Ministry for the
Environment
Manatū Mō Te Taiao

Essential Freshwater:

Impact of existing periphyton and proposed dissolved inorganic nitrogen bottom lines

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1 Introduction

Nitrogen concentrations in rivers in New Zealand are regulated by the National Policy Statement for Freshwater Management (NPS-FM; NZ Government, 2017). Nitrogen concentrations in rivers that support conspicuous periphyton (eg, gravel bed rivers) must be managed to control the periphyton biomass to levels that are prescribed by the NPS-FM. In rivers that do not support conspicuous periphyton biomass (eg, soft-bottomed rivers), nitrate must not exceed toxic concentrations that are prescribed by the NPS-FM. Nitrogen concentrations and loads must also be managed to meet objectives in receiving environments such as lakes and estuaries. There is also a separate requirement that freshwater quality within a freshwater management unit must be maintained at its current level (where community values are currently supported) or improved (where community values are not currently supported).

The most permissive level of periphyton biomass that is allowed by the NPS-FM (ie, the bottom line) is 200 mg m^{-2} which must not be exceeded by more than 8% of monthly samples in streams and rivers belonging to the default class. The NPS-FM does not prescribe the nitrogen concentrations that are required to achieve this biomass and this responsibility is borne by regional councils as part of designing regional plans that implement the NPS-FM. It is generally recognised that nutrient concentration criteria are highly site specific (Biggs, 2000; Snelder, 2018). A recent analysis suggests that total nitrogen concentrations that are consistent with the periphyton bottom line vary spatially between approximately[1] 0.2 to 3.5 mg L^{-1} (Snelder, 2018). The most permissive level of nitrate that is allowed by the NPS-FM (ie, the bottom line) is 6.9 mg nitrate-nitrogen L^{-1}, which is a concentration that is associated with chronic (ie, non-lethal) effects for 20% of test species (Hickey and Martin, 2009).

As part of the Essential Freshwater programme, the government is considering changes to nitrogen regulations. It is argued that the regulations in the NPS-FM are insufficient to protect ecological heath. It is proposed that a new regulation is introduced whereby the maximum concentration of dissolved inorganic nitrogen (DIN) allowed in all rivers and streams (ie, a bottom line) would be 1 mg L^{-1}. This concentration would apply in rivers that do not support conspicuous periphyton biomass (thereby reducing the bottom line from 6.9 mg L^{-1} to 1.0 mg L^{-1}) and in rivers for which the nitrogen concentration to achieve the periphyton bottom line is equivalent to a DIN concentration greater than 1 mg L^{-1}.

This study aimed to determine the impact of the proposed new regulation of DIN (referred to hereafter as the Essential Freshwater proposal). The impact is quantified in terms of the catchment excess nitrogen yield under current conditions. The excess nitrogen yield is the quantity of nitrogen (as an annual load; kg yr^{-1}) in excess of the load that will achieve an instream concentration criterion, divided by the catchment area (ie, a catchment yield; kg ha^{-1} yr^{-1}). The catchment excess nitrogen yield represents the amount by which the current nitrogen load would need to be reduced to achieve the instream concentration criterion. The load is expressed as a yield to standardise the 'load reduction effort' between catchments of differing size.

The study approached the analysis of the impact nationally in two steps. First, the excess load based on the bottom lines for riverine nitrogen under the current NPS-FM (ie, the periphyton and nitrate toxicity bottom lines) was estimated for all segments of a digital representation of the national river network. Second, the additional impact of the Essential Freshwater proposal bottom line of 1 mg

[1] The values reported here are based on recalibration of Snelder's (2018) original TN targets to the test dataset.

DIN L^{-1} was estimated for all segments. The study therefore updates the understanding of the impact of the current NPS-FM with respect to riverine nitrogen and quantifies the additional impact of the proposed bottom line of 1 mg DIN L^{-1}. Because the study represents all river segments nationally at reasonably high spatial resolution, the results illustrate the magnitude of the impact of both policies and the geographic areas in which they occur.

The government is also considering a proposal to introduce an attribute for dissolved reactive phosphorus (DRP) in the NPS-FM. Phosphorus has not been included in this study because the dynamics of phosphorus loss and transport are more complex than for nitrogen; phosphorus is more likely to be present in forms that are bound to sediment and less available for uptake by plants. An initial investigation showed that the proposed DRP bottom line will have limited spatial impact (approximately 0.1 per cent of rivers), when excluding the rivers that would be naturally high in DRP.

2 Methods

2.1 Spatial framework

The spatial framework for the analysis comprised a digital representation of New Zealand's surface water network, including river segments and the land areas that drain to these. This representation was based on a GIS-based digital drainage network comprising rivers and catchment boundaries that is the basis for the River Environment Classification (REC; Snelder and Biggs, 2002). We used version two of the digital network, which was derived from 1:50,000 scale contour maps. The network represents New Zealand's rivers as 590,000 segments (delineated by upstream and downstream confluences), each of which is associated with a sub-catchment.

2.2 Estimates of current concentrations and loads

Estimates of current concentrations of total nitrogen (TN) and nitrate-nitrogen (NO_3-N) for every segment of the river network were provided by statistical models fitted to a 'training dataset' comprising observations of TN and NO_3-N at 764 and 855 state of environment monitoring sites respectively. The monitoring sites were distributed throughout New Zealand as described by Whitehead (2018). The modelled response was the median of monthly values of TN and NO_3-N observed at each site between 2013 and 2017.

The predicted concentrations were generated using Random Forest (RF) regression models fitted to the site median values and a suite of predictor variables (the 'training data'). The models were fitted using the same methods and predictor variables as Whitehead (2018) but included five additional predictors representing land use intensity based on numbers of pastoral animals. These land use intensity predictors incorporate publicly available information about the distribution of pastoral animals (https://statisticsnz.shinyapps.io/livestock_numbers/) to improve on the predictor describing the proportion of catchment occupied by pastoral land cover. The animals in each catchment were represented as a livestock standard metric of 'stock unit (SU) equivalents', which is a commonly used measure of metabolic demand by New Zealand's livestock (Parker 1998). The predictors express land use intensity as the total stock units and the stock units by four stock types (dairy, beef, sheep and deer) type divided by catchment area (ie, SU ha^{-1}).

The RF model performance for the models was good, with a Nash-Sutcliffe efficiency of 0.72 and 0.63 for TN and NO_3-N respectively compared to 0.71 and 0.59 for the models of Whitehead (2018). The root mean square deviation of the TN and NO_3-N models were 0.26 and 0.45 log_{10} mg m^{-3} respectively and bias was close to zero for both models. This represents a small improvement on performance achieved by Whitehead (2018) due to the inclusion of the land use intensity predictors.

Current yields of TN for every segment of the river network were provided by statistical models fitted to calculated TN yields at 682 state of environment monitoring sites distributed throughout New Zealand using methods described by Snelder et al (2018). The yields were calculated using observations of TN concentrations made at monitoring sites described by Whitehead (2018) that had at least 10 years of monthly observations up to the end of 2017. The yields were calculated using either observed daily flows for sites with continuous flow recorders or modelled daily flows estimated using the TopNet hydrological model (McMillan et al, 2013). Predictions of TN yields (kg ha^{-1} yr^{-1}) were derived using a RF model fitted to the site yields and the same suite of predictor variables as the TN concentration model. The TN yield RF model performance was good (Nash-Sutcliffe efficiency of 0.62 and root mean square deviation of 0.23 log_{10} kg ha^{-1} yr^{-1}) and bias was low (-0.14 %).

It is noted that TN was included as a model term representing nitrogen, and not DIN because TN produced higher R^2 values (see Larned et al, 2015 for details). Although DIN is representing the form of nitrogen that is used by periphyton, it has often been found that biomass is more closely correlated with total rather than dissolved forms of nitrogen (eg, Dodds et al, 2002). However, the Ministry has received advice from the Essential Freshwater Science and Technical Advisory Group (STAG) to use DIN as the metric for the Essential Freshwater proposal (STAG, 2019).

2.3 Nitrogen concentration criteria and assessing current compliance

Four nitrogen concentration criteria that define bottom lines under specific circumstances were considered. First, the proposed new bottom line for DIN (1 mg DIN L^{-1}) was assumed to apply in all circumstances where the current NPS-FM regulations would allow a higher concentration of DIN. Second, it was assumed that the current NPS-FM bottom line for nitrogen concentration in rivers that do not support conspicuous periphyton was the toxicity criteria of 6.9 mg NO_3-N L^{-1}. It was assumed that river segments that do not support conspicuous periphyton are associated with fine bed substrates (ie, soft-bottomed segments). River segments with coarse and fine bed substrates were discriminated using substrate size index values of <3 and ≥3 respectively. Substrate size index values were based on modelled estimates that are available in the Freshwater Environments of New Zealand database (FENZ; Leathwick et al, 2010) as described by (Snelder et al, 2013).

The third and fourth concentration targets were based on achieving the current NPS-FM bottom line for river segments that potentially support conspicuous periphyton. A key assumption in this analysis was that periphyton bottom lines would be achieved purely by managing instream nutrient concentrations. This is a conservative assumption (ie, it maximises the impact of the current NPS-FM requirements) because measures other than nutrient concentration management can contribute to achieving periphyton objectives. Stream shading may be a more effective measure for achieving the periphyton bottom lines in many, particularly small, streams and rivers. Stream shading may reduce the need partially or wholly to reduce instream nitrogen. In some situations it may be possible to manage periphyton biomass by managing river flows, for example where additional flushing flows can be provided from hydro power facilities. However, it is expected that nitrogen load reductions are the most generally applicable method of managing periphyton biomass.

It was assumed that all segments with coarse bed substrates as indicated by substrate size index values ≥3 (ie, hard-bottomed segments) potentially support conspicuous periphyton. Concentration targets for TN to achieve the NPS-FM bottom line for periphyton biomass were based on Snelder (2018). The targets differ across 21 classes defined by the second level of the REC (REC; Snelder and Biggs, 2002). A test of these targets indicated they were overly stringent relative to periphyton biomass and nitrogen concentrations observed at 173 river monitoring sites in six regions; Northland, Bay of Plenty, Manawatū-Whanganui, Wellington, Canterbury and Southland. As suggested by Snelder (2018), the original TN targets were recalibrated to match the observations at the 173 river monitoring sites.

The approach to defining TN concentration targets by Snelder (2018) was not associated with site-specific predictions of biomass, but with a more general estimate of the risk that a given biomass objective (in this case the bottom line) would not be achieved. This risk is specified in terms of two spatial exceedance criteria of 10% and 20%. The spatial exceedance criteria means that if all locations comply with the TN concentration target, a randomly drawn location will have a risk of 10% or 20% (depending on the chosen spatial exceedance criteria) of exceeding the bottom line for periphyton (Snelder, 2018). This approach to defining the TN targets is a means to managing the uncertainty involved in specifying nutrient criteria to achieve periphyton biomass objectives. We have not considered if nutrient criteria that allow for a degree of risk of non-compliance are consistent with the requirements of the NPS-FM (see Section 4 for further discussion).

We consider the spatial exceedance criteria is a normative rather than scientific decision and have therefore demonstrated the consequences of two options rather than choosing a particular option (see Discussion for more information on the implications of these choices).

In summary, the current level of compliance of instream nitrogen concentrations were assessed for four alternative scenarios;

1. Scenario 1, the current NPS-FM based on the 10% spatial exceedance criteria for periphyton,
2. Scenario 2, the current NPS-FM based on the 20% spatial exceedance criteria for periphyton,
3. Scenario 3, the current NPS-FM based on the 10% spatial exceedance criteria and the proposed new bottom line for DIN
4. Scenario 4, the current NPS-FM based on the 20% spatial exceedance criteria and the proposed new bottom line for DIN

For scenario 1 and 2, compliance was assessed for each network segment with fine bed substrates (ie, soft-bottomed) by comparing the predicted NO_3-N concentration with the toxicity bottom line criteria of 6.9 mg NO_3-N L^{-1}. Compliance for all remaining segments with coarse substrates were assessed by first looking up their REC Source of flow class from the REC database. For each segment, the predicted TN concentration was compared with the relevant periphyton bottom line criteria given the REC class (Table 1) for the 10% (Scenario 1) and the 20% (Scenario 2) spatial exceedance criteria.

For scenario 3 and 4, compliance was first assessed as for Scenario 1 and 2. It was then assumed that DIN was equivalent to NO_3-N and compliance with the proposed new DIN bottom line was assessed by comparing the predicted NO_3-N concentration for all segments with 1 mg NO_3-N L^{-1}. Any segments that were compliant under Scenario 1 and 2 but which had NO_3-N > 1 mg L^{-1} were designated as non-compliant.

Table 1: Concentration targets for TN to achieve the NPS-FM bottom line for periphyton biomass in 21 REC (Source-of-flow) classes. The targets are defined for two alternative spatial exceedance criteria (10% and 20%) in terms of median concentrations in mg L^{-1}.

REC Class	Spatial exceedance criteria	
	10%	20%
CX/GM	1.0	2.9
CX/M	1.7	3.8
CX/H	1.7	3.7
CX/L	1.3	3.4
CX/Lk	0.4	1.2
CW/GM	0.5	1.3
CW/M	0.5	1.6
CW/H	0.6	1.8
CW/L	0.5	1.3
CW/Lk	0.3	0.8
CD/M	0.3	0.9
CD/H	0.3	0.8
CD/L	0.3	0.8
CD/Lk	0.2	0.7
WX/L	0.5	1.5
WX/H	0.6	1.7
WW/H	0.8	2.5
WW/L	0.3	0.9
WW/Lk	0.3	0.8
WD/L	0.1	0.4
WD/Lk	0.3	1.0

2.4 Load targets and local excess loads

The TN load target for rivers were based on assumption that median concentration increases in proportion to the load at a site, ie, the following relationship applies:

$$\frac{Concentration_1}{Load_1} = \frac{Concentration_2}{Load_2}$$

Therefore, the maximum allowable load (MAL) for each segment of the river network for Scenarios 1-4 were derived from the current concentration and load and the target concentration at that point was therefore estimated as:

$$MAL = Concentration_{Target} \frac{Load_{Current}}{Concentration_{Current}}$$

where $Load_{Current}$ is the estimated current load of TN (kg yr^{-1}) for the network segment. For Scenarios 1 and 2, $Concentration_{Current}$ and $Concentration_{Target}$ was the current concentration of NO_3-N and 6.9 mg L^{-1} respectively if the segment was designated as soft-bottomed or current concentration of TN and the relevant target from Table 1 if the segment was designated as hard-bottomed. For Scenarios 3 and 4, $Concentration_{Current}$ and $Concentration_{Target}$ was as for Scenario 1 and 2, unless NO_3-N > 1 mg L^{-1}, in which case $Concentration_{Current}$ was for NO_3-N and $Concentration_{Target}$ was 1 mg L^{-1}.

At each network segment where the current load was greater than the MAL, the local excess load was estimated as:

$$Local\ excess\ load = Load_{Current} - MAL$$

where $Load_{Current}$ is the estimated current load of TN. The local excess load is the load in excess of the MAL or the amount by which the current load would need to be reduced to comply with the segment's target concentration criteria (kg yr^{-1}).

It is noted that MAL and local excess load are always in terms of TN even though the criteria are specified in terms of mix of TN, NO_3-N and DIN. The underlying assumption therefore is that loads of NO_3-N and DIN change in proportion to change in the TN load.

2.5 Catchment excess load

The catchment excess load represents the minimum load reduction (kg yr^{-1}) required at a segment to decrease the current load at that segment and all upstream segments to the MAL. The catchment excess load differs from the local excess load in that it considers the excess load upstream. Thus, a segment may not itself have an excess load but, if it is situated downstream of segment(s) that have local excess load(s), it will have an excess that reflects a reconciliation of those upstream local excess loads. In other words, the catchment excess load is the amount by which the current load would need to be reduced at a segment to comply with the concentration criteria at that segment and all upstream segments.

The catchment excess load is a more appropriate characteristic than the local excess load to assess the compliance with nitrogen criteria at any point in the network because it accounts for necessary load reductions in the upstream catchment. However, if larger load reductions are required further downstream of any segment, then reductions greater than the catchment excess load may be required. It is noted that requiring larger reductions than the minimum (ie, the catchment excess load) involves making judgements about which parts of a catchment need to contribute to required load reductions, which is an allocation (ie, normative) decision. This analysis does not consider these types of decisions and the catchment excess load only quantifies the minimum (ie, necessary) load reduction at each network segment.

The catchment excess load was evaluated at all network segments in three steps. First, the local excess load was evaluated for all network segments. Second, the catchment excess load for the most upstream network segments was defined to be their local excess load. Third, the digital drainage network representing each individual catchment that drains to the sea was traversed in the downstream direction. Beginning at the most upstream network segments, the catchment excess load was compared to the local excess load of the next segment downstream. If the local excess load at the next downstream segment was less than the catchment excess load of the upstream segment, the catchment excess load of the downstream segment was updated to be the catchment excess load of the upstream segment. If the reverse applied, the catchment excess load of the downstream receiving environment was updated to be its local excess load. The catchment excess load took a positive value (kg $year^{-1}$) at any segment in the catchment for which the current TN load exceeded the MAL.

The catchment excess load was expressed as a yield by dividing by the upstream catchment area (kg ha^{-1} $year^{-1}$). It is important to recognise that all yields reported in this study are from catchments with diverse land uses and often headwaters that are in the natural state. These catchment yields and are therefore generally considerably smaller than typical yields of nitrogen from pasture (eg, root zone losses estimated by OVERSEER).

Maps of the catchment excess yield were defined by colouring the drainage network using a colour scale that reflected the catchment excess yield at each network segment. Finally, we evaluated excess loads for the 15 jurisdictional regions in New Zealand (Nelson City was merged with the Tasman District) and the entire country by summing catchment excess loads over all terminal segments (i.e. a network segments intersecting the coastline) loads by region and nationally.

2.6 Load reduction required and impact of proposed DIN criteria

The catchment excess load was expressed as a required load reduction by dividing by the current TN load. This measure is referred to as the ‘load reduction required’ and is quantified as a percentage. (%). The load reduction required is a useful measure because it is expressed relative to the status quo. Values of the load reduction required were mapped to describe the pattern of minimum necessary load reductions for the four scenarios.

The impact of the proposed new regulation of DIN over and above that of the current NPS-FM requirements is indicated by the difference between scenarios in the load reduction required. The difference between these measures for Scenario 1 and 3 indicates the impact of the proposed regulation based on a spatial exceedance criterion of 10% and the difference between these measures for Scenario 2 and 4 indicates the impact of the proposed regulation based on a spatial exceedance criterion of 20%.

3 Results

3.1 Compliance with criteria

Compliance with current NPS-FM nitrogen criteria was sensitive to the TN concentration criteria adopted (ie, Scenario 1 or 2; Figure 1). Under Scenario 1, the analysis estimated that 15% of segments nationally had concentrations higher than the current NPS-FM bottom lines (Figure 1). Under Scenario 2, the analysis estimated that 4% of segments nationally had concentrations higher than the current NPS-FM bottom lines. All exceedances were associated with the periphyton concentration criteria except for a single segment in South Canterbury that had a predicted NO_3-N concentration in excess of the toxicity bottom line. Only six monitoring sites in the training dataset for the RF NO_3-N model had median concentrations greater than 6.9 mg m^{-3}. The RF modelling method does not predict outside the range of the training data and tends to have maximum predictions that are somewhat lower than the most extreme values. Therefore, although there were monitoring sites with NO_3-N concentrations above the NOF toxicity bottom line, the RF model generally did not predict values greater than the NO_3-N toxicity bottom line.

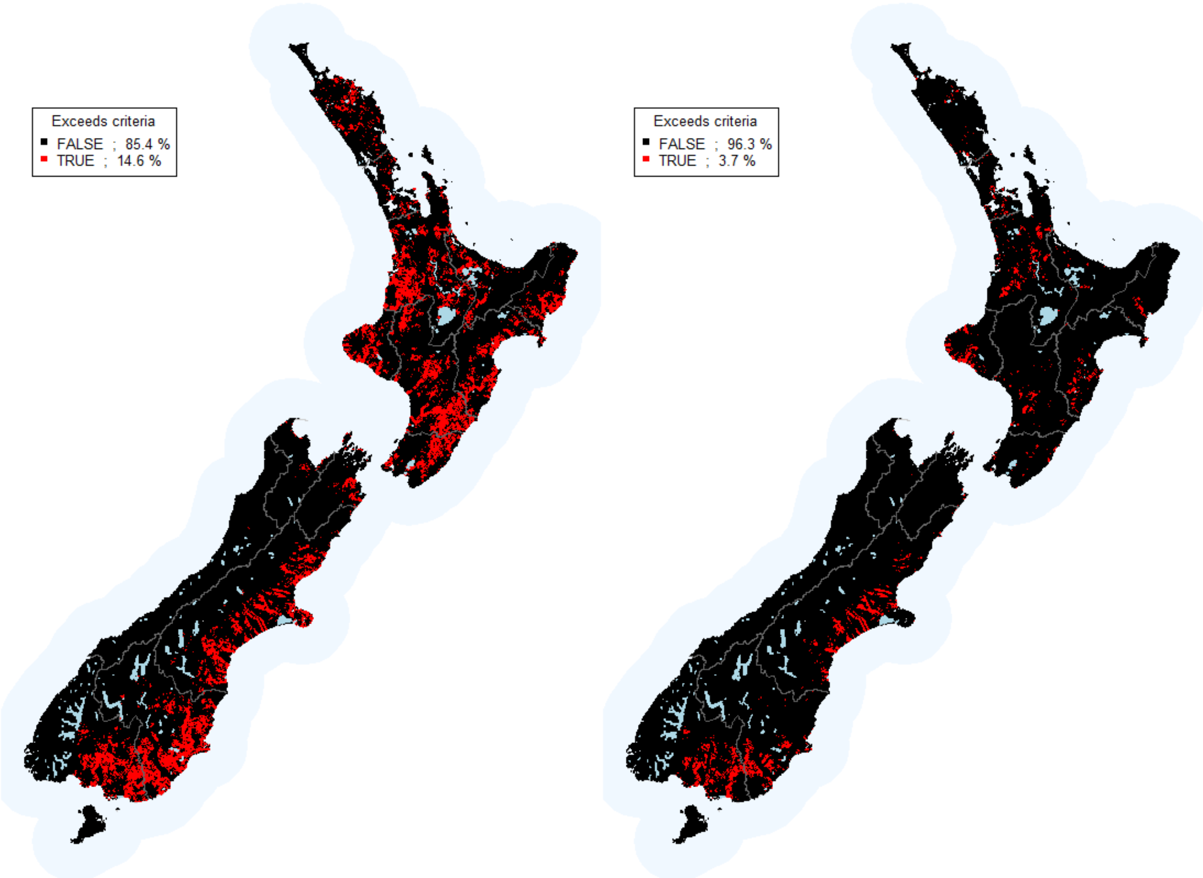

Figure 1: Maps showing segments classified by compliance with NPS-FM nitrogen criteria based on 10% spatial exceedance for periphyton (Scenario 1) and 20% spatial exceedance for periphyton (Scenario 2). The dark grey line is the regional boundary and the pale blue polygons represent large lakes.

Predicted DIN concentrations of 1 mg L^{-1} or greater occurred in 5.5% of segments nationally (Figure 2). These segments were concentrated in the Waikato, Taranaki, Manawatū-Whanganui, Canterbury and Southland regions.

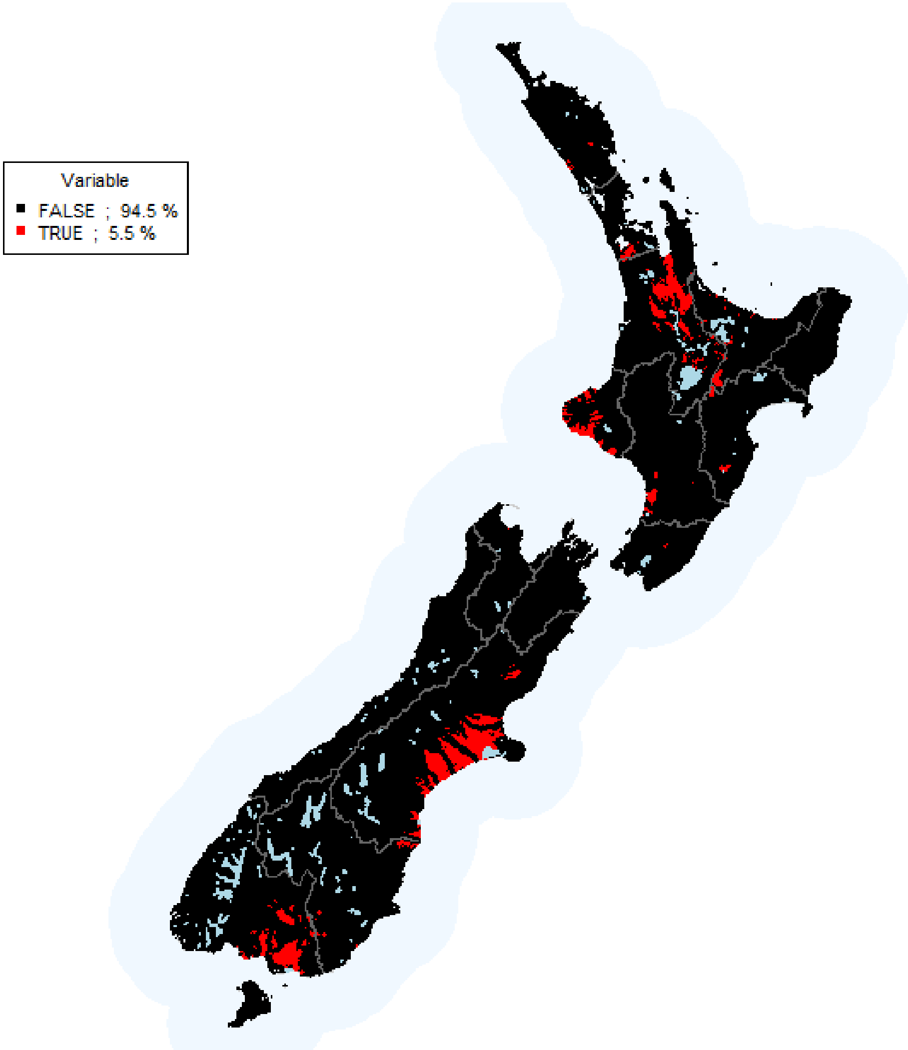

Figure 2: Map showing segments where estimated DIN exceeds 1 mg L^{-1}.

The Essential Freshwater proposal increases the proportion of non-complying segments over those that are non-complying under the NPS-FM by approximately 5% (Figure 3). Under Scenario 3, 19% of segments had concentrations higher than the criteria (ie, the current NPS-FM bottom lines for a spatial exceedance of 10% or DIN of 1 mg L^{-1}; Figure 3) compared to 15% under Scenario 1 (Figure 1). Similarly, under Scenario 4, 9% of segments had concentrations higher than the criteria (ie, the current NPS-FM bottom lines for a spatial exceedance of 20% or DIN of 1 mg L^{-1}; Figure 3) compared to 4% under Scenario 2 (Figure 1).

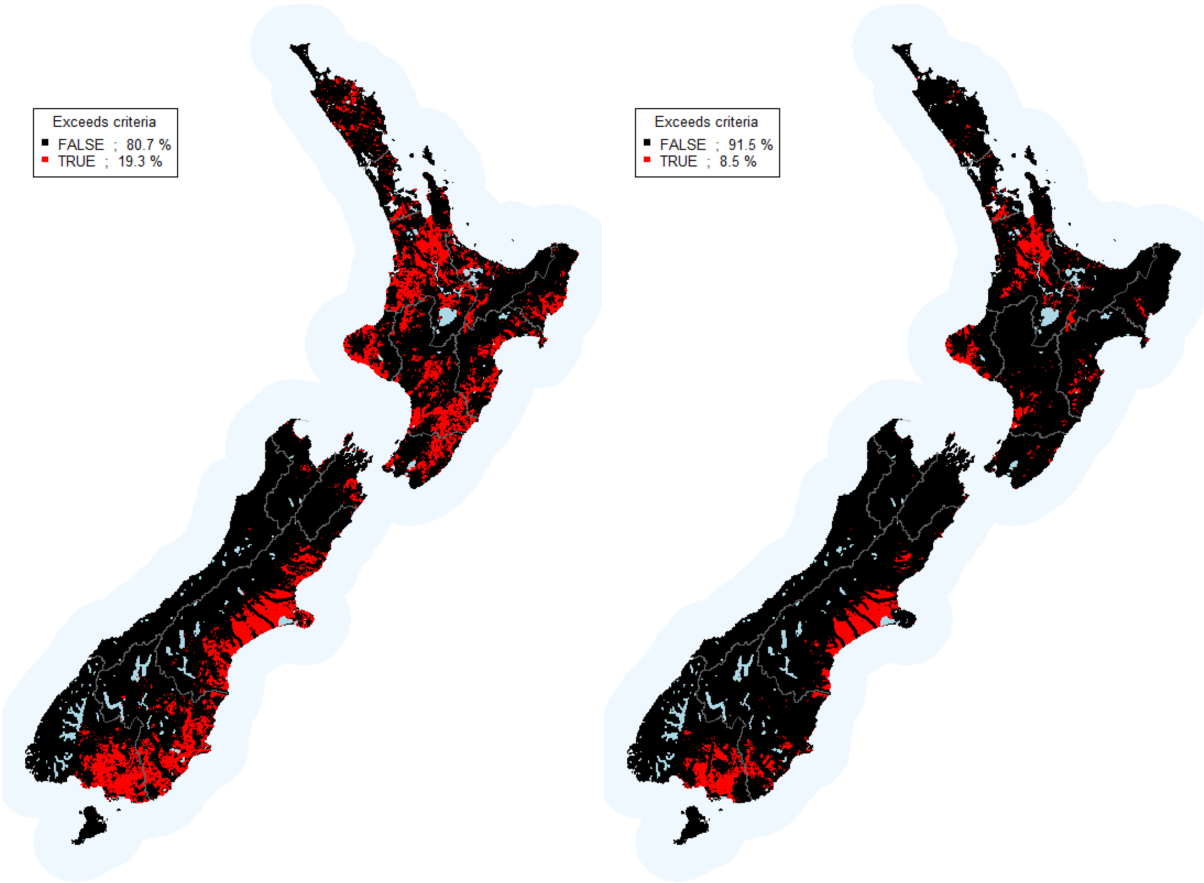

Figure 3: Maps showing segments classified by compliance with the Essential Freshwater proposal based on 10% spatial exceedance for periphyton (Scenario 3) and 20% spatial exceedance for periphyton (Scenario 4).

River segments that are currently compliant under the NPS-FM, but which would be non-compliant under the Essential Freshwater proposal (ie, the addition of the 1 mg DIN L^{-1} criteria) are shown on Figure 4. Small areas of non-compliant segments are broadly distributed nationally but the majority of these are concentrated in low elevation areas (that are classified in this analysis as soft-bottomed) in the Waikato, Taranaki, Manawatū-Whanganui, Canterbury and Southland regions.

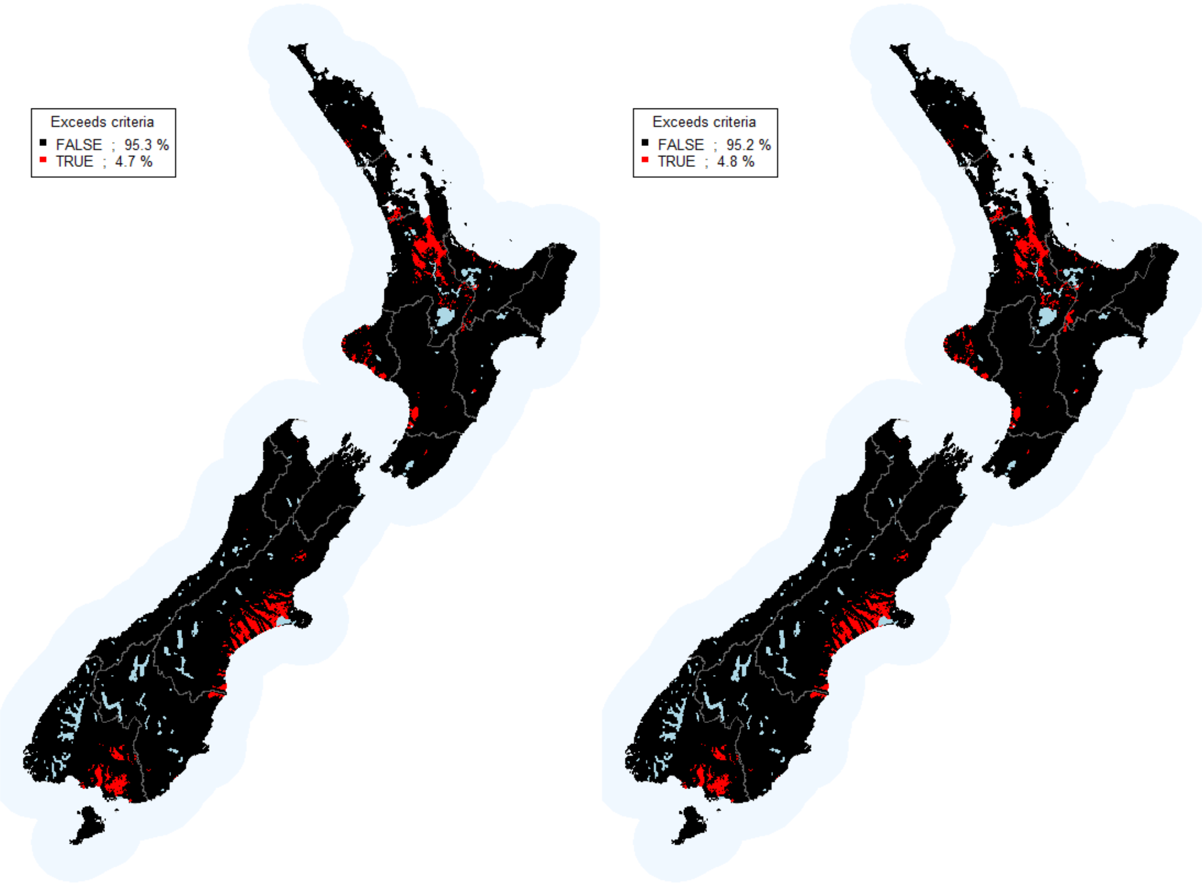

Figure 4: Maps showing segments that would be classified as compliant under the NPS-FM but which would be non-compliant under the Essential Freshwater proposal. The left-hand map is based on 10% spatial exceedance for periphyton (Scenario 3) and the right-hand map is based on 20% spatial exceedance for periphyton (Scenario 4).

3.2 Catchment excess loads and yields

The catchment excess yield under the NPS-FM was higher and more broadly distributed for Scenario 1 (ie, the 10% spatial exceedance criteria) than for Scenario 2 (ie, the 20% spatial exceedance criteria; Figure 5). This is expected due to the greater stringency of the 10% spatial exceedance criteria compared to the 20%. Segments with excess loads occurred throughout New Zealand but were generally associated with catchments with high proportions of urban or agricultural land use. The highest proportions of segments with excess yields occurred in the Waikato, Taranaki, Manawatū-Whanganui, Hawkes Bay, Wellington, Canterbury, Otago and Southland regions (Figure 5).

The load reductions required under the NPS-FM were higher and more broadly distributed for Scenario 3 (ie, the 10% spatial exceedance criteria) than for Scenario 4 (ie, the 20% spatial exceedance criteria; Figure 6). The required load reductions were variable and exceeded 50% under Scenario 3 in a considerable proportion of the non-compliant segments in the Waikato, Taranaki, Manawatū-Whanganui, Hawkes Bay, Canterbury and Southland regions (Figure 6). Under Scenario 4, required load reductions of greater than 50% were generally restricted to the Canterbury and Manawatū-Whanganui region.

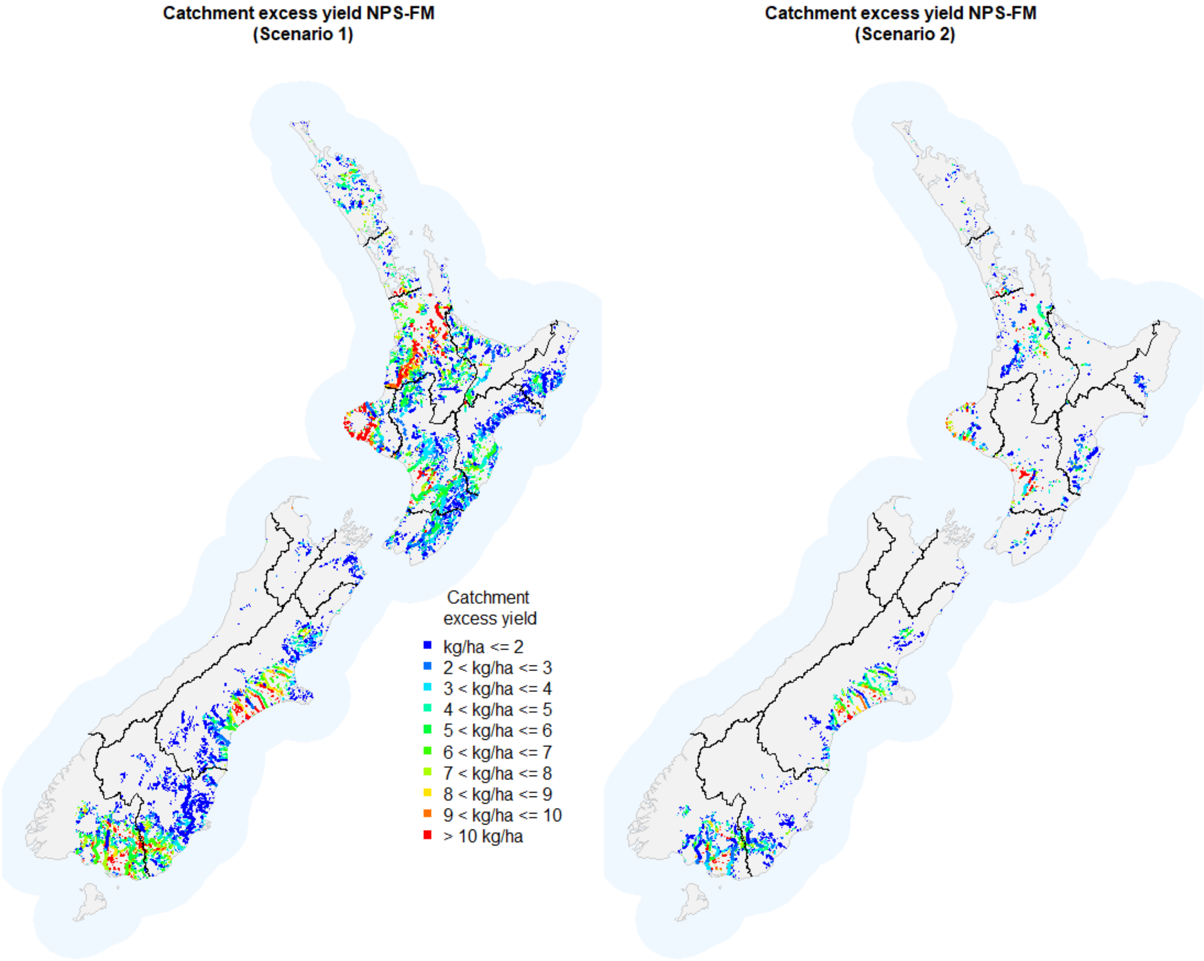

Figure 5: Maps showing the catchment excess yields for all network segments for the NPS-FM nitrogen criteria based on 10% spatial exceedance for periphyton (Scenario 1) and 20% spatial exceedance for periphyton (Scenario 2).

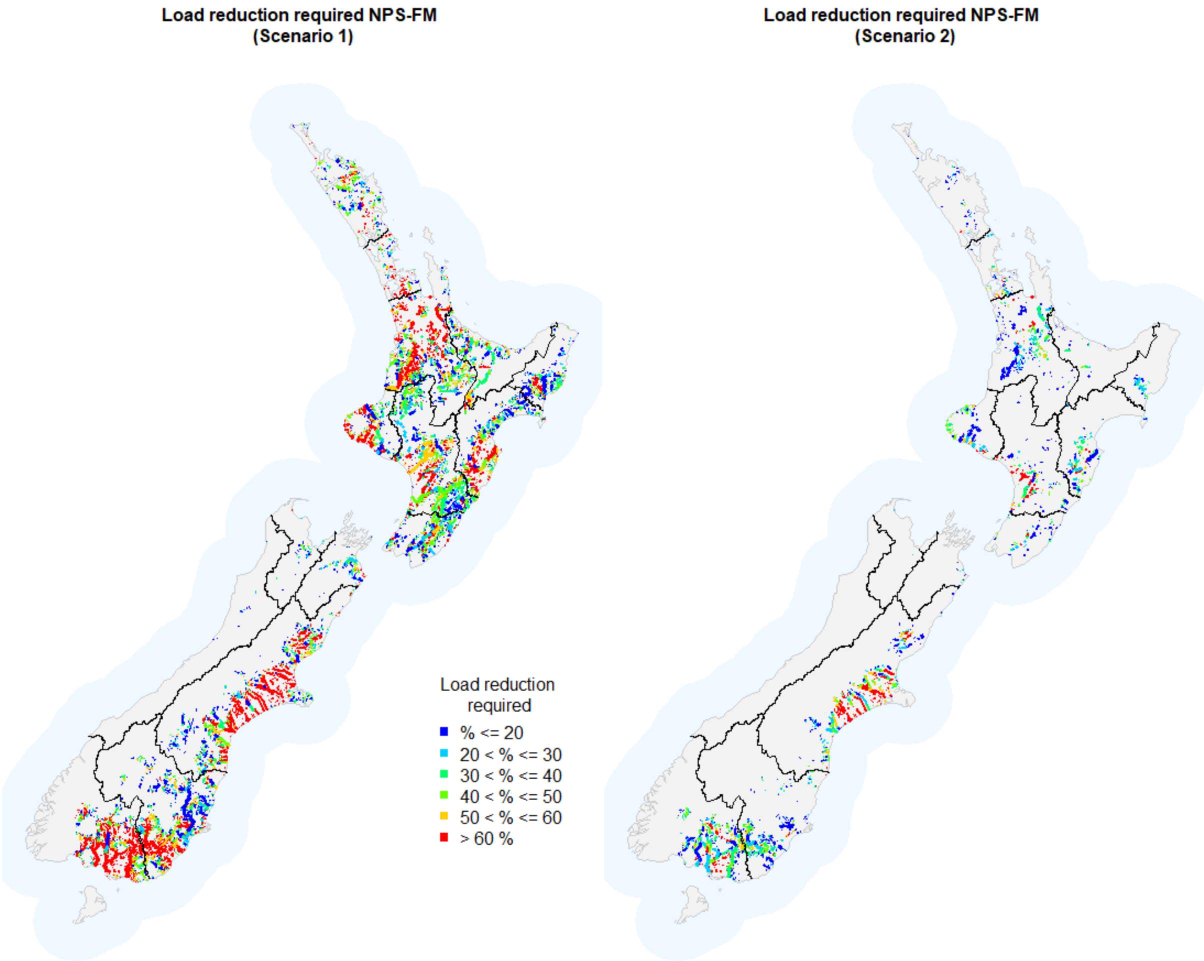

Figure 6: Maps showing the load reduction required for all network segments for the NPS-FM nitrogen criteria based on 10% spatial exceedance for periphyton (Scenario 1) and 20% spatial exceedance for periphyton (Scenario 2).

The catchment excess yield under the Essential Freshwater proposal was higher and more broadly distributed for Scenario 3 (ie, the 10% spatial exceedance criteria) than for Scenario 4 (ie, the 20% spatial exceedance criteria; Figure 7). Segments with excess loads occurred throughout New Zealand but were generally associated with catchments with high proportions of urban or agricultural land use. The highest proportions of segments with excess yields occurred in the Waikato, Taranaki, Manawatū-Whanganui, Hawkes Bay, Wellington, Canterbury, Otago and Southland regions (Figure 7).

The load reductions required under the Essential Freshwater proposal were higher and more broadly distributed for Scenario 3 (ie, the 10% spatial exceedance criteria) than for Scenario 4 (ie, the 20% spatial exceedance criteria; Figure 8). The required load reductions were variable and exceeded 50% under Scenario 3 in a considerable proportion of the non-compliant segments in the Waikato, Taranaki, Manawatū-Whanganui, Hawkes Bay, Canterbury and Southland regions (Figure 8). Under Scenario 4, required load reductions of greater than 50% were generally restricted to the Canterbury and Manawatū-Whanganui region.

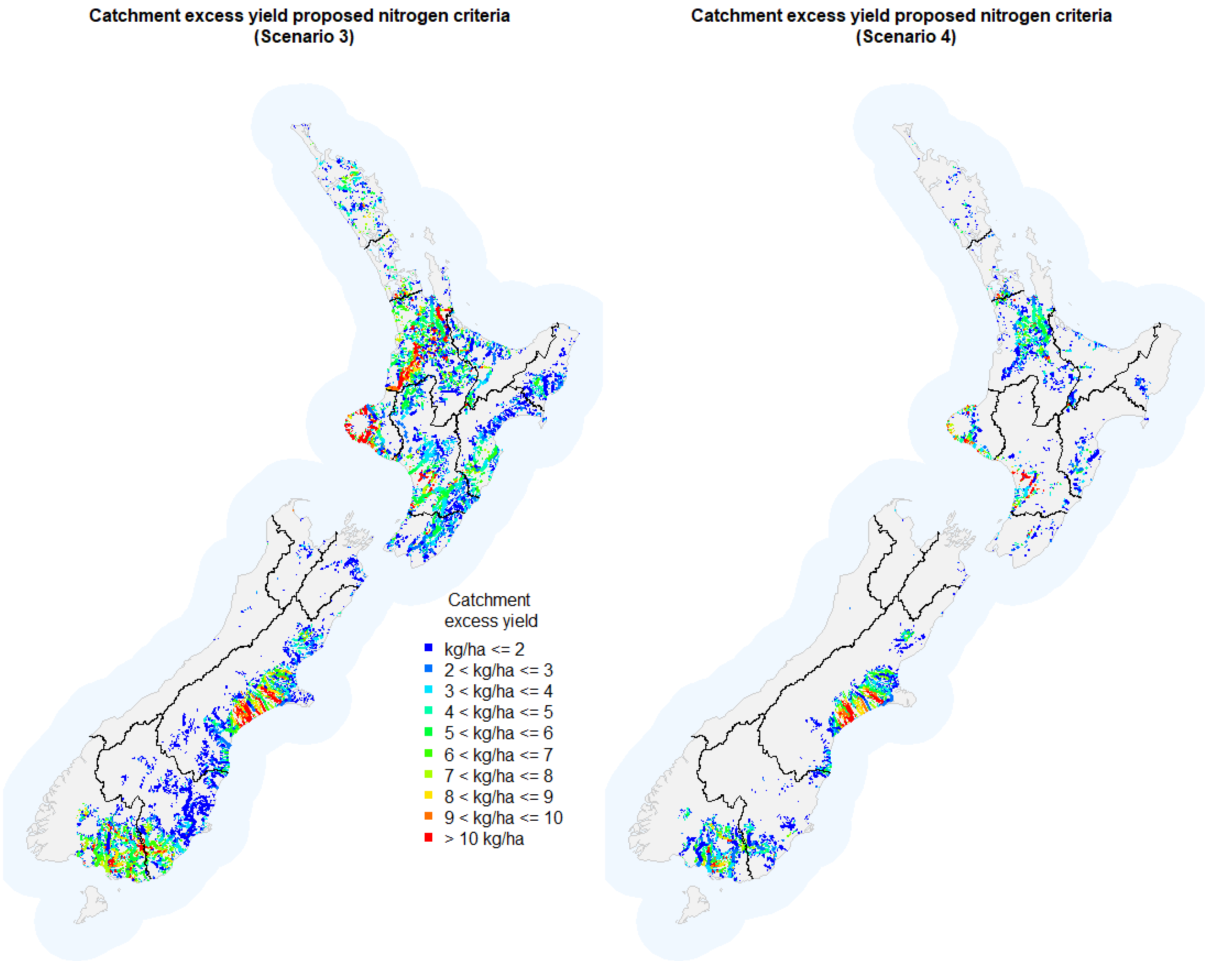

Figure 7: Maps showing the catchment excess yields for all network segments for the Essential Freshwater proposal based on 10% spatial exceedance for periphyton (Scenario 3) and 20% spatial exceedance for periphyton (Scenario 4).

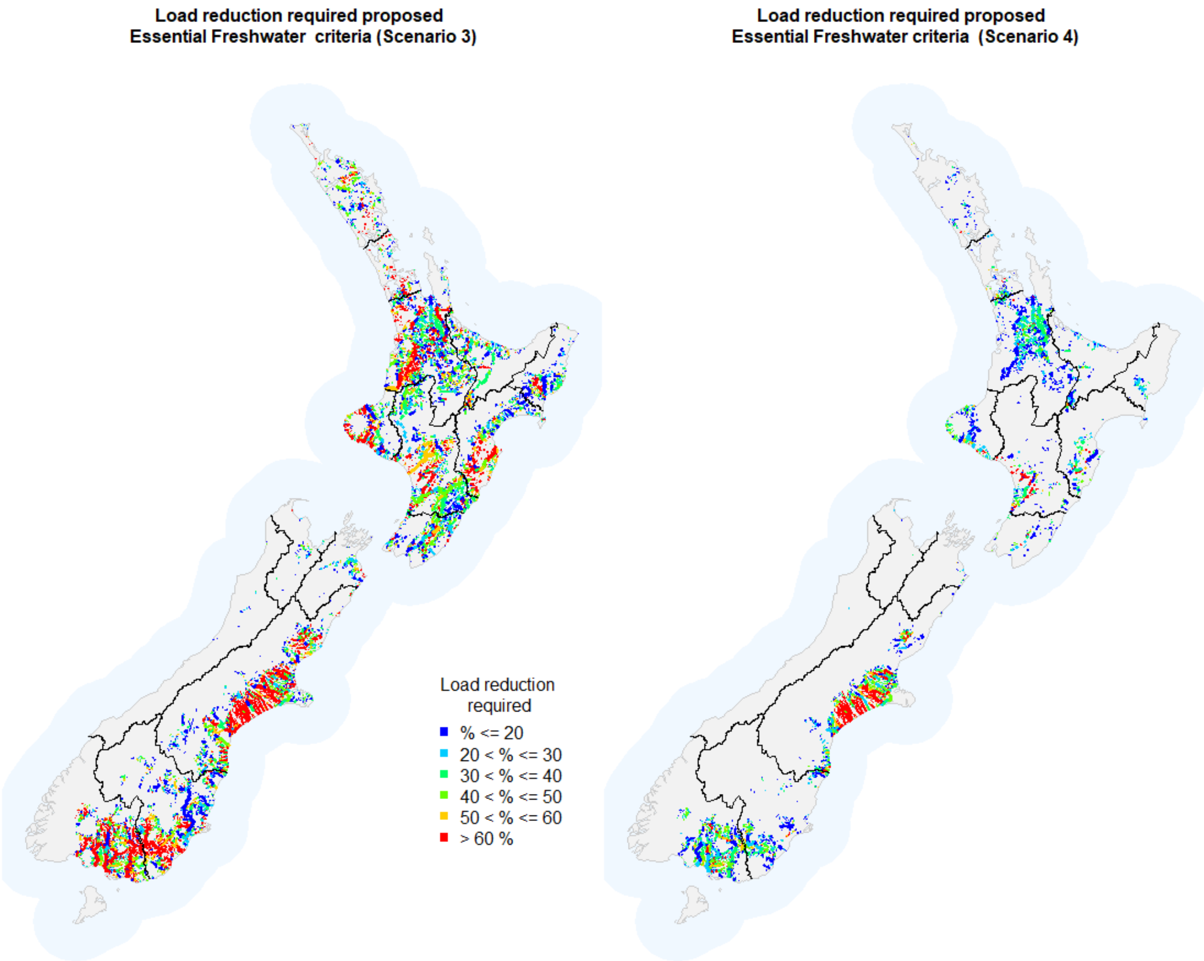

Figure 8: Maps showing the load reduction required for all network segments for the Essential Freshwater proposal based on 10% spatial exceedance for periphyton (Scenario 3) and 20% spatial exceedance for periphyton (Scenario 4).

Catchment excess yields were higher under the Essential Freshwater proposal (Figure 7) than the NPS-FM (Figure 5) but the differences were subtle and areas that had substantial differences were restricted spatially. Areas that had higher excess yields under the Essential Freshwater proposal were locations that are currently compliant under the NPS-FM (Figure 1), but which would be non-compliant under the Essential Freshwater proposal (Figure 3). These areas are particularly prominent in the Waikato, Taranaki, Manawatū-Whanganui, Canterbury and Southland regions.

The difference in the load reduction required between the Essential Freshwater proposal and NPS-FM were larger when the periphyton criteria was based on the 20% spatial exceedance criteria than the 10% spatial exceedance criteria (Figure 7). This is expected due to the higher stringency of the 10% spatial exceedance criteria compared to the 20%.

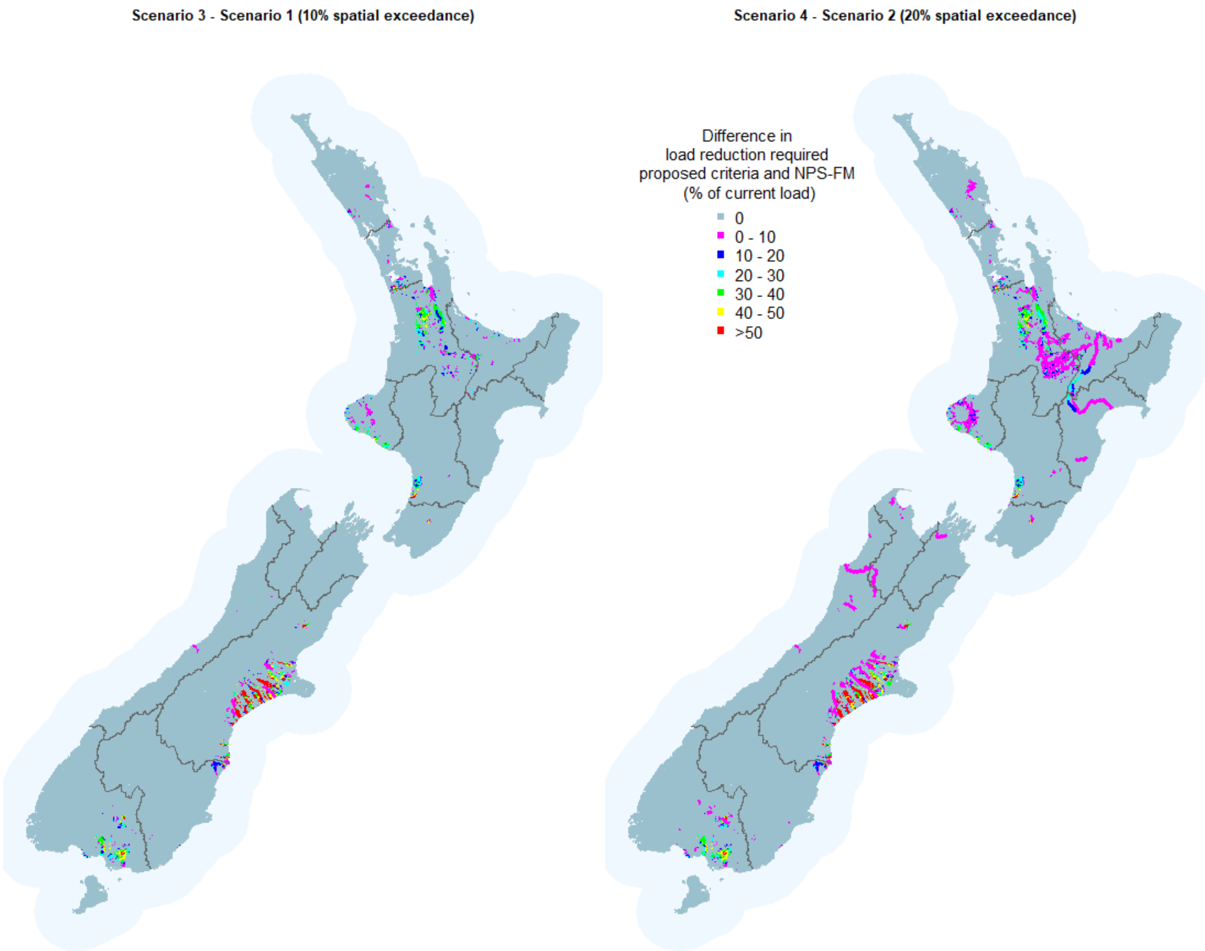

Figure 9: Maps showing the difference in the load reduction required for all network segments between the Essential Freshwater proposal and the NPS-FM. The map on the left is based on the 10% spatial exceedance for periphyton and represents the difference in the load reduction required between Scenario 3 and Scenario 1. The map on the right is based on the 20% spatial exceedance for periphyton and represents the difference in the load reduction required between Scenario 4 and Scenario 2.

The total load of TN discharged to the ocean was estimated to be 186 Gg year^{-1}, which is comparable with estimates of 187 Gg year^{-1} and 167 Gg year^{-1} estimated by Snelder et al (2018) and Elliott et al (2005) respectively (Table 2). Excess loads under the NPS-FM as a proportion of current total TN discharged to the ocean varied regionally (Table 2). The regions with the largest excess loads under the NPS-FM as a proportion of current total TN were Canterbury, Southland, Taranaki, Manawatū-Whanganui and Waikato. The regions with the largest difference in load reductions required between the NPS-FM and Essential Freshwater proposal were Canterbury, Taranaki, Auckland, Bay of Plenty and Southland. The regional differences in the load reductions required between the Essential Freshwater proposal and the NPS-FM were not large and ranged from 4.4% for Canterbury to 1% for Southland. The differences in load reductions required between the NPS-FM and Essential Freshwater proposal were less than 0.2% for all other regions. The differences in the excess yields and load reductions required were not strongly dependent on the periphyton spatial exceedance criteria and were only greater than 1% for Bay of Plenty (1.6% or 0.2% for 20% and 10% periphyton spatial exceedance criteria respectively). This occurs because the differences in the load reductions required between the Essential Freshwater proposal and the NPS-FM are generally associated with soft-bottomed segments. These locations have local excess loads of zero under the NPS-FM but would have local excess loads under the Essential Freshwater proposal if their current DIN concentration exceeds 1 mg DIN L^{-1}.

Table 2: Regional and national load of TN discharged to the ocean, excess loads and load reductions required under the four scenarios and differences between NPS-FM and Essential Freshwater proposal. The first values in columns 2 to 6 are excess loads that have units of Gg yr-1 and the values in brackets in columns 3-6 are load reductions required and are expressed as percentages of current total load. columns 7 and 8 represent the impact of the Essential Freshwater proposal. The first values in columns 7 and 8 are the differences in excess loads between the NPS-FM and the Essential Freshwater proposal with units of Mg yr-1. The values in brackets in columns 7 and 8 are differences in the load reductions required between the NPS-FM and the Essential Freshwater proposal and are percentages of current total load.

Region	Total Load	Excess loads				Difference	
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 3 - Scenario 1	Scenario 4 - Scenario 2
Northland	9.6	1.83 (19.1)	0.12 (1.2)	1.83 (19.1)	0.13 (1.4)	4 (0)	4 (0)
Auckland	3.5	0.97 (27.7)	0.3 (8.6)	1.03 (29.4)	0.36 (10.3)	60 (1.7)	60 (1.7)
Waikato	25.5	11.87 (46.5)	3.33 (13.1)	11.89 (46.6)	3.35 (13.1)	19 (0.1)	23 (0.1)
Bay of Plenty	8.5	1.46 (17.2)	0.1 (1.2)	1.48 (17.4)	0.23 (2.7)	20 (0.2)	135 (1.6)
Gisborne	4	0.54 (13.5)	0.06 (1.5)	0.54 (13.5)	0.06 (1.5)	0 (0)	0 (0)
Taranaki	9.6	4.16 (43.3)	1.53 (15.9)	4.32 (45)	1.74 (18.1)	158 (1.6)	210 (2.2)
Manawatu- Wanganui	21.2	11.31 (53.3)	2.92 (13.8)	11.36 (53.6)	2.97 (14)	48 (0.2)	48 (0.2)
Hawkes Bay	11.1	3.22 (29)	1.41 (12.7)	3.22 (29)	1.43 (12.9)	0 (0)	19 (0.2)
Greater Wellington	6.1	2.73 (44.8)	0.81 (13.3)	2.73 (44.8)	0.81 (13.3)	1 (0)	4 (0.1)
Tasman	3.6	0.12 (3.3)	0.01 (0.3)	0.12 (3.3)	0.02 (0.6)	1 (0)	2 (0.1)
Marlborough	3.1	0.18 (5.8)	0.03 (1)	0.18 (5.8)	0.03 (1)	0 (0)	0 (0)
West Coast	17.1	0.04 (0.2)	0 (0)	0.04 (0.2)	0 (0)	0 (0)	0 (0)
Canterbury	23.4	7.73 (33)	4.68 (20)	8.68 (37.1)	5.71 (24.4)	949 (4.1)	1036 (4.4)
Otago	15.2	2.99 (19.7)	0.84 (5.5)	3.01 (19.8)	0.85 (5.6)	16 (0.1)	16 (0.1)
Southland	24.2	9.83 (40.6)	3.97 (16.4)	10.03 (41.4)	4.22 (17.4)	202 (0.8)	245 (1)
National total	185.7	58.98 (31.8)	20.11 (10.8)	60.46 (32.6)	21.91 (11.8)	1478 (0.8)	1802 (1)

3.3 Impacts in catchments

National scale

There were 27,773 or 28,627 segments that complied with the current NPS-FM nitrogen criteria but which did not comply with the Essential Freshwater proposal (ie, 4.7 or 4.8% of the river network; Figure 4) depending on the spatial exceedance criteria. Hereafter these segments are referred to as impacted segments. The catchments upstream of the impacted segments were identified and are shown on Figure 10 (and are referred to hereafter as impacted catchments). The proportion of New Zealand's land area belonging to an impacted catchment (13%) exceeds the proportion of impacted segments because the catchment includes all segments upstream of a single impacted segment. Many of the impacted catchments are subsumed within larger impacted catchments. A search through all impacted catchments found that they are represented by 1355 individual large catchments (ie, all other impacted catchments are subsumed within these 1355 catchments the outlines of which are shown in Figure 10).

The level of impact on an impacted segment can be large; the typical case being where it is assumed that the nitrate criteria under NPS-FM is 6.9 mg NO_3-N L^{-1} but under the Essential Freshwater proposal this would reduce to 1.0 mg DIN L^{-1}. This can lead to large difference in the excess load between the current NPS-FM (ie, Scenario 1 and 2) compared to the Essential Freshwater proposal (ie, Scenario 3 and 4). However, as is shown in Section 3.2, these local (segment scale) impacts are often over-ridden when the catchment excess load at the bottom of the catchment was taken into account. The following examples of individual catchments indicate in more detail why this occurs.

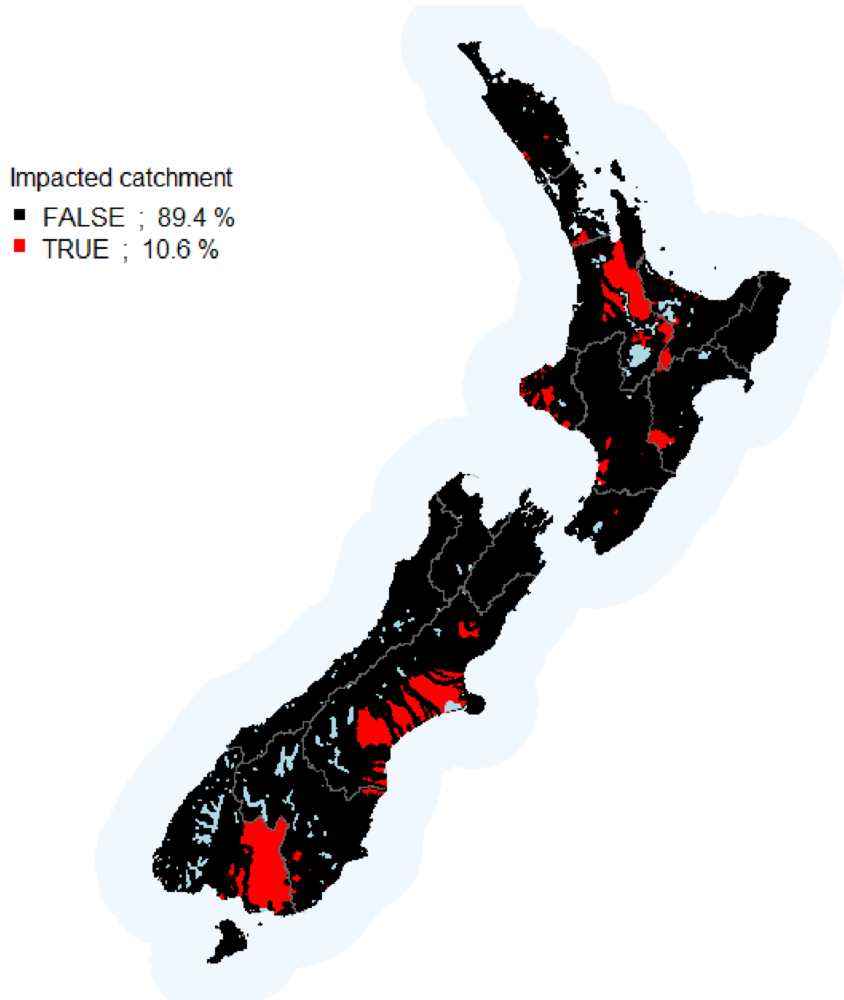

Figure 10: Catchments upstream of segments that complied with the current NPS-FM nitrogen criteria, but which did not comply with the Essential Freshwater proposal.

Mataura River catchment, Southland

Under the NPS-FM the estimated excess nitrogen yield at the bottom of the Mataura River catchment in the Southland region is 6.9 kg ha^{-1} $year^{-1}$ (Figure 11) and 3.6 kg ha^{-1} $year^{-1}$ for spatial exceedance criteria of 10% and 20% respectively (ie, Scenario 1 and 2). The estimated excess nitrogen yield under the Essential Freshwater proposal (ie, Scenario 3 and Scenario 4) is the same as for the NPS-FM. This is because, under both sets of scenarios, the excess yields at the bottom of the catchment are determined by the nitrogen criteria to achieve the periphyton bottom lines. Those criteria are more stringent than the Essential Freshwater proposal of 1 mg DIN L^{-1}; being 0.3 mg TN L^{-1} and 0.8 mg TN L^{-1} respectively for spatial exceedance criteria of 10% and 20% respectively.

However, there are areas within the Mataura River catchment for which the Essential Freshwater proposal has an impact (ie, increases the excess nitrogen yield). These impacted segments can be seen by comparing the left- and right-hand maps in Figure 11. For example, there are large areas in the mid Mataura catchment that have an excess nitrogen yield of zero under the NPS-FM but which have excess nitrogen yields of up to 10 kg ha yr^{-1} under the Essential Freshwater proposal. These impacted segments coincide with locations that are classified as fine bed substrates (Figure 12) and are generally referred to as spring fed systems within the Mataura River catchment. Because these areas have fine substrates, the analysis has assumed that they do not support conspicuous periphyton and under the NPS-FM, the relevant nitrogen criterion is 6.9 mg NO_3-N L^{-1}. However, the analysis has assumed that under the Essential Freshwater proposal, the nitrogen criterion is 1.0 mg DIN L^{-1}. Therefore, in situations where the current DIN concentration is greater than 1.0 mg DIN L^{-1}, the Essential Freshwater proposal will have an impact.

The Mataura River analysis indicates that the Essential Freshwater proposal has no effect on the excess nitrogen yield at the bottom of the catchment. However, Figure 11 indicates that there are large exceedances of the proposed nitrogen criteria at finer (sub-catchment) scales. It is likely that there would be significant local reductions in nitrogen loading required if these sub-catchment scale exceedances of the Essential Freshwater proposal's nitrogen criteria were to be managed to comply with the bottom line (ie, 1.0 mg DIN L^{-1}). While the current NPS-FM requirements already imply these impacted locations would likely need to contribute to nitrogen reductions in the catchment as a whole, the imposition of the Essential Freshwater proposal for nitrogen criteria likely represents additional constraints within the catchments of the impacted segments, which would reduce flexibility in terms of how the wider catchment-level required load reductions would be achieved and have a greater impact on land use. The question then is whether these sub-catchment scale exceedances of the Essential Freshwater proposal's nitrogen criteria will be recognised when the council implements the Essential Freshwater proposal. The answer to that question is associated with the definition of Freshwater Management Units (FMUs); defining more (fine-scaled) FMUs, or sites at which objectives are set, will increase the number of situations where management actions would be required to comply with the Essential Freshwater proposal's nitrogen criteria. However, because the definition of FMUs and the number of sites where objectives must be set are not strongly specified by the NPS-FM, we were unable to assess the impact of the sub-catchment scale exceedances of the Essential Freshwater proposal's nitrogen criteria.

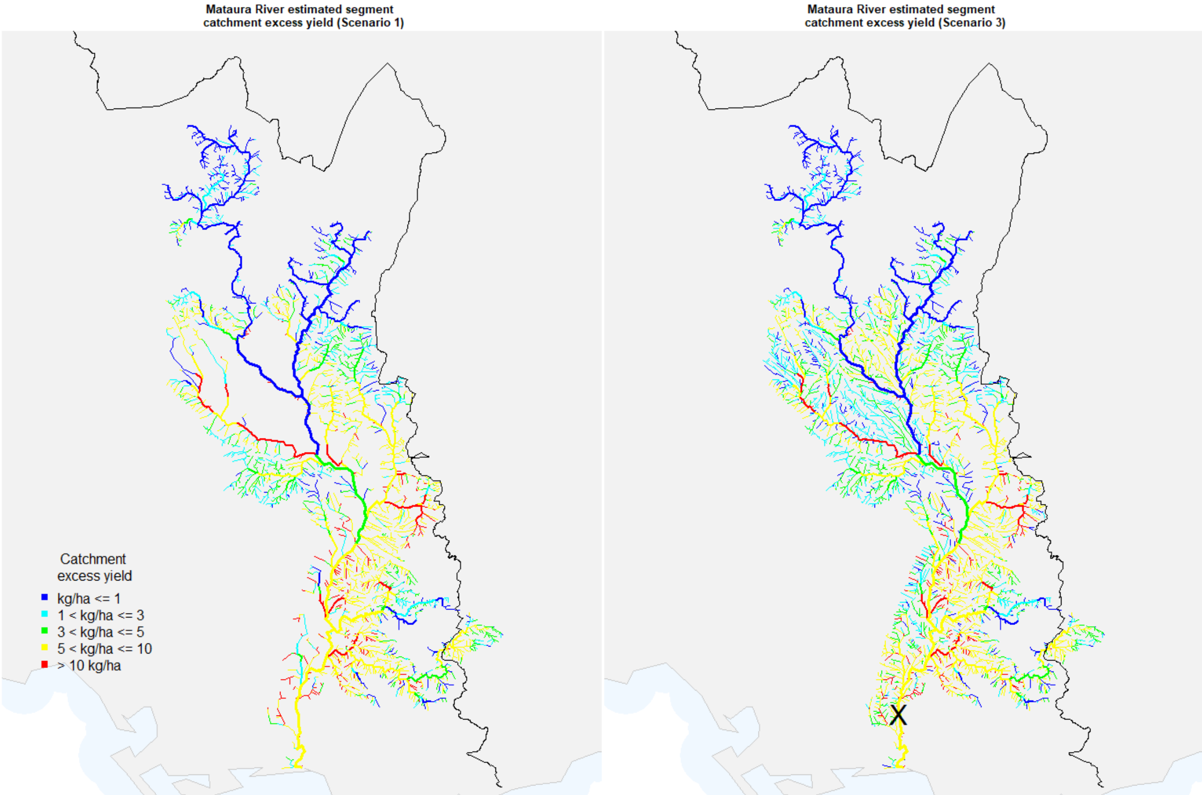

Figure 11: Maps showing the catchment excess yields in the Mataura River catchment in the Southland region under the NPS-FM (Scenario 1; right hand map) and the Essential Freshwater proposal (Scenario 3; left hand map). The location at the bottom of the catchment marked X is a soft-bottomed segment.

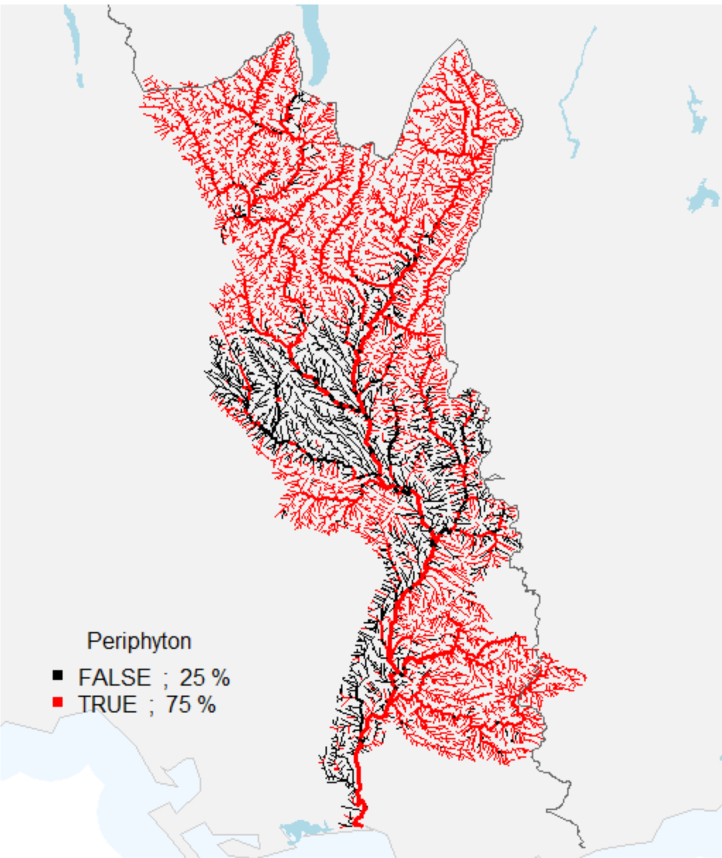

Figure 12: Map showing the Mataura River catchment classified according to whether the analysis has assumed the network segments can support conspicuous periphyton. The classification is based on coarse and fine bed substrates which are discriminated using substrate size index values of <3 and ≥3 respectively.

Hinds/Hekeao plains freshwater management unit, Canterbury

The Hinds/Hekeao plains FMU in Canterbury comprises several intensively farmed catchments, the largest of which is the Hinds River. The Hinds River has its source in the Canterbury foothills and flows across the plains largely as a single-thread gravel bed river. Tributaries of the Hinds River and most of the other smaller catchments in the FMU are predominantly lowland low gradient systems with soft bottoms (ie, substrate index < 3) (Figure 13). The Hinds/Hekeao plains FMU has some of the highest surface water median nitrate-nitrogen concentrations in the country due to intensive agriculture and natural factors. The majority of the FMU has estimated median nitrate-nitrogen concentrations in excess of 1 mg L^{-1}. As noted in Section 3.1, RF models produce maximum predictions that are somewhat lower than the most extreme observed values. Because the concentrations in the Hinds/Hekeao plains FMU are among the highest nationally, the RF model predictions tend to underestimate the observed concentrations at monitoring sites in the FMU. Therefore, the results described below are likely to underestimate the true load reductions required.

Under the NPS-FM the estimated excess nitrogen yield at the bottom of the Hinds River catchment is 12 kg ha^{-1} $year^{-1}$ (Figure 14) and 10 kg ha^{-1} $year^{-1}$ for spatial exceedance criteria of 10% and 20% respectively (ie, Scenario 1 and 2). The estimated excess nitrogen yield under the Essential

Freshwater proposal (ie, Scenario 3 and Scenario 4; Figure 14) is the same as for the NPS-FM. This is because it has been assumed the Hinds River main stem would support conspicuous periphyton (Figure 13). Therefore, under both sets of scenarios, the excess yields at the bottom of the Hinds River catchment are determined by the nitrogen criteria to achieve the periphyton bottom lines. Those criteria are more stringent than the Essential Freshwater proposal of 1 mg DIN L^{-1}; being 0.3 mg TN L^{-1} and 0.8 mg TN L^{-1} for spatial exceedance criteria of 10% and 20% respectively.

In the Hinds/Hekeao plains FMU there are 40 individual waterways (including the Hinds River) that discharge to the coast. In this analysis it has been assumed that many of these smaller waterways would not support conspicuous periphyton (Figure 13). Therefore, the catchment excess loads for these waterways are evaluated as zero for the current NPS-FM scenarios (ie, scenario 1 and 2, left-hand map; Figure 14). However, the catchment excess loads for these waterways have positive values (ie, load reductions are required) for the scenarios representing the Essential Freshwater proposal (ie, scenario 3 and 4, right-hand map; Figure 14). There is therefore a potentially large local impact of the Essential Freshwater proposal in the FMU.

There is potential to achieve periphyton objectives by stream shading in many of the waterways within the FMU. The advantage of using shading to achieve periphyton objectives is sometimes only local because nutrients flow downstream to receiving environments that cannot be shaded. In these circumstances reduction of instream nutrient concentrations is necessary to achieve periphyton objectives in the downstream receiving environments and the overall benefit afforded by shading may be minor or zero. However, in the Hinds/Hekeao plains FMU most of the waterways are relatively small (eg, 90% are stream order three or less and 75% have catchments smaller than 12 km^2). It may therefore be possible to achieve periphyton objectives (where applicable) by shading in all receiving environments and this would reduce the overall TN load reductions required to achieve NPS-FM periphyton bottom lines. The assumption that periphyton objectives will be achieved purely by managing instream nitrate-nitrogen concentrations in the Hinds/Hekeao plains FMU is, therefore, likely conservative (ie, it maximises the impact of the current NPS-FM requirements). In addition, this likely minimises our estimated impact of the Essential Freshwater proposal in the FMU.

To meet the periphyton bottom line, the council may choose to employ any combination of mitigation methods. The combination of methods chosen would influence the reduction in nutrient loading required. The impact of the Essential Freshwater proposal would be to constrain the council’s choice in how they meet the periphyton bottom line as the DIN bottom line would also have to be met.

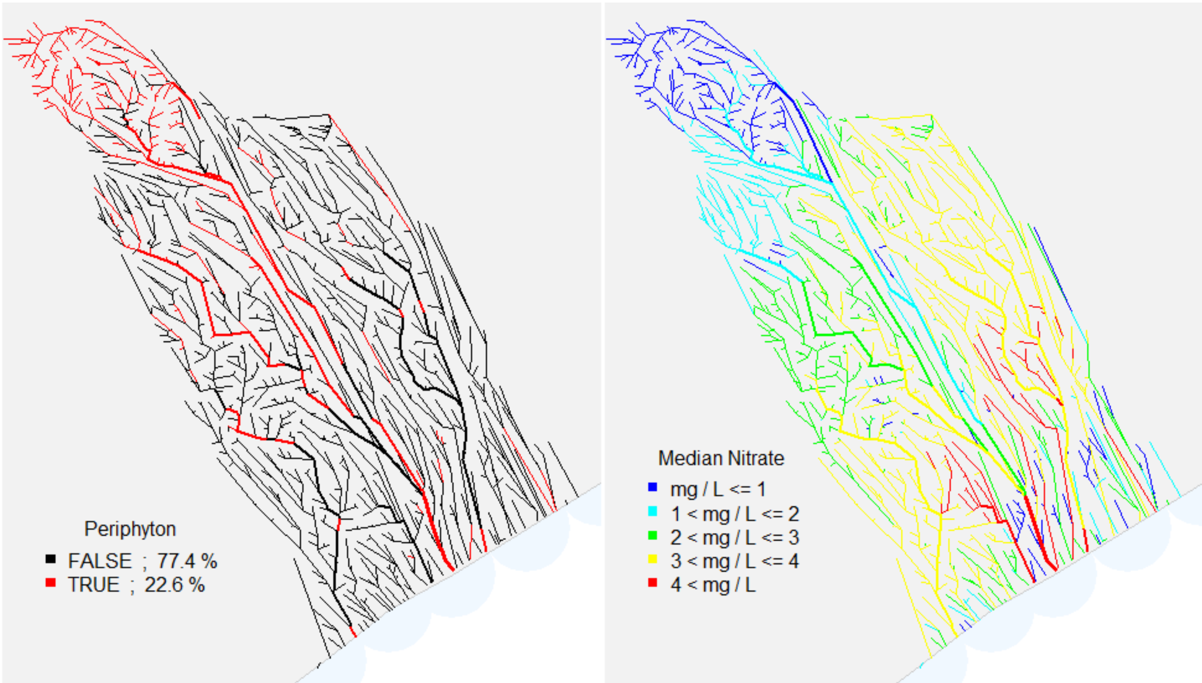

Figure 13: Maps showing the Hinds/Hekeao plains FMU classified according to whether the analysis has assumed the network segments can support conspicuous periphyton (left hand map). The right-hand map shows segments classified by estimated current median nitrate-nitrogen concentrations.

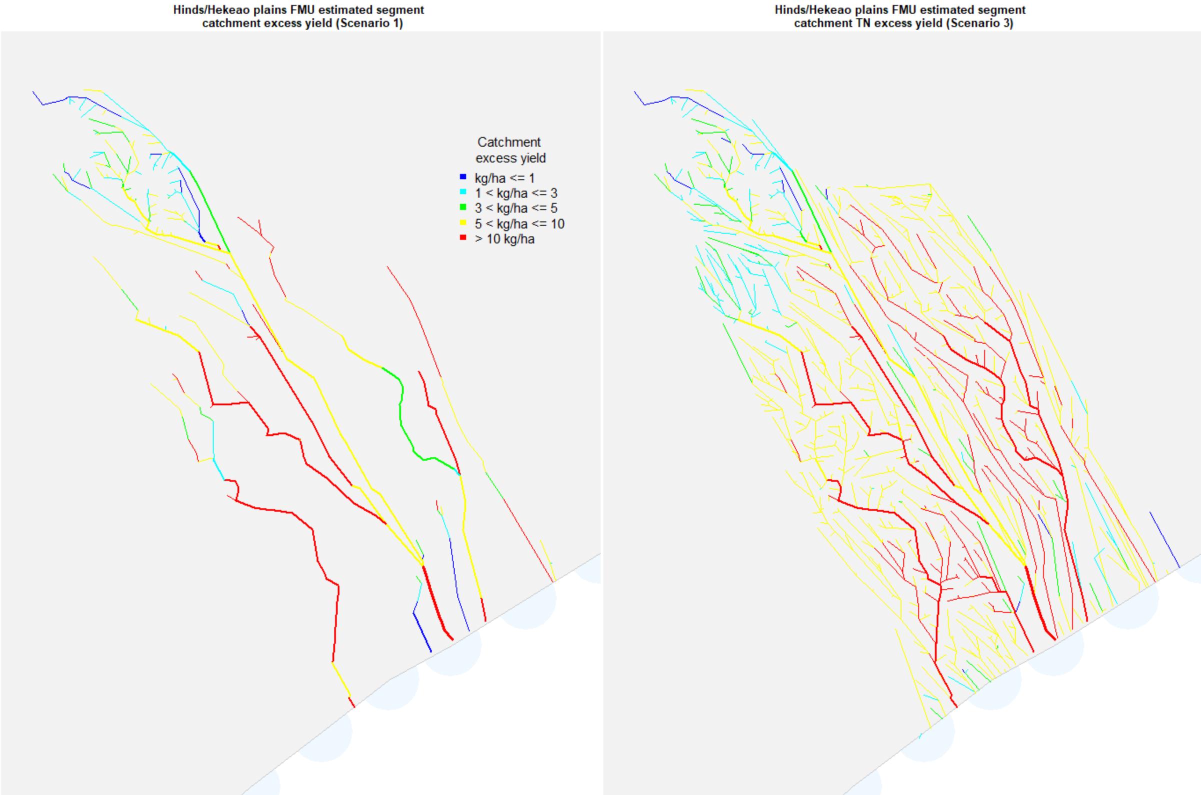

Figure 14: Maps showing the catchment excess yields in the Hinds/Hekeao plains FMU in the Canterbury region under the NPS-FM (Scenario 1; left hand map) and the Essential Freshwater proposal (Scenario 3; right hand map).

Piako and Waihou River catchments, Waikato

Results of analysis

The Piako and the Waihou River catchments in Waikato are two intensively farmed catchments that discharge into the Firth of Thames. The Piako River flows north from the Morrinsville and Matamata areas across an intensively farmed predominantly lowland catchment to its mouth west of Thames. The Piako is predominantly a single-thread soft-bottomed river over its entire catchment (Figure 15). The Waihou River drains the western aspects of the Coromandel and Kaimai ranges and an intensively farmed predominantly lowland area north of Putaruru. The eastern tributaries of the Waihou River that drain the ranges are predominantly hard-bottomed streams and rivers (ie, substrate index > 3) and the lowland tributaries are generally single-thread soft-bottomed streams and rivers (ie, substrate index < 3; Figure 15). The majority of the lowland parts of both catchments have estimated median nitrate-nitrogen concentrations of between of 1 and 2 mg L^{-1} (Figure 15).

Under the existing NPS-FM the estimated excess nitrogen yield at the bottom of the Waihou River catchment is 7 kg ha^{-1} $year^{-1}$ (Figure 16) and 3 kg ha^{-1} $year^{-1}$ for spatial exceedance criteria of 10% and 20% respectively (ie, Scenario 1 and 2). The estimated excess nitrogen yield at the bottom of the Waihou River under the Essential Freshwater proposal (ie, Scenario 3 and Scenario 4; Figure 16) is the same as for the NPS-FM. At the bottom of the Piako River catchment, the estimated excess nitrogen yield under the Essential Freshwater proposal is also the same as the NPS-FM (ie, Scenario 1 and 2; 14 kg ha^{-1} $year^{-1}$ and Scenario 3 and 4; 12 kg ha^{-1} $year^{-1}$). The equivalence of the NPS-FM and Essential Freshwater proposal is because, in this analysis there are locations on the main stems of both rivers that are assumed to support conspicuous periphyton (Figure 15). Therefore, under both sets of scenarios, the excess yields at the bottom of the catchments are determined by the nitrogen criteria to achieve the existing periphyton bottom lines. Those criteria are more stringent than the Essential Freshwater proposal of 1 mg DIN L^{-1} (Table 3).

Table 3: Nitrogen criteria for the Waihou and Piako catchments under the Essential Freshwater proposal and existing periphyton attribute

	Essential Freshwater proposal	Existing periphyton attribute - 10% spatial exceedance	Existing periphyton attribute - 20% spatial exceedance
Waihou	1 mg DIN L^{-1}	0.3 mg TN L^{-1}	0.9 mg TN L^{-1}
Piako	1 mg DIN L^{-1}	0.15 mg TN L^{-1}	0.4 mg TN L^{-1}

Predictions of periphyton extent compared to periphyton measurements

To conduct a national scale analysis, we assumed that segments classified as hard-bottomed will support periphyton and used predicted values of segment substrate to discriminate hard and soft-bottomed segments. Our analysis indicated that hard-bottomed segments occur in some, but not all, parts of the Piako and Waihou main stems, and the periphyton attribute would therefore apply at these locations. These results are supported by observations of periphyton biomass in parts of the catchment. Though the Piako River is predominantly soft-bottomed, field surveys indicate that periphyton does accumulate during low and stable flows (Matheson and Wells, 2017). The field surveys were of two sites on the Piako River (Paeroa-Tahuna Road and Kiwitahi) that were soft-bottomed and had little shading (Figure 15). The more upstream site at Kiwitahi had periphyton biomass higher than the NOF bottom line (Figure 15). In the Waihou River, periphyton was present at low levels at the survey site at Te Aroha (Figure 15), despite the substrate being predominantly sandy. Nearer the river mouths, the tidal influence increases, and the rivers become deeper, which reduces the likelihood of high periphyton biomass.

However, the extent of hard-bottomed segments (and correspondingly, segments that must be managed for the periphyton attribute) may not be accurately reflected by our analysis. Our analysis indicated that some segments near the river mouths were hard-bottomed, resulting in the finding that the excess yields at the bottom of both catchments are equivalent under the two pairs of scenarios. The achievement of periphyton bottom lines at these segments produces the large excess yields (ie, required load reductions) for the NPS-FM (ie, Scenario 1 and 2). This may under-estimate the impact of the Essential Freshwater proposal. In fact, the lower sections of both rivers are dominated by soft-bottomed segments that do not support periphyton. In our analysis, estimated segment substrate size in the main stem of the Piako River was rarely higher than 2.5 and it is only occasional segments that were predicted to exceed this analysis's nominal threshold for supporting periphyton. It is possible that a more detailed investigation of these catchments would conclude that values are not being significantly compromised by excessive periphyton at all locations where the model predicts periphyton could occur. For example, staff of Waikato Regional Council (Alicia Catlin and Mark Hamer, *pers. comm.*) consider that the segment of the Piako River close to the river mouth that this analysis has classified as supporting conspicuous periphyton is incorrect (Figure 15). Rejecting the suggestion that nitrogen in this segment needs to be managed to achieve periphyton objectives would significantly reduce the assessment of excess yields (and therefore required load reductions) under the NPS-FM, which in turn would increase the impact of the Essential Freshwater proposal.

Implications of how councils choose to define Freshwater Management Units

Similar to the other catchment examples, the implications of the Essential Freshwater proposal will depend on how councils choose to define FMUs. There are large local differences in the load reduction required for the Essential Freshwater proposal compared to the NPS-FM because many of the smaller tributaries of both rivers are classified by the analysis as soft-bottomed (ie, not supporting conspicuous periphyton). For example, there are many tributaries on the eastern side of the Piako River that have load reductions required of between 30% and 50% of current TN loads under the Essential Freshwater proposal which have excess yields of zero under the NPS-FM (Figure 17). In practice, the additional impact of the Essential Freshwater proposal in these smaller tributaries would depend on the details of the management structure that implements the policy. Key to this would be the structure of the FMUs and/or locations for which objectives are defined and monitoring is carried out. For example, if each catchment was managed as a single FMU and the objective was defined for one location on the main stem, these areas of non-compliance under the Essential Freshwater proposal may not be recognised and there would be no additional reduction in nitrogen loads required. By contrast, if there were many points throughout the catchments for which objectives were defined and monitoring carried out, the non-compliance with the Essential Freshwater proposal would be recognised and there would be significant local reductions in nitrogen loads required.

In both catchments there are many individual streams that are classified as soft-bottomed and that are assumed not to support conspicuous periphyton (Figure 15). Therefore, the catchment excess loads for these streams are evaluated as zero for the current NPS-FM scenarios (ie, scenario 1 and 2, left-hand map; Figure 15). However, the catchment excess loads for these streams have positive values (ie, load reductions are required) for the scenarios representing the Essential Freshwater proposal (ie, scenario 3 and 4, right-hand map; Figure 15). There is therefore a potentially large local impact of the Essential Freshwater proposal in these streams and this further indicates that the assessment of the impact of the proposal, over and above the NPS-FM impact, may be under-estimated.

There is potential to achieve periphyton objectives by stream shading in many of the waterways within the Piako and the Waihou River catchments. The advantage of using shading to achieve periphyton objectives in these smaller tributaries is potentially significant if concentrations do not need to be managed to achieve periphyton in the downstream main stems. The assumption that periphyton objectives will be achieved purely by managing instream nitrate-nitrogen concentrations in the Piako and the Waihou River catchments is, therefore, likely conservative (ie, it maximises the impact of the current NPS-FM requirements). In addition, this likely minimises our estimated impact of the Essential Freshwater proposal in the catchments.

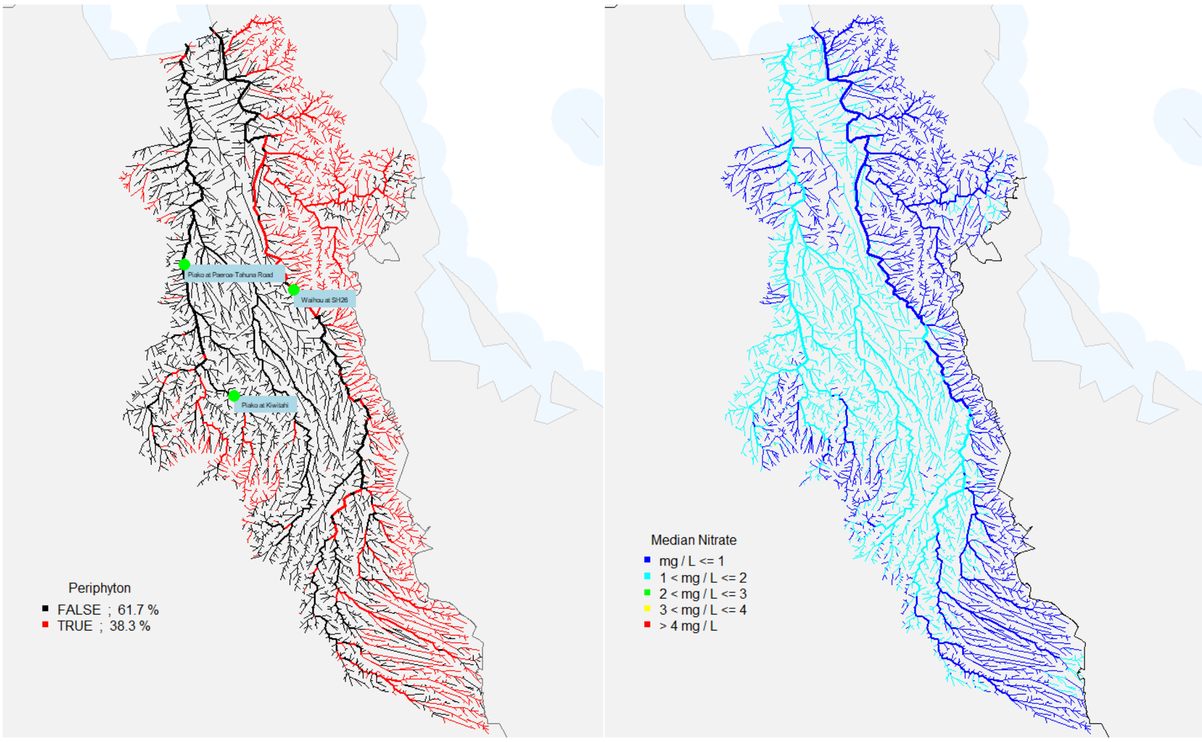

Figure 15: Maps showing the Piako (west) and the Waihou (east) river catchments classified according to whether the analysis has assumed the network segments can support conspicuous periphyton (left-hand map). The right-hand map shows segments classified by estimated current median nitrate-nitrogen concentrations.

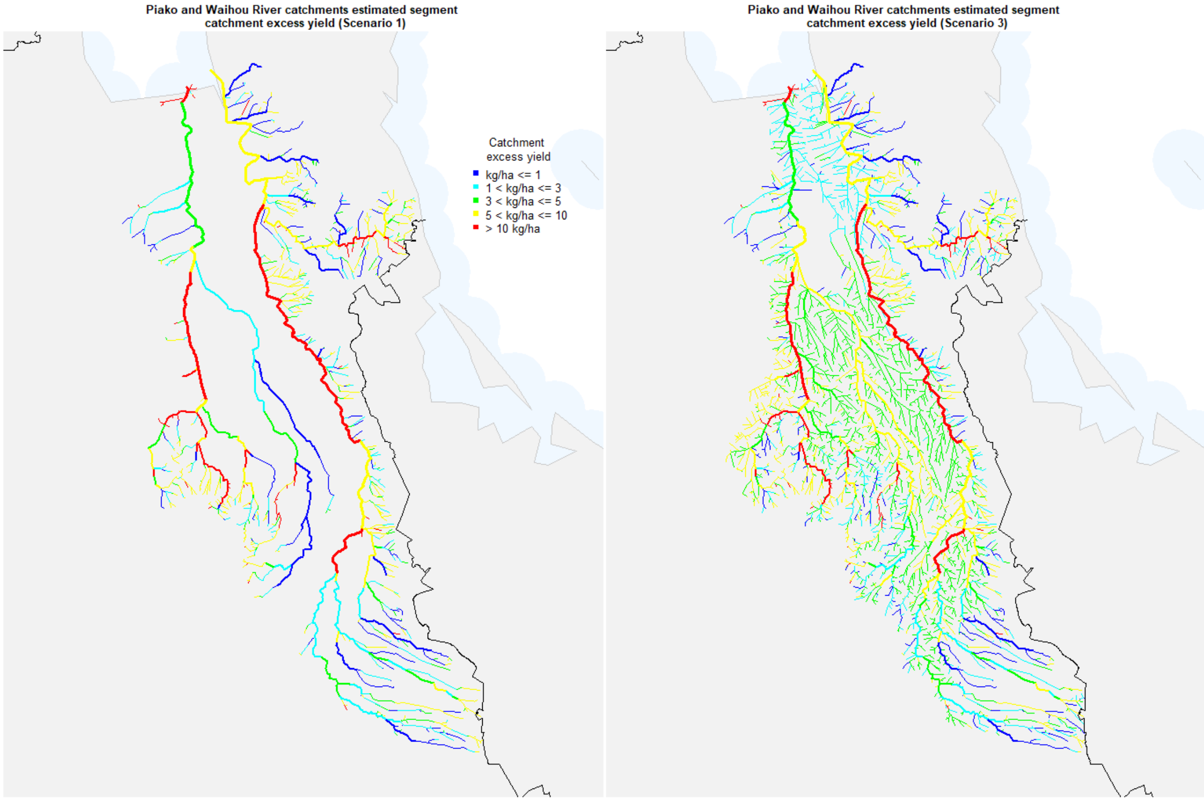

Figure 16: Maps showing the catchment excess yields in the Piako (west) and the Waihou (east) River catchments in the Waikato region under the NPS-FM (Scenario 1; left hand map) and the Essential Freshwater proposal (Scenario 3: right hand map).

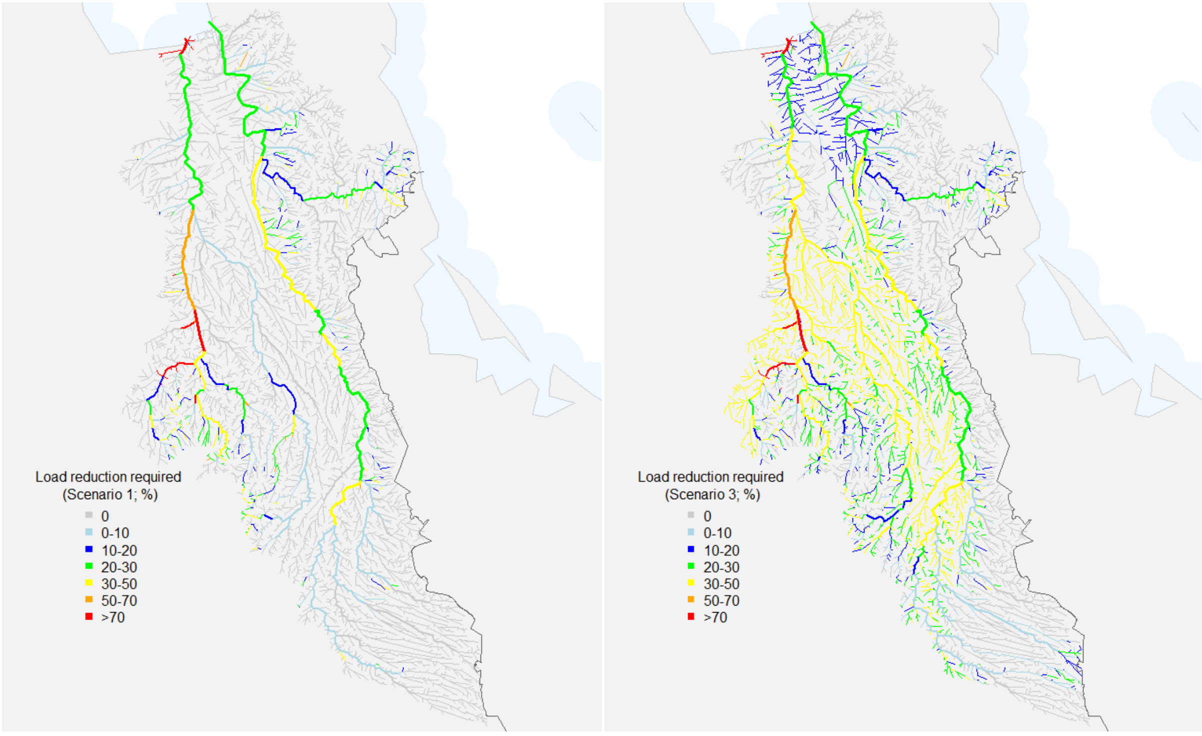

Figure 17: Maps showing the load reductions required (%) in the Piako (west) and the Waihou (east) river catchments in the Waikato region under the NPS-FM (Scenario 1; left hand map) and the Essential Freshwater proposal (Scenario 3; right hand map).

4 Discussion and conclusions

This analysis investigates the Essential Freshwater proposal to introduce a new regulation whereby the maximum concentration of dissolved inorganic nitrogen (DIN) allowed in all rivers and streams (ie, a bottom line) would be 1 mg L^{-1}. The analysis has quantified the impact of both the existing NPS-FM and the Essential Freshwater proposal in terms of catchment excess loads (ie, the minimum load reduction to achieve the designated bottom lines) and the load reduction required (ie, the necessary reduction from the current load expressed in percent). The analysis indicates that the overall impact of the Essential Freshwater proposal at national to regional scales would not be particularly large. This is because the analysis has first taken into account the NPS-FM and the load reductions required to comply with this are often more stringent than the Essential Freshwater proposal.

Although the Essential Freshwater proposal has a small impact at national to regional scales, it is likely to be more significant locally. This is because the Essential Freshwater proposal will generally have effect in lowland soft-bottomed streams that do not support conspicuous periphyton. These systems are often tributaries of main stem rivers and have (sub) catchment areas that are subject to intensive agriculture. Managing their concentrations to comply with the Essential Freshwater proposal will require actions that in some cases will be difficult to achieve under existing land use.

We consider that our analysis under-estimates the impact of the Essential Freshwater proposal. This is mainly because our quantification of the catchment excess loads and the load reduction required are based on a reconciliation at the downstream end of every sea-draining catchment. This would be accurate if the only location for implementing both the NPS-FM and the Essential Freshwater proposal were the downstream ends of catchments. However, in general, it is likely that implementation of the Essential Freshwater proposal will involve establishing objectives and monitoring locations at sub-catchment scales. The spatial framework for implementation is defined by freshwater management units (FMU) and the number and location of sites for which objectives are set, which are established as part of implementation. Where an FMU framework isolates sub-catchments that do not support conspicuous periphyton (and where current concentrations of DIN are > 1 mg L^{-1}), the Essential Freshwater proposal will have a significant impact because under the NPS-FM the bottom line is 6.9 mg L^{-1}. While isolating these areas as FMUs does not alter our quantification of the catchment excess loads and the load reduction for the catchment as a whole, it is likely to increase the overall impact because it will increase the management constraints. To develop a more complete understanding of the impacts of the Essential Freshwater proposal, we recommend a case study approach in catchments with streams that do not support conspicuous periphyton (and where current concentrations of DIN are > 1 mg L^{-1}) and for which sub-catchment scale freshwater management units are either already defined or can be assumed.

An additional reason that our analysis likely underestimates the impact of the Essential Freshwater proposal is that there is potential to achieve periphyton objectives by stream shading in some waterways. Our analysis has ignored this and has assumed the existing NPS-FM periphyton bottom lines would be achieved only by nutrient management. The advantage of using shading to achieve periphyton objectives is sometimes only local because nutrients flow downstream to receiving environments that cannot be shaded. In these circumstances reduction of instream nutrient concentrations is necessary to achieve periphyton objectives in the downstream receiving environments and the overall reduction in periphyton afforded by shading may be minor or zero. However, there are situations where local shading may be sufficient to achieve NPS-FM bottom lines because downstream receiving environments do not support conspicuous periphyton such as lower reaches of the Piako River catchment in the Waikato region (see Section 3.3).

The analyses were conducted using two sets of TN criteria for the periphyton bottom line that were specified in terms of two spatial exceedance criteria of 10% and 20%. The spatial exceedance criteria represent risks that a site drawn at random will fail to achieve the bottom line. The risk of non-achievement reflects the uncertainties associated with defining criteria for nutrients. Although this risk is not generally explicitly acknowledged in objective setting processes, any criteria that is obtained by nominating a response and using a regression line to define the associated level of a stressor implicitly accepts that approximately 50% of cases (assuming normal residuals) will fail to achieve the specified response value. The periphyton criteria of Snelder (2018) explicitly acknowledges the uncertainty associated with the stressor-response relationship and provides a range of options for the risk of non-achievement. In practice, all decisions that define nutrient criteria are subject to a risk of non-achievement and though not generally quantified, it is generally acknowledged by the requirement to monitor and revise environmental regulations, standards and plans. The two sets of TN criteria used in this study do not represent a policy choice associated with either the NPS-FM or the Essential Freshwater proposal. Rather the criteria represent a realistic range in choices of criteria that would be made at the level of implementation of the periphyton objectives under the current NPS-FM provisions. Given that the Essential Freshwater proposal is linked to the current NPS-FM periphyton attribute, the implementation of the DIN criteria would also be affected by choices at the implementation step and, therefore, so will the impact of the proposal.

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