade (Davies-Colley and Quinn, 1998). Finally, grazing pressure by invertebrates can keep periphyton levels low, given sufficient numbers of grazing invertebrates such as mayflies, midges, snails and some caddisflies and stoneflies (Welch et al., 2000; Winterbourn and Fegley, 1989). Note that the types of invertebrates in a stream are also controlled by factors such as climate, source of flow, geology and land use, as well as by the extent and nature of any periphyton blooms (Biggs, 2000b; Suren and Riis, 2010).

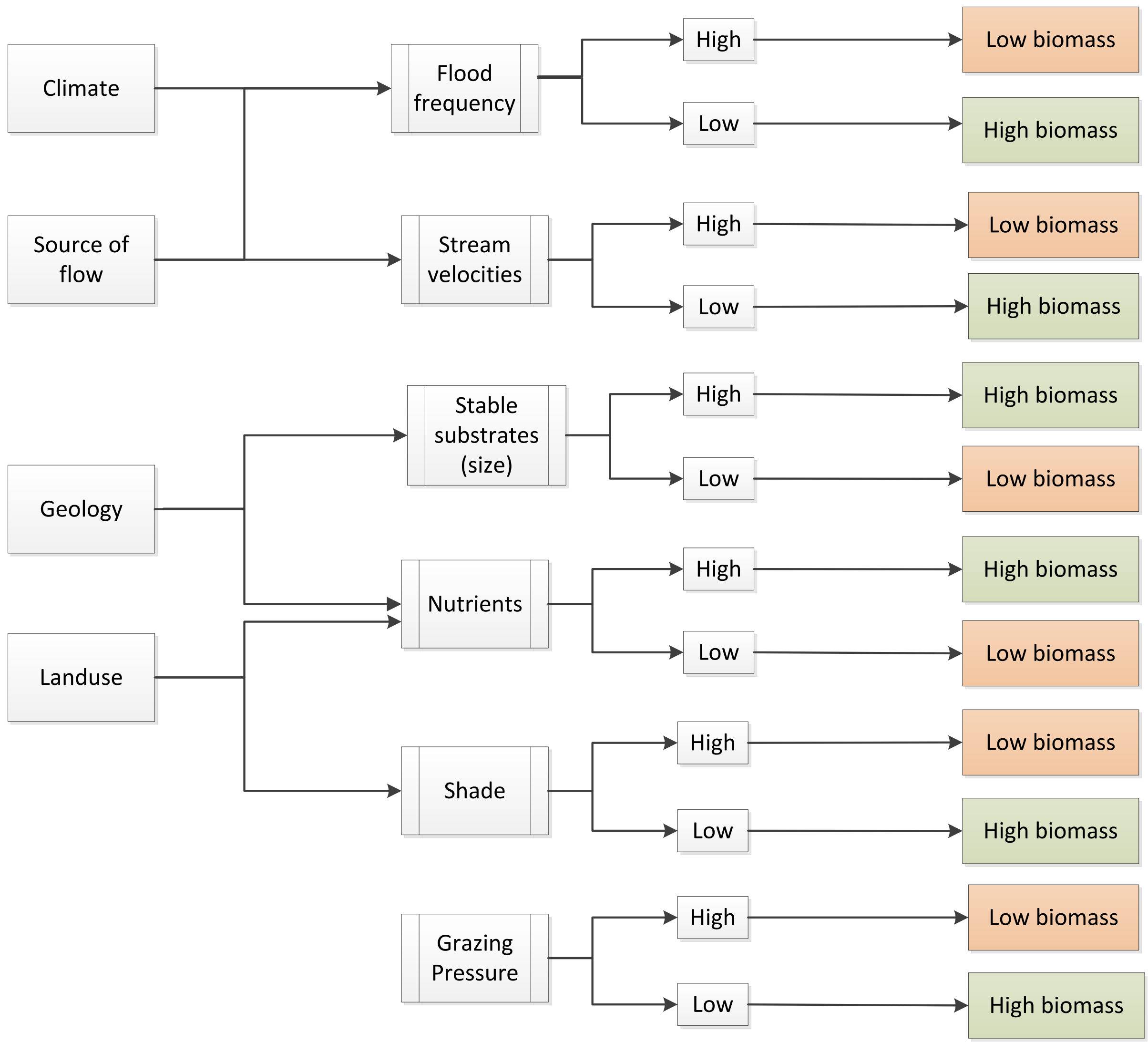


Figure 1 Diagram illustrating the interplay of differing environmental factors on periphyton biomass. The resultant biomass in a stream reflects the complex interaction between these environmental factors.

Periphyton biomass can influence many instream values, such as recreation, aesthetics, and ecology. In recognition of this, in 2000 Ministry for the Environment (MfE) produced interim guidelines for periphyton cover and biomass for the maintenance of aesthetics, benthic biodiversity, and trout habitat and angling values (Biggs, 2000b). The guidelines were specified as either estimates of percentage cover of the stream bed by periphyton mats (comprising diatoms/cyanobacteria) or filamentous algae, or measures of chlorophyll *a* (the photosynthetic pigments that is found in all algae and used as a surrogate for periphyton biomass), determined from quantitative samples collected from the stream substrates. For example, maintenance of aesthetics and recreation would be achieved in rivers having less than 60% cover of diatom films greater than 0.3 cm thick, or less than 30% cover of filamentous algae (greater than 2 cm long). Benthic biodiversity would also be maintained if a maximum of chlorophyll *a* biomass of <50 mg m^{-2} is maintained (Biggs, 2000b).

More recently, in a review of the Biggs (2000) guidelines, (Matheson et al., 2013) highlighted a number of limitations. One was that the MFE guidelines provided separate thresholds for mat forming algae (such as the diatoms and cyanobacteria) and filamentous algae. However, it is possible for combined cover by both types of periphyton to be high, while cover by each type is below the MfE threshold. For example, 30% cover of diatom/cyanobacterial mats combined with 25% cover of filamentous algae (each of which meets the respective guideline) is likely to constitute an unacceptable condition which would negatively impact in stream values. To solve this anomaly, Matheson et al. (2013) recommended the use of a periphyton weighted composite cover (PeriWCC) such that:

$$\text{PeriWCC} = \%\ \text{filamentous cover} + (\%\ \text{mat cover}/2)$$

Matheson et al. (2013) also suggested four bands for PeriWCC such that <20% = “excellent”; 20 – 39% = “good"; 40 – 55% = “fair"; >55% = “poor”. They showed that invertebrate metrics such as the MCI, QMCI and percentage of EPT responded in a relatively consistent manner to increases in PeriWCC, and suggested that these four bands could form the basis of provisional general periphyton cover thresholds to protect benthic biodiversity.

A second limitation of the MfE periphyton guidelines is the fact that the relationships presented in these guidelines linking periphyton biomass, nutrient concentrations, and biomass accrual time were derived using data primarily from gravel-bed rivers. These empirically derived relationships did not consider other important regulators of periphyton growth, such as light availability or substrate stability (Biggs, 2000a). Matheson et al. (2013) highlight the fact that this limitation makes it difficult to apply the model to rivers other than open, gravel-bed rivers. Consequently, they suggest that the nutrient thresholds in the periphyton guidelines represent worst-case scenarios, and applicable to streams where periphyton growth will be optimal. Such streams would be typified as having no shade, high water clarity, gravel cobbles substrates, and long periods of low stable flow.

1.2 Periphyton links to the NPS-FM

The National Policy Statement for Freshwater Management (NPS-FW) requires regional councils to establish freshwater objectives and set limits to give effect to those objectives. It also requires that the overall quality of fresh water within a region is maintained or improved. The NPS-FW has also identified a number of specific water quality attributes under the National Objectives Framework (NOF) that councils must monitor, and has set minimum acceptable states (i.e. 'national bottom lines') for those attributes to support the compulsory values of ecosystem health and human health for recreation. Periphyton is one of seven NOF attributes included to ensure the maintenance of healthy freshwater ecosystems. Other attributes include water quality parameters such as nutrients (nitrate-N and ammonia-N) to avoid levels approaching those where chronic toxicity can occur, and bacterial contamination from *E. coli* to ensure safe contact recreation is maintained. These water quality parameters will not be discussed further in this report.

The NOF specifies that periphyton abundance (biomass) should be measured as chlorophyll *a*, the dominant pigment of algae. Although monitoring periphyton biomass using chlorophyll *a* is relatively expensive, (Snelder et al., 2013) highlight that chlorophyll *a* is a relevant variable representing periphyton biomass, is a standard metric for measuring periphyton abundance internationally, has been used extensively in New Zealand, and is useful because it summarises biomass as a single quantity. Statistical models relating periphyton biomass to other factors such as water chemistry and flow regimes are generally stronger for chlorophyll *a* than for other measures such as percent cover.

The NOF proposes four bands (A to D) for periphyton biomass, with the D band representing conditions that fail to meet the National "bottom line". The NPS-FM emphasises that management objectives for periphyton biomass (and other attributes included in the NOF) cannot be set in the D band. The proposed threshold for the D band for periphyton is a chlorophyll *a* biomass of 200 mg/m². Biomass exceeding this level is generally associated with invertebrate communities dominated by taxa such as snails, worms and midges, which are characteristic of degraded ecosystems. The A band for maximum chlorophyll biomass is less than 50 mg/m². Periphyton biomass within this band is expected to be associated with invertebrate taxa such as mayflies, caddis flies and stoneflies, which are found only in areas of high water quality and good habitat conditions.

The NOF chlorophyll bands also include an exceedance frequency, recognising that even streams flowing through unmodified catchments can experience occasional algal blooms particularly in periods of extended low flows. Thus streams flowing through catchments dominated by nutrient rich rocks have an acceptable exceedance frequency of 2/12 months (16% of the time), whilst streams flowing through catchments dominated by nutrient poor rocks have an acceptable exceedance frequency of 1/12 months (8% of the time). However, stream ecosystems are highly resilient to short-term or infrequent algal blooms, and ecological health is generally not expected to decline in the long term when algal blooms are short-lived or infrequent (Suren et al., 2003a).

1.3 Implementing the NPS-FM in the Bay of Plenty

Implementation of the NPS-FM requires that periphyton thresholds (or bands) are proposed for streams in each Water Management Area (see Section 2). In the Bay of Plenty, these bands will be established by the Bay of Plenty Regional Council (BOPRC) in consultation with the community, and will reflect both the current state of a particular waterway (determined from a monitoring programme), and the values that the community place on that waterway. Once values have been identified, appropriate bands for the different NOF attributes will be determined. There is also a requirement under the NPS that attributes are maintained within the nominated band thresholds and, if the community wishes, enhanced so that the current state moves into a higher band. Neither setting nor maintaining periphyton bands can be achieved without information about the current state of periphyton in streams, and changes to that state in the future. The only way to obtain this information is to commence a periphyton monitoring programme.

A key part of the NPS involves the need to set limits to maintain ecological health, of which nutrient limits are of particular relevance to periphyton. This reflects that fact that nutrient supply is the major controlling factor most likely to be influenced by human activities, and therefore most amenable to management. Limit setting requires a good understanding of relationships between periphyton biomass and nutrients. Such relationships will also be controlled by other factors such as flow regime, stream shade and substrate stability (refer back to Section 1.1 and Figure 1). Any periphyton monitoring that is started by BOPRC thus also needs to include observations of other relevant factors, which may explain observed variation in periphyton biomass over time. Such factors could include flow, temperature and shade, all of which can be highly variable in both space and time.

To be defensible, setting any nutrient limits must be effects based, which requires a robust understanding of linkages between periphyton, nutrients and flow regime. Such information can only be gleaned through the development of a comprehensive periphyton monitoring programme. Such a programme needs to sample a wide range of sites for a sufficiently long time, with sufficiently high temporal resolution to be able to detect and demonstrate relationships between periphyton biomass, nutrients and flow. Flow variability in particular is why periphyton monitoring programmes have to be prolonged to be useful.

Increases in nutrients associated with landuse activities is mainly a problem only if there is a measurable increase in periphyton, which then impacts one or more other values of a waterway such as ecology, fishing, or aesthetics (Biggs, 2000b). However, there are many streams throughout the Bay of Plenty where high nutrient levels will not always increase periphyton biomass because periphyton growth is limited by other factors. For example, excessive periphyton is rarely observed in streams that have substrata dominated by highly mobile pumice, or that are heavily shaded. This suggests that not all streams and rivers will require nutrient management for periphyton. An obvious exception to this is, however, when levels of nutrients such as nitrate are high enough to lead to potentially chronic or acute toxic effects on organisms. Note that this statement is also made with the caveat that any streams draining into sensitive receiving environments such as estuaries may need nutrient management to prevent algal blooms in estuaries, as these ultimate receiving environments are often more sensitive to increased nutrients than rivers (Wilcock et al., 2007).

A periphyton monitoring programme should therefore be able to define the extent of potential adverse effects of periphyton blooms on streams throughout the region, and should provide quantitative evidence of the effects on periphyton of changes to nutrient concentration.

In summary, implementation of the NPS-FM requires BOPRC to commence a periphyton monitoring program in order to:

- determine the level to which periphyton biomass is currently occurring in selected waterways throughout the region,
- in consultation with the community, help the Council set periphyton biomass limits according to the NOF bands,
- determine whether periphyton biomass is increasing or decreasing over time as a result of land use change, and implementation of Council policies and plans,
- generate data to be used to investigate linkages between a stream's nutrient and flow regime in order to help set nutrient limits to maintain periphyton biomass in the appropriate NOF band.

The remainder of this document addresses issues that need to be considered as part of establishing a periphyton monitoring program in the Bay of Plenty region. In Part 2 we consider the identification Freshwater Management Units (specified in the NPS-FM as part of the process of policy implementation) and relevance to periphyton monitoring. In Part 3, we outline a process for selecting sites for inclusion in a periphyton monitoring programme, while in Part 4 we finally propose a suite of monitoring procedures, including field and laboratory methods. It is hoped that the implementation of recommendations made in this report will assist in the development of a periphyton monitoring programme for the Bay of Plenty, which will feed directly into community consultation about limit setting and the need to minimise the frequency and magnitude of periphyton blooms arising from land use activities.

Part 2: Freshwater management units

2.1 Importance of spatial classification

Implementation of the NPS-FW in the Bay of Plenty requires community discussions about the desired state of fresh water relative to its current state. As part of this discussion process BOPRC will need to provide information on the current state of waterways (see, for example Suren et al 2015), as well as information on the pressures responsible for the current state. Council will work with communities to establish freshwater objectives (i.e. desired states) for water quantity and quality throughout the region, and set limits to resource use which allow those objectives to be met.

As part of implementing the NPS-FM, BOPRC has identified nine Water Management Areas (WMAs) (Figure 2) to allow prioritisation of targeted work for each area. Council have identified two WMAs, the Rangitaiki and the Kaituna-Maketu, as the first priority. Discussions are planned with communities in each of these areas on how to implement the NPS-FW, and in particular how to set limits for water quantity and quality. There is, however, a high degree of natural variability within each WMA, meaning that NOF attributes such as periphyton will vary greatly. This natural variability will make it difficult to accurately describe the current state of all waterways, or set meaningful nutrient limits to minimise the chance of periphyton blooms.

In recognition of natural spatial variability between waterways, the NPS-FM (2014) requires councils to create Freshwater Management Units (FMUs). FMUs are a group of water bodies that are similar, both physically and in terms of their values. The NPS-FM emphasises that each Regional Council has to define an appropriate spatial scale of their FMUs. Some form of spatial classification is therefore required to group streams on the basis of factors that set overarching constraints on water quality and ecology. From an ecological perspective, a spatial framework should characterise and group stream reaches based on environmental factors known to influence ecological communities. Within New Zealand, two classification systems for freshwaters exist: the River Environment Classification (REC), and Freshwater Ecosystems of New Zealand (FWENZ).

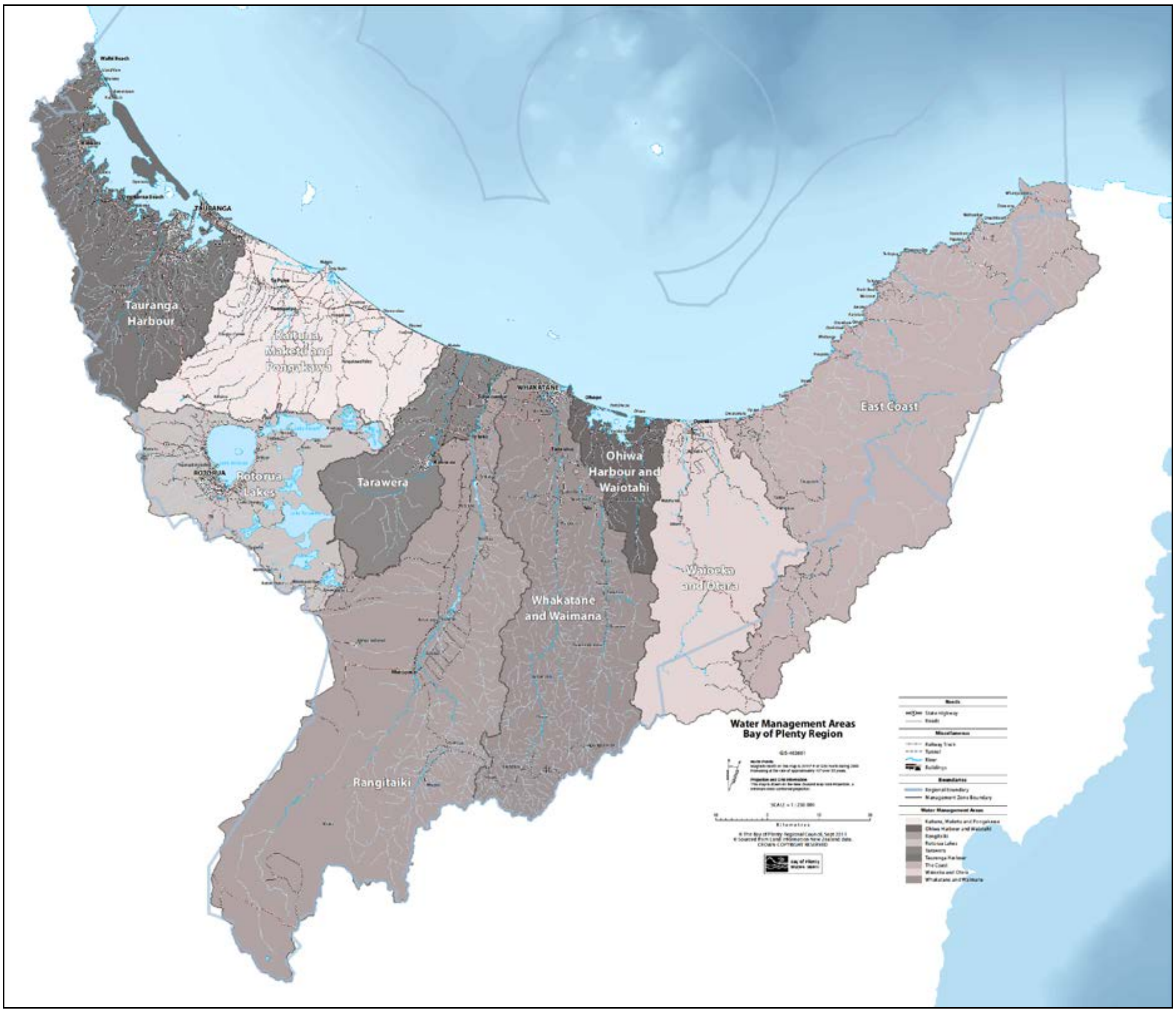


Figure 2 Map of the nine Water Management Areas identified in the Bay of Plenty region.

The REC was developed by NIWA to provide a spatial framework for regional (or larger) scale environmental monitoring and reporting, environmental assessment and management (Snelder and Biggs, 2002). The REC defines spatial variation in a wide range of stream characteristics, including physical and biological. It is a multi-scale classification, delineating patterns at a range of scales from hundreds of km^2 to ~1 km^2. It is based on a hierarchy of classes within which ecological similarity (e.g. water quality or biological communities) varies from general to specific, as the classification level is decreased. The hierarchical classification is expressed in the order of Climate, Source of Flow, Geology, Land cover (see Table 1).

Table 1 List of the four REC factors showing the classes within each factor, the number of classes, and the cumulative number of classes found within the Bay of Plenty region. Note that for the purposes of our analysis, all streams in the HS, Al, MD and SS geology categories were all combined into a single non-volcanic (Non_VA) geological class.

REC factor	**Classes within REC factor**						**No of classes**	**Cumulative number of classes**
Climate	Warm extremely wet (WX)	Warm wet (WW)	Warm dry (WD)	Cool extremely wet (CX)	Cool wet (CW)	Cool dry (CD)	6	6
Source of flow	Mountain (M)	Hill (H)	Lowland (L)	Lake (Lk)			4	16
Geology	Volcanic (VA)	Hard Sedimentary (HS)	Alluvium (Al)	Mudstone (Md)	Soft sedimentary (SS)		5	37
Land cover	Agriculture (P)	Exotic forest (EF)	Native Forest (IF)	Urban (U)			4	94

The highest REC classification level (Climate) groups streams within large areas with broadly similar climate in terms of mean annual temperature and rainfall. In contrast, lower levels of the REC describe characteristics that vary at smaller spatial scales. For example, the fourth level of the REC, Land Cover, classifies land use patterns, which often vary within catchments or sub catchments. Thus the spatial extent that each level in the REC classification operates at decreases as the number of classification levels increases. As the classification level is reduced, variation within a class decreases because the number of shared controlling factors increases. Thus, all streams within a single REC climate classification may have very different sources-of-flow, geology and landcover, and therefore have large differences in their water quality or ecology. However, streams within a smaller composite REC class of Climate/Source-of-flow/Geology/Landcover will be constrained by all these levels, and consequently have only small differences between them.

In contrast, FWENZ is a hierarchical multivariate classification system based on environmental factors that are correlated with aquatic communities (Clapcott et al., 2011). These factors include a range of climatic measurements (e.g., the minimum and maximum temperature, rainfall, solar radiation), flow (e.g., mean flow, flow variability) nutrient status (predicted clues N yield), predicted riparian shade and estimated substrate size. While some of these factors (for example climate) have been obtained from actual measurements, others (for example substrate size and shade) have been derived from empirical models, and extrapolated throughout the country. The FWENZ classification has four levels, containing either 20 groups (level I), 100 (level II), 200 (level III) or 300 groups (level IV) at a national level. As with any classification, there is a trade-off between having a high number of classification groups (with low between stream variability) compared to a low number of classification groups (with high between stream variability). Thus at the 300 group level, streams within each group are the most similarities to each other, whereas at the 20 group level, streams are more dissimilar. A key question to be determined when using the FWENZ approach is to decide on what an appropriate number of classification units should be.

Any periphyton monitoring programme implemented in the Bay of Plenty thus needs some form of spatial classification for grouping sites into similar stream types based on attributes likely to affect periphyton. Once a spatial classification has been developed, it can then be used in part of a site selection process. Either the REC or FWENZ could be used to develop a classification from which to assist with the site selection process. Once streams have been assigned to their appropriate classification, another major task would be to determine how many sites from each class should be surveyed, as well as the exact location of each site within a particular class.

2.2 Suggested FMU framework for periphyton monitoring

A FMU framework for the Bay of Plenty has recently been proposed (Suren and Carter 2015) based on the REC classification of geology (simplified into volcanic and non-volcanic), and the FWENZ predicted substrate size classification (simplified into soft bottomed or hard bottomed streams). This spatial classification explained a high degree of variability in water quality, invertebrate and fish communities. Implementation of the geology/substrate type classification created four FMUs, encompassing 98.5% of all waterways throughout the region. If the non-volcanic soft-substrate class was removed, this number would be reduced only slightly, with 97% of waterways belonging to one of three remaining classes.

The division of geological classes into volcanic and non-volcanic material reflects the complex history of geological activity in the region, and the pervasive legacies of the massive eruptions from the Ōkataina and Taupō volcanic centres that covered much of the region with ash and pumice. This volcanically derived geology contrasts sharply with the hard sedimentary geology found typically in the eastern part of the region. Differences in nutrient and flow regimes are expected between these geology types. Streams draining catchments dominated by volcanic geology are expected to have naturally higher nutrient levels, and flows dominated more by groundwater inputs. In contrast, streams draining catchments dominated by non-volcanic geology are expected to have lower natural nutrient levels, and flows dominated by rainfall run-off.

The division of streams according to substrate size reflects the dominant role that substrate can play on stream ecological communities, including periphyton (Biggs et al., 2001), macrophytes (Riis and Biggs, 2003), invertebrates (Death, 2000; Minshall, 1984) and fish (Jowett and Boustead, 2001). For example, streams dominated by fine, highly mobile substrates such as mud, pumice and sand generally support less periphyton biomass and have lower invertebrate densities than streams dominated by larger less mobile substrates such as cobbles and boulders. In contrast, streams dominated by fine substrates can often support luxurious macrophyte growths which help stabilise fine substrates with their roots. While there is an obvious interaction between flood frequency, substrate size, and the resultant degree of substrate movement, streams dominated by smaller substrates require a smaller increase in stream flow to initiate substrate movement. In general, the higher the frequency of substrate movement in a stream, the more sparse the resultant biological communities will be (Biggs et al., 2001). This does not mean that soft bottomed streams cannot support high algal biomass. Indeed, this has often been observed during periods of low flow during the summer. However, such proliferations are expected to be short lived, and would be washed away with only relatively small increases in flow. In contrast, relatively higher flows would be needed to reduce periphyton biomass in hard bottomed streams reflecting the presence of thicker boundary layers around the large substrate particles as well as higher substrate stability. This is likely to result in a large degree of patchiness in a hard bottomed stream following a flood with areas in eddies supporting more periphyton. Periphyton communities are thus likely to recover to their original biomass much faster in hard bottomed streams as these patches represent important sources for recolonisation.

These mechanistic differences between volcanic and non-volcanic geology, and streams dominated by hard and soft substrates can be used to develop decision support diagrams as part of any limit setting process undertaken under the NPS. This decision support diagram (Figure 3) shows the inherent characteristics of each of the 4 FMUs and how attributes such as nutrients, bacteria, algae or sediment are likely to affect instream values. Such a decision support diagram could be used to help prioritise actions in terms of setting limits for nutrients, bacteria or algae. For example, algal biomass may reach undesirable levels in hard-bottomed streams, and streams draining catchments dominated by volcanic material may be naturally high in nutrients. Thus, nutrient management may be extremely important in these streams, and policies and rules would need to be developed to reflect this. In contrast, algal biomass is unlikely to reach undesirable levels for long periods of time in soft bottomed streams, implying that nutrient management in these streams may not be as important if the management objective is to maintain low algal biomass. Note that this example also assumes that nutrient levels are below those thresholds known to have chronic or acute toxic effects on biota, or adverse effects on drinking water quality.

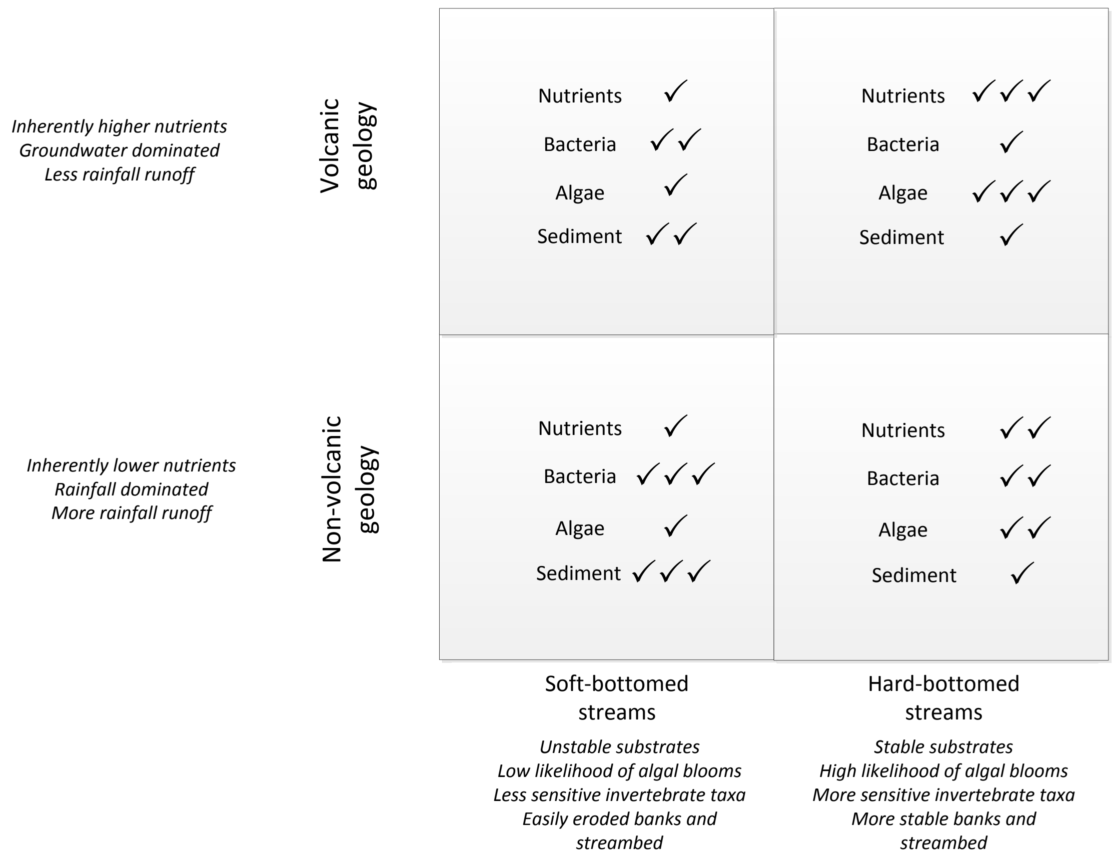


Figure 3 Decision support diagram showing the effects of the proposed geology substrate-type FMU framework in setting limits for the NOF attributes including nutrients, bacteria, algae and sediment. Depending on the spatial classification of a stream, setting limits on specific attributes may be extremely important (✓✓✓), moderately important (✓✓), or only slightly important (✓).

Another example concerns setting limits for bacterial loadings to achieve this usable contact recreational grade. Soft bottomed streams can support naturalised bacterial populations amongst the stream bed (Devane, 2015), and this material can easily be mobilised during even relatively small flood events. Thus, different policies and plans may need to be produced recognising these inherent differences between natural bacterial loadings in hard and soft bottomed streams. Furthermore, bacterial loadings may be higher in streams subject to more rainfall run-off (i.e. in non-volcanic catchments), whilst streams in volcanic catchments may be somewhat protected from bacteriological contamination from the catchment if this material enters the soil water instead of directly running off into the stream. The implication of this is that fencing or riparian planting may need to be along wider riparian strips in non-volcanic catchments as run-off may be the prime mechanism for the transport of contaminants into surface waters (assuming similar catchment slopes).

It is suggested that this decision support framework represents a useful planning tool to help set policies and rules within each water management area. It is also acknowledged that communities in each of the nine Water Management Areas that BOPRC has created may want different outcomes for streams of a particular FMU (i.e., geology substrate-type class), despite the fact that these streams may support similar ecological values. These different outcomes would, however, simply reflect potentially different values that the community place on the same stream type, and would not be inconsistent with the intent of the NPS-FW in terms of councils managing waters to meet community expectations.

The geology substrate-type classification that we suggest is an appropriate first step at creating FMUs for the Bay of Plenty also meets the three key criteria of FMUs as outlined in the Introduction. Firstly, the classification seems to explain the most variation to water quality, invertebrates and fish communities. Although we recognise that these values are ecologically-based, we suggest that they would also be identified by the community as being of importance. We do, however, acknowledge that these ecologically-based values are likely to be only a small subset of the final set of values selected by the community.

Secondly, the geology-substrate type classification varies spatially. The four FMUs that we have identified clearly consist of both waterways within a single catchment (i.e., contain hydrologically connected water bodies), and are also found in many areas throughout the region (i.e., consist of a group of hydrologically similar, but disconnected waterbodies). The geology substrate-type classification also highlights that individual catchments contain more than one type of FMU. For example, many of the hard-bottomed streams flow from high elevations into lower elevations, where their classification changes to soft-bottomed. This change in classification along a river continuum reflects natural geomorphological processes where substrate size generally decreases towards the sea.

Closely connected to the natural spatial variation of the geology substrate-type FMU is the fact that this spatial framework allows council and the communities to make consistent decisions about the size of any ensuing management unit. Given the inverse relationship between the size of individual FMUs and the ability to properly manage these, it is likely that decisions about the final size of an FMU will be subject to much debate between council staff and the community. BOPRC will need to work with the community to address possible tensions between the level of detail that is technically justifiable while catering for the desire of stakeholders for spatially distinctive policies and limits.

2.3 Need for clear objectives

Two objectives under the NPS–FW for a periphyton monitoring programme are to:

- determine the level to which periphyton biomass is occurring in selected waterways throughout the region,
- investigate linkages between a stream's nutrient and flow regime in order to help set nutrient limits to maintain periphyton biomass in the appropriate NOF band.

These objectives could, however, be interpreted in a number of ways. For example, one interpretation could be focussed at describing "*the extent to which waterways throughout the region experience excessive periphyton proliferations*". For this objective, it is important to ensure that selected sites represent the range of environmental conditions found throughout the region. Ideally, a monitoring programme would be comprise the same proportion of sites in different environmental classes as are found within the region. Under the proposed geology-substrate type spatial classification (Suren and Carter 2015), approximately 43% of waterways belonged to the volcanic hard-substrate class, 31% to the volcanic soft-substrate class, and 24% to the non-volcanic hard-substrate class. Any monitoring regime would consequently select sites in proportion to these classes.

It is, however, highly likely that periphyton biomass in streams dominated by highly mobile fine pumice stream beds would be naturally low, irrespective of nutrient levels (See Figure 3). Thus although soft bottomed streams comprise approximately 30% of waterways in the region, it could be tacitly assumed that such streams are unlikely to display excessive periphyton blooms, and consequently do not need to be monitored. These streams could thus automatically be placed in the A-band. Furthermore, it would not be necessary to define relationships between periphyton biomass and nutrients in these streams, as biomass is most likely constrained by other factors. Consequently, setting nutrient limits may not be relevant in these soft-bottomed streams. However, a strategy of sampling of waterways in proportion to their dominant classes would provide a true estimate of the extent to which waterways in the region experience excessive periphyton blooms.

An alternative interpretation of these two objectives could be to describe "*the extent to which excessive periphyton blooms occur in waterways throughout the region,* ***where such blooms are not limited by shade or physical habitat****".* In this way, streams which are naturally soft-bottomed, or heavily shaded could be omitted from monitoring, leaving more resources available to increase the number of monitoring sites in areas where such blooms are likely. Effectively, this objective would be monitoring a subset of potential sites selected for the first objective, and not monitoring soft bottomed streams with the same frequency at which they occur in the region. Such a strategy would allow a more focused monitoring programme of sites where blooms are likely, and may therefore provide higher quality data of the relationships between land cover, nutrients, flow regime in periphyton biomass. It is consequently recommended that this second interpretation for the objectives be used in designing a field sampling programme to implement the NPS-FW requirements. In this way, monitoring would focus more on unshaded, hard-bottomed sites where periphyton blooms are likely to occur in response to increased nutrients. Site selection should thus include a wide range of unshaded, hard-bottomed streams across a gradient of both nutrient and flood frequency.

Sites would still need to be selected on the basis of a spatial classification, to ensure the widest possible a range natural environmental and land-use gradients is sampled. A monitoring program focused on hard bottomed streams does not, however, imply that nutrient limits are not important for soft bottomed streams. Such limits would still need to be set if soft bottomed streams flowed into sensitive receiving environments such as lakes or estuary. However, the nutrient limiting setting process would be based upon maintaining the desired state of the ultimate receiving environment, rather than minimising periphyton growth within the soft bottomed streams.

Part 3: Site selection

3.1 Background

Kilroy et al 2008 emphasised that an overall requirement for site selection for periphyton monitoring is to have sites representative of a wide range of nutrient conditions and flood frequency encountered in the region. They suggested assigning sites to three separate enrichment x flood frequency classes (low, medium, high: Figure 4). Ideally, at least three replicate sites should be chosen in each of these classes.

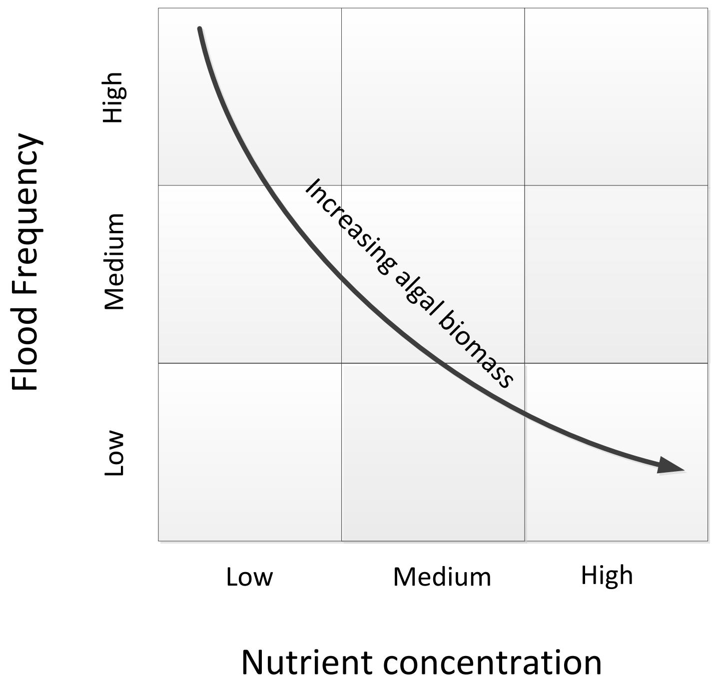


Figure 4 Proposed nutrient x flood frequency matrix showing the response of algal biomass to increasing nutrients and decreasing flood frequency. Note there will be lowest biomass in streams of low nutrients and high flood frequency, and highest biomass in streams with high nutrient concentration, and low flood frequency (From Kilroy et al 2008).

Nutrient classes for the matrix need to be defined from data obtained from BOPRCs current Natural Environment Resources Monitoring Network (NERMN) water quality monitoring program. A useful way of placing sites within "low", "medium", "high", nutrient categories is suggested by Kilroy et al (2008), as without prior knowledge it is difficult to suggest the boundaries between these three categories. Their suggested approach is to first plot mean dissolved inorganic nitrogen (DIN) versus mean dissolved reactive phosphorus (DRP) from all available sites, using log transformed data. Concentric zones are then marked on the resultant scatterplot corresponding to low, medium and high nutrient concentrations. Kilroy et al (2008) suggested that the values of maximum DRP the equivalent to the published average values (Wetzel 2001) separating oligotrophic, mesotrophic and eutrophic lakes on the basis of total P (10 and 30 mg/m^3 respectively: Figure 5).

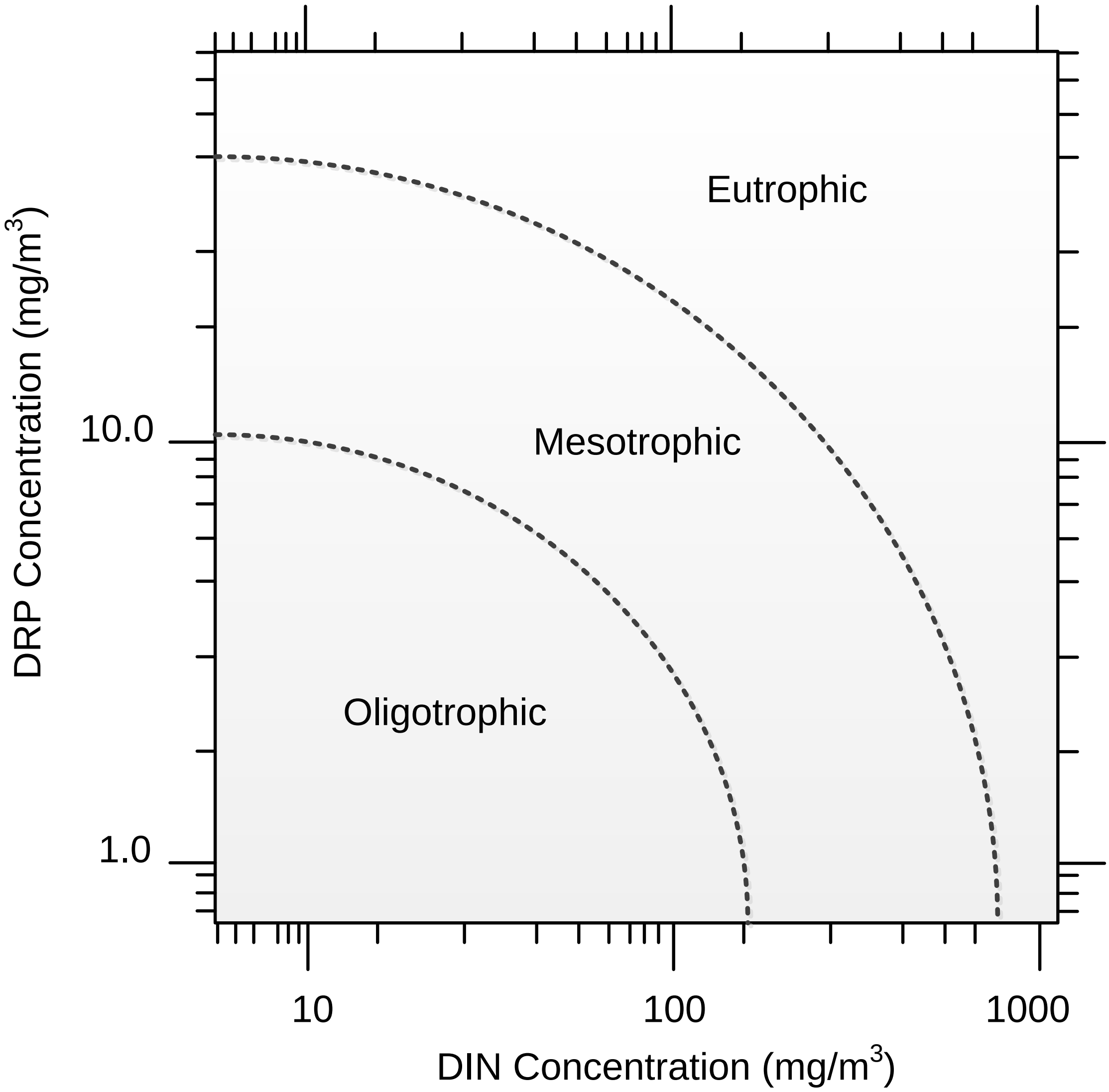


Figure 5 Example of how sites could be allocated to one of three a priori nutrient concentrations on the basis of their mean DRP and DIN concentrations (modified from Kilroy et al 2008).

One challenge about this approach is the fact that many water quality monitoring sites are in the lower reaches of catchments in larger rivers, and there is little information about nutrient concentrations in many of the smaller rivers and streams. This means that most streams within the Bay of Plenty region cannot be assigned to a nutrient level class. A possible way around this problem would be to use the FWENZ database, which includes predicted CLUES nitrogen loading from all waterways throughout the Bay of Plenty region (Figure 6).

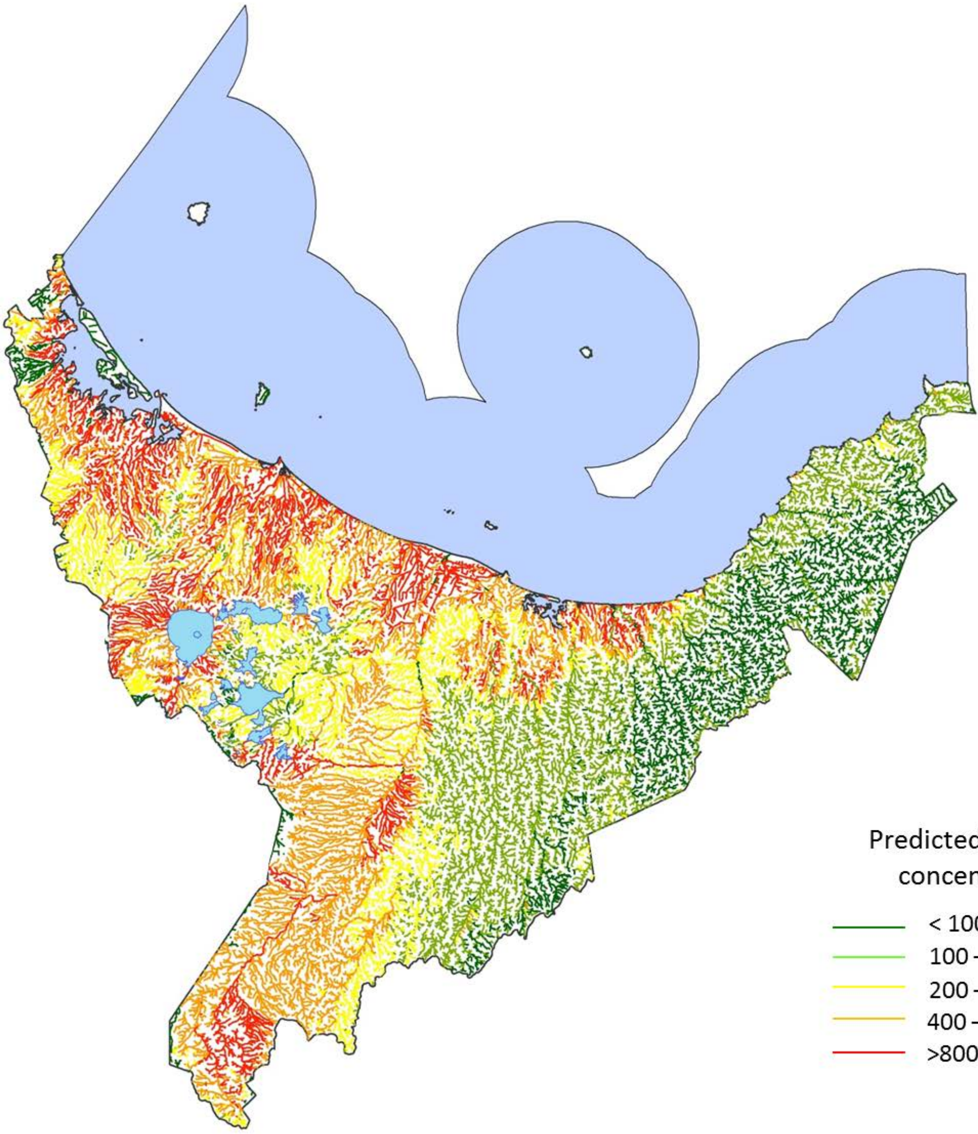


Figure 6 Map showing predicted nitrogen yield from waterways throughout the Bay of Plenty based on modelled clues data (source: CLUES database).

Before this approach is taken, however, it is necessary to validate the accuracy of the CLUES nitrogen concentrations against data held by BOPRC as part of its NERMN monitoring programme. Water quality monitoring data was obtained from 48 sites throughout the region, and average dissolved inorganic nitrogen (DIN) concentrations calculated. The monitoring period varied from >25 years (since 1989) to <4 years (since 2011), and frequency varied from continuous monthly to monthly every three years. Average DIN concentrations were calculated at all sites as long as there were 20 or more observations. These sites were allocated their appropriate in NZReach number, and the relevant CLUES nitrogen loading extracted from the CLUES programme. A strong relationship was observed between the predicted CLUES N- loadings from these streams and measured nitrogen (Figure 7), giving us confidence that the CLUES database could be used to allocate all other waterways to their respective nutrient classes on the basis of nitrogen concentrations.

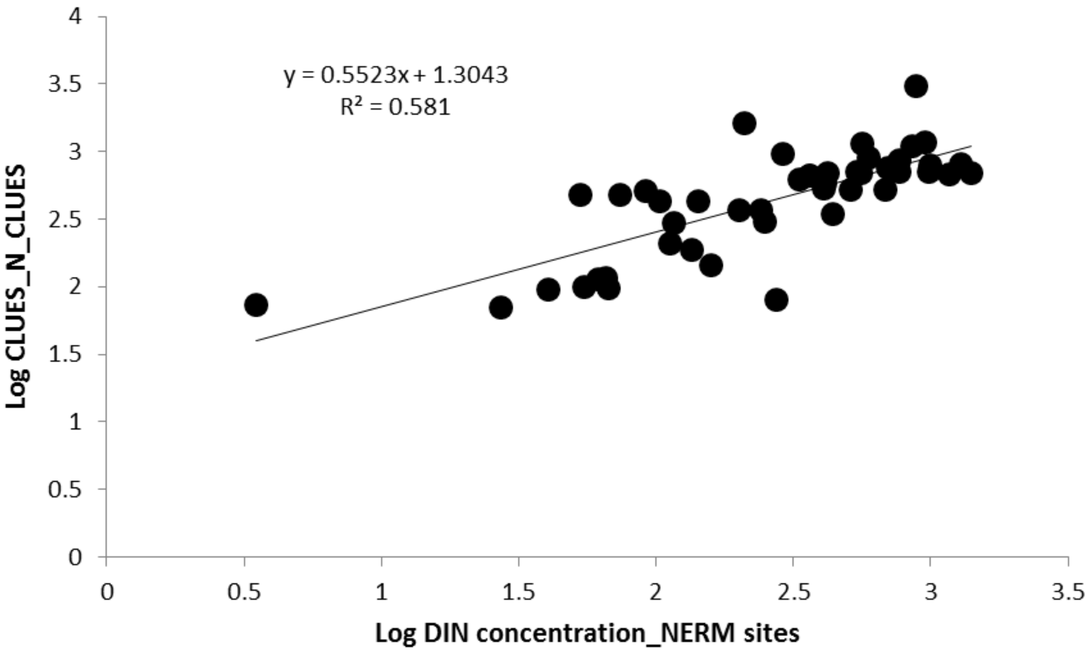
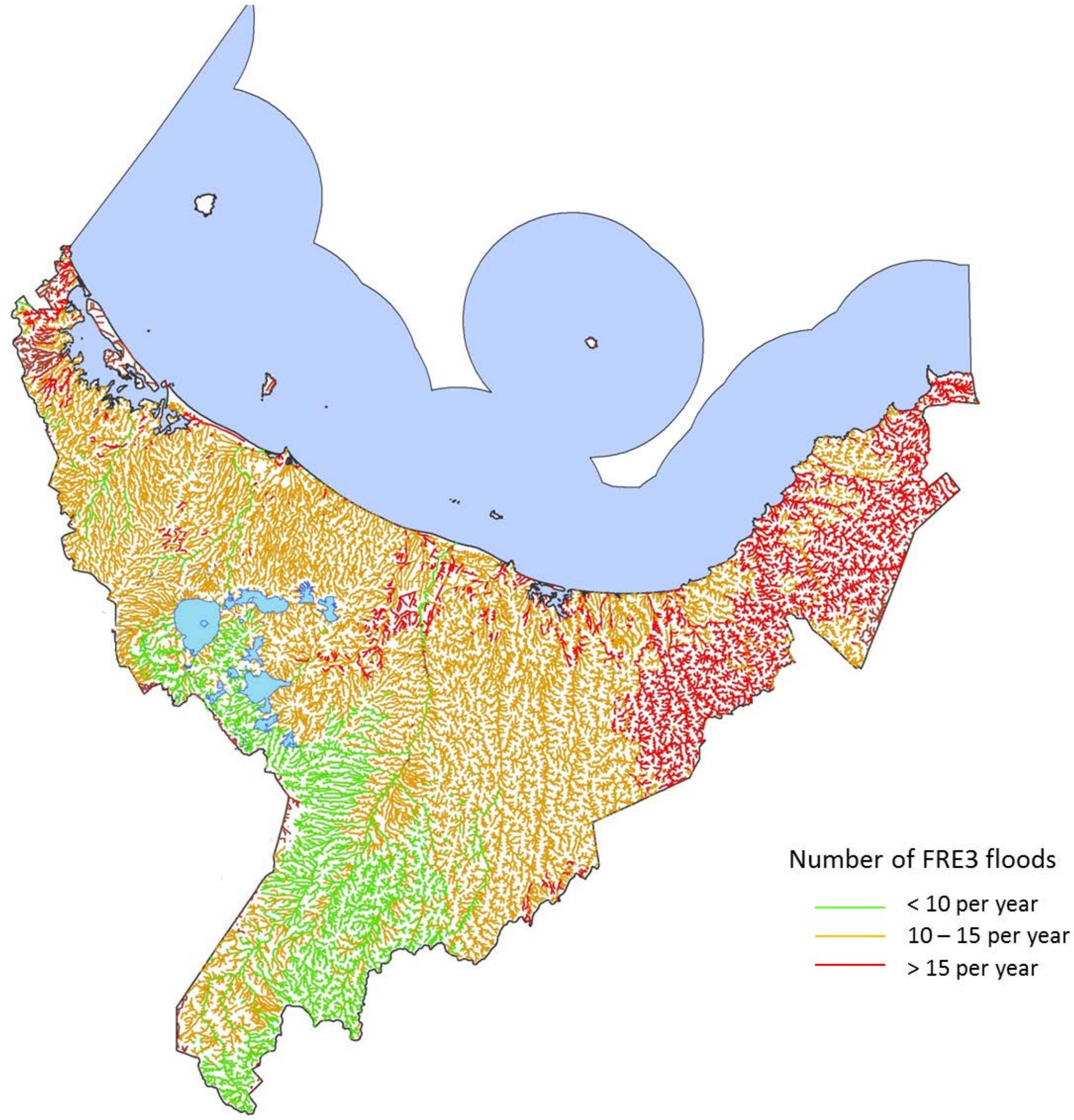


Figure 7 Plot of average DIN concentration measured from 52 water quality monitoring sites against predicted CLUES concentration at the same sites.

Ideally, any sites selected for monitoring periphyton would also have their flows continuously monitored to obtain the relevant flow statistics to identify flood frequency classes. Unfortunately, there is only limited flow data available from throughout the region, as BOPRC monitors flow at only 26 sites. Some of these are lake fed or spring fed, which would reduce the number of FRE3 events. Other sites are below dams that would further alter their natural flow patterns. This may explain why there was no correlation between observed FRE3 Furthermore, most flow monitoring is done on relatively large waterways, and so there is little information on flow statistics in the many smaller streams. However, NIWA has modelled low flows of waterways throughout the Bay of Plenty region (Booker, 2014), and this data will be useful in assigning waterways to different flood frequency classes based on estimations of FRE3.



Wilcock et al (2007) presented a decision-support system to help in determining whether a particular stream would require nutrient management. The system highlighted the importance of stream shade and substrate stability in influencing algal communities. They considered that periphyton proliferations would be unlikely in streams with greater than 80% shade. The FWENZ database contains data showing predicted riparian shade, and this could be used to help select sites. The accuracy of riparian shade layer in the FWENZ database was assessed by comparing modelled data with visual observations of shade collected as part of either the council's ongoing NERMN state of environment monitoring, or other surveys. Predicted riparian shade and observed shade corresponded closely (Figure 8), suggesting that the FWENZ riparian shade data is a relatively accurate representation of actual shade at sites throughout the region (Figure 9). This gives us confidence to use the FWENZ data as part of selecting unshaded sites for periphyton monitoring.

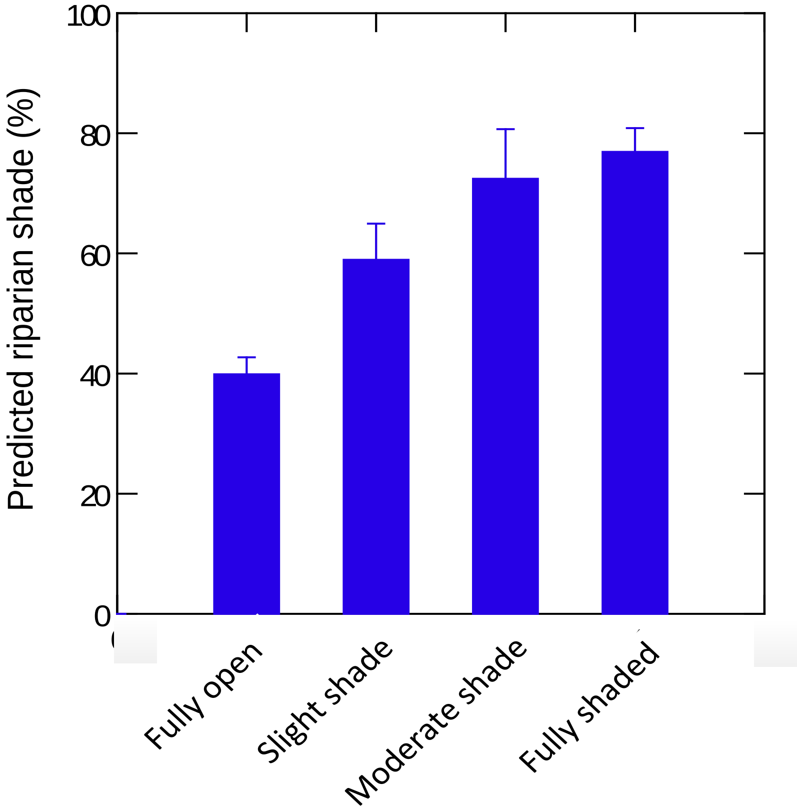


Figure 8 *Relationships between field based assessments of shade (in 4 categories), and predicted riparian shade as calculated in the FWENZ database.*

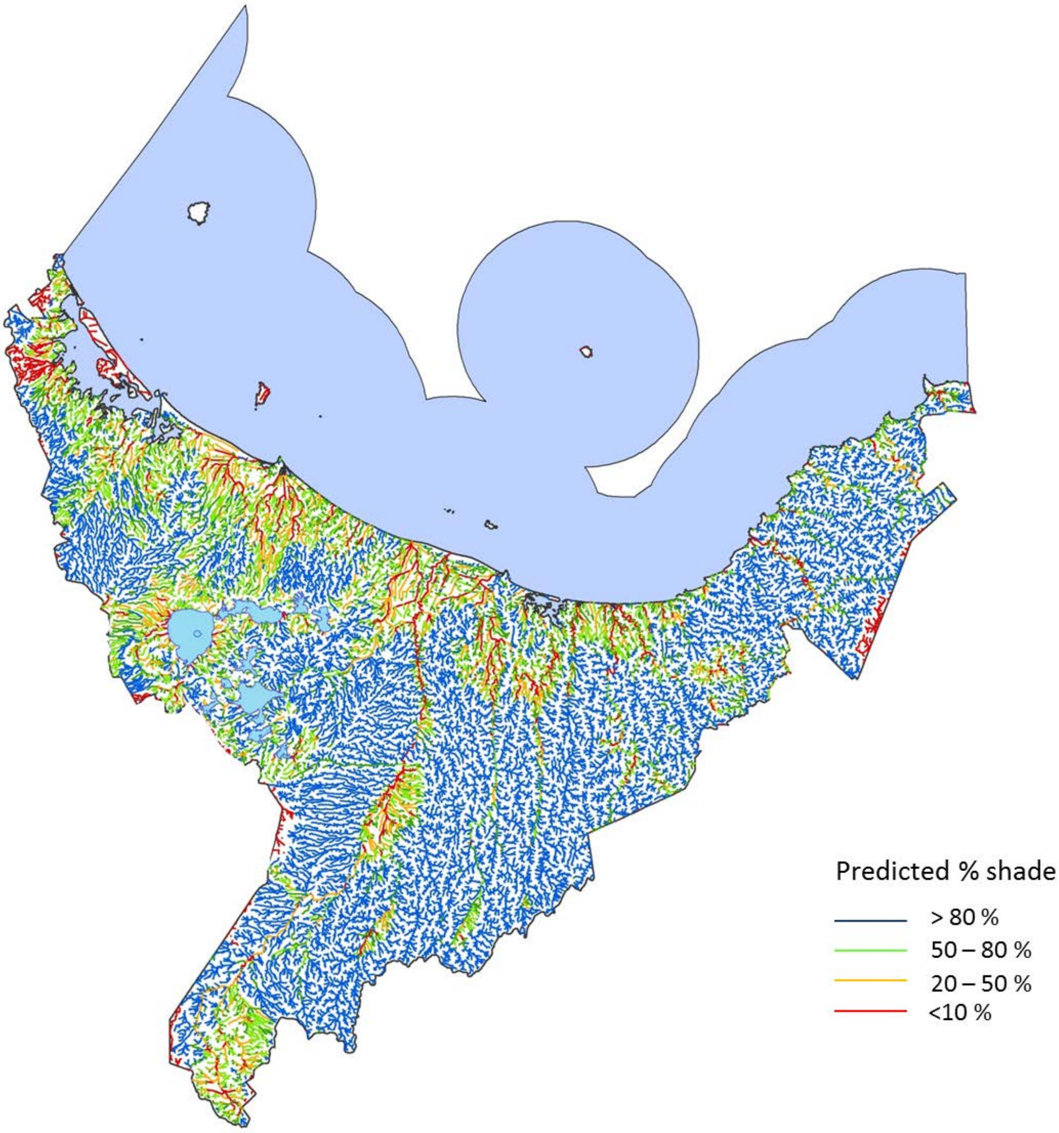


Figure 9 Map showing predicted riparian shade when coded into four percentage classes ranging from fully open sites (0 – 20% shade), to fully forested sites (80 – 100% shade).

Wilcock et al (2007) also suggested that sites with more than 70% soft substrates are unlikely to require nutrient management, as periphyton is not as likely to grow in these streams to the same extent when compared to streams dominated by hard substrates. The FWENZ database contains a predictor variable (called ReachSed) for average stream bed of size. The accuracy of this was tested against measured stream bed size collected as part of recent BOPRC monitoring programs throughout the region. Since 2012, assessments of stream habitat have included quantification of stream bed substrate size in each study reach using the Wolman technique. This involves walking up a section of stream randomly selecting stream bed particles, measuring their b-axis, and categorising them into different sizes (e.g., silt – mud, sand, gravel, small cobbles, large cobbles, boulders, bedrock). A substrate index (Jowett, 1993) is then calculated which converts the percentage data of the substrate classes into a single number.

A relatively strong relationship was observed between measured substrate sizes and predicted reach sediment (Figure 10). As such, we are confident that the FWENZ database is accurate enough to help filter out sites that are dominated by fine substrate (Figure 11). A final choice of site selection would be confirmed by on-site field inspections.

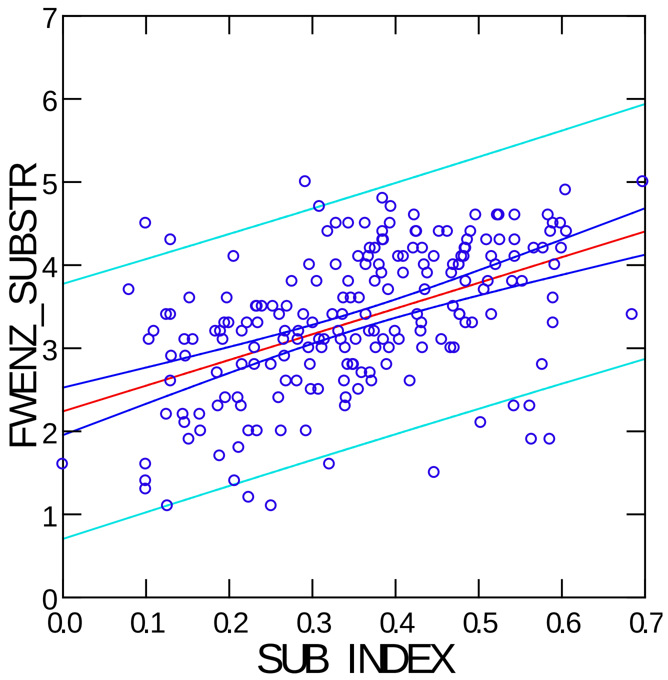


Figure 10 *Regression analysis between measured substrate size (expressed as the substrate index) and predicted substrate size from the FWENZ database (r2 = 0.25, P < 0.001).*

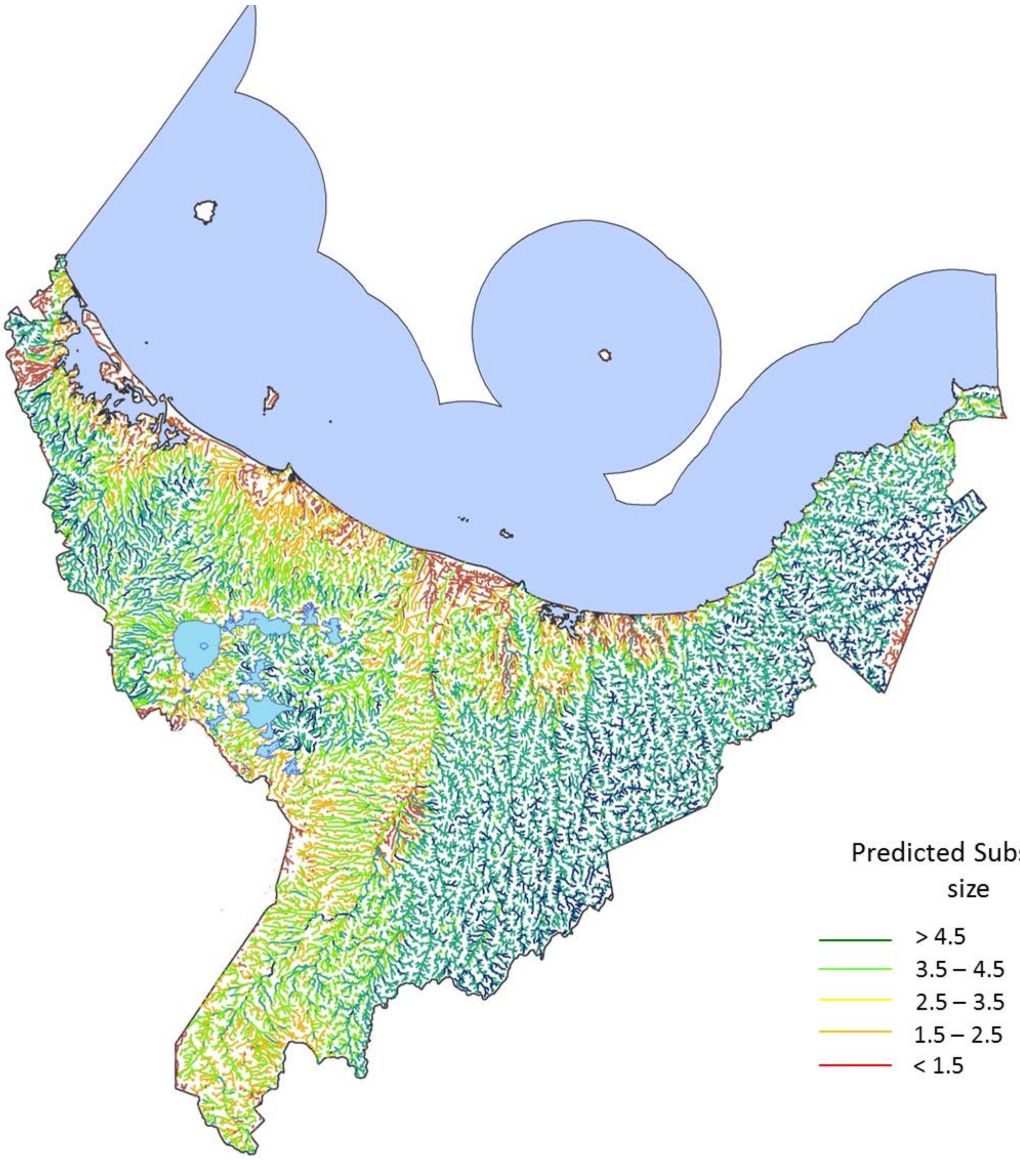


Figure 11 Map showing predicted substrate size when coded into five substrate size classes ranging from fine sand, pumice and mud (0 – 2), to large cobbles and boulders (> 4.3).

3.2 Suggested protocol for site selection

Based on the above, we suggest the following protocol is used to select sites suitable for ongoing periphyton monitoring in the Bay of Plenty region (Figure 12). This protocol involves analysis of field data from NERMN, modelled flow data (from NIWA) and nutrient, substrate size, and shade data from the CLUES and FWENZ databases. The following eight steps are suggested:

1 Assign all waterways in the region (or WMA) to an appropriate water quality class using predicted CLUES DIN and DRP data. Relevance of the CLUES data is confirmed based on strong relationships between average DIN and that predicted by CLUES.

2 Partition the region into zones of differing flood frequency (measured by FRE3), using modelled flow data. Allocate all stream reaches (NZReach) to one of three flood frequency classes (e.g., <10, 10-15, >15 FRE3 floods per year).

3 Allocate all waterways in the region to their respective nutrient-flood frequency class.

4 Use the FWENZ database, filter out all sites with a predicted reach sediment of less than 0.3, representing sites dominated by fine pumice material.

5 Use the FWENZ database, filter out all sites with more than 80% of stream shade.

6 Remove all NZreaches from large rivers greater than stream order 5, reflecting the difficulty of sampling these. Remove all first order NZreaches, reflecting the fact that many of these are likely to be ephemeral.

7 Using GIS, select waterways that cross under roads.

8 Assign all selected NZreaches to their appropriate FMU classification. Note that this classification will essentially be based on Geology, as Substrate Type had been factored out by selecting only Hard-bottomed streams in Step 4.

9 Assign each NZreach to its appropriate WMA area. Select combinations of each nutrient and flood frequency classes within individual WMAs. Only select the resultant nutrient and flood frequency classes which are relatively common in each WMA.

10 Assign a random number to selected NZreaches in each WMA, and sort all NZreaches in ascending order of this random number.

11 Select the first 20 occurring NZReaches in each common nutrient and flood frequency classes in each WMA and plot their location in GIS.

12 Make site visits to confirm suitability of selected sites for monitoring. Other sites may also be selected during the site visits if these are either at, or near to where other NERMN water quality or invertebrate samples are being collected, and where flows are gauged. Final site selection made following site visits and assessing each site on the basis of factors such as substrate suitability, shade, physical and legal access, and with consideration of operational (financial) limitations.

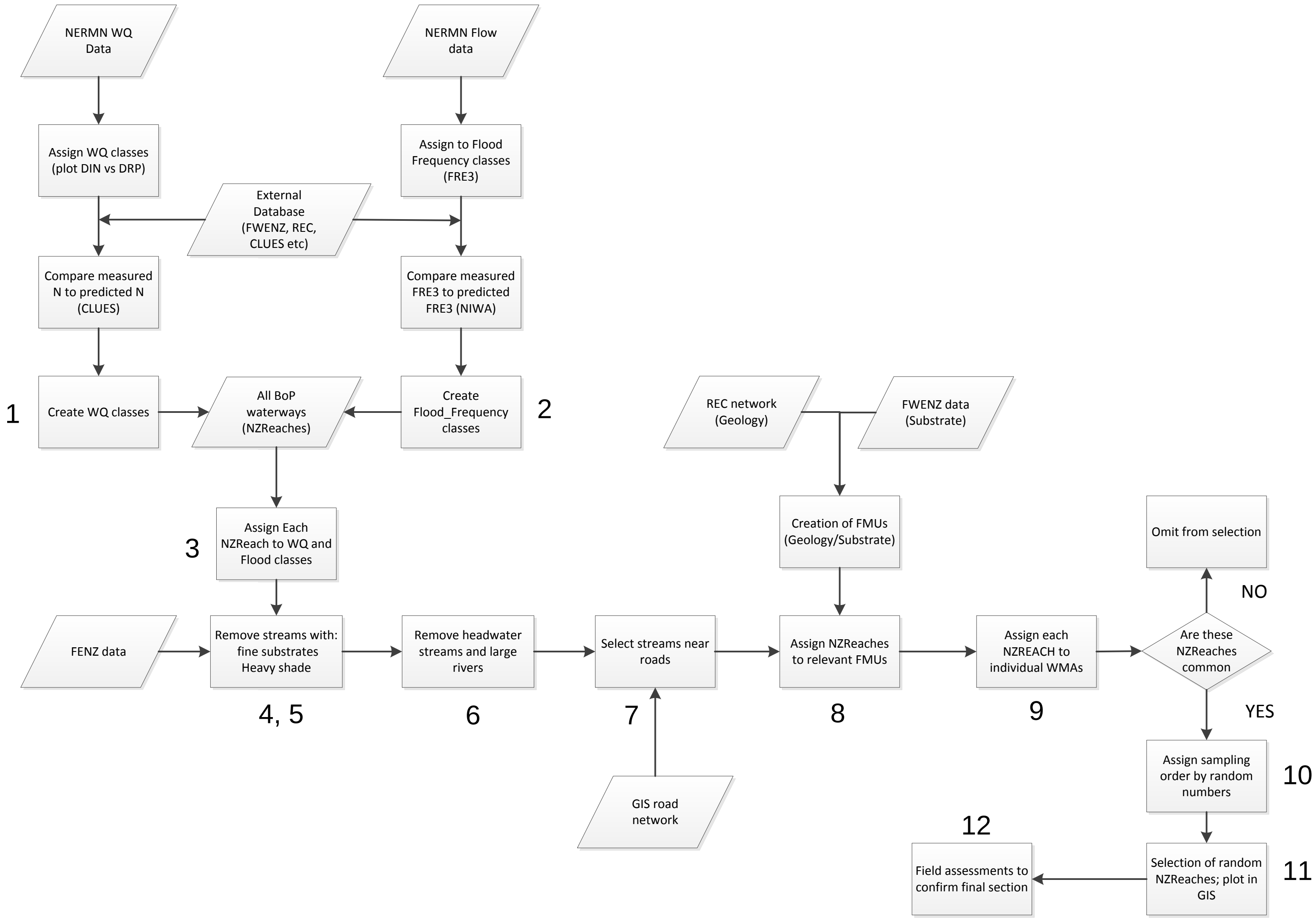


Figure 12 *Schematic flow chart showing the suggested steps used to help select sites for a periphyton monitoring programme throughout the Bay of Plenty region, or within specific water management areas.*

3.3 Results of site selection

The CLUES database identified a total of 24,859 NZreaches where predicted DRP and DIN were calculated. This data was plotted on an x, y graph (Figure 13), and nutrient classes allocated to each site based on the nutrient levels recommended by Kilroy et al 2008. This analysis clearly showed that the vast majority of sites (93.7%) belonged to the eutrophic nutrient status class, while only 6.6 % of sites belonged to the mesotrophic nutrient status class. Only 15 sites (representing 0.06% of total NZreaches) were in the Oligotrophic nutrient status class (Figure 13). This suggests that, at best, streams belonging to only two nutrient classes could be adequately sampled as part of a periphyton monitoring programme.

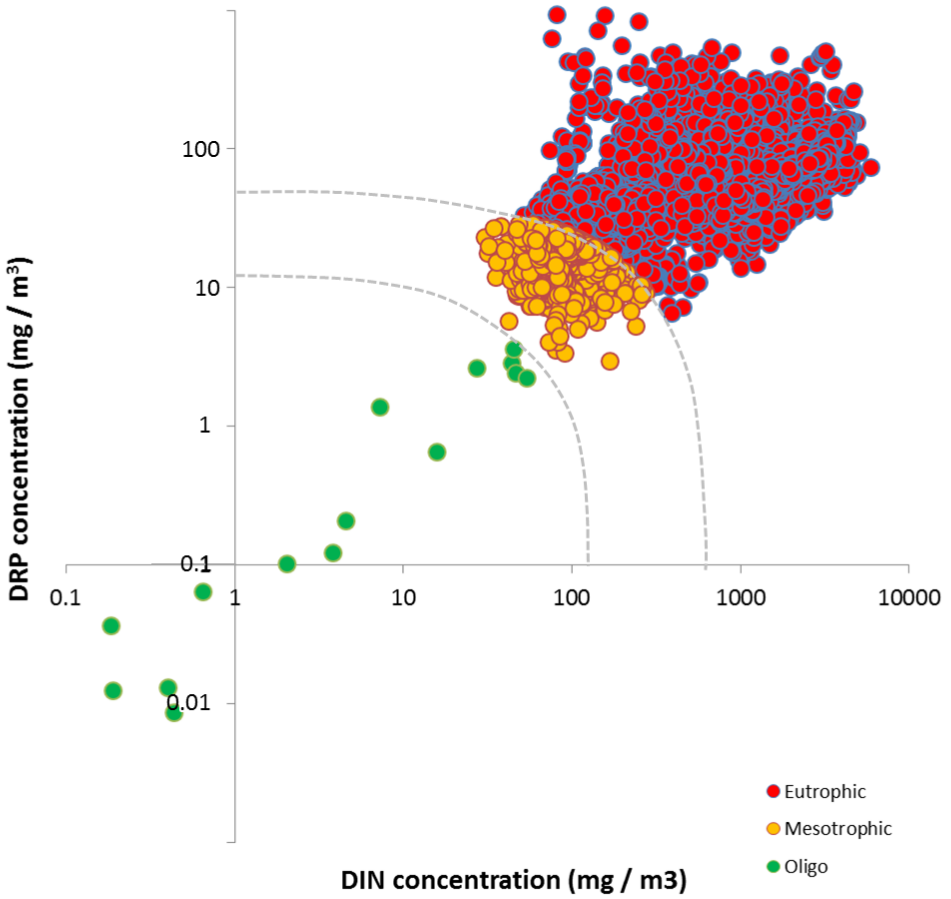


Figure 13 Plot of DIN and DRP (on a log-scale) from all in NZreaches in the Bay of Plenty estimated from the CLUES database showing the number of sites as allocated to oligotrophic, mesotrophic, and eutrophic nutrient classes. Dashed lines indicate boundaries between nutrient classes.

All 24,859 NZreaches when next allocated one of three FRE3 flood frequency classes: Low, < 10 floods per year; Medium, 10 to 15 floods per year; High > than 15 floods per year. The majority of NZreaches (54.6%) were characterised with a medium frequency of FRE3 floods, whilst similar numbers of NZreaches (ca. 15%) were characterised by either a high FRE3 and mesotrophic waters, or a low frequency of FRE3 floods and eutrophic waters (Figure 14). Another 2 classes contained approximately 6% of NZReaches. Combining flood frequency and nutrient classes clearly showed that only five of the potential nine flood frequency - nutrient class combinations could be sampled, as the other four combinations occurred only rarely within the region (Figure 14).

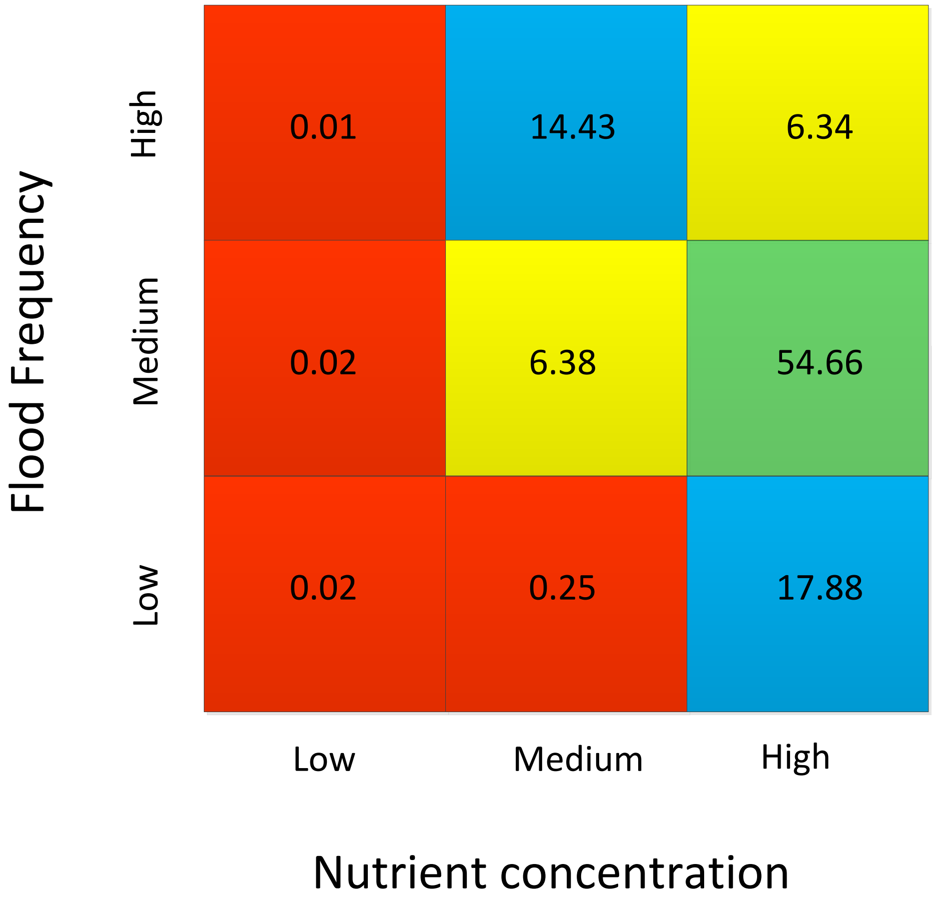


Figure 14 *Percentage of NZreaches in the Bay of Plenty found in each of nine potential nutrient x flood frequency classes as proposed by Kilroy et al 2008. Some classes contained too few NZreaches to warrant a monitoring program (red cells), whilst other classes contained a majority of NZreaches (green cell). Other classes contained proportionately fewer NZreaches, but potentially still enough to consider sampling periphyton from (blue and yellow cells).*

Allocating all NZreaches to their appropriate substrate or shade category showed that approximately 36% of the 24859 NZreaches were regarded as being unshaded (< 80% shade) and dominated by hard substrates. Filtering these from the original dataset resulted in a total of 8842 NZReaches. Small headwater streams, and large rivers greater than Order 5 were then removed from this dataset, leaving 6414 NZReaches. GIS was then used to determine which of these 6414 NZreaches flowed under roads (including a mixture of sealed and unsealed public roads, and forestry roads). A total of 2425 NZreaches were subsequently selected from this analysis.

Of these reaches, 693 belonged to the non-volcanic/hard-bottomed FMU geology/ substrate class, and 1732 belonged to the volcanic/hard-bottomed FMU class. A total of 14 different nutrient x flood frequency groups were identified in the 2 FMU classes, however some of these contained only a few NZreaches. Any nutrient/flood frequency group that contributed < 3% to NZReach numbers were removed from further consideration. This left 7 different nutrient x flood frequency groups within the 2 FMU classes, with a total of 2280 NZreaches (Table 2).

Table 2 List of the most common streams belonging to different nutrient x flood frequency classes in the 2 hard-bottomed FMUs individual WMAs, showing the number of NZReaches in each class. Classes with > 3% of NZReaches were subsequently selected (Y), and each NZReach within these classes was allocated a random number and prioritised for site selection, pending a final field visit.

Geol_Type	**Nutrient Class**	**FRE3_CAT**	**Total**	**Select**
Non_VA_Hard	**Eutrophic**	High	151	Y
		Low	1	N
		Medium	244	Y
	Mesotrophic	High	201	Y
		Medium	93	Y
	Oligo	High	1	N
		Medium	2	N
VA_Hard	**Eutrophic**	High	81	Y
		Low	525	Y
		Medium	1066	Y
	Mesotrophic	High	10	N
		Low	11	N
		Medium	35	N
	Oligo	Low	4	N

Sites within each of the seven nutrient x flood frequency classes were then assigned a random number and ranked accordingly. A number of sites within each group were then identified for field-based assessments based on their relative frequency of occurrence. A total of 95 sites were thus selected, with the VA_Hard_Medium_Eutrophic class being the most frequently assessed, with the Non_Va_Hard High_Eutrophic and Medium_Mesotrophic sites being assessed the least Table 3. These sites were spread throughout the region, and where possible sites were located in both the upper and lower parts of a catchment

Table 3 The number of streams in the most common nutrient x flood frequency classes where field inspections were made to choose sites for on-going periphyton monitoring.

FWU_FRE3_Nuts_ASSESSED	Number	Region_Rank
VA_Hard_Medium_Eutrophic	45	1
VA_Hard_Low_Eutrophic	14	2
Non_VA_Hard_Medium_Eutrophic	13	3
Non_VA_Hard_High_Mesotrophic	9	4
VA_Hard_High_Eutrophic	6	7
Non_VA_Hard_High_Eutrophic	4	5
Non_VA_Hard_Medium_Mesotrophic	4	6

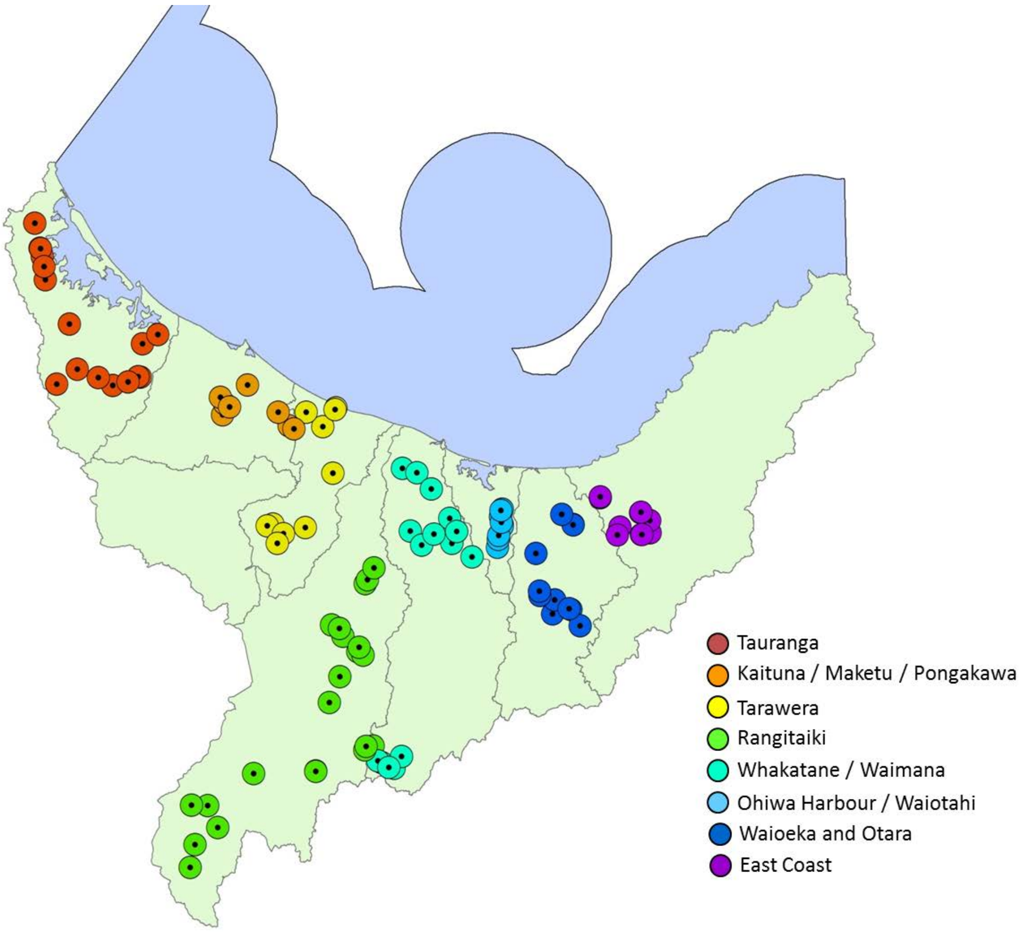


Figure 15 Map showing the spatial distribution of sites selected for initial site visits to assess their final suitability for a monitoring programme.

Site inspections of these 95 sites scored them on their suitability for periphyton monitoring. Each site was assessed on the basis of their suitability for six attributes including:

(i) presence of large substrates

(ii) unshaded

(iii) wadeable

(iv) ease of physical access

(v) legal access

(vi) ability to flow gauge.

Each attribute was scored from one (highly suitable) to three (highly unsuitable). A resultant site suitability score was calculated ranging from six (all attributes highly suitable), to 14 (most attributes highly unsuitable). Any sites with a total attribute score greater than eight were removed from further consideration, leaving 56 sites in the short list. These 56 sites were coded to their appropriate FMU and nutrient x flood frequency class, and the final sites were chosen to maintain approximately the same proportion of nutrient x flood frequency classes as found in the region. Sites were also selected to ensure where possible coverage in upper and lower parts of the same catchment, and to encompass as wide spatial coverage as possible.

This process resulted in the selection of 30 sites located throughout the region from one of six FMU nutrient x flood frequency classes (Table 4). Of these 30 sites, nine were located in the Rangitaiki WMA, six in the Whakatane/Waimana WMA, and five in the Tauranga Harbour WMA (Figure 16). Sites were also selected in a variety of land uses, and in both upper and lower areas of catchments to see whether increasing nutrient concentrations arising from land use activities is having any demonstrable effect on increasing the likelihood of algal blooms. Each of these sites will be monitored monthly where algal biomass will be quantified, cover of dominant algal groups assessed, and water quality samples collected. All sampling details are outlined in the following section.

Table 4 Final number of streams in the most common nutrient x flood frequency classes selected for periphyton monitoring throughout the region.

FWU_FRE3_Nuts_SELECTED	Number	Region_Rank
VA_Hard_Medium_Eutrophic	11	1
VA_Hard_Low_Eutrophic	5	2
Non_VA_Hard_Medium_Eutrophic	5	3
Non_VA_Hard_High_Mesotrophic	3	4
Non_VA_Hard_High_Eutrophic	2	5
VA_Hard_High_Eutrophic	4	7

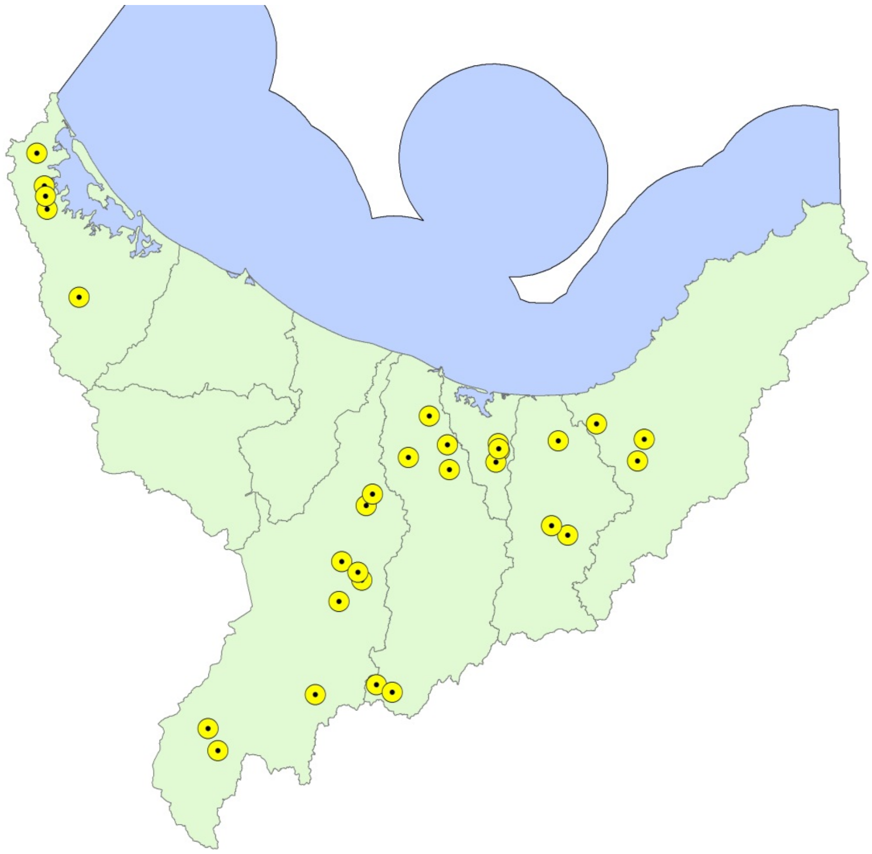


Figure 16 Location of the 30 sites finally selected for the long-term monthly monitoring of algae in streams throughout the region.

3.4 Reach selection

Periphyton communities can vary over small spatial scales, reflecting small differences in the size, shape and stability of the streambed, hydraulic flow conditions around the streambed, invertebrate grazing pressure, and competition from other algae. Periphyton biomass is usually naturally higher in riffle habitats than runs[1], reflecting the coarser and more stable substrates that define riffles. In addition, fast-flowing water in riffles leads to thinner boundary layers around periphyton, which can lead to an increased uptake of dissolved nutrients from the water. Conversely, biomass in riffles is also constrained by high velocity because algae growing into the water column can be sloughed and washed away. The highest periphyton biomass in rivers often develops in the lower shear-stress environment of runs.

Because riffles and runs are characterised by such different hydraulic habitats, one or the other needs to be selected for sampling to maximise between sites. Biggs and Kilroy (2000) recommended sampling periphyton in runs because this hydraulic habitat type is found most commonly in a wide range of rivers. Fast flowing riffles, in contrast, are mainly restricted to steep gradient streams with course substrates, and these conditions are often absent from sites throughout the Bay of Plenty. We thus recommend sampling in runs.

[1] Riffle habitats are characterised by generally fast flowing, shallow and turbulent water flowing over large substrates: Run habitats are generally slower flowing non-turbulent water that flows over smaller substrates. Riffles occur where the local stream gradient increases, whereas runs are in a gentler gradient.

3.5 Number of samples

Even though a periphyton sampling program may be restricted to collecting material only from run habitats, considerable variation can still occur within individual runs. Such variability reflects a complex interaction of random colonisation processes, competition between algae growing on a particular cobble, and grazing pressure from invertebrates, the distribution of which is also highly patchy. To overcome this small-scale variability, it is recommended that 10 replicate samples be collected from two transects and pooled into the one sample per survey at each site. These samples are returned to the laboratory where they are either pooled or analysed separately for chlorophyll biomass.

3.6 Sample collection

The quantitative procedures to estimate periphyton biomass using chlorophyll a are outlined in detail by (Biggs and Kilroy, 2000), and so will not be repeated here in full detail. Of the two quantitative methods highlighted by Biggs and Kilroy, Method QM1b (Scrubbing a delineated area of a rock) is considered a more appropriate method than method QM 1a, which collects a sample by scrubbing the entire area of the rock from a stone. Although both methods have drawbacks, fixed area sampling has fewer inherent errors in it than whole rock sampling (Cathy Kilroy, NIWA Christchurch pers comm 2015). Although scrubbing the entire surface of a rock will minimise any small-scale patchiness on the rock, the equation given by Biggs and Close to calculate the effective surface area for algal colonisation may not be applicable to all rock types in all streams.

Use of this equation to correct for surface error is thus likely to introduce considerable uncertainty into calculations of chlorophyll biomass.

A potential complicating factor for scrubbing a fixed area is the fact that algal communities can vary on top of a single rock, reflecting factors such as near-bed velocity regimes, the attachment and tensile strengths of algae to the rock, competition between different algal groups, and differential grazing pressure due to small-scale habitat preferences of invertebrates. Although patchy cover on rocks is definitely an issue, this can be minimised by positioning the sampling circle (the lid of the plastic container used to store the sample in) on the rock so that it encloses a more or less representative sample of periphyton cover over the whole rock. For more homogeneous cover, the sample is simply collected from the centre of the rock. In other words, rocks are collected randomly, and some discretion is used in selecting the sampling area on the rock.

Once all periphyton has been scraped from a fixed area of each rock (for approximately a 1 min scraping time), it is placed into the labelled plastic container for transport back to the laboratory on ice and in a chilly bin.

Biggs and Kilroy (2000) also outline the preferred method to extract chlorophyll from the collected samples. This involves the following steps:

1. Remove any invertebrate, gravel leaves moss from the sample.
2. Using a blender, homogenise the sample for up to 30 seconds.
3. If necessary, take a sub sample of this and dilute to a known volume.
4. Filter or material through GFC filter paper.
5. Place the filter paper into a centrifuge tube, and add a known volume of 90% ethanol.

6 Place these centrifuge tubes into a water bath (78°C), and leave for 5 min.

7 Store the samples in a fridge overnight to cool.

8 Measure the chlorophyll concentration in the sample using a spectrophotometer.

More details on the spectrophotometric method can be found in Section 7 of Biggs and Kilroy (2000).

3.7 Visual estimates

Because the above procedures are relatively time-consuming and expensive, Snelder et al (2013) suggested that a significant proportion of monitoring could be carried out for "low risk systems" using the quicker and less costly visual estimate methodologies. They also highlight the fact that cover estimates can be used to estimate chlorophyll *a* data (Kilroy et al., 2013). Because BOPRC currently does not monitor periphyton, we have no way of knowing *a priori* which sites are "low risk systems". Because of this, it is suggested that chlorophyll *a* monitoring is done at all sites on a monthly basis for at least three years, which is stipulated in the NOF framework. However, it is also recommended that cover estimates are conducted concurrently with biomass estimates using chlorophyll *a*. These cover estimates should be done using the methods as outlined in (Kilroy et al., 2013). In particular, it is suggested to use the Rapid Assessment Methodology (RAM) 2 as outlined by Biggs and Kilroy (2000). Such a methodology involves quantifying the cover of different algal classes at five equally spaced places across four transects placed perpendicular to the streamflow. (Kilroy et al., 2013) identified 8 algal classes for visual monitoring:

- No visible algal cover.
- thin algal films (<0.5 mm thick).
- thick algal mats (0.5 - >5 mm thick).
- Sludge.
- Short filamentous green algae (<2 cm long).
- Long filamentous Green algae (>2 cm long).
- Cyanobacteria.

These groupings were made to minimise the number of different algal categories, but as far as possible to separate cover that represented different chlorophyll a concentrations, and represented algal groups of special interest to river managers (e.g., potentially toxic Phormidium mats). Note that (Kilroy et al., 2013) highlighted significant inter-operator variability in distinguishing the “no algal cover” and “thin algal film” classes, as there was a measurable chlorophyll in some samples collected from stones which were visually assessed as having no perceptible algal cover. However, they note that such confusion is a relatively unimportant as when compared to the other visual categories, both these algal groups represented small amounts of standing crop. (Kilroy et al., 2013) also highlighted that practical instruction and experience reduce variability in the interpretation of categories, and suggests that periodic checks for consistency are made particularly on long-term surveys.

All algal cover data can be analysed by such methods including converting it to an index such as the PeriWCC. This in turn can be correlated to biomass estimates of algae using chlorophyll a. Furthermore, the 4 cover bands of PeriWCC as originally suggested by Matheson et al. (2013) could form the basis of an alternative measure of periphyton biomass than the potentially more costly chlorophyll measure, and be used in lieu of the NOF attribute bands if good relationships between PeriWCC and chlorophyll exist.

Monthly monitoring of periphyton biomass for three years from the selected sites will provide important information to categorise the current state of sites into one of the four chlorophyll a biomass bands as outlined in the NOF. This information will then be provided to community groups as part of the council's public consultation process required under the NPS. It is only through provision of this data of the current state of periphyton biomass at sites throughout the region can the public and the council properly define what the appropriate desired NOF attribute class is for different stream types. In the absence of this information, it is difficult (for either the council or the community to define what a desired state would be for different rivers throughout the region.

3.8 Environmental data

Because one of the eventual outcomes of the periphyton monitoring is to develop nutrient budgets for streams, monthly nutrient samples will also be collected from each site and analysed for DIN and DRP. Given the strong links between a stream's flow regime and periphyton communities, each site will also be gauged on every sampling occasion. It is hoped to have at least some sites in gauged catchments, so that flow relationships between the sampling site and the gauged flow record can be developed. In other catchments with no flow records, it is hoped that monthly flow gauging can be used to help develop relationships to the nearest gauged catchments. Water temperature is also a highly relevant ecological parameter to collect as well, as periphyton growth is generally higher in warmer waters.

Temperature is best collected using small dataloggers that can record temperature every 15 minutes. In this way, average monthly minimum and maximum temperatures can be calculated at each site.

Therefore at each site the following parameters will be collected on a monthly basis:

1. Chlorophyll biomass.
2. Periphyton cover of dominant groups.
3. Water quality including nutrients.
4. Measures of streamflow.
5. Water temperature.

The following data collected occasionally (e.g., every 3 or 6 months, or one-off) will provide additional data for use in developing relationships between periphyton and environmental variables:

1. Substrate composition (Wolman – or a quicker method would be to assess substrate composition in each periphyton view (using the usual categories) then work out the average over the reach.
2. An assessment of shading.

3 Water surface slope (one-off survey, at, say, approx. median flow, over a 50 m reach length encompassing the survey area; can be used as a surrogate for water velocity).

It is envisioned that this data will provide important information to allow us to meet the main objectives of the periphyton monitoring programme outlined above, namely to:

- determine the level to which periphyton blooms are currently occurring in waterways throughout the region,
- help the Council set periphyton biomass limits according to the NOF bands,
- determine whether periphyton biomass is increasing or decreasing over time as a result of land use change, and implementation of Council policies and plans,
- generate data to be used to investigate linkages between a stream's nutrient and flow regime in order to help set nutrient limits according to the NOF bands.

In addition to this, collection of both cover and chlorophyll a data will allow strong relationships between these two variables to be developed within each site. If strong relationships are found, further long-term monitoring as part of the council's NERMN monitoring programme could involve collection of periphyton cover data from sites throughout the region instead of the more costly chlorophyll a data. Kilroy et al (2013) suggested that visual assessments could distinguish sites and occasions as effectively as chlorophyll a, and highlighted that chlorophyll a estimates can be derived from visual estimate of periphyton cover. Furthermore, they suggested that inter operator variability in visual assessments need not be a major concern given adequate training. This suggests that cover estimates of periphyton biomass could be made by summer students as part of the council's normal NERMN summer monitoring programs, after giving them adequate training to maximise consistency.

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