Modelling national land-use capacity

Exploring bottom lines and headroom under the NPS-FM 2014.
Update Report.

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Executive summary

Purpose and key questions

The National Policy Statement for Freshwater Management (NPS-FM) 2014 introduced a National Objectives Framework (NOF) to assist Regional Councils and communities to set freshwater objectives through their regional plans. Appendix 2 of the NPS-FM includes some compulsory water quality 'attributes', for which objectives must be set. Two key features of the NPS-FM are:

A. 'national bottom lines' (minimum acceptable states), and

B. a requirement that overall water quality must be maintained or improved within a region.

The key question that we are trying to answer through this research is how much capacity or 'headroom' for land-use intensification is possible, and where this capacity is located, taking account of a) how the bottom lines and 'maintain or improve' requirements constrain further contaminant loss from the land and b) creation of headroom by improving current land use practice (that is, mitigation). The analysis takes account of:

- the current state of lakes, streams and rivers in relation to bottom lines, and
- effects of changes in contaminant loading (from land-use change, intensification, or mitigation) on water quality, both locally and at locations downstream.

This study assumes freshwater objectives will be set to 'maintain' current water quality that is at or above the bottom line; it does not consider water quality objectives set at levels higher than the current state that may be decided by regional councils and their communities that wish to 'improve' water quality.

Approach

A catchment model was applied to explore land use capacity under the NPS-FM, at a national scale. The following water quality attributes were considered:

- The microbial water quality indicator *E.coli* in streams and rivers as it relates to the human health for recreation bottom line (secondary contact, e.g., wading and boating) and also the minimum acceptable state (MAS) for full immersion activities (primary contact, the bottom of the B NOF band for 95th percentile concentrations).
- Nitrate concentrations in streams and rivers as they relate to ecosystem health toxicity bottom lines for median concentrations and 95th percentile concentrations.
- Nitrogen (N) and phosphorus (P) concentrations as they relate to stream periphyton bottom lines for ecosystem health (tentative national scale nutrient-periphyton relationships were developed for this analysis).
- Lake nitrogen and phosphorus, related to risks of excessive phytoplankton biomass for ecosystem health.

Bottom lines and current-state concentrations for each attribute were assessed at 'nodes', which were located at river monitoring sites, stream and river mouths (terminal reaches), just upstream of confluences of rivers, and lakes. The current concentration of the attribute at each node was determined from monitoring data (where available, covering the period 2009-2013) and models based on that data. Changes in concentration at each node were determined using the current concentration and changes in load predicted by the catchment model.

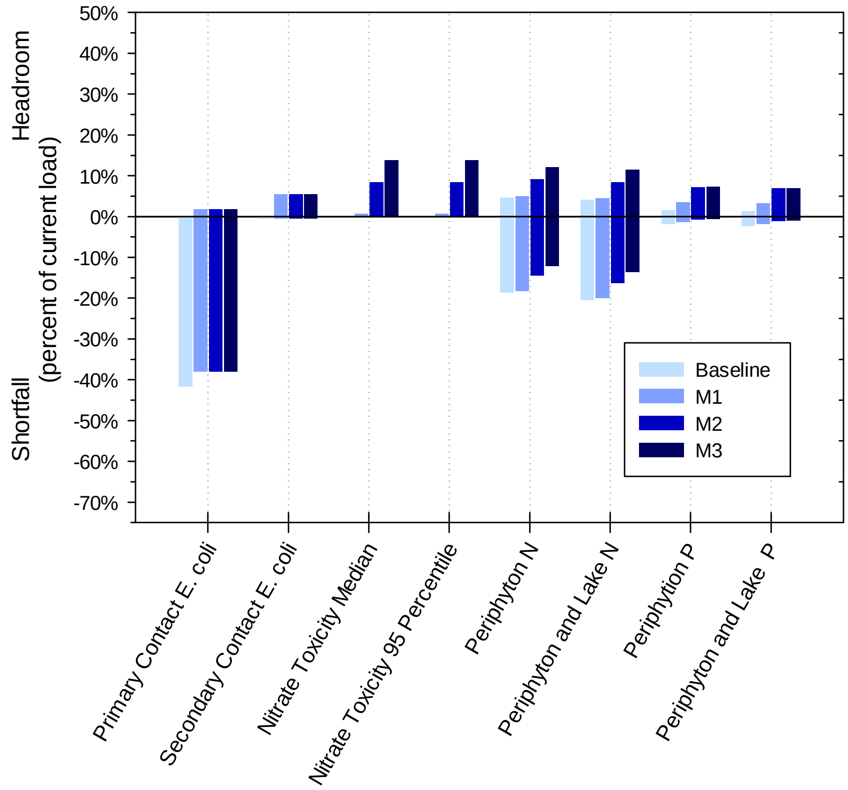
Four scenarios of mitigation were considered: current, basic, moderate, and advanced (denoted by Baseline, M1, M2, M3 respectively). The Baseline level takes account of the estimated current degree of mitigation implementation. The mitigations are considered as bundles of practices. For example, for dairying, the M3 level includes a range of practices such as stock exclusion from streams, effluent best practices, and fertiliser management. The mitigation levels are cumulative, such that the M3 bundle includes all measures in the M1 and M2 bundles plus additional mitigations introduced only at the M3 level. For all of these scenarios, land use (that is, the division into main land-use classes such as dairy and exotic forest) was kept at current levels.

Variations in the model were used to test the effect of different assumptions around the location where assessment occurs, and the interpretation of 'maintain'. In regards to the locations where bottom lines and maintain-or-improve conditions are applied two model variants were investigated: A) 'All nodes', based on monitoring locations, confluences of streams and rivers, and all terminal reaches; and B) 'Reduced nodes', based only on monitoring stations and terminal reaches of stream order greater than 2.

Similarly, two interpretations of 'maintain' were investigated: 1) 'Maintain current concentration', whereby water quality remains at the current concentration (or periphyton at the current biomass); and 2) 'Maintain within band', whereby water quality can move to the bottom of the current attribute state band if it currently lies above the bottom line. The two variants of locations and two interpretations of maintain were combined into four overall model variants for each mitigation scenario.

Key results

The report contains maps of 'shortfall' and 'headroom' (expressed in terms of load per unit area), along with aggregated shortfall by region or nationally (expressed as a load). Shortfall is the load reduction necessary to reach the bottom line; headroom is the load increase that could occur before the bottom line is reached or concentrations exceed current levels (whichever is more restrictive), and is created by application of mitigation measures. The report also contains 'exceedance maps' depicting, for each subcatchment, the maximum degree to which bottom line concentrations are exceeded at any downstream node. The effect of mitigations on creating headroom and reducing shortfall are summarised nationally in the graph below, for the 'all nodes, maintain current concentration' model variant.



At the national level, our modelling shows that the most restricting attribute is *E. coli* when considered in relation to primary contact (e.g., swimming). Mitigation goes mostly toward achieving the MAS rather than creating headroom, and even after mitigation is applied there are a significant number of locations around the country that do not meet the MAS. We note that primary contact is not compulsory, and so where it will apply depends on the objectives set by councils and their communities.

Secondary contact bottom lines for *E. coli* are breached only in small areas in Southland and Waikato. Consequently, there is little shortfall, and *E. coli* load reductions achieved through mitigation largely go towards creating headroom. The headroom created is fairly modest, though (about 5.4% of current load), because mitigation beyond current levels only reduces loads to a modest degree.

Nitrate toxicity bottom lines are breached only in some isolated areas such as parts of South Canterbury, and significant headroom for development can be created through mitigation (about 13.8% of current load at the M3 level), while maintaining water quality.

Periphyton bottom lines are breached in a number of locations (for example, approximately 31.5% of the country lies upstream of locations that exceed nitrogen concentrations related to periphyton bottom lines). Lake nutrient bottom lines add further a constraint, by increasing the shortfall and reducing the headroom slightly. For nitrogen loads, periphyton and lake phytoplankton bottom lines provide more constraint than nitrate toxicity.

Assessing concentrations at the reduced set of nodes had only a small influence on headroom and shortfall (less than 3% of current load). This is partly because all terminal reaches of stream order greater than two were still included in the analysis, and such locations tend to constrain headroom in the catchment upstream. The increase is partly due to neglecting order 1 and 2 terminal reaches.

Allowing movement within a band had little effect on headroom for *E. coli* in relation to primary contact because the MAS constrains the headroom. *E. coli* in relation to secondary contact, nitrate toxicity, TN, and TP, allowing movement within a band enabled a significant increase in headroom (by about 15%, 25%, 6% and 4.5% of current load respectively).

Key assumptions, limitations and uncertainties

This project involves many uncertainties and simplifying approximations, and so should only be used as a general estimate, and not to derive detailed spatial information or for limit setting. Key uncertainties relate to establishing the effectiveness of mitigation measures (especially for *E. coli*), the current degree of mitigation, and the relationship between nutrient concentrations and periphyton abundance.

An important assumption is that Regional Councils give effect to Objective A2 of the NPS-FM by seeking (through their regional plans) to maintain or improve water quality measured at assessment nodes (or a subset of those nodes), for each attribute. In reality, councils could potentially choose alternate approaches to infer maintain or improve at any location (e.g., use modelling, or monitor a proxy such as land use change, extent of riparian fencing or planting etc., to complement or fill spatial and temporal gaps in water quality monitoring). A further limitation to the assessment node approach is that it does not account for Councils choosing nodes on their merits, potentially placing them in problematic locations or specific sites of community interest which they want to focus management effort on. This is partially addressed by incorporating known State of Environment (SoE) and Recreational Water Quality (RWQ) monitoring sites into the analysis.

A particular approach was taken to distributing headroom and shortfall spatially, and other approaches such as spatial economic optimisation may result in different configurations of headroom and shortfall, or different distributions of mitigation effort (rather than assuming even distribution).

The modelling approach did not consider multiple attributes simultaneously, reduction of point or urban sources, potential for future mitigations beyond those modelled, or estuarine constraints, although the approach used in this study could potentially be extended to include those considerations.

1 Introduction

1.1 Background

An objective of the National Policy Statement for Freshwater Management (NPS-FM) 2014 is for overall water quality to be maintained or improved within a region. The NPS-FM introduced a National Objectives Framework (NOF) for water quality attributes such as *E. coli* concentrations, with 'bottom lines' for compulsory values of ecosystem health and human health as it relates to recreation (New Zealand Government 2014). A key question of interest is how this framework affects capacity or 'headroom' for further land use development, because the NPS-FM framework is intended to maintain or improve water quality. Because of this, we are reliant on improving current land-use practice through 'mitigation', or changing land uses to allow more development 'headroom'. Quantifying that level of mitigation and the headroom it creates is a key objective of this report. Headroom will not be created in catchments of degraded waterbodies until water quality improves to meet bottom lines. But in catchments of water bodies with water quality currently better than bottom lines, any mitigation effectively creates headroom. Note that this assumes water quality is only 'maintained' in the catchments; regional councils and their communities can still decide to improve water quality to even higher levels if they wish.

1.2 Project aim

In this project, we use a catchment model to explore current and future potential land use mitigation scenarios, and their effects on the ability of water bodies to meet bottom lines. The two key questions we are seeking to answer are:

1. Where are catchments currently failing to meet bottom lines?
2. How much headroom could be generated from mitigations, while maintaining water quality, and where could this headroom be generated, so that further land-use development could occur?

In terms of point 1, we will explore which catchments or parts of catchments fail to meet bottom lines for some identified key attributes and by how much. We will also explore the level of load reduction will bring those catchments up to the bottom line. For point 2, we will explore how much headroom can be generated nationally, for different levels of mitigation, and where the most headroom can be generated.

The project was iterative. This final report builds on earlier approaches by updating various model inputs and placing emphasis on alternative approaches for representing the 'maintain or improve' provisions of the NPS-FM.

1.3 Document structure and terminology

Section 2 provides a brief overview of the modelling exercise including the model used, the attributes studied, the mitigation scenarios tested, and the key limitations and assumptions of the exercise. Next, Section 3 summarises the modelling results under the current situation, provides summary tables and maps, and then discusses both the catchments that meet bottom lines and those that fail to meet bottom lines. Section 4 presents the headroom and shortfall for the mitigation scenarios, along with sensitivity to the locations at which water quality is assessed and interpretations of 'maintain'. The detailed appendices include the catchment model details, background on the periphyton modelling work, the details of the mitigation scenarios, and the full tables and maps of model results, per attribute.

A key term in this report is 'nodes'. Bottom lines and current state concentrations for each attribute were assessed at 'nodes', which are river monitoring locations, stream and river mouths, locations just upstream of confluences of rivers, and lakes. The current or 'baseline' concentration of an attribute at each node was determined from monitoring data (where available) and models. Changes in concentration at each node in response to mitigation in the upstream catchment were determined using the current concentration along with changes in the load predicted by the catchment model (including the effect of mitigation measures).

Some of the terminology used in this document is worth clarifying before we move on. We appreciate that some terms used here may be used elsewhere with slightly different meanings. Key terms include:

- Attribute – a measurable characteristic of fresh water, including physical, chemical and biological properties, which support particular values (from NPS-FM 2014).
- Attribute state (or state) – the level to which an attribute is to be managed, for the attributes specified in Appendix 2 of the NPS-FM 2014 (Figure 1-1).
- Bottom line – the boundary between attribute states C and D (Figure 1-1).
- Exceedance - for any node, the maximum factor by which bottom-line concentrations are exceeded at any downstream node.
- Mitigation – land-use management practices which reduce contaminant losses from land and increase efficiency of water use.
- Headroom – the load increase that could occur before the bottom-line is reached (Figure 1-1 scenario II) or the current state is not maintained (Figure 1-1 scenario I), whichever is more restrictive.[1]
- Reference conditions - conditions in a catchment where there is no land development.
- Shortfall – the load reduction necessary to meet the bottom line; this is derived from the difference between the improved state achievable through mitigation and the bottom line, for locations that fail to meet the bottom line after mitigation (Figure 1-1 scenario IV).[2]
- Terminal reach – a stream or river reach at the coast.

[1] When assessing 'headroom' and 'shortfall' for *E. coli* in relation to primary contact (activities likely to involve full immersion, like swimming), the minimum acceptable state is considered rather than the bottom line.

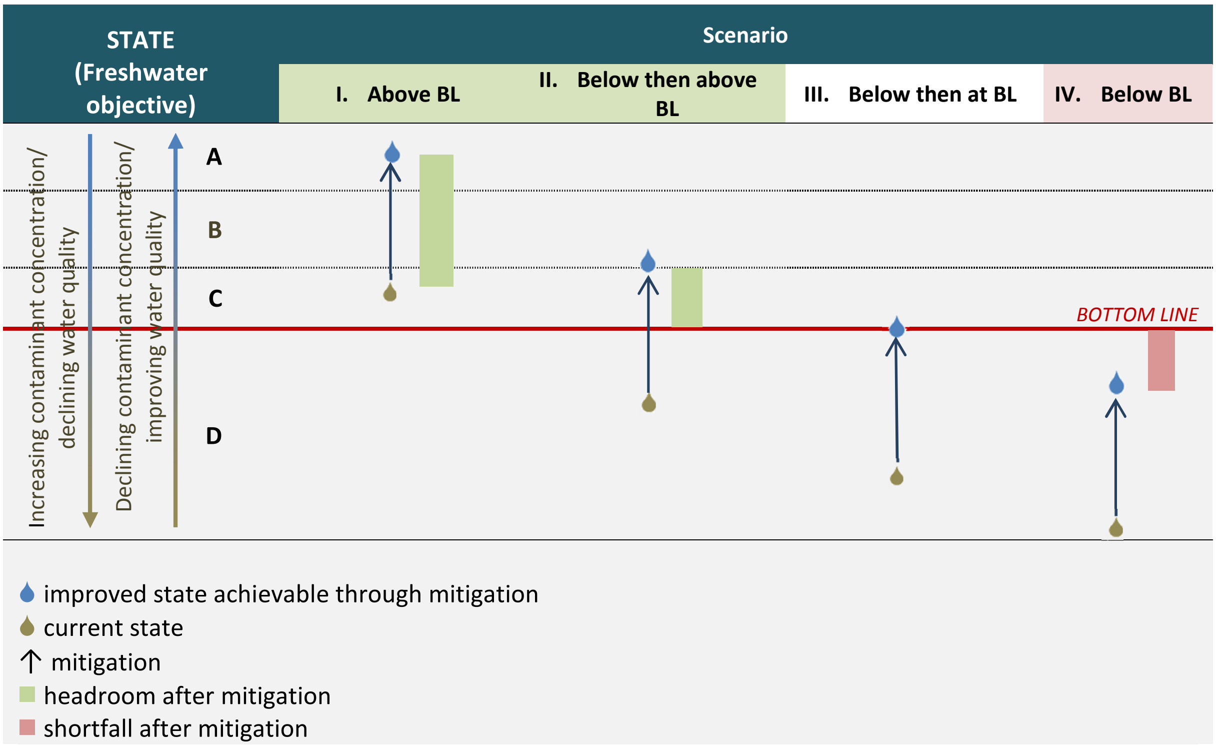


Figure 1-1: Key terminology in relation to the concept of 'bottom lines' and headroom created by mitigation. Some scenarios also allow for headroom creation by movement within a band (not shown). Note that communities may choose to set an objective to manage to a state better than the bottom line.

2 Methodology

2.1 Overview of modelling methodology

Differences between bottom lines and current state concentrations for a number of attributes were determined at assessment ‘nodes’. Two options for the set of nodes were considered for this comparison and in subsequent analysis:

1. **All nodes**. River monitoring locations (487-585 nodes, depending on the attribute), terminal reaches (locations where rivers reach the coast, 10,300 nodes), immediately upstream of confluences of rivers of Strahler order 4 or larger (approximately 5,000 nodes), and lakes (2,900 nodes, 114 of them monitored). Monitoring sites are discussed further in Section 2.3.

2. **Reduced nodes.** The reduced set of nodes was comprised of monitoring sites (487-585 sites, depending on the attribute), monitored lakes (114), and terminal (coastal) reaches of stream order greater than 2 (about 1553 reaches). The selection of monitoring sites only rather than including confluences of large streams and un-monitored lakes was intended to represent a case where councils assess ‘maintain or improve’ only at measurement locations. Terminal reaches of larger streams and rivers were retained as nodes to provide coverage of entire catchments that might otherwise be excluded, but small coastal streams were excluded to approximate the likely impracticality of extending water quality monitoring to the large number (8700) of small coastal streams. The excluded area amounts to about 5% of the area of New Zealand. In reality, councils may choose other approaches to infer maintain or improve at un-monitored locations.

The current concentration at a node was determined from monitoring data (where available) or statistical models (Section 2.3) that estimate concentrations from catchment attributes (where measurements are not available). Changes in concentration at a node were derived from changes in the load predicted by a catchment load model (this applied both to stream nodes and lakes), assuming that concentrations changed by the same percentage as loads.

The catchment load model was based on CLUES version 10.3 (Appendix A). This model uses land-use areas defined by each subcatchment of the digital stream network of the River Environment Classification version 1 (REC, Snelder et al. 2005), along with source coefficients (load per unit area), to determine source loadings into streams. The source coefficients are derived from a simplified version of OVERSEER (version 6.2) for pasture, and other source coefficients are derived from calibration to observed loads nationally. The sources are adjusted for mitigation (as described later). Point sources from CLUES are also added. The loads are then accumulated down the REC stream network (comprised of approximately 576,000 stream segments, which we will call reaches) accounting for losses in streams and lakes.

For the current study, land use was prepared by MPI. The layer was based on the MPI FarmsOnline database (with a licence for this project) which was overlaid with Land Cover Database 4 (LCDB4) land cover to more accurately identify vegetation types. Sheep and beef pasture was split into intensive, hill, and high categories based on LENZ classes as described in Woods et al. (2006), and land-uses were reclassified into nearest standard CLUES classes.

Headroom was determined in the following way: First, mitigation (if any) was applied to the load generated in each subcatchment; then, loads in each subcatchment were increased up to the amount of mitigation, provided that **all** nodes downstream of the subcatchment remain above the bottom line. If there is a node downstream constraining the increase in load (Scenarios II to IV in Figure 1-1), then all subcatchments upstream of that node have a load increase less than the amount of mitigation. This has important implications for headroom, because a single location below the bottom line can limit the headroom for the entire catchment upstream. Following that step, increases beyond the amount of mitigation were considered, up to the 'demand' level, provided that all nodes downstream comply with the 'maintain or improve' requirement. The level of demand was used so that loads did not increase to an unrealistic level, and as a basis for distributing headroom across subcatchments. The demand was determined by running a scenario with all Land Cover Database (LCDB) class 1-4 land converted to dairy, and increasing source coefficients for agricultural land by a nominal 20% to allow for intensification (in addition to conversion to dairy).

Two interpretations of 'maintain' were considered:

a. **Maintain current concentration**, whereby concentrations were not allowed to increase (or periphyton at the current biomass). An exception in this case was for locations with fine substrate, where concentrations were allowed to increases, as these are not capable of supporting conspicuous periphyton biomass (Snelder et al. 2013).

b. **Maintain within band**. If a node is above the bottom line currently, then the state can fall to the bottom of the current NOF band (bands are described in Appendix 2 of the NPS-FM or, for nutrients as they relate to periphyton, the values in Appendix B). If a node is below the bottom line currently, concentrations cannot increase. Allowing concentration to fall to the lower band boundary may introduce additional headroom compared with option a.

The exceedance for each subcatchment was then determined, and this was used to create the exceedance maps. For any subcatchment, the exceedance is the maximum factor by which bottom-line concentrations are exceeded at any downstream node, expressed as a multiple of the bottom-line concentration (or MAS for primary contact). This was determined by:

a) calculating the fraction by which the bottom-line concentration is exceeded for each node, and then

b) for each subcatchment, searching downstream for the node with the largest fraction. This fraction then becomes the exceedance factor for the subcatchment. Accordingly, a node that exceeds the bottom-line concentration can constrain headroom in all upstream subcatchments.

The exceedance takes account of all downstream nodes, and does not just represent the conditions in the local stream. This is important, because even a single location that is below the bottom line will cause the entire upstream catchment to have an exceedance greater than 1.

The remaining shortfall was calculated after the preceding steps. This involved examining how much the load needs to decrease at each node to meet the bottom line. This reduction was then divided by the accumulated load above reference conditions (as determined by a scenario with no agriculture), to give a reduction fraction for each node. The node with the largest reduction fraction within a catchment was found, and this fraction was applied to the load above reference conditions for all subcatchments upstream of that point, to give the shortfall in each subcatchment.

In the previous steps, a particular method was used to distribute increases or decreases in load at a node across upstream subcatchments. If increases in load were permitted, then this was allocated first on the basis of the amount of mitigation in each subcatchment, and then on the basis of all subcatchments having the same proportion of load demand filled. Where decreases were required at a node, it was assumed that all upstream subcatchments would have the same fraction reduction of load in excess of reference load.

Four scenarios of mitigation were considered: current, basic, moderate, and advanced (denoted by Baseline, M1, M2, M3 respectively), as discussed in Section 2.4.

For each of these mitigation levels, four model variants were used to represent the two levels of nodes (1 and 2) and the two options for 'maintain' (a and b):

1a. All nodes, Maintain current concentration.

1b. Reduced nodes, Maintain current concentration.

2a. All nodes, Maintain within band.

2b. Reduced nodes, Maintain within band.

2.2 Attributes explored for rivers and lakes and associated bottom lines

The attributes explored in this study, and the associated bottom lined (or MAS) are summarised in Table 2-1.

Table 2-1: Attributes used in this study.

Attribute	Bottom line or (minimum acceptable state for primary contact)
Rivers	
E. coli – primary contact	95th percentile concentration 540 per 100 ml.
E. coli – secondary contact	Median concentration 1000 per 100 ml.
Nitrate toxicity - median	6.9 mg NO_3-N per litre.
Nitrate toxicity – 95th percentile	9.8 mg NO_3-N per litre.
Nitrogen with respect to periphyton	TN concentrations expected to ensure a periphyton biomass of 200 chl-*a*/m^2 is exceeded in no more than 8% of samples for low-productivity streams, or 17% of samples for high-productivity streams. See Table 2-2 for details. No bottom lines for streams with fine substrate, as these are not capable of supporting conspicuous periphyton.
Phosphorus with respect to periphyton	DRP concentrations expected to ensure a periphyton biomass of 200 chl-*a*/m^2 is exceeded in no more than for low-productivity streams, or 17% of samples for high-productivity streams. See Table 2-2 for details. No bottom lines for streams with fine substrate, as these are not capable of supporting conspicuous periphyton.
Lakes	
Total Nitrogen (TN) with respect to phytoplankton	750 mg/m^3 for seasonally stratified and brackish lakes, 800 mg/m^3 for polymictic lakes, annual median.
Total phosphorus (TP) with respect to phytoplankton	50 mg/m^3 annual median.

The scope of the project did not include bottom lines for phytoplankton (trophic state) (chl-*a*) because this would require relationships between nutrient loading and phytoplankton, which would have added additional complexity and because the bottom lines for TN and TP address phytoplankton indirectly.

Since the NPS-FM does not contain nutrient concentrations corresponding to periphyton bottom-lines, new relationships were developed as described in detail in Appendix B and summarised in Table 2-2. Streams with soft sediment substrate (SegSed types less than 3 in FENZ[2] (ReachSubstrate in Leathwick et al. 2008)) are not expected to support conspicuous periphyton. For this reason, based on draft attribute guidance from MfE, bottom lines were not applied for periphyton to such streams[3].

[2] http://www.doc.govt.nz/conservation/land-and-freshwater/freshwater/freshwater-ecosystems-of-new-zealand/
[3] In the modelling a, large bottom-line concentrations of 100,000 mg/m^3 for TN and 10000 mg/m^3 for DRP were used so that they did not constrain headroom.

Table 2-2: Summary of TN and DRP concentrations corresponding to the periphyton bottom line for different river classes in the REC (detailed in Appendix B).

REC Class[1]	DRP (mg/m^3)		TN (mg/m^3)	
	Productive[4]	Non-Productive	Productive[4]	
CDH	103.4	20.7	337	430
CDL	108.5	14.2	566	389
CDLk	98.1	23.6	134	426
CDM	146.6	42	303	470
CWGM	-	106.1	-	575
CWH	-	61.2	-	633
CWL	-	33.2	-	541
CWLk	-	24.7	-	426
CWM	-	71.4	-	549
CXGM	-	100.7	-	598
CXH	-	350.3	-	1667
CXL	-	350.3	-	1399
CXLk	-	48.7	-	537
CXM	-	335.9	-	1148
WDH[3]	130.5	17.8	278.7	254.2
WDL	136.9	12.2	468	230
WDLk	117.8	11.4	651	293
WWH	-	62.5	-	709
WWL	-	11.2	-	336
WWLk	-	20.5	-	420
WXH	-	61.5	-	606
WXL	-	38.8	-	560
WXLk[2]	-	11.2	-	336

Notes: [1]Climate source-of-flow classes. First letter: C – cool. W –Warm. Second letter: W – Wet, D – Dry, X – extremely wet. Third and later letters: L – Low-elevation, Lk – Lake, H Hill, M –Mountain.
[2]Set at WWLk lake value, conservatively low. [3]Ratio of CDL to CDH applied to WDL. [4]Productive streams are those with REC geology classes SS, VA, VB in WD, CD climate classes.

2.3 Estimation of current concentrations

Current measured concentrations of nutrients and *E. coli* at stream monitoring sites were obtained from summaries of NIWA and Regional Council monitoring data from 2009 to 2013 in the State of Environment monitoring dataset (Larned et al. 2015), downloaded from the MfE Data Service website (https://data.mfe.govt.nz/). The statistical models (random forests) described in (Unwin and Larned 2013) were applied to the SOE dataset to estimate concentrations at river nodes where concentrations have not been measured. The performance of the revised model was similar to that reported in Unwin and Larned (2013).

Measured lake water quality was obtained from the SOE database (references above), supplemented with data from the Lakes Water Quality database (Verburg 2012). A regression model was developed for estimating current concentrations of TN and TP in lakes, and this used only the SOE data, for consistency of data handling. This followed the same linear regression form for the logarithm of concentrations, and used the same initial predictor list, as previous models for trophic lake index developed by MfE (King 2011). The residual standard error was 57% and 75% for TN and TP respectively, with adjusted R^2 of 0.81 and 0.61 respectively in log space.

2.4 Mitigation options and effectiveness

Four scenarios of mitigation were considered: current, basic, moderate, and advanced (denoted by Baseline, M1, M2, M3 respectively). The Baseline level takes account of the estimated current degree of mitigation implementation. The mitigations are considered as bundles of practices. For example, for dairying, the M3 level includes a range of practices such as stock exclusion from streams, effluent best practices, and fertiliser management. The mitigation levels are cumulative, such that the M3 bundle includes all measures in the M1 and M2 bundles plus additional mitigations introduced only at the M3 level. For all of these scenarios, land use (that is, the division into main land-use classes such as dairy and exotic forest) was kept at current levels.

Details of the mitigation bundles and their effectiveness are presented in Appendix C, along with some information on costs and current implementation of mitigation practices. A range of effectiveness of mitigation bundles has been developed but for this modelling work we only used the median value of effectiveness from Appendix C.

In general, the same mitigation bundles and corresponding load reduction factors were applied for each region. An exception was for irrigation efficiency in Canterbury, which was expected to influence N losses (Appendix D). Consideration of irrigation was not incorporated in other regions because the extent of dairy irrigation is much less than in Canterbury.

The mitigation effectiveness takes account of the current degree of implementation, which drew on a national Survey of Rural Decision Makers by Landcare Research as summarised in the previous study, but updated in 2016 with a new survey, as discussed in Appendix C.

The final mitigation factors used are given in Table 2-3 (including taking account of the current level of mitigation).

Table 2-3: Summary of mitigation factors used in the modelling. See in Appendix C for details. The numbers are the load after mitigation as a fraction of the load before mitigation. For example, a mitigation factor of 0.9 would correspond to a 10% reduction in source load, and a factor of 1.0 corresponds to no reduction.

Contaminant	Land use	M1	M2	M3
Nitrogen	Dairy	0.99	0.76	0.56
	Dairy Canterbury	0.86	0.68	0.54
	Deer	0.99	0.86	0.86
	Hill sheep and beef	1	0.95	0.95
	Intensive sheep and beef	0.999	0.92	0.92
Phosphorus	Dairy	0.80	0.47	0.24
	Dairy Canterbury	0.80	0.47	0.24
	Deer	0.23	0.22	0.19
	Hill sheep and beef	0.91	0.88	0.88
	Intensive sheep and beef	0.90	0.48	0.48
E. coli	Dairy	0.97	0.97	0.97
	Dairy Canterbury	0.97	0.97	0.97
	Deer	0.75	0.75	0.75
	Hill sheep and beef	1	1	1
	Intensive sheep and beef	0.86	0.86	0.86

2.5 Key assumptions and limitations

As with any modelling, a number of simplifying assumptions need to be made so that we can undertake a useful and workable predictive exercise. This project involves many uncertainties and simplifying assumptions and approximations, and so should only be used as a general estimate to enable national level screening of potential issues. The scale of the modelling means detailed scrutiny at fine spatial scales should not be attempted and results should not be used to derive detailed spatial information or for specific limit-setting exercises. However, we anticipate that the model will be useful for identifying magnitudes and directions of headroom and capacity, sensitivity to assumptions about 'maintaining' state, the relative degree of constraint by different attributes, and broad spatial patterns of headroom and shortfall, and in highlighting the cumulative spatial implications of bottom lines.

Key assumptions, uncertainties, and limitations of this exercise are:

- The effectiveness, current implementation and potential scope for mitigation measures (Appendices C, D and E) are uncertain. This especially applies to *E. coli*.
- The relationship between nutrient concentrations and periphyton biomass (Appendix B) is very uncertain. These relationships are built on limited data and are trying to represent complex biological responses[4] using a simple linear regression approach. A further simplification was made in using a single concentration for each REC

[4] Including the complex relationships between periphyton and other attributes such as flows and water temperature.

climate/source-of-flow class. Further, a judgement was made about the percentage of reaches in which the modelled periphyton could exceed the specified biomass.

- The statistical models used to estimate current concentrations are uncertain and make simplifying approximations. For example:
  - point sources are not directly taken into account (except as an unknown proportion of the concentrations at monitored sites)
  - distinctions between different pastoral enterprises are not accounted for (i.e., no distinction is made between sheep and beef, dairy or deer farming enterprise even though these are known to have different effects on water quality).
  - For both nitrate toxicity and *E. coli* (secondary contact), the number of reaches or nodes that are below the bottom line are likely to be under-estimated because the model tends to under-predict concentrations at the extreme end of the range at which these bottom lines could come into play (Unwin and Larned 2013).
- The method chosen to distribute changes in load was only one of a multitude of possible methods. For example, spatial optimisation methods could have been used (this approach would have introduced significant complexity at the national scale of this study). Hence, the results of the analysis represent only one potential realisation of the extent and spatial distribution of headroom and shortfall.
- The CLUES catchment model for loads involves considerable uncertainty. The approximation that concentrations and loads behave proportionally introduces further uncertainty.
- An important assumption is that Regional Councils give effect to Objective A2 of the NPS-FM by seeking (through their regional plans) to maintain or improve water quality measured at assessment nodes, for each attribute. In reality, councils could potentially choose alternate approaches to infer maintain or improve at any location (e.g., use modelling, or monitor a proxy such as land use change, extent of riparian fencing or planting etc., to complement or fill spatial and temporal gaps in water quality monitoring). A further limitation to the assessment node approach is that it does not account for Councils choosing nodes on their merits, potentially placing them in problematic locations which they want to focus management effort on. This is partially addressed by incorporating known State of Environment (SoE) and Recreational Water Quality (RWQ) monitoring sites into the analysis.
- The modelling approach did not consider multiple attributes simultaneously, nor interactions between attributes (for example, N or P limitation for phytoplankton).
- The modelling did not consider reduction of point or urban sources.
- There is potential for mitigation measures beyond those modelled (e.g., off-paddock stock management systems for land uses other than dairy) which may provide other management options before land use change in areas where there is a shortfall.
- Other NPS-FM attributes such as ammonia toxicity, dissolved oxygen and cyanobacteria – planktonic are not included.

- The underlying models do not make any allowance for the potential for concentrations to change even if the land-use and mitigation level is the same as at present (the 'load to come'). This is a situation expected to arise where the current concentrations have not yet adjusted to past changes due to long time lags that can occur in some catchments (e.g., some locations in the Taupo Volcanic Zone).

3 Current situation in relation to bottom lines

The number and percent of reaches, stream nodes (i.e., assessment nodes that lie on streams), and lakes that are currently below the bottom line (or minimum acceptable state for primary contact recreation) are shown in Table 3-1. In relation to nodes, the full set of nodes was used. Maps of the multiple of bottom line concentration are in Appendix E.

The percent of subcatchments that are upstream of nodes that are below the bottom line (or MAS for primary contact) are shown in Table 3-2, for the 'all nodes' model variant. These subcatchments are shown in the exceedance maps for the Baseline scenario in Appendix H. The percent of area nationally is approximately equal to the percent of subcatchments. Because many of these subcatchments are in undeveloped or forested areas, we also tabulate the percentage of catchments that are pastoral and are upstream of nodes that are below the bottom line (as a percent of all subcatchments nationally), because this gives a gauge of the pastoral subcatchments where some reduction in loading (through mitigation, land-use change, or de-intensification) might be achieved (i.e., is 'manageable').

The exceedance factor maps showing the highest multiple in any downstream node (Appendix H baseline scenarios) generally have higher values and redder colours than the maps showing the in Appendix E (which shows the exceedance of bottom lines only in the local stream reach), and this is also reflected in the contrast between Table 3-1 and Table 3-2. This contrast arises because a single node that is below the bottom results in all the upstream catchment being coloured in orange or red (exceedance factor greater than 1). This is an important distinction to consider when assessing headroom, because increases in loading in a subcatchment can affect all reaches and lakes downstream of that subcatchment, not just the local node, and a single node can constrain loads in the entire upstream catchment. Hence maps showing the maximum downstream multiple are more relevant to headroom than maps showing the local factor.

For ***E. coli* in relation to primary contact**, 50.6% of stream reaches (and 73.6% of stream nodes) are estimated to be below the minimum acceptable state (Table 3-1). The difference between the percent of nodes and reaches is because the nodes are generally on larger streams (end of 4^{th} order streams or larger) or at the coast where there is more likely to be an influence of development compared with headwater reaches. Subcatchments upstream of nodes that are below the bottom line represent 74% of all subcatchments (Table 3-2). Conversely for 26% of subcatchments (that is, 100% minus 74%), all nodes downstream are better than the minimum acceptable state. In many cases, the concentration exceeds the minimum-acceptable-state concentration by a factor of 4 or more. When subcatchments that have no pastoral development are excluded, the proportion of subcatchments with some downstream node worse than the minimum acceptable state reduces to 45.7% of all subcatchments. This is because many of the subcatchments that are upstream of nodes worse than the bottom line are undeveloped or in forestry.

For ***E. coli* in relation to secondary contact**, only a small proportion of locations are below the bottom line (0.02% of stream reaches, 0.19% of nodes) (Table 3-1). These reaches and nodes occur mainly in Southland and Waikato. Only 1.9% of subcatchments (Table 3-2) are upstream of nodes worse than the bottom line for secondary contact, and when undeveloped subcatchments are removed this percentage reduces to 1.3%. Where concentrations exceed the bottom-line concentration, the exceedance is generally less than a factor of 2.

For **nitrate toxicity**, there are very few nodes or reaches below the bottom line (Table 3-1), and all of these are for monitoring sites located in south Canterbury. The associated upstream areas are also small (less than 0.1% nationally of all subcatchments) (Table 3-2). The results for the median toxicity and 95-percentile toxicity are similar (because higher observed 95-percentile concentrations are larger than median concentrations, and the bottom line is also larger), so our later discussions are restricted to the 95-percentile numbers shown in table and map form. This result is because the ratio between measured 95-percentile and median concentrations is similar to the ratio of the respective NOF values.

For **nitrogen in relation to periphyton**, 12.6% of stream reaches (16.8% of nodes) are below the bottom line (Table 3-1), 31.5% of subcatchments lie upstream of reaches that are below the bottom line, and 21.8% of subcatchments are developed and lie upstream of stream nodes that are below the bottom line (Table 3-2). These locations occur in many of the intensively-farmed parts of New Zealand. However, there are some nodes in intensively-farmed areas that are not below the bottom line, because the streams have fine sediment that would not be likely to support conspicuous periphyton biomass. The multiple by which bottom line concentrations are exceeded is variable, but can be up to 4 or more. Occasionally, a single node with coarse sediment can implicate upstream reaches in relation to bottom lines, even though most of the upstream reaches have fine sediment. This condition could be triggered by unusual conditions such as a steep reach which results in coarse sediment and associated introduction of bottom lines (recalling that periphyton attributes are not applied in fine-sediment streams).

For **nitrogen in relation to lakes,** 19.8% of lakes are estimated to be below the bottom line for TN (Table 3-1). By including lakes, the proportion of subcatchments upstream of nodes that are below the bottom line increases from 31.5% (periphyton only considered, not lakes) to 32.7% (when lake TN is considered as well as periphyton) (Table 3-2). This fairly modest increase is because bottom-line concentrations for TN in relation to periphyton average around 500 g/m^3 while bottom-line concentrations for lakes are generally larger (generally 800 g/m^3). The lakes still have some influence in areas where the streams are soft-bottomed (where periphyton bottom line does not come into play).

For **phosphorus in relation to periphyton**, 9.9% of stream reaches (16.4% of nodes) are below the bottom line (Table 3-1), 13.5% of subcatchments lie upstream of nodes that are below the bottom line, and 8.6% of subcatchments are developed and lie upstream of nodes that are below the bottom line (Table 3-2). These locations occur in intensively-farmed parts of the country but not all parts, either simply because the concentrations are less than the bottom-line concentration or because the streams have fine sediment that would not support conspicuous periphyton. The multiple by which bottom-line concentrations are exceeded is variable, but can be up to 4 or more.

For **phosphorus in relation to lakes** 11.5% of lakes are estimated to be below the bottom line for TP (Table 3-1). The proportion of subcatchments upstream of nodes that are below the bottom line increases from 13.5% without lakes to 16.0% when lake phosphorus is considered in addition to stream periphyton (Table 3-2). An example of this effect is Lake Wairarapa, where the lake is below the bottom line but associated stream nodes are not.

Table 3-1: Current number and proportion of stream reaches (out of 576,000 nationally), stream nodes (out of 15,876) and lakes (out of 2,900) that are below the bottom line (or MAS for primary contact).

	Attribute	Number of reaches (stream nodes) or lakes	Percent of reaches (stream nodes) or lakes
Reaches	Primary Contact *E. coli*	291504 (11549)	50.6% (73.6%)
	Secondary Contact *E. coli*	14 (14)	0.02% (0.09%)
	Nitrate Toxicity Median	4 (3)	0.001% (0.03%)
	Nitrate Toxicity 95 Percentile	4 (4)	0.001% (0.04%)
	Periphyton N	72334 (2631)	12.6% (16.8%)
	Periphyton P	57094 (2568)	9.9% (16.4%)
Lakes	Lake N	545	19.8%
	Lake P	315	11.5%

Table 3-2: Subcatchments with a location downstream that is below the bottom line (or minimum acceptable state), as percentage of all subcatchments nationally (out of 576,000).

Attribute	Subcatchments (% of all subcatchments nationally)	Subcatchments with some pastoral development (% of all subcatchments nationally)
Primary Contact *E. coli*	74.0	45.7
Secondary Contact *E. coli*	1.9	1.3
Nitrate Toxicity Median	0.0	0.0
Nitrate Toxicity 95 Percentile	0.0	0.0
Periphyton N	31.5	21.8
Periphyton and Lake N	32.7	22.8
Periphyton P	13.5	8.6
Periphyton and Lake P	16.0	10.1

The shortfall for the Baseline mitigation scenario (no mitigation beyond the current level) and 'All-nodes, Maintain current concentration' model variant is summarised in Table 3-3. A breakdown by region is given in Appendix G. The shortfall for *E.coli* in relation to primary contact is a large proportion of the national load, reflecting the considerable degree to which current state is below the minimum acceptable state. In contrast, the shortfall for secondary contact and nitrate toxicity is a small proportion of the national load. The shortfall for N in relation to periphyton is 14.3% and for combined lake and periphyton N is 16.6% of the load nationally. Regionally, the percentages can be larger; for example in Taranaki the shortfall is 41.5% of the load from the region for N. For P, the shortfall is only a small percentage of the national load. This reflects the large load of P that arises naturally in some erosion-prone areas. Regionally, the proportion can be up to 10%, and locally the shortfall can be in the order of 1 kg/ha (see maps in Appendix H).

Table 3-3: Shortfall nationally as a percentage of current load, for the 'All nodes, Maintain current concentration' model variant.

Attribute	Current load (t nutrient/y or peta *E. coli*/y)	Shortfall as a % of current load
Primary Contact *E. coli*	19100	63.6
Secondary Contact *E. coli*	19100	1.8
Nitrate Toxicity Median	188700	0.07
Nitrate Toxicity 95 Percentile	188700	0.07
Periphyton N	188700	14.3
Periphyton and Lake N	188700	16.6
Periphyton P	51800	1.3
Periphyton and Lake P	51800	2.1

4 Headroom and shortfall with mitigations

The effect of mitigation on headroom and shortfall, and the effects of variants of node locations and maintain-or-improve, are summarised nationally in Figure 4-1 to Figure 4-4, and Table 4-1 and Table 4-2.

For the 'All nodes, Maintain Current Concentration' model variant, a complete set of maps of exceedance factor and headroom and shortfall (all attributes and mitigation levels) is in Appendix G and the degree of mitigation is tabulated by region and nationally in Appendix H. Some example maps showing the effect of variants of node locations and maintain-or-improve variants are presented in Appendix F.

The results for *E. coli* are the same across mitigation levels, because there are few mitigation options beyond those in M1 and the same mitigation fraction was used for M2 and M3 scenarios.

For ***E. coli*** **in relation to primary contact**, there is no headroom without mitigation for the 'All nodes, Maintain current concentration' model variant, because the current concentration must be maintained and all streams are upstream of some node. When mitigation is introduced for this model variant, there is potential to create headroom; however, most of the mitigation goes towards meeting the minimum acceptable state rather than creating headroom. Hence, despite a reduction in load of 5.5% overall due to mitigation (Table G-1), the headroom created amounts to only 1.3% of the current load. The shortfall is reduced from 41.6% to 38.0% (Table 4-1), and the maps show that the extent and degree of exceedance are reduced marginally. The reduction in load due to mitigation is modest, because for many mitigation measures there is already a considerable degree of implementation (Table 2-3 and Appendix C). These results vary by region. For example, in the West Coast region mitigation reduces the load by 8.1% and a large proportion of this mitigation goes towards creating headroom (Table G-1).

In the underlying CLUES *E. coli* model, the source load per unit land area is the same for all pastoral land-use, given the soils and climate. While separate source terms were investigated during calibration of CLUES, the terms were not able to be differentiated statistically. Hence, land could change from intensive sheep and beef to dairy land without increasing the load (barring the effect of mitigation measures). This is relevant when considering the implications of the headroom results for land-use change within pastoral classes.

When the number of nodes is reduced by neglecting un-monitored stream confluences and smaller terminal reaches (Reduced nodes model variants), there is some increase in headroom (about 1% of current load, see Table 4-2). This is partly due to neglecting small terminal reaches (where the concentration can increase without constraint) and partly due to focussing on monitoring sites rather than all non-terminal nodes. In the exceedance maps, reducing the nodes results in a fringe of areas around the coast that are above the bottom line, and also general reductions in exceedance at interior nodes (Figure F-1). Reducing the nodes also results in headroom around the coast, and for mitigation scenarios some additional headroom in interior areas (Figure F-2). Nodes are still at the outlet of larger streams, limiting the effect of node reduction, but consistent with a future scenario where all larger streams would be monitored. There is also a modest decrease in shortfall (about 4% of current load). Increasing the size of terminal reaches that are neglected would enable more headroom, but third-order streams at the coast have an average catchment area of 12 km^2, so moderate size streams would then be 'uncontrolled' in the model – but in reality they would be still subject to controls as Councils would still need to set objectives that apply to them, possibly by assuming they are subject to the constraints of the adjoining catchment, or by using models.

When concentrations are permitted to move within a band (Maintain within band model variants), further headroom is created (an increase of approximately 3% of the current load). This applies even for the Baseline mitigation scenario, because some nodes are above the bottom line and concentrations (along with upstream loads) can increase within a band for those nodes. This behaviour is illustrated (for nitrate, where it is clearest) in Figure F-3, where additional headroom is evident for the 'Maintain within band' variant, even for the baseline scenario. Shortfall is not altered though (compared with the Maintain constant concentration model variants), because increases in loading only occur in locations where downstream nodes are already above the bottom line (locations below the bottom line do not alter as a result of allowing movement within a band).

When concentrations are permitted to move within a band and the number of nodes is reduced (Reduced nodes, Maintain within band model variant) the headroom increases to 4.6% of the current load with no mitigation, and to 6.8% with mitigation, reflecting the additive effects of reducing the number of nodes and allowing movement within bands.

For ***E. coli*** **in relation to secondary contact**, the state is generally well above the bottom line. For the 'All nodes, Maintain current concentration' model variant, shortfall is only 0.5% of the current load, and most of the added mitigation goes towards creating headroom rather than towards meeting the bottom line. For the 'All nodes, Maintain current concentration' model variant, headroom created is 5.4% for mitigation scenarios compared with 5.5% reduction in load from mitigation, and remaining shortfall is 0.4% of current loads after mitigation. In the headroom/shortfall maps, there is widespread generation of headroom due to mitigation in pastoral areas. The remaining exceedance reduces slightly in extent and degree. The overall load reduction due to new mitigation is still fairly modest, though, due to the large current degree of mitigation implementation.

When the set of nodes is reduced, there is a small increase in headroom (about 0.8% of current load) but negligible reduction in shortfall (because most of the nodes that are removed have little shortfall anyway).

Allowing movement within a band introduces a substantial degree of headroom (14.8% additional load) because most locations are above the bottom line, allowing loads to increase to some degree while remaining within the original band.

For **nitrate toxicit**y, there is very little current shortfall for any of the scenarios, and most of the mitigation goes towards creating headroom (Table G-3 and Table G-4). For the 'All nodes, Maintain current concentration' model variant, only a small amount of headroom is created at the M1 level of mitigation as current uptake of the relevant measures is already considerable; mitigation at the M3 level reduces current load by 13.8%, and virtually all of this goes towards creating headroom. The largest headroom is created in regions that have high loads from dairying, such as Taranaki and the Waikato.

As with *E. coli*, there is only a small amount of headroom created by reducing the number of assessment nodes.

Maintaining concentrations within current bands rather than at current concentrations releases a significant amount of headroom (an additional 25% of the current load). When the number of nodes is reduced and concentrations are allowed to move within a band, there is headroom of approximately 30% for no mitigation, increasing to approximately 45% for M3 mitigation (with variation between the median and 95% nitrate metric).

For **N in relation to periphyton**, there is some headroom even at baseline mitigations levels and the 'All nodes, Maintain current concentration' model variant, because for streams with fine sediment there are no concentration constraints. A large proportion of the mitigation goes towards creating headroom. At the M3 level, mitigation reduces current load by 13.9%, and headroom created through mitigation is approximately 7% of current load. At the M1 level, little headroom is created by mitigation, because mitigation measures at this level have largely been implemented already. These results vary regionally (Table G-5); generally, areas such as Taranaki that have a high proportion of pastoral land in dairy also have load reduction at the M3 level, but the degree to which this goes towards creation of headroom also varies regionally, depending on the current degree of exceedance of the bottom line. Shortfall is reduced by about 6% nationally as a result of mitigation, and this is reflected in some reductions in the extent and degree of exceedance. Considerable areas of exceedance of the bottom line for periphyton remain, however. Without mitigation, 31.5% of the subcatchments that have some pastoral development lie upstream of nodes that are below the bottom line (when all nodes are considered); with M3 mitigation this reduces to 26.7 % (Table 4-1). The maps show a mixture of areas of headroom and shortfall. Without mitigation (and for the 'All nodes, Maintain current concentration' model variant) most of the headroom is concentrated in the upper North Island and shortfall areas predominate over headroom areas, while for the M3 scenario there are considerable areas of headroom which are roughly in balance with areas of shortfall.

Reducing the number of nodes increases headroom to a small degree (by about 3% of current load). Allowing concentrations to move within a band increases the headroom by about 6% but has no effect on the shortfall (as explained for *E. coli*). The 'Reduced nodes, Maintain within band' model variant had 18.3% headroom at the M3 mitigation level, and shortfall was reduced.

When **lake TN** is introduced as an additional factor, there is a small (about 1% of current load) decrease in headroom and a small increase in shortfall (Table 4-1 and Table G-6). The increases reflect the additional constraints from lakes, but they are small because the catchment area of lakes is small in relation to the total area of the country, and because stream concentration requirements are of the same magnitude as the lake concentration requirements. When focussing only the catchments of the lakes, the influence of introducing the lake constraint may be more pronounced than when all of the area of the country is considered.

For **P in relation to periphyton**, there is some headroom even when all nodes are included, because streams with fine substrate have no concentration constraint. Most of the mitigation goes towards creating headroom. For example, at the M3 level, mitigation is 6.8% of the current load, and additional headroom is 5.8% for the 'All nodes, Maintain current concentration' model variant (Table 4-1 and Table G-7). These percentages are suppressed somewhat nationally due to the large load that occurs naturally due to background erosion. For example, the model estimates that over 80% of the P load comes from natural erosion sources. If natural erosion sources were excluded, headroom would be a larger proportion of the national load. For locations where there is less background erosion, headroom will be larger in relation to the current load. The headroom and shortfall percentages vary regionally; for example, in Northland mitigation is 35.8% of the load generated in the region, and headroom is 32.8% (Table G-7).

Introducing mitigation at the M3 level reduced shortfall from 1.8% to 0.6% for the 'All nodes, Maintain current concentration' model variant, with similar reductions for other node location and maintain-or-improve model variants; this reduction is reflected in substantial reductions in the extent and degree of exceedance. Without mitigation, 8.6% of the subcatchments that have some pastoral development lie above nodes that are below the bottom line (when all nodes are considered); with mitigation this reduces to 3.8%.

Reducing the number of nodes has a small effect on headroom and shortfall. Allowing movement within bands has a moderate effect on headroom (increase of about 4.5%) but no effect on shortfall.

When **lake TP** is introduced as an additional factor (Table G-8), there is a small reduction in headroom (0.4% of current load) and a corresponding small increase in shortfall. Mitigation removes the exceedance in some locations, for example, the catchment of Lake Wairarapa (as shown in the maps).

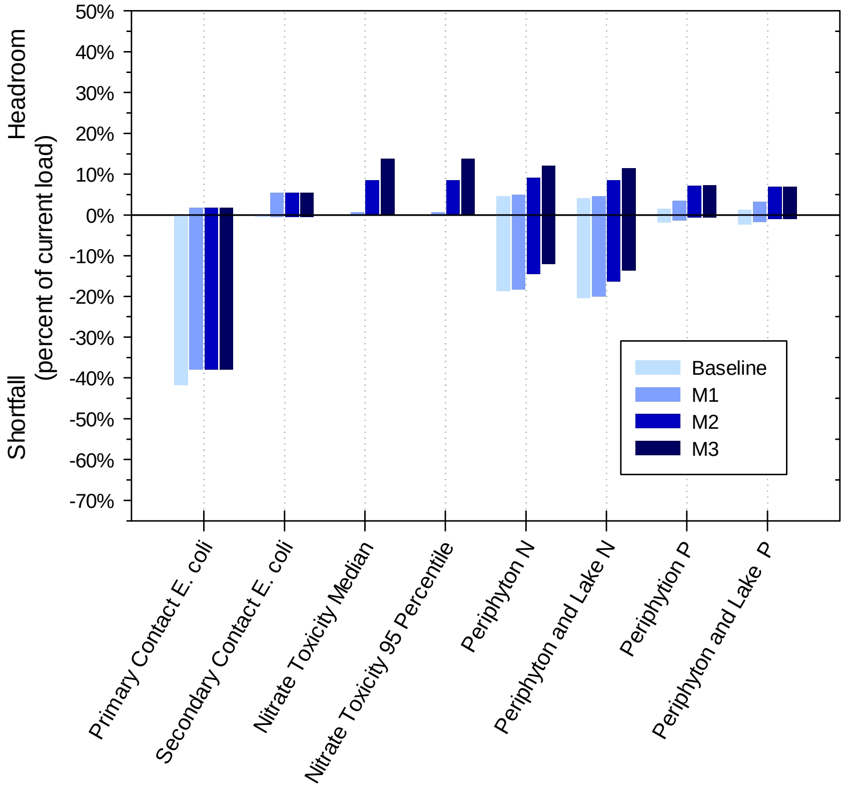


Figure 4-1: Headroom and shortfall as a percent of total national load. All nodes, Maintain current concentration model variant.

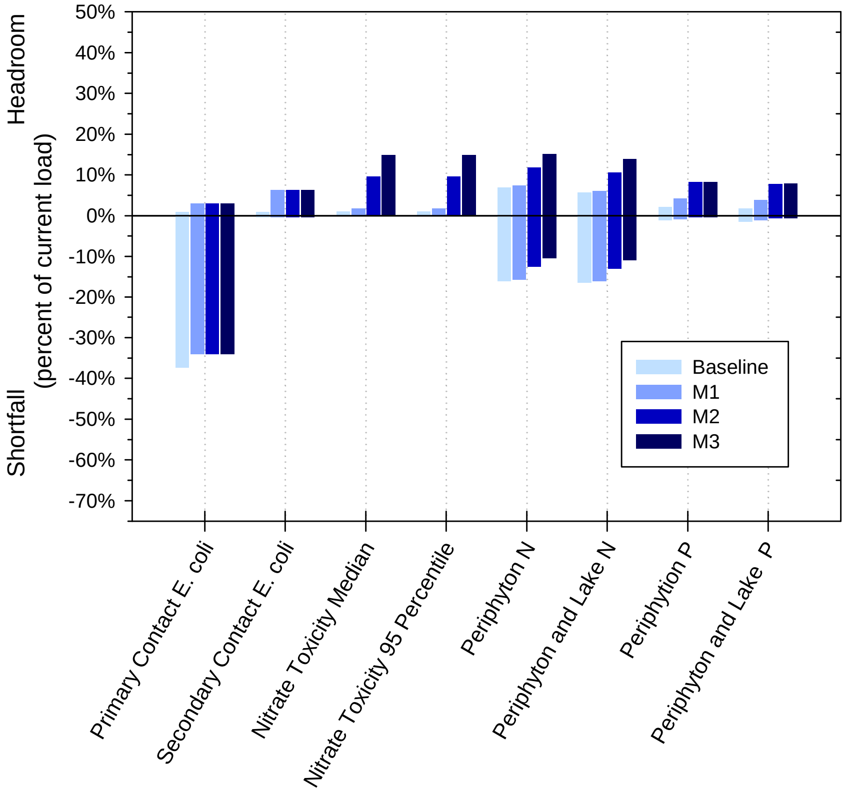


Figure 4-2: Headroom and shortfall as a percent of total national load. Reduced nodes, Maintain current concentration model variant.

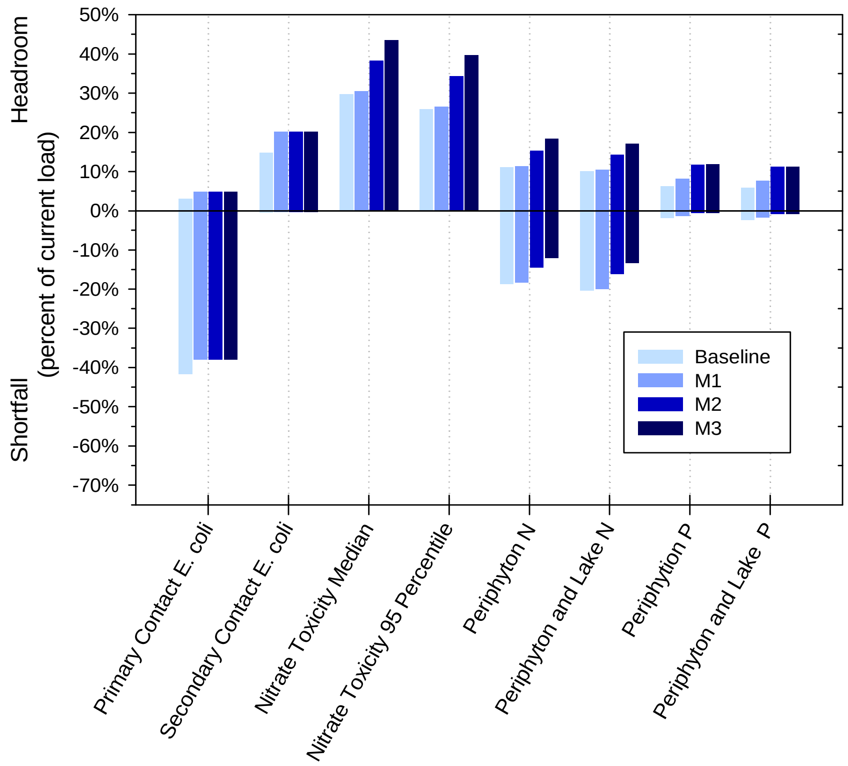


Figure 4-3: Headroom and shortfall as a percent of total national load. All nodes, Maintain within band model variant.

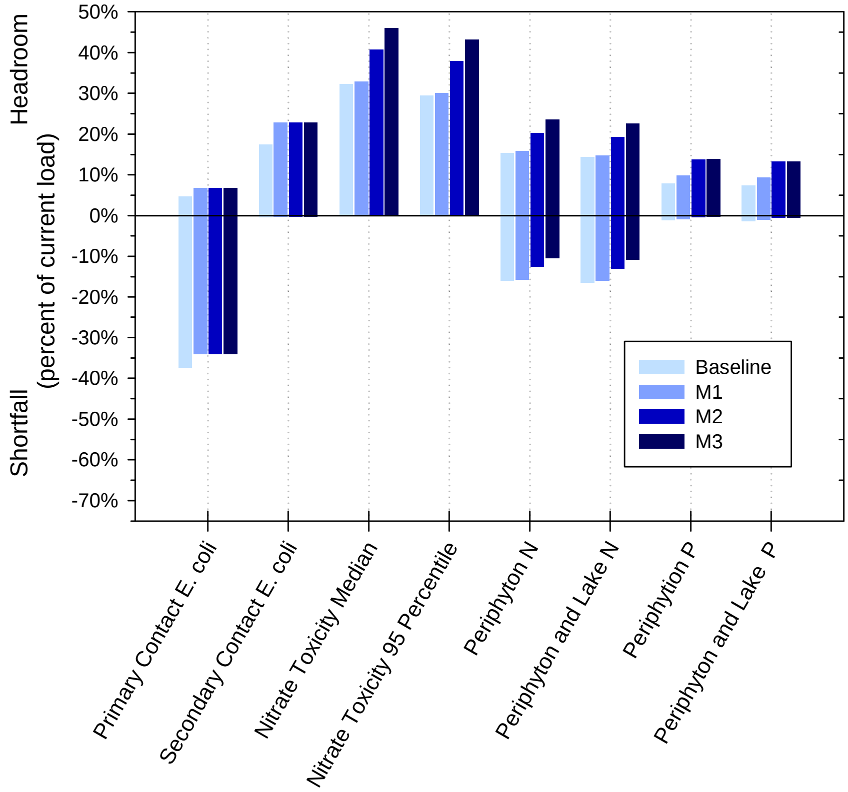


Figure 4-4: Headroom and shortfall as a percent of total national load. Reduced nodes, Maintain within band model variant.

Table 4-1: Subcatchments with a location downstream that is below the bottom line (or minimum acceptable state), as percentage of all subcatchments nationally, for various attributes and mitigation levels.

	Subcatchments (% of all subcatchments nationally)				Subcatchments with pastoral development (% of all subcatchments nationally)			
Attribute	Baseline	M1	M2	M3	Baseline	M1	M2	M3
All nodes, Maintain current concentration								
Primary Contact *E. coli*	74.0	73.3	73.3	73.3	45.7	44.9	44.9	44.9
Secondary Contact *E. coli*	1.9	1.8	1.8	1.8	1.3	1.3	1.3	1.3
Nitrate Toxicity Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate Toxicity 95 Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Periphyton N	31.5	31.5	29.3	26.7	21.8	21.8	19.4	18.5
Periphyton and Lake N	32.6	32.6	30.7	28.1	22.8	22.7	20.3	19.4
Periphyton P	13.5	11.8	8.5	8.5	8.6	7.8	3.9	3.8
Periphyton and Lake P	15.9	14.2	10.8	10.8	10.0	9.0	4.8	4.5
Reduced nodes, Maintain current concentration								
Primary Contact *E. coli*	68.9	68.2	68.2	68.2	45.9	45.7	45.7	45.7
Secondary Contact *E. coli*	1.9	1.8	1.8	1.8	1.3	1.3	1.3	1.3
Nitrate Toxicity Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate Toxicity 95 Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Periphyton N	26.9	26.9	24.8	22.0	19.1	19.0	16.6	15.5
Periphyton and Lake N	27.2	27.2	25.2	22.4	19.3	19.3	16.9	15.8
Periphyton P	7.8	7.2	5.6	5.6	5.3	4.8	3.0	2.5
Periphyton and Lake P	9.1	8.6	7.0	6.9	5.9	5.4	3.4	2.9
All nodes, Maintain within band								
Primary Contact *E. coli*	74.0	73.3	73.3	73.3	45.7	44.9	44.9	44.9
Secondary Contact *E. coli*	1.9	1.8	1.8	1.8	1.3	1.3	1.3	1.3
Nitrate Toxicity Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate Toxicity 95 Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Periphyton N	31.5	31.5	29.3	26.7	21.8	21.8	19.4	18.5
Periphyton and Lake N	32.6	32.6	30.7	28.1	22.8	22.7	20.3	19.4
Periphyton P	13.5	11.8	8.5	8.5	8.6	7.8	3.9	3.8
Periphyton and Lake P	15.9	14.2	10.8	10.8	10.0	9.0	4.8	4.5
Reduced nodes, Maintain within band								
Primary Contact *E. coli*	68.9	68.2	68.2	68.2	45.9	45.7	45.7	45.7
Secondary Contact *E. coli*	1.9	1.8	1.8	1.8	1.3	1.3	1.3	1.3
Nitrate Toxicity Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate Toxicity 95 Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Periphyton N	26.9	26.9	24.8	22.0	19.1	19.0	16.6	15.5
Periphyton and Lake N	27.2	27.2	25.2	22.4	19.3	19.3	16.9	15.8
Periphyton P	7.8	7.2	5.6	5.6	5.3	4.8	3.0	2.5
Periphyton and Lake P	9.1	8.6	7.0	6.9	5.9	5.4	3.4	2.9

Table 4-2: Shortfall and headroom nationally as a percentage of current load, for various attributes and mitigation levels. Green shading denotes headroom, with darker shading for greater headroom. Red shading denotes headroom, with darker shading for greater headroom.

Attribute	Current load (ton nutrient/year or peta *E. coli*/year)	Headroom (% of current load) Baseline	M1	M2	M3	Shortfall (% of current load) Baseline	M1	M2	M3
All nodes, Maintain current concentration									
Primary Contact *E. coli*	13400	0.0	1.8	1.8	1.8	41.6	38.0	38.0	38.0
Secondary Contact *E. coli*	13400	0.0	5.4	5.4	5.4	0.5	0.4	0.4	0.4
Nitrate Toxicity Median	199700	0.0	0.7	8.4	13.8	0.04	0.04	0.03	0.02
Nitrate Toxicity 95 Percentile	199700	0.0	0.7	8.4	13.8	0.04	0.04	0.03	0.02
Periphyton N	199700	4.6	5.0	9.1	12.0	18.6	18.2	14.5	12.1
Periphyton and Lake N	199700	3.9	4.3	8.3	11.1	20.4	20.0	16.1	13.3
Periphyton P	52200	1.5	3.5	7.2	7.3	1.8	1.3	0.6	0.6
Periphyton and Lake P	52200	1.3	3.2	6.8	6.9	2.3	1.7	0.9	0.8
Reduced nodes, Maintain current concentration									
Primary Contact *E. coli*	13400	0.8	3.0	3.0	3.0	37.4	34.1	34.1	34.1
Secondary Contact *E. coli*	13400	0.8	6.2	6.2	6.2	0.5	0.4	0.4	0.4
Nitrate Toxicity Median	199700	1.1	1.8	9.5	14.9	0.04	0.04	0.03	0.02
Nitrate Toxicity 95 Percentile	199700	1.1	1.8	9.5	14.9	0.03	0.03	0.02	0.01
Periphyton N	199700	6.9	7.3	11.8	15.1	16.1	15.8	12.5	10.4
Periphyton and Lake N	199700	5.6	6.1	10.5	13.8	16.5	16.1	13.1	10.9
Periphyton P	52200	2.2	4.2	8.2	8.2	1.2	0.9	0.4	0.4
Periphyton and Lake P	52200	1.8	3.9	7.7	7.8	1.4	1.1	0.6	0.6
All nodes, Maintain within band									
Primary Contact *E. coli*	13400	3.2	4.9	4.9	4.9	41.6	38.0	38.0	38.0
Secondary Contact *E. coli*	13400	14.8	20.2	20.2	20.2	0.5	0.4	0.4	0.4
Nitrate Toxicity Median	199700	29.8	30.5	38.2	43.6	0.04	0.04	0.03	0.02
Nitrate Toxicity 95 Percentile	199700	25.9	26.6	34.3	39.7	0.03	0.03	0.02	0.01
Periphyton N	199700	11.0	11.4	15.3	18.3	18.6	18.2	14.5	12.1
Periphyton and Lake N	199700	10.1	10.5	14.3	17.1	20.4	20.0	16.1	13.3
Periphyton P	52200	6.3	8.2	11.8	11.9	1.8	1.3	0.6	0.6
Periphyton and Lake P	52200	5.9	7.8	11.3	11.3	2.3	1.7	0.9	0.8
Reduced nodes, Maintain within band									
Primary Contact *E. coli*	13400	4.6	6.8	6.8	6.8	37.4	34.1	34.1	34.1
Secondary Contact *E. coli*	13400	17.4	22.8	22.8	22.8	0.5	0.4	0.4	0.4
Nitrate Toxicity Median	199700	32.3	33.0	40.7	46.1	0.04	0.04	0.03	0.02
Nitrate Toxicity 95 Percentile	199700	29.4	30.1	37.9	43.2	0.03	0.03	0.02	0.01
Periphyton N	199700	15.4	15.8	20.2	23.5	16.1	15.8	12.5	10.4
Periphyton and Lake N	199700	14.4	14.8	19.3	22.6	16.5	16.1	13.1	10.9
Periphyton P	52200	7.8	9.9	13.8	13.8	1.2	0.9	0.4	0.4
Periphyton and Lake P	52200	7.4	9.4	13.2	13.3	1.4	1.1	0.6	0.6

In summary, this modelling exercise has allowed the exploration of questions relating to current state with regard to NPS-FM bottom lines (or other minimum acceptable states) for selected water quality attributes. The modelling exercise also explored the extent to which potential future mitigation practices could either allow those bottom lines to be met or create ‘headroom’ which could potentially allow further development in certain catchments. The study also identified sensitivity of the results to variations in the locations at which bottom lines and ‘maintain’ provisions are applied, and the implications of allowing concentrations to move within a band. Key results and assumptions, limitations, and uncertainties are presented in the Executive Summary.

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Appendix A Description of the CLUES model

The Catchment Land Use for Environmental Sustainability model (CLUES) is a modelling system for assessing the effects of land use change on water quality and socio-economic factors at the catchment or regional scale. Water quality in CLUES is indicated by mean annual loads and yields of total nitrogen, total phosphorus (TP), total suspended solids (TSS) and *E. coli*. CLUES also estimates median annual concentrations of TN and TP. CLUES was developed by NIWA for the Ministry of Agriculture and Forestry (MAF) in association with the Ministry for the Environment (MfE), in collaboration with Lincoln Ventures, Harris Consulting, AgResearch, Crop and Food Research, and Landcare Research. The primary purpose of the model is to allow the rapid assessment of the impacts of land use and land management to inform policy making, environmental assessment and catchment planning.

CLUES consists of the following components within the ESRI ArcGIS platform: a geodatabase containing model inputs and outputs; a user interface for river reach selection, scenario creation, run control, and output display options; a suite of sub-models responsible for different modelling routines; and reporting and display tools. The CLUES framework showing how these components are linked is given in Figure A-1. The water quality component models used in this report and the geodatabase are described below. A steady-state rather than dynamic modelling approach was adopted to reduce input data needs and run times in order to enable rapid scenario assessment to facilitate catchment planning applications.

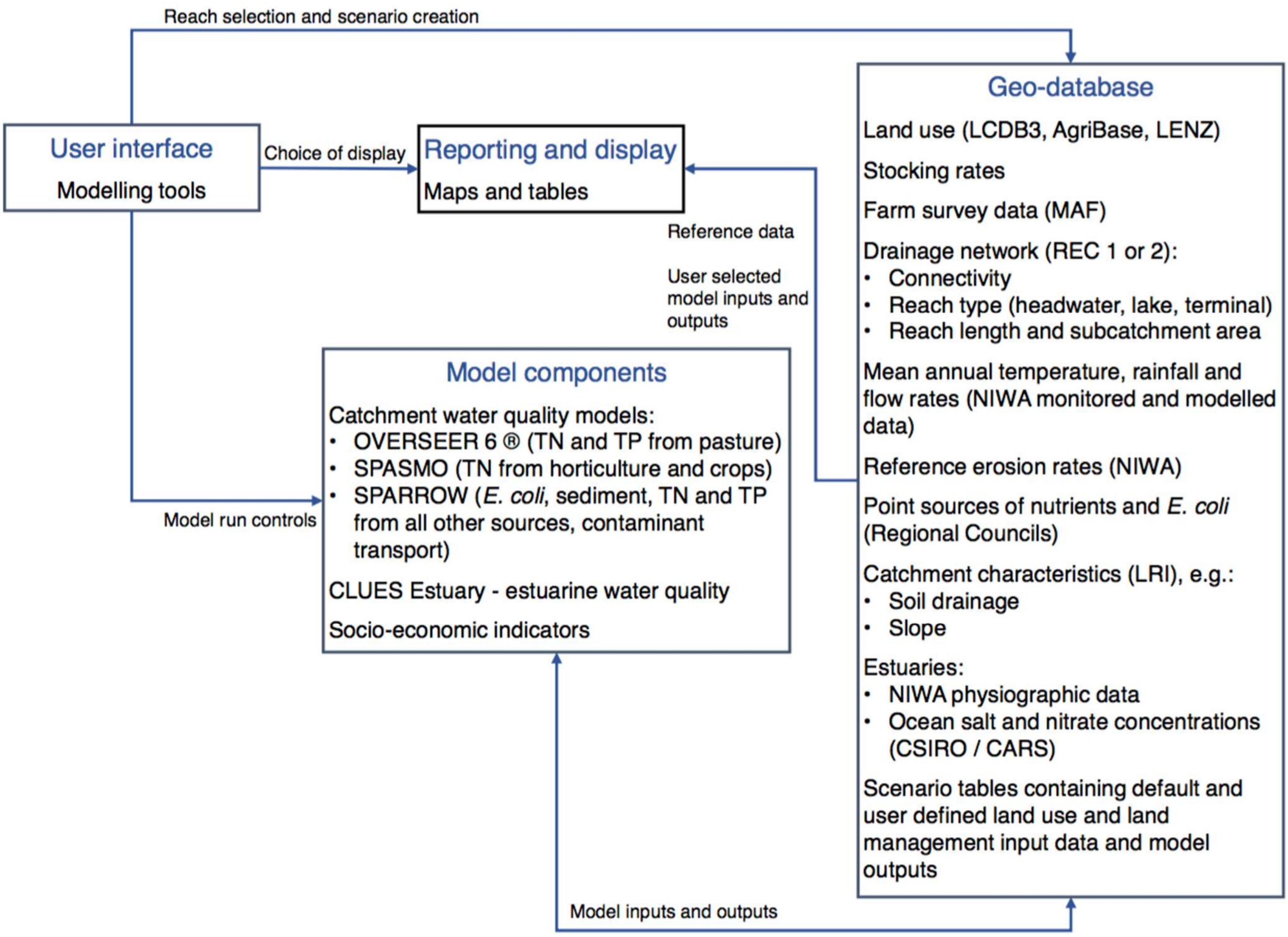

Figure A-1: CLUES modelling framework (Source: Semadeni-Davies et al. 2011).

The CLUES framework integrates the following water quality models:

- **SPARROW** (Spatially Referenced Regression on Watershed attributes) − predicts annual average stream loads of total nitrogen, total phosphorus, sediment and *E. coli*. It includes extensive provisions for stream routing and loss processes (storage and attenuation).This modelling procedure was originally developed by the USGS (Smith et al. 1997) and has since been applied and modified in the New Zealand context with extensive liaison with the developers. **SPARROW** has been applied to nitrogen and phosphorus in Waikato (Alexander et al. 2002) and subsequently to the whole New Zealand landscape (Elliott et al. 2005). The **SPARROW** sediment transport routines were assessed by Elliott et al. (2008) and simulations compared favourably with measured sediment load data. The SPARROW calibration for *E. coli* is summarised in the CLUES user manual (Semadeni-Davies et al. 2016).

- **OVERSEER®** (AgResearch) (Wheeler et al. 2006) − computes nutrient leaching for various land uses (dairy, sheep/beef lowland, sheep/beef hill country, sheep/beef high country, and deer). It provides annual average estimates of nitrogen and phosphorus losses from these land uses, given information on regional rainfall, soil order, topography and fertiliser applications. A simplified version of OVERSEER v6.2 is used in CLUES.

- **SPASMO** (Soil Plant Atmosphere System Model, HortResearch) − calculates the nitrogen budget for a range of horticultural enterprise scenarios. Detailed simulations for many cases (combinations of crops, climate, fertiliser use) have been run (using a daily time step) to build look-up tables that CLUES queries. It has been validated against data from grazed pasture (Rosen et al. 2004) and pasture treated with herbicide (Close et al. 2003; Sarmah et al. 2005). In CLUES, mean annual loads derived from SPASMO runs are used.

The GIS platform means that the model can be used in tandem with standard GIS tools and users are can add their own geospatial data. In addition to the ArcMap toolbox, the CLUES interface has a range of tools which allow users to develop land use change and land management (i.e., stocking rates, farm intensification and mitigation, forest harvest) scenarios. The base areal unit of CLUES is the sub-catchment which comes from the NIWA River Environment Classification (REC) of the national stream and sub-catchment network[5]. Each sub-catchment is associated with a river reach; there are approximately 576,000 reaches nationally. CLUES returns results for each reach, these are reported as maps and tables which can be exported to other applications for further analysis or reporting.

Geo-spatial data needed to run CLUES are provided at national, regional, catchment and sub-catchment levels. Terrain data is at 30 m resolution. In addition to REC, data provided are land use, runoff (derived from rainfall less evapotranspiration), slope, soil data (from the NZ Land Resources Inventory, NZLRI, Fundamental Soils Layer[6]), contaminant point sources and lakes. Land use in each sub-catchment is represented by the percentage of the sub-catchment area covered by each of 19 land use classes. The land use layer provided with CLUES was developed with extensive reference to the LCDB2 (Land Cover Database)[7], AgriBase (AsureQuality Ltd)[8], and LENZ (Land Environments of New Zealand)[9] land use geo-databases and refers to land use in 2002. Considerable effort was expended, with Landcare Research, to ensure that the spatial data coverage was as accurate as possible. CLUES does not contain a groundwater model. That is, the water quality

[5] http://www.niwa.co.nz/our-science/freshwater/tools/rec (date of last access 29 June 2016)
[6] soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers/ (date of last access 29 June 2016)
[7] http://www.mfe.govt.nz/more/environmental-reporting/reporting-act/land/classification-systems(date of last access 29 June 2016)
[8] https://www.asurequality.com/our-solutions/agribase/ (date of last access 29 June 2016)
[9] http://www.landcareresearch.co.nz/resources/maps-satellites/lenz (date of last access 29 June 2016)

effects of groundwater are not simulated – rather, it is assumed that water percolating into the ground will emerge in the same surface river reach sub-catchment.

Further details on the modelling framework can be found in Elliott et al. (2016) and Woods et al. (2006), and information on setting up and running CLUES scenarios can be found in Semadeni-Davies et al. (2011; 2016). This study used CLUES v. 10.

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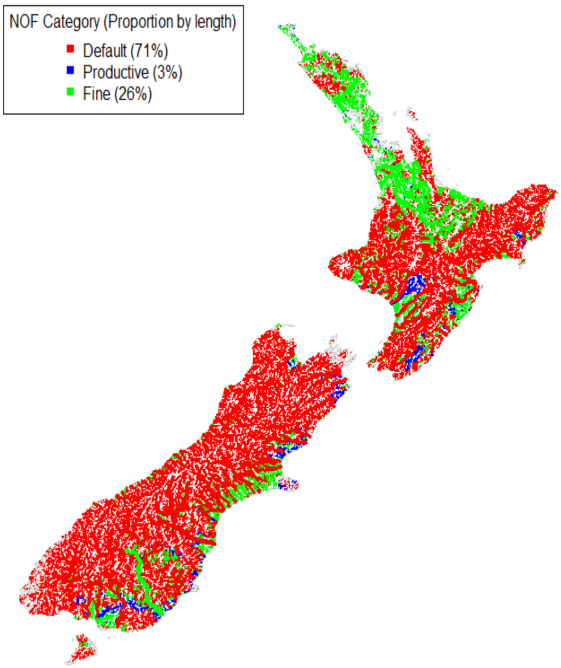
Appendix B Identifying nutrient concentration thresholds to achieve periphyton objectives across climate and source of flow REC classes

Addendum to: Identifying nutrient concentration thresholds to achieve periphyton objectives across climate and source of flow REC classes

Introduction

An analysis of nutrient concentration thresholds for the land capacity study is fully described by Larned et al. (2015; Appendix B). The analysis estimated nutrient concentration criteria for REC Source of Flow classes that will achieve NOF periphyton attribute bands (defined as chlorophyll *a* thresholds of 50 mg m^{-2} (A/B band threshold), 120 mg m^{-2} (B/C band threshold) and 200 mg m^{-2} (C/D band threshold) with long term exceedance criteria of 8% of the samples (1/12 sampling occasions).

The present study repeated the previous analysis but estimated nutrient criteria required to achieve a long term exceedance criterion of 17% of samples (2/12 sampling occasions). This is consistent with the “productive class”, for which the NOF has defined alternative exceedance frequency criterion for stream types that are naturally productive due to geological enrichment and particularly long accrual periods. The “Productive” periphyton class is discriminated using categories of the River Environment Classification (REC; Snelder and Biggs, 2002). The Productive periphyton class is defined by REC “Dry” Climate categories (i.e., Warm-Dry (WD) and Cool-Dry (CD) and Geology categories that have naturally high levels of nutrient enrichment due to their catchment geology (i.e., Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)). The majority of New Zealand streams and rivers fall into the “Default” periphyton class but 3% of sites are classified as Productive (Figure 1).



Classification of rivers and streams for NOF periphyton attribute. The Default class (red) has an exceedance of 8% of samples; the Productive class (blue) has an exceedance frequency of 17% of samples. Locations that are likely to have fine substrates, which will not support conspicuous amounts of periphyton, are shown in green.

Data and methods

Data for the analysis was derived from observations made at NRWQN monitoring sites (see Larned et al. 2015; Appendix B for details). Weighted Composite Cover (WCC) was calculated for all sampling occasions at the NRWQN sites as the mean filamentous cover plus half the mean mat cover. We computed the 83rd percentile value of WCC at each site (i.e., the value of WCC exceeded by 17% of samples) and used this as the response variable in the analysis that follows.

WCC was converted to chlorophyll *a* using a relationship between WCC and chlorophyll *a* that was derived as part of the development of the NOF periphyton attribute using a combined HRC and ECan dataset (n = 1084) (see Larned et al. 2015 for details).

We fitted linear models to the site values of the 83rd percentile value of WCC using the same predictors as described by Larned et al. (2015; Appendix B). A summary of the fitted models is provided in Table 1. Both models were unbiased but had large uncertainties, which was consistent with the relatively low proportion of variation explained (Table 1).

Table 1. Summary of the regression models fitted to the NRWQN data.

	Model 1 (TN)	Model 2 (DRP)
r^2	0.38	0.33
Adjusted r^2	0.33	0.28
Significant variables retained after stepwise eliminations	FRE3, 7DayFlowMins, nNeg, PAR, log10TN, log10NPratio	FRE3, 7DayFlowMins, nNeg, T95, PAR, log10DRP
Model uncertainty (RMSD[1])	1.77	1.84
Model bias	0	0

1. Uncertainty is expressed in terms of the square root transformed response.

We used the regression equations to predict WCC for each segment of the digital river network for various set values of TN and DRP as described by Larned et al. (2015; Appendix B). We then calculated the proportion of segments that exceeded each of three proxy chlorophyll *a* thresholds (83rd percentile values of WCC of 21%, 34% and 45%) for each REC Source-of-flow class. The concentrations of TN and DRP for which 5%, 10% and 20% of the segments exceeded the thresholds was linearly interpolated from these data.

We nominated the TN and DRP criteria for each REC Source-of-flow class to be the concentration at which 20% of segments were predicted to exceed the each of the three WCC thresholds for 17% of samples. The proportion exceedance approach was taken because the high model uncertainty at the site scale (i.e., large RMSD values; Table 1) indicated the model predictions for individual segments was low.

Results

Results are shown in Table 2 and 3. Results for the TN concentration criteria associated with an allowable exceedence of 17% of samples were generally greater than for an allowable exceedence of 8% of samples (Table 2). The exceptions to this were for the REC Source of Flow classes CDLk, CXGM and CWGM. The reason for this is probably that the TN model fitted to the 83rd percentile values of WCC was slightly different to that fitted to the 92nd percentile values of WCC. The former model included the predictors FRE3, 7DayFlowMins, nNeg, PAR, log10TN, log10NPratio whereas the latter included these predictors and T95 (compare Table 1 in this report with Table 10 in Larned et al. 2015). This is a difficulty with empirical (regression) models that is not easily overcome. It is suggested that the concentration criteria associated with an allowable exceedance of 8% of samples is used for the CDLk class instead of the analytical result shown in Table 2. It is noted that the allowable exceedance is always 8% for the CXGM and CWGM classes.

Results for the DRP concentration criteria associated with an allowable exceedence of 17% of samples were always greater than for an allowable exceedence of 8% of samples (Table 3). This outcome probably reflects the fact that the DRP model fitted to the 83rd percentile values of WCC included the same predictors as that fitted to the 92nd percentile values of WCC (compare Table 1 in this report with Table 10 in Larned et al. 2015). It is noted the TN:DRP ratios associated with the present analysis are rather low (generally < 10 compared to a NRWQN average of 14.3). This indicates that the DRP thresholds assessed in this study are generally rather high and may not be realistic.

The analysis produced a DRP criteria to achieve the periphyton attribute state in the WDL class that appeared low compared to other classes (46.5 mg m^{-3}). This also occurred in the original analysis Larned et al. (2015; Appendix B). Larned et al. (2015) made an adjustment to the analytical result by replacing the analytical DRP criteria for WDL class. The adjustment of Larned et al. (2015) was based on achieving reasonable TN:DRP ratios. However, the TN:DRP ratios produced by the present analysis are rather high and may not be realistic and this suggests that the adjustment of Larned et al. (2015) may not be appropriate. An alternative adjustment is based on preserving the ratio of the concentration thresholds for the WDL and WWL class for the 8% of samples exceedance criteria (i.e., 12.2/11.2). This would replace 45.6 mg m^{-3} with 139.6 mg m^{-3}.

Table 2: The TN concentration (mg m^{-3}) for which 20% of all segments (order > 3) belonging to each REC class exceeded the WCC cover thresholds of 21, 34 and 43% for 17% and 8% of samples. The criterion for 17% of samples is associated with the NOF periphyton attribute "productive class". These WCC thresholds correspond to the NOF chlorophyll *a* thresholds of 50, 120 and 200 mg m^{-2}. The grey shaded REC classes are those for which the concentrations shown in the 17% column apply if the REC Geology category is Soft-Sedimentary (SS), Volcanic Acidic (VA) or Volcanic Basic (VB).

Class	21%		34%		43%	
	17%	8%	17%	8%	17%	8%
CWL	280	6	847	269	1497	541
WWL	253	4	778	58	1397	336
WDL	19	3	468	6	840	230
WDLk	80	4	651	219	1404	293
WWLk	45	3	787	213	1403	420
WXL	315	5	916	261	1648	560
WWH	412	11	1084	339	1911	709
WXH	309	7	959	293	1682	606
CWH	244	7	664	299	1176	633
CWLk	26	4	473	217	831	426
CXL	514	233	1447	731	2582	1399
CXH	450	249	1218	846	2162	1667
CDLk	4	3	134	219	681	426
CXLk	21	5	452	250	816	537
CXM	224	92	608	591	1075	1148
CWM	8	5	352	267	661	549
CDH	9	3	337	219	705	430
CDL	211	4	566	162	1015	389
CDM	4	3	303	245	654	470
CXGM	13	10	290	322	510	598
CWGM	18	3	119	269	290	575
ALL	152	6	537	252	958	496

Table 3: The DRP concentration (mg m^{-3}) for which 20% of all segments (order > 3) belonging to each REC class exceeded the WCC cover thresholds of 21, 34 and 43% for 17% and 8% of samples. The criterion for 17% of samples is associated with the NOF periphyton attribute "productive class".

These WCC thresholds correspond to the NOF chlorophyll *a* thresholds of 50, 120 and 200 mg m^{-2}. The grey shaded REC classes are those for which the concentrations shown in the 17% column apply if the REC Geology category is Soft-Sedimentary (SS), Volcanic Acidic (VA) or Volcanic Basic (VB).

Class	21%		34%		43%	
	17%	8%	17%	8%	17%	8%
CWL	6.7	0.4	74	4.4	234.6	33.2
WWL	0.8	0.3	40.2	0.6	128.2	11.2
WDL	0.3	NA	13.6	0.3	136.9**	12.2*
WDLk	1.1	0.3	36.7	0.6	117.8	11.4
WWLk	0.5	0.3	54.5	0.4	186.2	20.5
WXL	11	0.4	85.8	8.9	270.6	38.8
WWH	17.2	0.6	125.7	17	405.1	62.5
WXH	12.9	0.4	108.5	13.6	342.9	61.5
CWH	11.6	0.5	87.4	15.9	277.8	61.2
CWLk	0.6	0.3	43.5	1.1	135.9	24.7
CXL	47.2	5.4	357.2	91.9	NA	350.3
CXH	53.2	13.5	408.3	140.9	NA	NA
CDLk	0.3	0.3	30.9	0.5	98.1	23.6
CXLk	2.3	0.3	53.4	12.2	176.8	48.7
CXM	25.5	6.6	183.6	88.8	NA	335.9
CWM	1.6	0.4	58.9	17.8	187.9	71.4
CDH	0.5	0.3	32.4	0.8	103.4	20.7
CDL	0.9	0.3	34.3	1	108.5	14.2
CDM	0.4	0.3	44.9	11.3	146.6	42
CXGM	3.2	0.8	50.6	27.2	161.1	100.7
CWGM	1.4	0.3	70.5	27.9	224.7	106.1
ALL	2.2	0.4	55.1	5.8	174.8	33.2

* This value was adjusted from an analytical result of 0.5 mg m^{-3}. See Larned et al. (2015; Appendix B) for details.
** This analytical value for the concentration threshold of 46.5 mg m^{-3} is low compared to the adjacent classes. The suggested adjustment is based on preserving the ratio of the concentration thresholds for the WDL and WWL class for the 8% of samples exceedance criteria (i.e., 12.2/11.2). This replaces 45.6 with 139.6 mg m^{-3}.

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Appendix C Mitigation details

The following report has been imported from a pdf letter prepared by AgResearch.

Farming, Food and Health. First™
Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

10th June 2016

Sandy Elliott
Programme Leader – Causes and Effects of Water Quality degradation
NIWA
Hamilton

Re: Updated mitigation tables

Dear Sandy

As requested, please find attached our revised mitigation tables that capture the updates requested by the National Capacity Study team. Some of specific changes we have made for the 2016 refresh have been: (1) some additional information from the most recent Landcare survey of rural decision makers - particularly around stock exclusion and off-paddock wintering; (2) revised the %effectiveness (downward) for off-paddock wintering based on recent research; (3) assumed an increase of around 20% of autumn feeding of lower N feed to dairy; and (4) updated the effectiveness of *E. coli* mitigations. Please take note of the caveats, especially around regional variation and scale of application. If you have any enquiries, don't hesitate to contact me.

Best wishes

Richard Muirhead
(email: richard.muirhead@agresearch.co.nz)
Encs

Generalized estimation of mitigation performance and costs

RW Muirhead and RM Monaghan
AgResearch, Invermay Agricultural Centre, Private Bag 50034 Mosgiel

Context

The following revised table of mitigation performance and associated costs (Table 1) is provided for the purpose of guiding broad scale analyses of the potential to mitigate losses of phosphorus (P), nitrogen (N) and the faecal indicator bacteria *E. coli* from pastoral farms. As requested by the project team, the farm types considered in our analysis are dairy, lowland sheep, hill country sheep-beef and deer farms. Metrics for the effectiveness and cost of management and mitigation measures have been generated for model farms where bundles of measures were assumed to be progressively applied:

- The M1 bundle considers implementing measures that are relatively cost-effective and introduce little complexity to on-going management of a farm system.
- The M2 bundle considers the implementation of management and mitigation measures that are less cost-effective than those in M1, but generally do not incur large up-front capital costs.
- The M3 bundle considers the implementation of measures that have large up-front capital costs (e.g., off-paddock stock confinement systems), have low cost-effectiveness, or are relatively un-proven.

The specific measures considered for each of the farm categories evaluated are detailed in Tables 2 to 5. Estimates of the cost and effectiveness of each were derived based on experimental and expert opinion and were progressively applied to a collection of model farms for which we have detailed information and we consider are typical of farm systems in some of the key dairy, sheep and deer farming regions of New Zealand. This includes a modelled irrigated Canterbury farm where we have assumed that one of the key managements for inclusion in the M1 bundle of measures is the upgrading and improved management of irrigation systems to reduce over-watering and thus N leaching losses, as guided by Dr John Bright from Aqualinc Research Ltd. We have attempted to account for the effects of measures that are already implemented on farms by making some assumptions about current levels of implementation (also detailed in Tables 2 to 5) based on the regionalised survey information documented in the spreadsheet from Landcare Research and found in Clean Streams Accord reports. For some measures not covered in these reports we have used a “best guess” approach.

Table 1 includes estimates of mitigation effectiveness for some measures that target faecal contamination. These measures were selected because there was some degree of confidence that their effectiveness could be approximated based on our current scientific knowledge. For dairy farms, the measures considered for decreasing faecal contamination were stock exclusion from streams and improved effluent management systems and practices; for sheep farms, stock exclusion from streams was the only measure considered. Stream water quality standards for *E. coli* in NZ are based on the 95th percentiles of the measured stream concentrations. The percentage decreases presented in Table 1 are calculated as the effectiveness of the mitigations to decrease the 95th percentile concentrations in the stream during base-flow conditions only; these measures will be much less effective at mitigating stream concentrations during storm events (Muirhead, 2016).

A number of additional caveats are attached to the generation and interpretation of Table 1. These include:

- Multiple strategies are applied on top of one another. Hence a percentage change will take into account the effect of a previous mitigation strategy.
- Ranges are given to encompass variability in factors such as soil type, climate and topography, and hence are only to be used as a guideline for the performance and cost of multiple strategies; nor are they to be seen as to encompass all variation between regions.
- Cost and effectiveness metrics for many of the N mitigation practices (e.g., less N fertiliser input) are heavily dependent on product returns and management system employed. The indicative estimates provided here assume a milk solids pay-out of $6.50/kg MS and modest use of N fertiliser (150 – 250 kg N/ha/yr).

Table 1. Range in cost and effectiveness of bundles of mitigation and management measures targeted at decreasing losses of N, P and *E. coli* (considered as an indicator of faecal microbial contamination) from land to water. Values for N mitigation for an irrigated Canterbury scenario are shown in parentheses (associated costings not provided). The effectiveness values for nutrients take account of current mitigation, but the values for *E. coli* do not take account of current mitigation.

Stock class	Nutrient	Bundle	Cost, $/ha/yr			Effectiveness, %		
			Median	Min	Max	Median	Min	Max
Dairy	N	M1	$7	$5	$12	1 (14)	0.2	2
		M2	$230	$95	$450	24 (32)	15	35
		M3	$750	$395	$1195	44 (46)	49	59
Dairy	P	M1	$10	$8	$15	20	13	75
		M2	$70	$30	$125	53	38	85
		M3	$640	$330	$970	76	63	94
	E. coli	M1	As for N			62	15	86
Sheep	N	M1	$0	$5	$11	0.1	0	0.2
		M2	$25	$12	$90	8	4	19
Sheep	P	M1	$10	$5	$17	10	0	38
		M2	$70	$25	$140	52	36	63
	E. coli	M1	As for N			44	11	61
Deer[1]	N	M1	$20	$13	$26	1	1	1
		M2	$90	$50	$135	14	6	22
Deer[1]	P[2]	M1	$105	$99	$110	77	65	88
		M2	$180	$130	$220	78	65	91
		M3	$190	$145	$230	81	69	93
	E. coli	M1	As for P			62	15	86
Hill country sheep	N	M1	Na			Na		
		M2	$20	$14	$26	5	1	11
	P	M1	$6	$5	$6	9	4	29
		M2	$26	$19	$33	12	4	29
	E. coli	M2	Na			Na		

Na = not applicable

[1]Mean values based on 2 farm types

[2]from McDowell (2014)

Table 2. Mitigation measures considered for each of the mitigation bundles constructed for dairy farms. A “Y” denotes that the measure has some effectiveness in decreasing N or P losses.

Bundle	Measure	Assumed level of implementation, %	N	P
M1	- with stock exclusion from streams	95[1]	Y	Y
	- with effluent Best Practice re infrastructure	49 – 85[2]	Y	Y
	- with laneway runoff diverted	10	Y	Y
	- with optimum Olsen P	75		Y
	- with low solubility P fertilisers	20		Y
	- with efficient irrigation (Canterbury only)	n/a	Y	
M2	- with reduced use of fertiliser N	50	Y	
	- with wetlands and/or sediment traps	20	Y	Y
	- with autumn substitution of N-fertilized pasture	20	Y	
	- with use of winter-active pasture species	0	Y	
	- with split grass-clover pastures	0		Y
	- with tile drain amendments	0		Y
M3	-with off-paddock wintering	11	Y	Y
	- with restricted grazing of pastures	0	Y	Y
	- with restricted grazing of cropland	0	Y	Y
	- with alum application to pasture	0		Y
	- with alum application to crop	0		Y

[1]assumes a “national average” as per email from Pike Brown and http://www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/srdm2015/7-land-management-and-technology-adoption/7-4-stock-exclusion.
[2]regionalised 2013 survey information used for each relevant model farm

Table 3. Mitigation measures considered for each of the mitigation bundles constructed for lowland sheep farms. A “Y” denotes that the measure has some effectiveness in decreasing N or P losses.

Bundle	Measure	Assumed level of implementation, %	N	P
M1	- with stock exclusion from streams	68[1]	Y	Y
	- with low solubility P fertilisers	10		Y
M2	- with wetlands and/or sediment traps	20	Y	Y
	- with use of winter-active pasture species	0	Y	
	- with tile drain amendments	0		Y
	- with split grass-clover pastures	0		Y

[1]assumes a “national average” as per email from Pike Brown and http://www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/srdm2015/7-land-management-and-technology-adoption/7-4-stock-exclusion.

Table 4. Mitigation measures considered for each of the mitigation bundles constructed for hill country sheep-beef farms. A "Y" denotes that the measure has some effectiveness in decreasing N or P losses.

Bundle	Measure	Assumed level of implementation, %	N	P
M1	- with low solubility P fertilisers	10		Y
M2	- with facilitated wetlands	40	Y	Y

Table 5. Mitigation measures considered for each of the mitigation bundles constructed for deer farms. A "Y" denotes that the measure has some effectiveness in decreasing N or P losses.

Bundle	Measure	Assumed level of implementation, %	N	P
M1	- with stock exclusion from streams	60[1]	Y	Y
	- with low solubility P fertilisers	10		Y
	- with alternative wallows	0		Y
M2	- with facilitated or constructed wetlands	0	Y	Y
M3	- with sediment traps	0		Y

[1]assumes a "national average" as per email from Pike Brown and http://www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/srdm2015/7-land-management-and-technology-adoption/7-4-stock-exclusion.

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Muirhead, R.W., Elliot, A.H., Monaghan, R.M. (2011) A model framework to assess the effect of dairy farms and wild fowl on microbial water quality during base-flow. *Water Research,* 45:2863-2874.

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Appendix D Effect of Irrigation Efficiency on N Leaching in Canterbury. Assessment by Aqualinc Research Limited

The following report has been imported from a pdf letter prepared by Aqualinc Research Ltd.

AQUALINC RESEARCH LIMITED

Our Ref: C15049

30 September 2014

Dr Sandy Elliott
NIWA
HAMILTON

Dear Sandy,

Generalised Irrigation Mitigation Factors

A generalised mitigation factor for adjusting nitrate-nitrogen leaching rates to reflect improvement in irrigation efficiency has been developed from existing modelled drainage flux data under a range of soil and climate types in Canterbury. Our approach is based on the assumption that Overseer 6 is the primary tool for assessing the benefits of other mitigation options.

Our approach to using Overseer 6 to estimate nitrate leaching losses under irrigation is to first estimate the nitrate leaching load (kg-N/ha) using the Default Irrigation method in Overseer 6 and secondly to scale the nitrate leaching load so obtained by a factor that is a function of the difference between the drainage that Overseer 6 models under the Default Irrigation method and the drainage that we model using IrriCalc (Bright, 2009)[10] with irrigation management methods that are appropriate for a particular irrigation method.

Generally Overseer 6 underestimates the drainage depth and so the nitrate leaching loss is generally scaled up.

Our scaling factor is based on an assumption proposed by Lilburne et al. (2013)[11]. This assumption is that the concentration of nitrate-nitrogen in the extra drainage water, i.e., that which is in excess of the drainage that Overseer 6 models, is 50% of the concentration output by Overseer 6. Thus a 50% increase in drainage only results in a 25% increase in load, relative to the load output by Overseer 6 using the Default Irrigation option.

The area-weighted average plant available water within a pasture's rootzone is 60mm. The area weighting was calculated across the potentially irrigable area of Canterbury. The ten percentile plant available water is about 37mm, the median is 62mm and the ninety percentile is 87mm.

[10] Bright, J.C. (2009) "Estimation of Seasonal Irrigation Water Use – Method Development". Aqualinc Research Report C08000/1. Prepared for Irrigation NZ, November 2009.

[11] Lilburne, L., Webb, T., Robson, M. and Watkins, N. (2013). "Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury (updated)". Report prepared for Environment Canterbury, September 2013.

The average annual drainage from soils with 60mm plant available water was modelled for three climate (rainfall) zones and the two most prevalent irrigation methods – boom or gun travelling irrigators and centre pivots. The drainage depths are presented in the table below, along with the Overseer 6 drainage depths.

Irrigation Method	Rainfall Zone (mean annual rainfall in mm)	Average Irrigation Efficiency	IrriCalc drainage depth	Overseer 6 drainage depth (Default Irr)	N Load adjustment factor
Boom	650	63%	476	216	1.6
Boom	750	62%	515	317	1.3
Boom	850	61%	566	418	1.2
Pivot	650	94%	286	216	1.2
Pivot	750	94%	341	317	1.04
Pivot	850	94%	403	418	0.96

The following examples illustrate how to use this information to work out mitigation factors for irrigation efficiency improvement.

If irrigation efficiency is improved by converting from Boom irrigation to Pivot irrigation in an area that has 650mm mean annual rainfall:

Mitigation factor = (Overseer N Load * Pivot adjustment factor) / (Overseer N load * Boom adjustment factor)

= 1.2 / 1.6

= 0.75

The Mitigation factors for the same conversion but in 750mm and 850mm rainfall zones are 0.80 and 0.80 respectively.

Definitive information on the area of land irrigated by each irrigation method is not yet available. However for the purpose of this project it is recommended the team assumes that 60% of the irrigated area in Canterbury is irrigated using boom irrigators or equivalent and 40% is irrigated using pivots.

If one then uses the 750mm mean annual rainfall 'band' as a mid-range representative value for rainfall across Canterbury's irrigated area and assumes that all boom irrigators are upgraded to pivots then the N load would be reduced on 60% of the irrigated area to about 80% of what the current load is.

Yours sincerely

John Bright
Managing Director
Aqualinc Research Ltd.

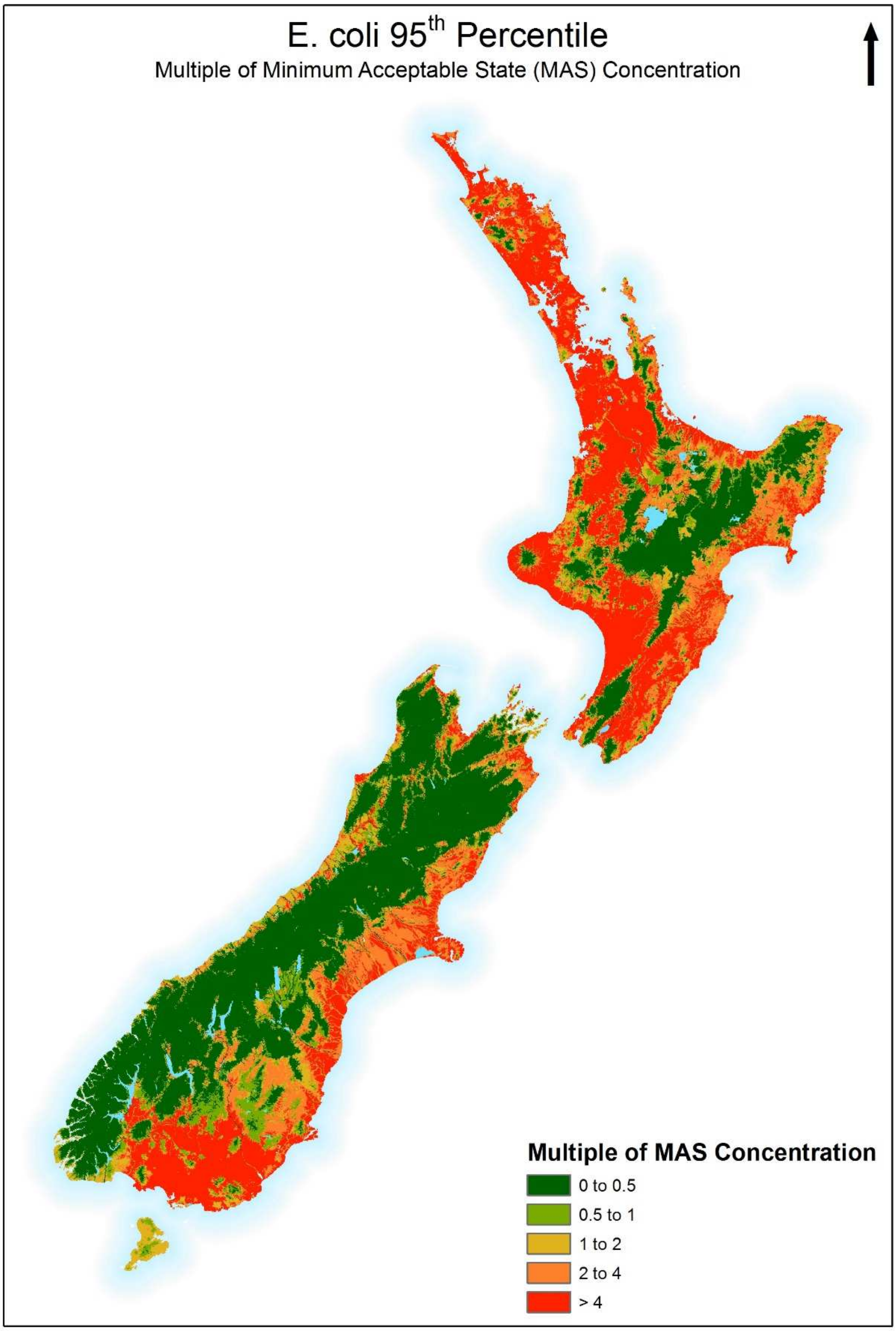
Appendix E Maps of current concentrations

The current concentrations as a multiple of the relevant bottom line values are shown in the maps below. Concentrations for streams are modelled values, and the relatively few measured sites would not be visible on these maps. The subcatchments are coloured according to the ratio in the relevant streams.

Concentrations for lakes maps are measured values (SOE values supplemented with Lakes Database values).

For the maps of TN and TP as they relate to periphyton, areas with fine sediment (where periphyton are not expected to be conspicuous) are shown in grey.


E. coli Median
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

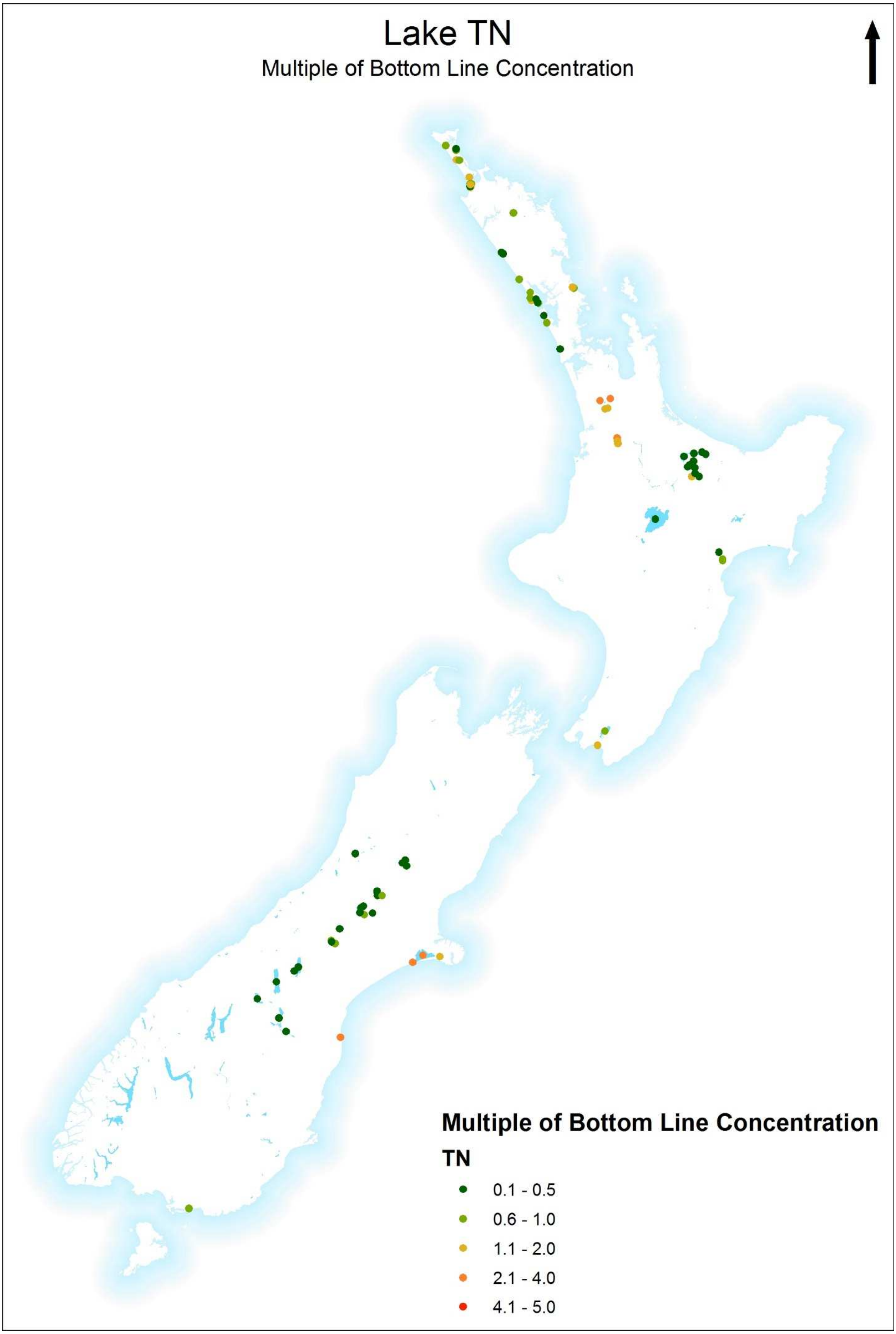

E. coli 95th Percentile
Multiple of Minimum Acceptable State (MAS) Concentration
Multiple of MAS Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Nitrate Median
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

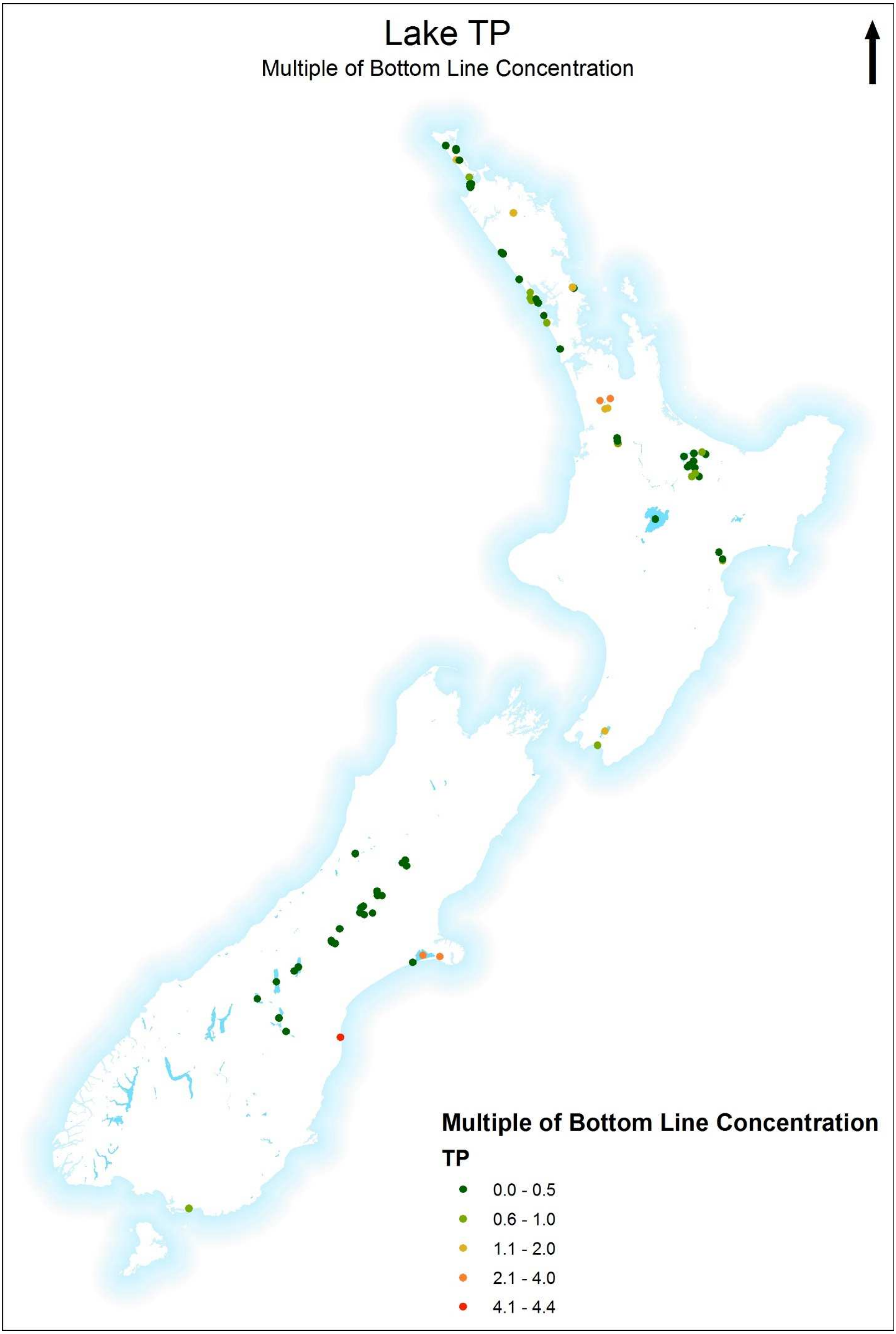
Nitrate 95th Percentile
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Nitrogen with respect to Periphyton
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
No threshold
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Phosphorus with respect to Periphyton
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
No threshold
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4



Lake TN
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
TN
0.1 - 0.5
0.6 - 1.0
1.1 - 2.0
2.1 - 4.0
4.1 - 5.0


Lake TP
Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
TP
0.0 - 0.5
0.6 - 1.0
1.1 - 2.0
2.1 - 4.0
4.1 - 4.4

Appendix F Selected maps of exceedance and headroom-shortfall illustrating effects of node location and maintain-or-improve model variants.

A full set of maps for the ‘All nodes, Maintain current concentration’ model variant are in Appendix H.

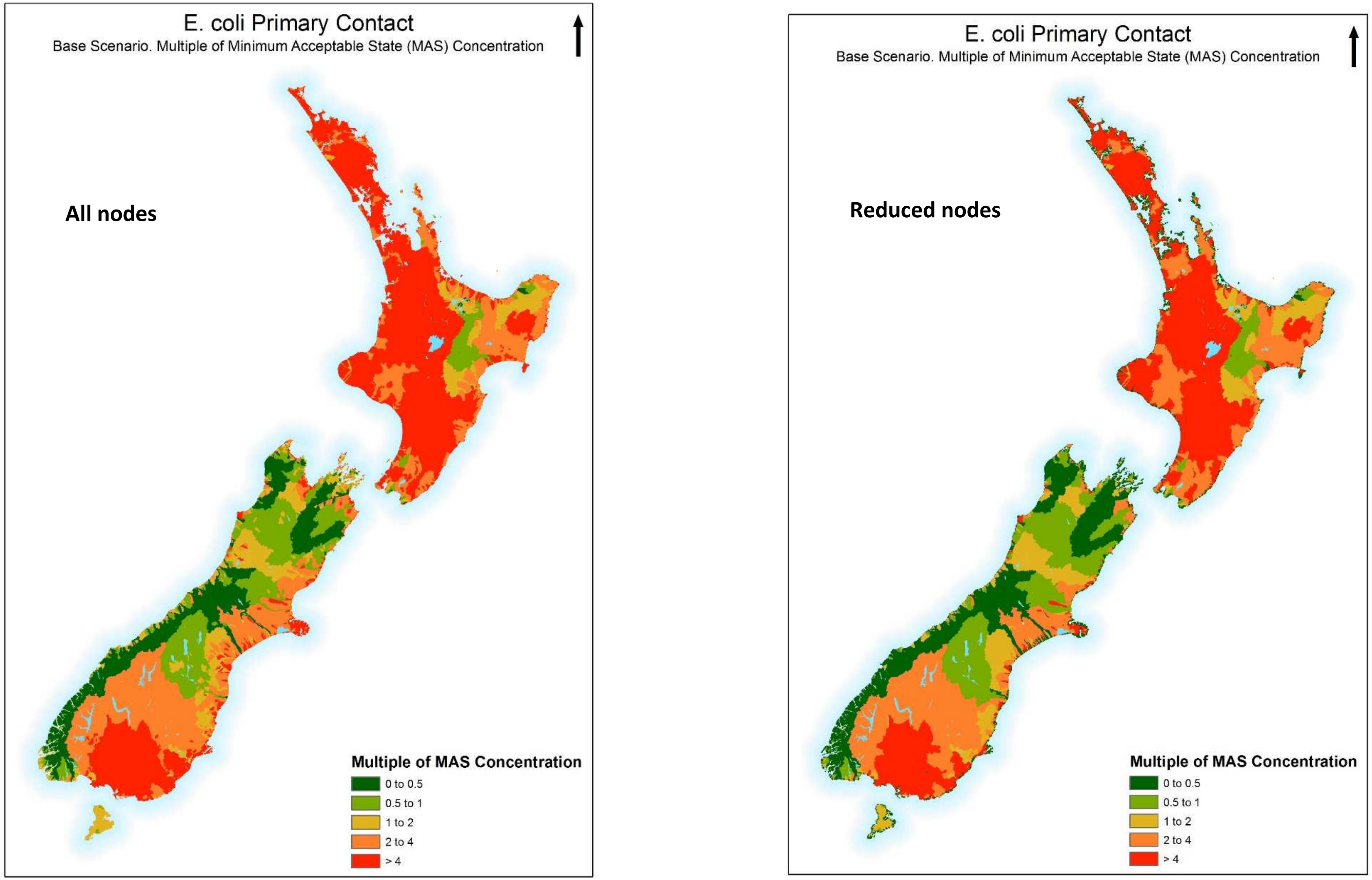
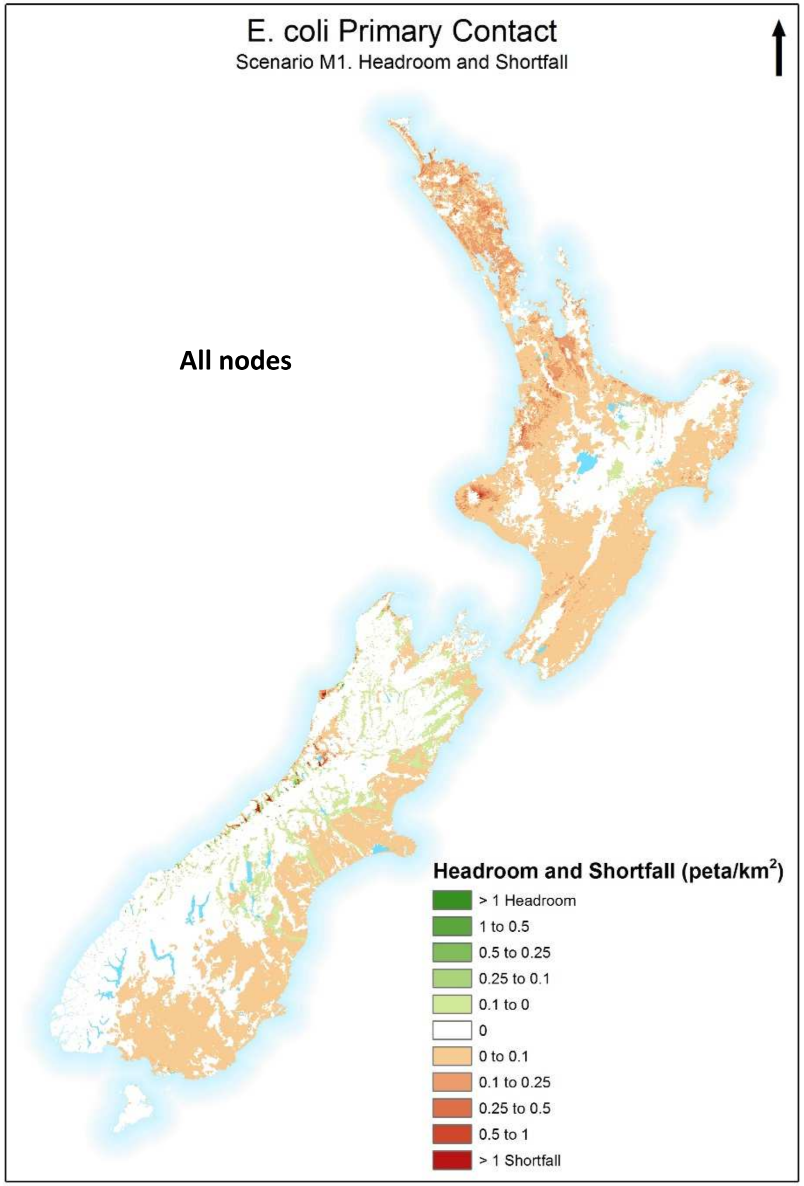


Figure F-1: Example of effect of reduced nodes on exceedance factor for the E. coli primary contact baseline scenario. 'All nodes' (left hand figure) and 'Reduced nodes' (right hand figure). In each case, the Baseline scenario and the 'Maintain current concentrations' model variant were used. Note the green fringe around the coastline for 'Reduced nodes', where there are no nodes. Also note the generally lower exceedance values for 'Reduced nodes' (for example, shrinkage in red areas) due to removal of stream confluence nodes.



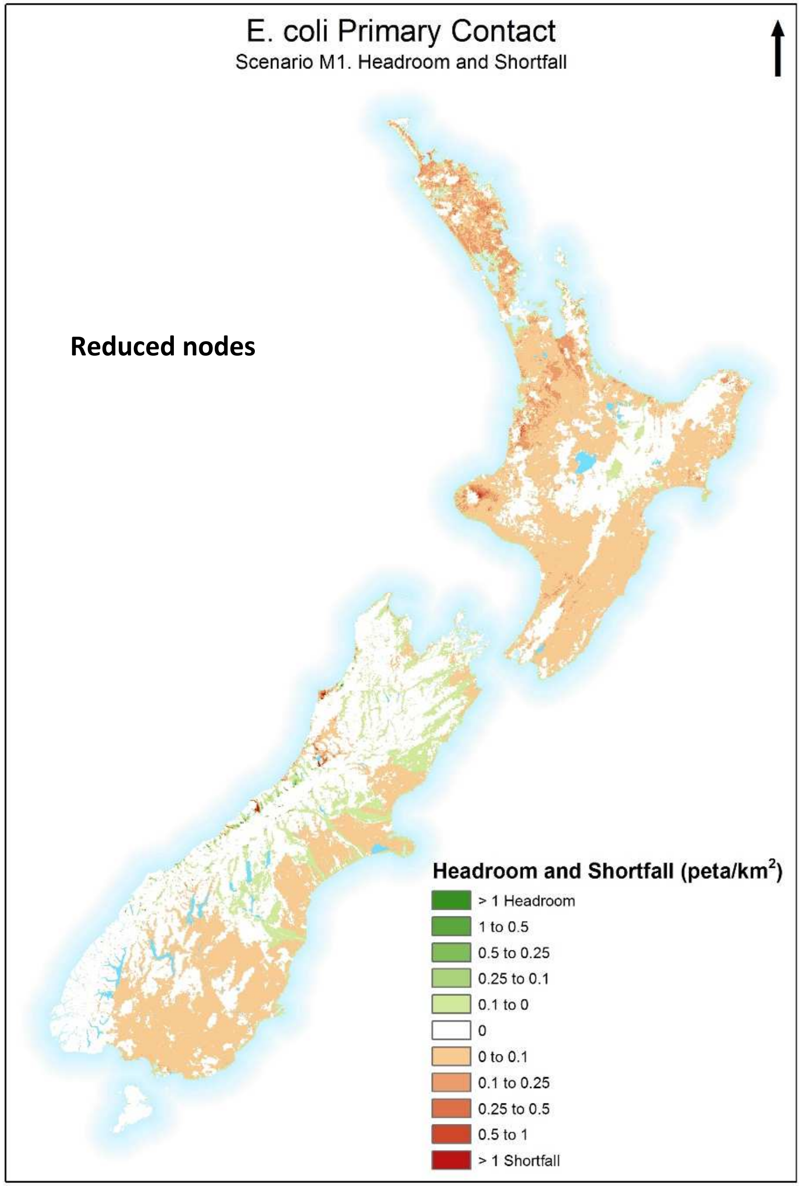
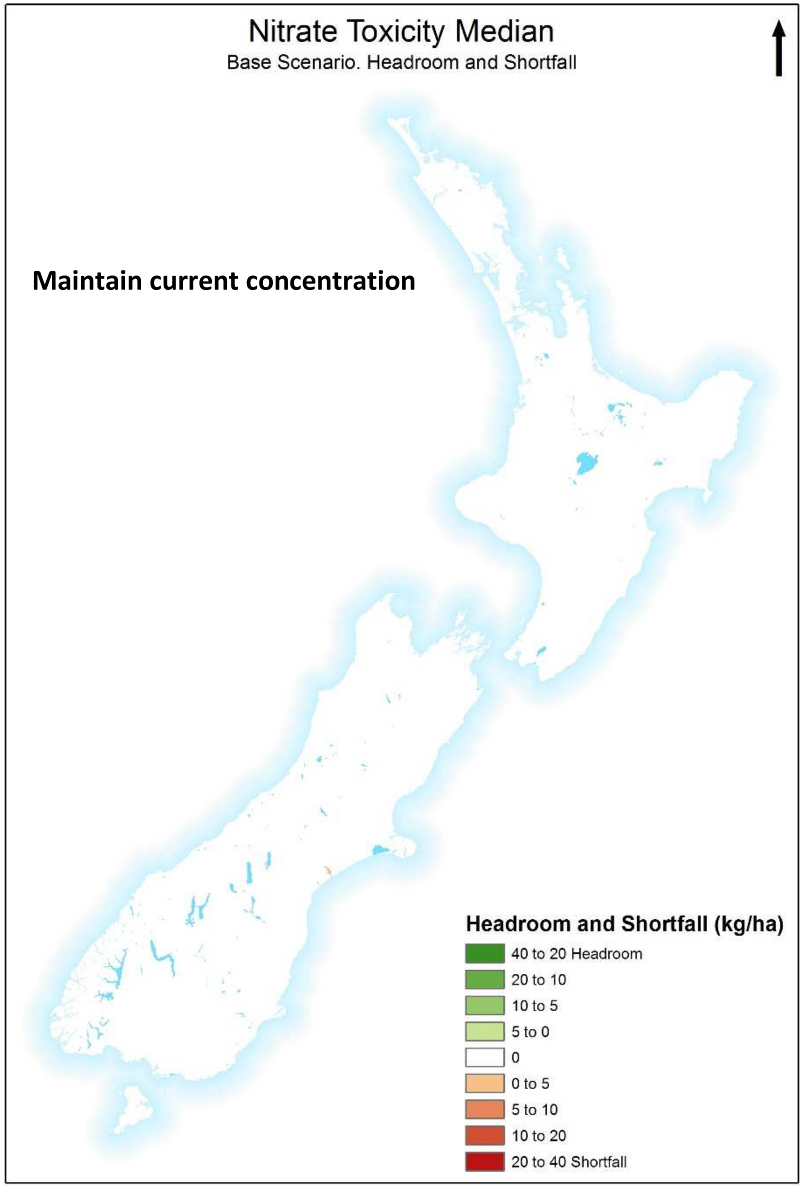


Figure F-2: Example of effect of reduced nodes on headroom and shortfall for the E. coli primary contact baseline scenario. 'All nodes' (left hand figure) and 'Reduced nodes' (right hand figure). In each case, the M1 mitigation scenario and the 'Maintain current concentrations' model variant were used. Note the appearance of additional headroom for some locations in for 'Reduced nodes', which is due to removal of stream confluence nodes. There are also areas of headroom fringing the coast for 'Reduced nodes; which are not readily visible.



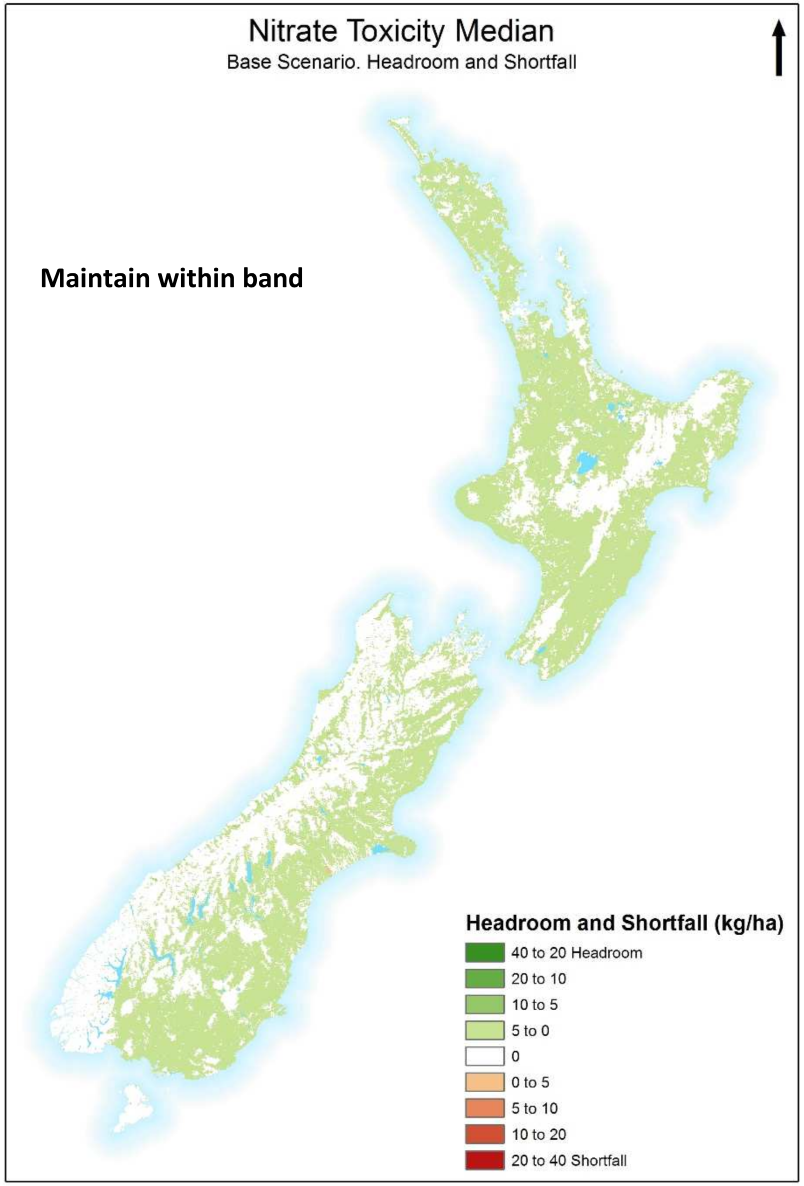


Figure F-3: Example of effect of allowing movement within bands. ''Maintain current concentration ' (left hand figure) and 'Maintain within band' (right hand figure). In each case, the 'All nodes' model variant was used. Note the appearance of headroom 'Maintain within band', which arises because the current state is above the bottom line and movement within a band is allowed.

Appendix G Results – full set of regional and national summary tables for the 'All nodes, Maintain concentrations' model variant.

In the tables below, the current source of the contaminant is given (with TN used for the nitrate toxicity table), and then the amount of mitigation, headroom and shortfall as a percentage of the current loading is given within each region and nationally, for each level of mitigation. A separate table is given for each attribute. The results are only given for the 'All nodes, Maintain current concentration' model variant.

Table G-1: Current source load and mitigation, headroom and shortfall for mitigation options for *E. coli* in relation to primary contact.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)				Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3	Base	M1	M2	M3
Auckland	375	9.1	9.1	9.1	0.0	0.0	0.0	0.0	70.0	60.9	60.9	60.9
Canterbury	818	8.1	8.1	8.1	0.0	4.7	4.7	4.7	25.7	21.9	21.9	21.9
BOP	288	6.0	6.0	6.0	0.0	0.8	0.8	0.8	52.2	47.1	47.1	47.1
Waikato	1525	4.6	4.6	4.6	0.0	0.0	0.0	0.0	76.5	72.0	72.0	72.0
Gisborne	434	3.0	3.0	3.0	0.0	0.0	0.0	0.0	55.5	52.8	52.8	52.8
Hawkes_Bay	474	5.7	5.7	5.7	0.0	0.1	0.1	0.1	65.4	59.6	59.6	59.6
Manawatu_Whanganui	812	4.3	4.3	4.3	0.0	0.0	0.0	0.0	84.8	80.6	80.6	80.6
Marlborough	69	8.9	8.9	8.9	0.0	4.4	4.4	4.4	32.6	27.1	27.1	27.1
Northland	1231	9.6	9.6	9.6	0.0	0.0	0.0	0.0	81.3	71.6	71.6	71.6
Otago	378	8.2	8.2	8.2	0.0	0.1	0.1	0.1	48.8	42.9	42.9	42.9
Southland	851	5.2	5.2	5.2	0.0	1.5	1.5	1.5	35.1	31.5	31.5	31.5
Taranaki	482	4.4	4.4	4.4	0.0	0.0	0.0	0.0	81.0	76.6	76.6	76.6
Nelson_Tasman	128	6.7	6.7	6.7	0.0	3.8	3.8	3.8	26.1	22.5	22.5	22.5
Wellington	261	4.8	4.8	4.8	0.0	0.1	0.1	0.1	70.0	65.1	65.1	65.1
West_Coast	5270	4.3	4.3	4.3	0.0	3.3	3.3	3.3	8.3	7.2	7.2	7.2
National	13394	5.5	5.5	5.5	0.0	1.8	1.8	1.8	41.6	38.0	38.0	38.0

Table G-2: Current source load and mitigation, headroom and shortfall for mitigation options for *E. coli* in relation to secondary contact.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)				Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3	Base	M1	M2	M3
Auckland	375	9.1	9.1	9.1	0.0	8.9	8.9	8.9	0.3	0.1	0.1	0.1
Canterbury	818	8.1	8.1	8.1	0.0	8.1	8.1	8.1	0.0	0.0	0.0	0.0
BOP	288	6.0	6.0	6.0	0.0	6.0	6.0	6.0	0.0	0.0	0.0	0.0
Waikato	1525	4.6	4.6	4.6	0.0	4.6	4.6	4.6	0.0	0.0	0.0	0.0
Gisborne	434	3.0	3.0	3.0	0.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0
Hawkes_Bay	474	5.7	5.7	5.7	0.0	5.7	5.7	5.7	0.0	0.0	0.0	0.0
Manawatu_Whanganui	812	4.3	4.3	4.3	0.0	4.3	4.3	4.3	0.0	0.0	0.0	0.0
Marlborough	69	8.9	8.9	8.9	0.0	8.9	8.9	8.9	0.0	0.0	0.0	0.0
Northland	1231	9.6	9.6	9.6	0.0	9.6	9.6	9.6	0.0	0.0	0.0	0.0
Otago	378	8.2	8.2	8.2	0.0	8.2	8.2	8.2	0.0	0.0	0.0	0.0
Southland	851	5.2	5.2	5.2	0.0	4.5	4.5	4.5	7.2	6.3	6.3	6.3
Taranaki	482	4.4	4.4	4.4	0.0	4.4	4.4	4.4	0.0	0.0	0.0	0.0
Nelson_Tasman	128	6.7	6.7	6.7	0.0	6.7	6.7	6.7	0.0	0.0	0.0	0.0
Wellington	261	4.8	4.8	4.8	0.0	4.8	4.8	4.8	0.0	0.0	0.0	0.0
West_Coast	5270	4.3	4.3	4.3	0.0	4.3	4.3	4.3	0.0	0.0	0.0	0.0
National	13394	5.5	5.5	5.5	0.0	5.4	5.4	5.4	0.5	0.4	0.4	0.4

Table G-3: Current source load and mitigation, headroom and shortfall for mitigation options for nitrate in relation to toxicity at the median concentration. Loads are for total N.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)				Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3	Base	M1	M2	M3
Auckland	4964	0.2	8.5	14.2	0.0	0.2	8.5	14.2	0.4	0.4	0.3	0.3
Canterbury	32728	3.2	9.7	13.1	0.0	3.2	9.6	13.0	0.2	0.1	0.1	0.0
BOP	12510	0.2	7.3	12.7	0.0	0.2	7.3	12.7	0.0	0.0	0.0	0.0
Waikato	27695	0.4	14.0	24.9	0.0	0.4	14.0	24.9	0.0	0.0	0.0	0.0
Gisborne	6925	0.0	2.8	3.0	0.0	0.0	2.8	3.0	0.0	0.0	0.0	0.0
Hawkes_Bay	9539	0.1	4.9	6.3	0.0	0.1	4.9	6.3	0.0	0.0	0.0	0.0
Manawatu_Whanganui	16134	0.2	7.7	12.0	0.0	0.2	7.7	12.0	0.1	0.1	0.1	0.1
Marlborough	5618	0.0	1.6	2.2	0.0	0.0	1.6	2.2	0.0	0.0	0.0	0.0
Northland	9158	0.2	9.5	16.2	0.0	0.2	9.5	16.2	0.0	0.0	0.0	0.0
Otago	12196	0.1	5.5	7.9	0.0	0.1	5.5	7.9	0.0	0.0	0.0	0.0
Southland	22534	0.1	5.8	9.6	0.0	0.1	5.8	9.6	0.0	0.0	0.0	0.0
Taranaki	11122	0.5	17.8	32.8	0.0	0.5	17.8	32.8	0.0	0.0	0.0	0.0
Nelson_Tasman	4950	0.1	3.8	6.5	0.0	0.1	3.8	6.5	0.0	0.0	0.0	0.0
Wellington	5860	0.1	6.3	9.9	0.0	0.1	6.3	9.9	0.0	0.0	0.0	0.0
West_Coast	17767	0.2	6.4	11.4	0.0	0.2	6.4	11.4	0.0	0.0	0.0	0.0
National	**199699**	**0.7**	**8.5**	**13.8**	**0.0**	**0.7**	**8.4**	**13.8**	**0.0**	**0.0**	**0.0**	**0.0**

Table G-4: Current source load and mitigation, headroom and shortfall for mitigation options for nitrate in relation to toxicity at the 95 percentile concentration. Loads are for total N.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)				Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3	Base	M1	M2	M3
Auckland	4964	0.2	8.5	14.2	0.0	0.2	8.5	14.2	0.4	0.4	0.3	0.3
Canterbury	32728	3.2	9.7	13.1	0.0	3.2	9.6	13.0	0.2	0.1	0.1	0.0
BOP	12510	0.2	7.3	12.7	0.0	0.2	7.3	12.7	0.0	0.0	0.0	0.0
Waikato	27695	0.4	14.0	24.9	0.0	0.4	14.0	24.9	0.0	0.0	0.0	0.0
Gisborne	6925	0.0	2.8	3.0	0.0	0.0	2.8	3.0	0.0	0.0	0.0	0.0
Hawkes_Bay	9539	0.1	4.9	6.3	0.0	0.1	4.9	6.3	0.0	0.0	0.0	0.0
Manawatu_Whanganui	16134	0.2	7.7	12.0	0.0	0.2	7.7	12.0	0.1	0.1	0.1	0.1
Marlborough	5618	0.0	1.6	2.2	0.0	0.0	1.6	2.2	0.0	0.0	0.0	0.0
Northland	9158	0.2	9.5	16.2	0.0	0.2	9.5	16.2	0.0	0.0	0.0	0.0
Otago	12196	0.1	5.5	7.9	0.0	0.1	5.5	7.9	0.0	0.0	0.0	0.0
Southland	22534	0.1	5.8	9.6	0.0	0.1	5.8	9.6	0.0	0.0	0.0	0.0
Taranaki	11122	0.5	17.8	32.8	0.0	0.5	17.8	32.8	0.0	0.0	0.0	0.0
Nelson_Tasman	4950	0.1	3.8	6.5	0.0	0.1	3.8	6.5	0.0	0.0	0.0	0.0
Wellington	5860	0.1	6.3	9.9	0.0	0.1	6.3	9.9	0.0	0.0	0.0	0.0
West_Coast	17767	0.2	6.4	11.4	0.0	0.2	6.4	11.4	0.0	0.0	0.0	0.0
National	**199699**	**0.7**	**8.5**	**13.8**	**0.0**	**0.7**	**8.4**	**13.8**	**0.0**	**0.0**	**0.0**	**0.0**

Table G-5: Current source load and mitigation, headroom and shortfall for mitigation options for N in relation to stream periphyton.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)				Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3	Base	M1	M2	M3
Auckland	4964	0.2	8.5	14.2	0.0	28.5	34.6	38.8	13.6	13.6	11.4	10.0
Canterbury	32728	3.2	9.7	13.1	0.0	5.1	8.7	10.3	31.5	29.7	26.5	24.7
BOP	12510	0.2	7.3	12.7	0.0	5.0	10.5	15.0	9.3	9.3	7.5	6.4
Waikato	27695	0.4	14.0	24.9	0.0	9.8	16.9	23.2	26.1	25.9	19.1	14.3
Gisborne	6925	0.0	2.8	3.0	0.0	0.5	2.0	2.1	6.7	6.7	5.3	5.2
Hawkes_Bay	9539	0.1	4.9	6.3	0.0	0.9	3.6	4.4	20.0	20.0	16.7	15.6
Manawatu_Whanganui	16134	0.2	7.7	12.0	0.0	1.6	4.9	6.2	22.2	22.1	17.2	14.1
Marlborough	5618	0.0	1.6	2.2	0.0	0.4	1.9	2.5	11.9	11.9	11.7	11.7
Northland	9158	0.2	9.5	16.2	0.0	16.8	22.8	27.4	9.2	9.1	6.0	3.9
Otago	12196	0.1	5.5	7.9	0.0	3.3	5.9	7.2	9.1	9.0	6.8	5.6
Southland	22534	0.1	5.8	9.6	0.0	3.0	4.3	5.1	19.7	19.6	15.4	12.5
Taranaki	11122	0.5	17.8	32.8	0.0	2.3	7.2	14.3	33.6	33.2	21.7	13.2
Nelson_Tasman	4950	0.1	3.8	6.5	0.0	0.5	3.9	6.5	0.9	0.9	0.6	0.4
Wellington	5860	0.1	6.3	9.9	0.0	0.7	1.4	1.6	16.6	16.5	12.6	10.3
West_Coast	17767	0.2	6.4	11.4	0.0	1.4	7.5	12.5	0.2	0.2	0.1	0.1
National	**199699**	**0.7**	**8.5**	**13.8**	**0.0**	**5.0**	**9.1**	**12.0**	**18.6**	**18.2**	**14.5**	**12.1**

Table G-6: Current source load and mitigation, headroom and shortfall for mitigation options for N in relation to combined stream periphyton and lakes.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)					Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3		Base	M1	M2	M3
Auckland	4964	0.2	8.5	14.2	27.7	33.7	37.9		13.8	13.8	11.5	10.0	4964
Canterbury	32728	3.2	9.7	13.1	4.8	8.4	10.0		34.1	31.9	30.4	28.1	32728
BOP	12510	0.2	7.3	12.7	4.9	10.4	14.9		9.6	9.5	7.7	6.6	12510
Waikato	27695	0.4	14.0	24.9	7.0	14.2	20.3		27.4	27.2	20.1	15.1	27695
Gisborne	6925	0.0	2.8	3.0	0.4	1.9	2.0		6.9	6.9	5.5	5.4	6925
Hawkes_Bay	9539	0.1	4.9	6.3	0.8	3.4	4.2		21.3	21.3	18.0	16.8	9539
Manawatu_Whanganui	16134	0.2	7.7	12.0	1.0	4.0	5.2		23.1	23.0	17.9	14.6	16134
Marlborough	5618	0.0	1.6	2.2	0.4	1.9	2.4		13.0	13.0	12.8	12.8	5618
Northland	9158	0.2	9.5	16.2	15.6	21.4	25.7		10.2	10.1	6.8	4.5	9158
Otago	12196	0.1	5.5	7.9	2.3	4.8	6.1		10.2	10.1	7.6	6.2	12196
Southland	22534	0.1	5.8	9.6	2.6	3.8	4.5		21.7	21.6	17.2	14.3	22534
Taranaki	11122	0.5	17.8	32.8	2.2	5.9	11.6		40.7	40.2	26.3	15.7	11122
Nelson_Tasman	4950	0.1	3.8	6.5	0.5	3.9	6.5		1.0	1.0	0.7	0.5	4950
Wellington	5860	0.1	6.3	9.9	0.6	1.3	1.4		24.7	24.4	16.5	11.5	5860
West_Coast	17767	0.2	6.4	11.4	1.3	7.5	12.4		0.7	0.6	0.5	0.4	17767
National	199699	0.7	8.5	13.8	4.3	8.3	11.1		20.4	20.0	16.1	13.3	199699

Table G-7: Current source load and mitigation, headroom and shortfall for mitigation options for P in relation to stream periphyton.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)				Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3	Base	M1	M2	M3
Auckland	482	8.3	34.3	30.5	0	28.1	48.8	45.9	8.4	5.9	0.6	1.5
Canterbury	4282	1.2	3.7	3.5	0	1.9	4.4	4.1	0.1	0.1	0.0	0.0
BOP	1248	4.7	13.3	14.3	0	9.2	16.0	16.9	4.2	3.0	1.2	1.2
Waikato	2537	8.9	24.1	28.7	0	13.0	23.3	26.3	12.7	9.0	4.1	3.0
Gisborne	12361	0.6	1.3	1.0	0	0.6	1.3	1.0	0.3	0.3	0.2	0.3
Hawkes_Bay	2455	3.5	9.0	8.2	0	3.5	8.4	7.8	7.1	5.8	4.2	4.3
Manawatu_Whanganui	3392	4.5	9.8	9.7	0	4.7	9.5	9.3	2.1	1.6	0.8	0.7
Marlborough	697	3.7	12.2	9.9	0	4.0	12.2	10.0	0.4	0.3	0.1	0.2
Northland	1736	8.0	29.5	31.4	0	21.3	39.4	41.4	5.9	3.8	0.4	0.5
Otago	2766	1.7	5.6	4.5	0	2.4	6.1	5.0	0.4	0.2	0.0	0.0
Southland	3214	2.2	6.7	6.7	0	2.9	7.3	7.2	1.1	0.7	0.1	0.1
Taranaki	1079	6.5	16.9	20.4	0	5.7	14.0	17.2	4.9	3.0	0.7	0.3
Nelson_Tasman	818	4.6	14.0	13.6	0	5.6	15.0	14.6	0.1	0.1	0.0	0.0
Wellington	1003	4.4	10.8	9.5	0	4.5	10.6	9.4	2.8	2.3	1.4	1.5
West_Coast	14093	0.6	1.9	2.0	0	0.7	2.0	2.1	0.0	0.0	0.0	0.0
National	**52164**	**2.3**	**6.6**	**6.8**	0	**3.4**	**7.1**	**7.2**	**1.8**	**1.3**	**0.6**	**0.6**

Table G-8: Current source load and mitigation, headroom and shortfall for mitigation options for P in relation to combined stream periphyton and lakes.

Region	Current load (peta/y)	Mitigation (%)			Headroom (%)					Shortfall (%)			
		M1	M2	M3	Base	M1	M2	M3		Base	M1	M2	M3
Auckland	482	8.3	34.3	30.5	27.4	48.0	45.1		8.5	6.0	0.6	1.6	482
Canterbury	4282	1.2	3.7	3.5	1.8	4.1	3.8		1.6	1.4	1.1	1.0	4282
BOP	1248	4.7	13.3	14.3	9.0	15.8	16.8		6.2	5.0	3.3	3.5	1248
Waikato	2537	8.9	24.1	28.7	10.8	20.7	23.6		14.4	10.4	5.0	3.8	2537
Gisborne	12361	0.6	1.3	1.0	0.6	1.2	1.0		0.4	0.3	0.3	0.3	12361
Hawkes_Bay	2455	3.5	9.0	8.2	3.2	8.1	7.4		7.5	6.2	4.4	4.6	2455
Manawatu_Whanganui	3392	4.5	9.8	9.7	4.5	9.3	9.0		2.2	1.7	0.8	0.7	3392
Marlborough	697	3.7	12.2	9.9	4.0	12.2	10.0		0.6	0.4	0.1	0.2	697
Northland	1736	8.0	29.5	31.4	20.1	38.1	40.1		6.1	3.9	0.4	0.6	1736
Otago	2766	1.7	5.6	4.5	2.1	5.8	4.7		0.8	0.7	0.5	0.4	2766
Southland	3214	2.2	6.7	6.7	2.7	6.7	6.6		2.0	1.5	0.6	0.4	3214
Taranaki	1079	6.5	16.9	20.4	4.3	10.7	13.3		9.6	6.4	2.2	1.2	1079
Nelson_Tasman	818	4.6	14.0	13.6	5.5	15.0	14.6		0.1	0.1	0.0	0.0	818
Wellington	1003	4.4	10.8	9.5	4.2	9.8	8.4		4.2	3.4	2.0	2.0	1003
West_Coast	14093	0.6	1.9	2.0	0.7	2.0	2.1		0.0	0.0	0.0	0.0	14093
National	52164	2.3	6.6	6.8	3.2	6.8	6.8		2.3	1.7	0.9	0.8	52164

Appendix H Results – full set of maps of exceedance and headroom-shortfall for the 'All nodes, Maintain concentrations' model variant.

These maps show a) Exceedance of baseline concentration and b) shortfall and headroom for each attribute and mitigation scenario.

Exceedance maps depict the factor by which the bottom line (or minimum acceptable level, MAS, for primary contact) concentration is exceeded at the most constraining downstream point, for each subcatchment. These maps are generated by calculating the estimated concentration as a multiple of the bottom line for each assessment node and lake, and then for each subcatchment tracing downstream to find the maximum multiple.

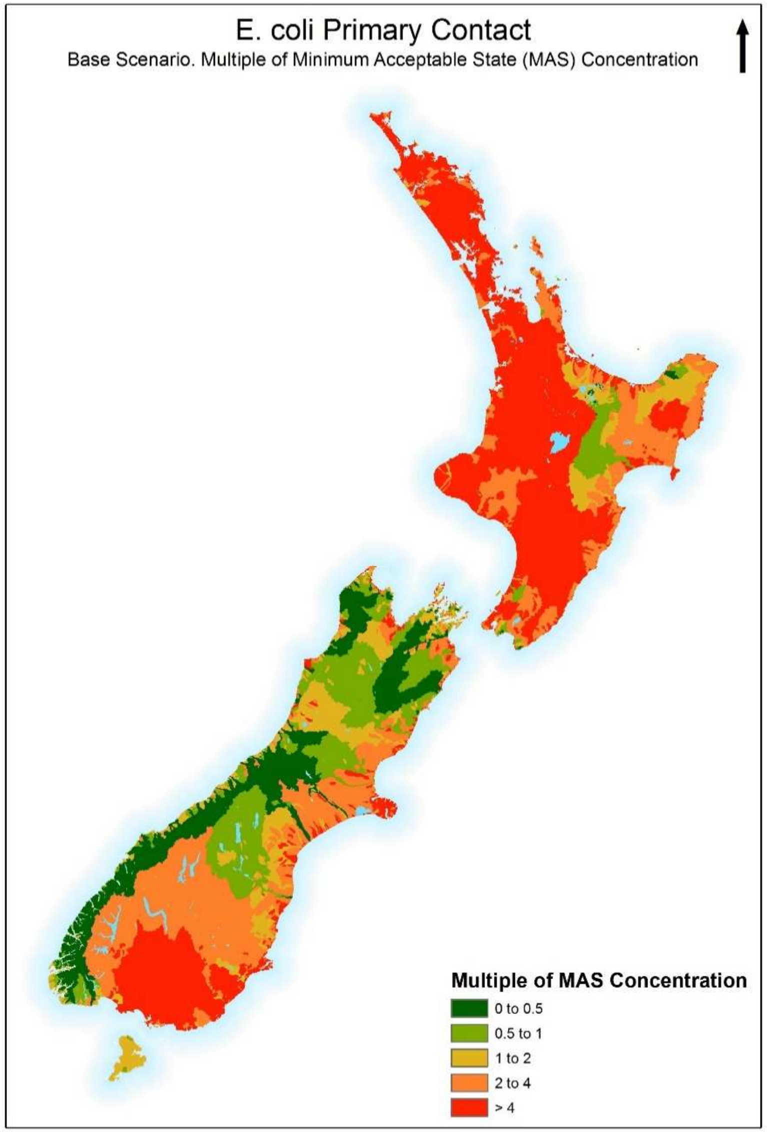
Headroom and shortfall maps show the subcatchment headroom or shortfall load divided by the subcatchment area. Subcatchments are white if there is no development but there is some point downstream that is below the bottom line, and also if there are no suitable areas for development (for example, native bush). The method for calculating headroom and shortfall is described in the main body of the report.

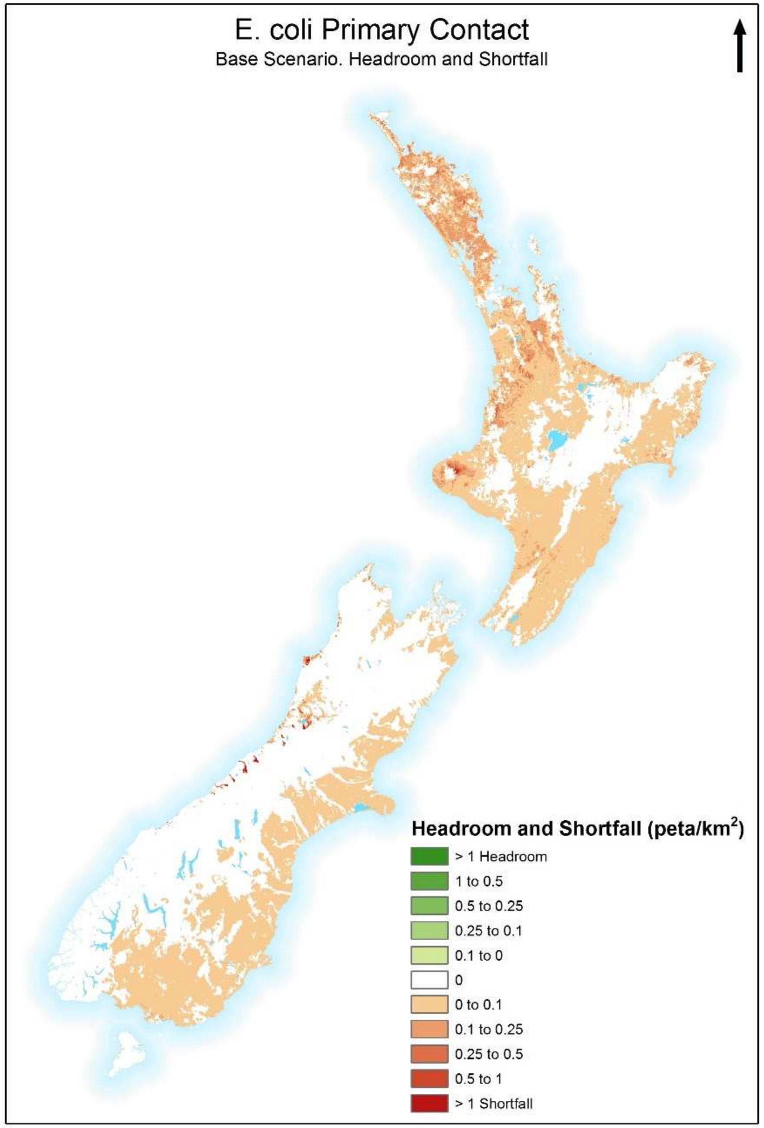
Maps are presented in the following order:

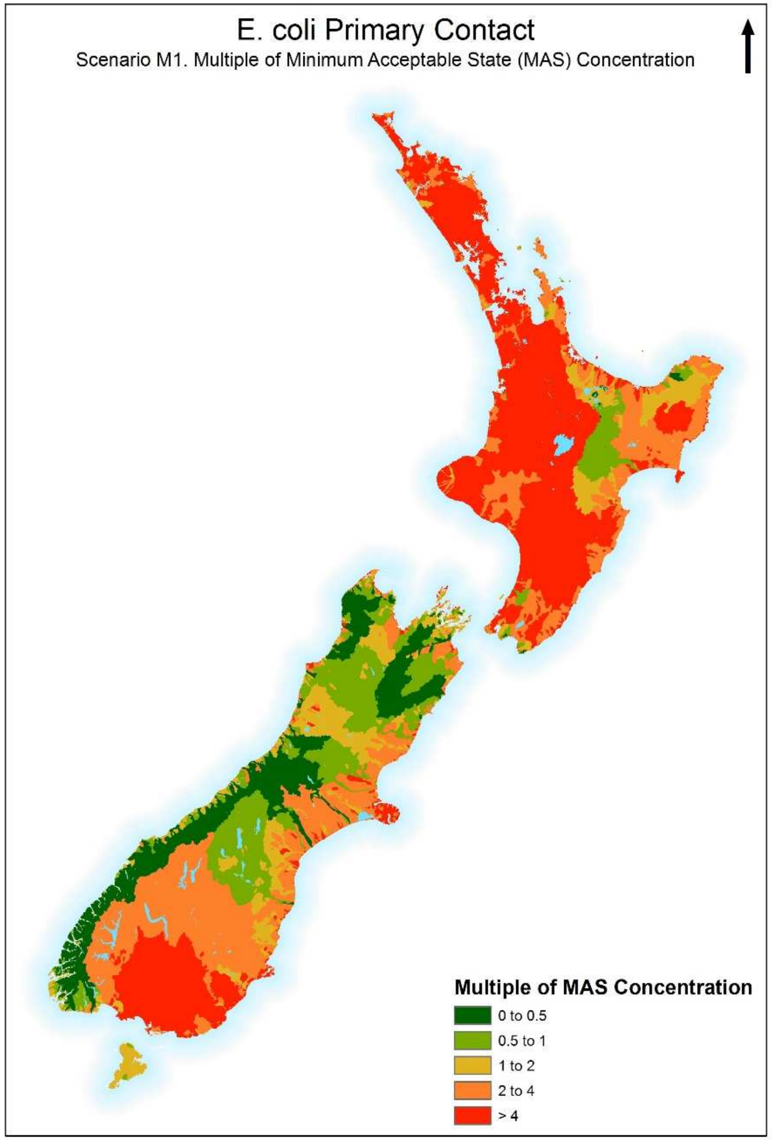
- *E. coli* for primary contact: Exceedance then headroom & shortfall maps for Base and M1. The results for M2 and M3 scenarios are the same as for M1, and so are not shown.
- *E. coli* for secondary contact: Exceedance then headroom & shortfall maps for Base and M1. The results for M2 and M3 scenarios are the same as for M1, and so are not shown.
- Nitrate toxicity median: Exceedance then headroom & shortfall maps for Base, M1, M2 and M3 scenarios respectively. Results for nitrate toxicity 95th percentile are very similar to those for nitrate toxicity median, and so are not shown.
- N with respect to periphyton for rivers: Exceedance then headroom & shortfall maps for Base, M1, M2 and M3 scenarios respectively.
- N with respect to periphyton for rivers and lakes: Exceedance then headroom & shortfall maps for Base, M1, M2 and M3 scenarios respectively.
- P with respect to periphyton for rivers: Exceedance then headroom & shortfall maps for Base, M1, M2 and M3 scenarios respectively.
- P with respect to periphyton for rivers and lakes: Exceedance then headroom & shortfall maps for Base, M1, M2 and M3 scenarios respectively.

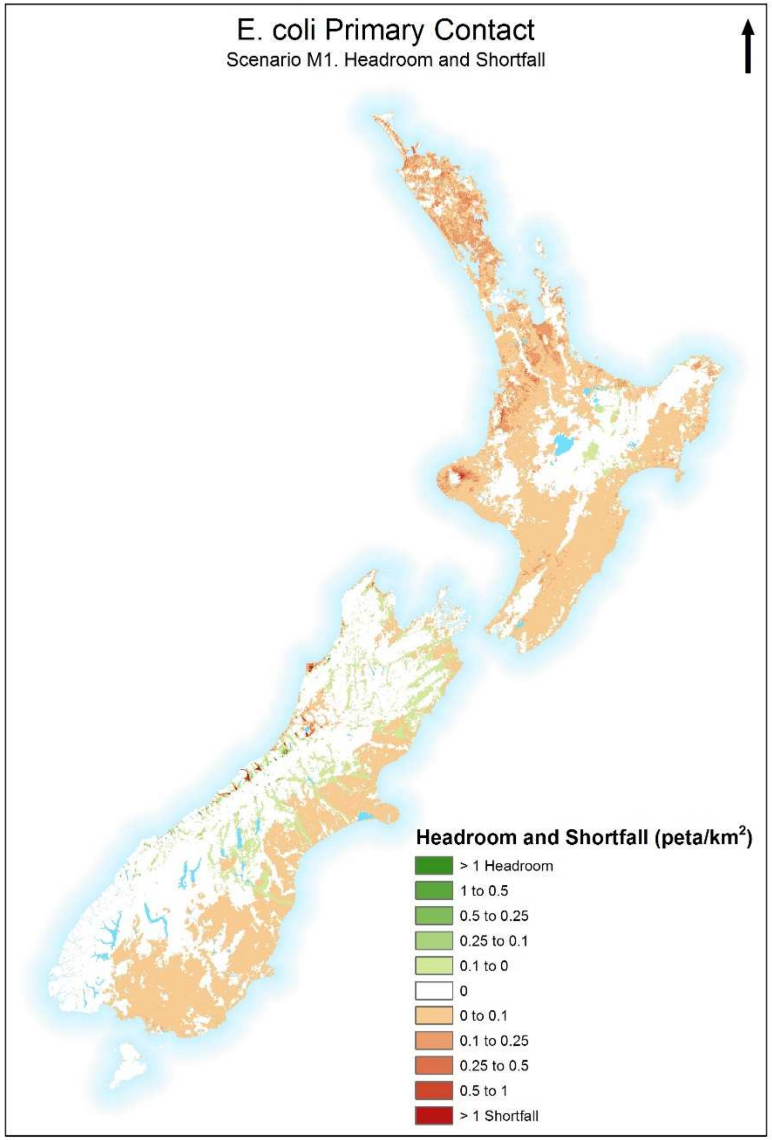
E. coli primary contact

The results for M2 and M3 scenarios are the same as for M1, and so are not shown.


E. coli Primary Contact
Base Scenario. Multiple of Minimum Acceptable State (MAS) Concentration
Multiple of MAS Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

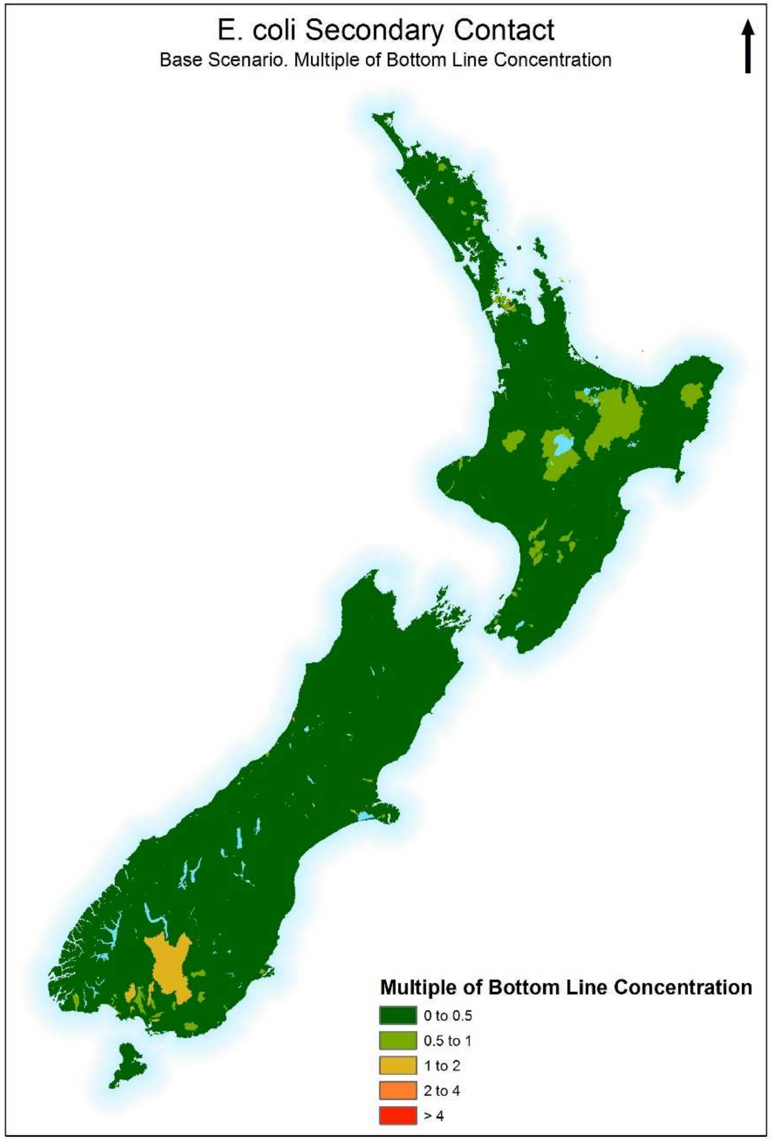

E. coli Primary Contact
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (peta/km2)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall


E. coli Primary Contact
Scenario M1. Multiple of Minimum Acceptable State (MAS) Concentration
Multiple of MAS Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

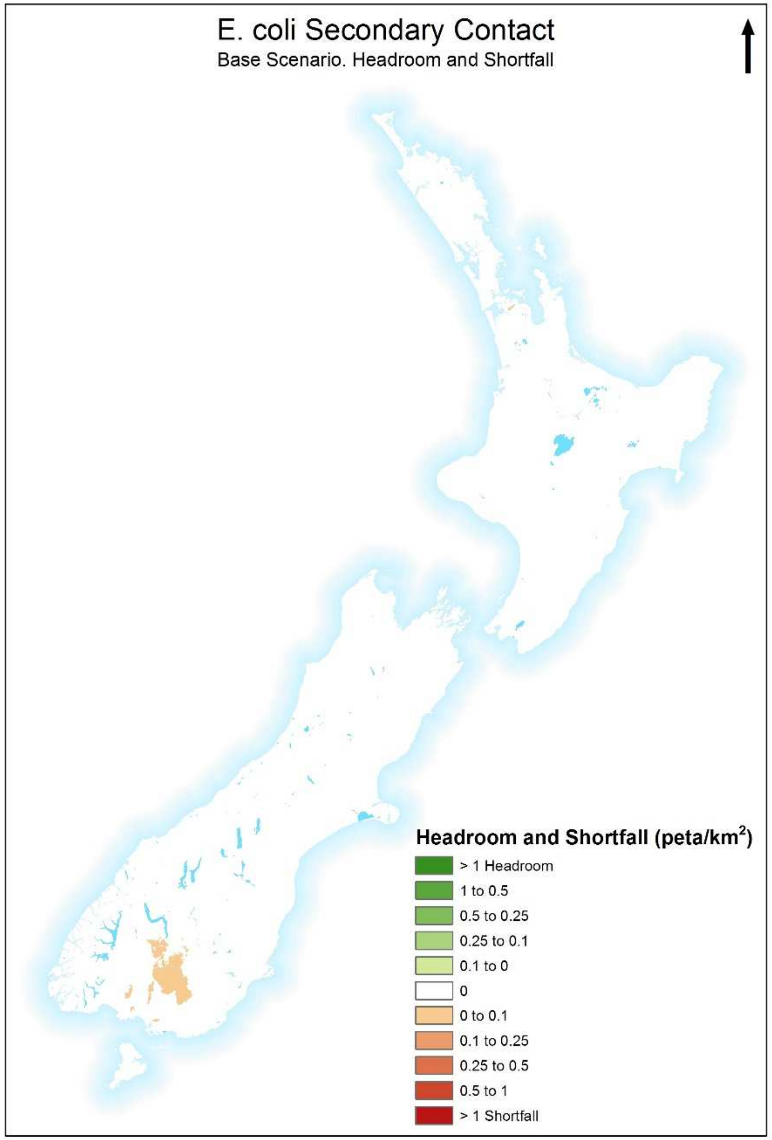

E. coli Primary Contact
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (peta/km^2)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

E. coli secondary contact

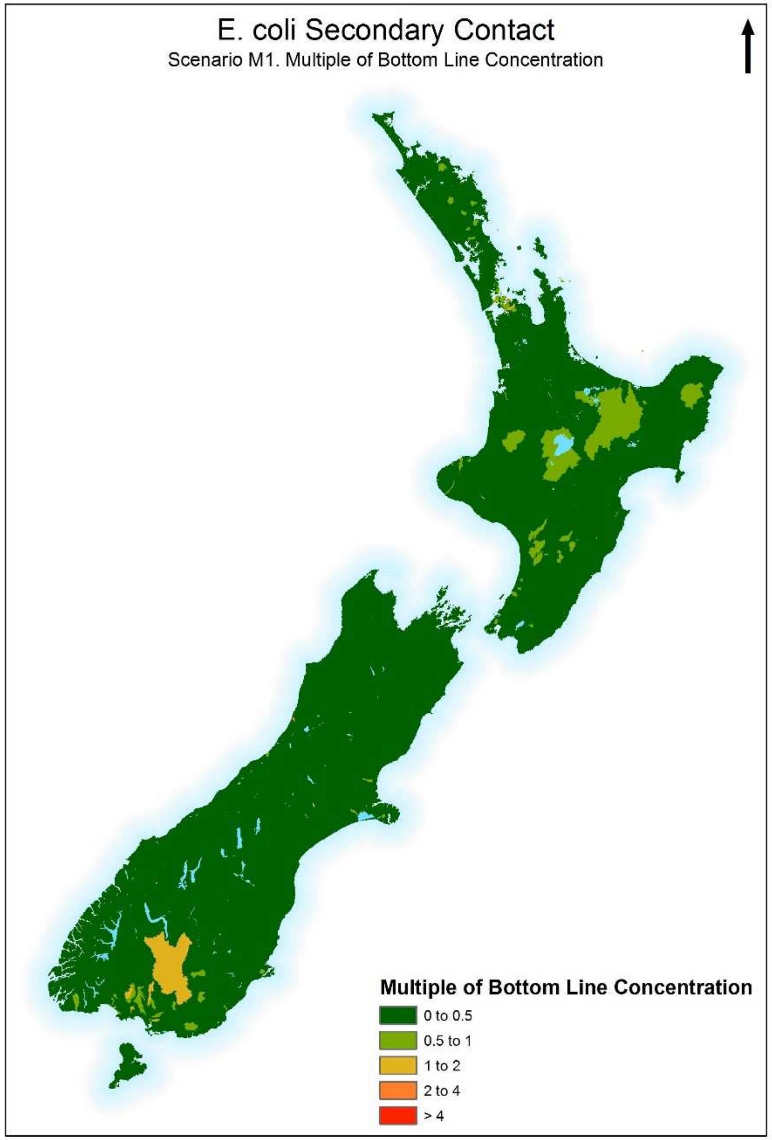
The results for M2 and M3 scenarios are the same as for M1, and so are not shown.

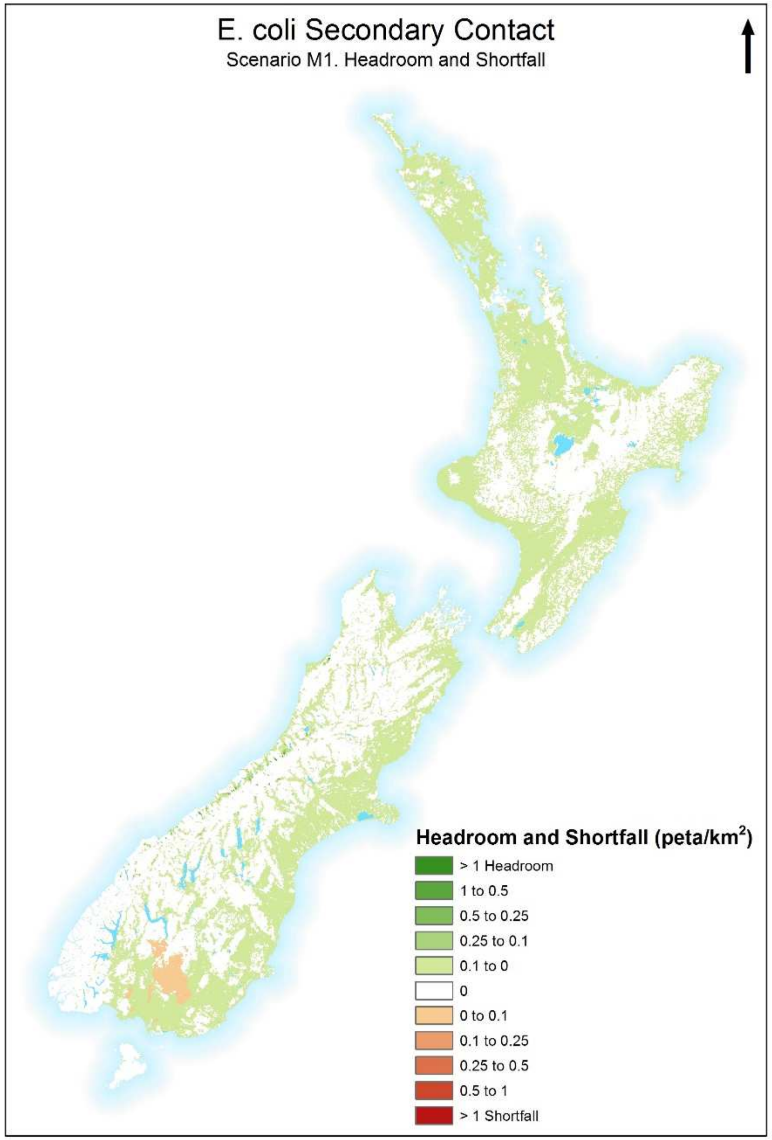


E. coli Secondary Contact
Base Scenario. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4



E. coli Secondary Contact
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (peta/km2)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

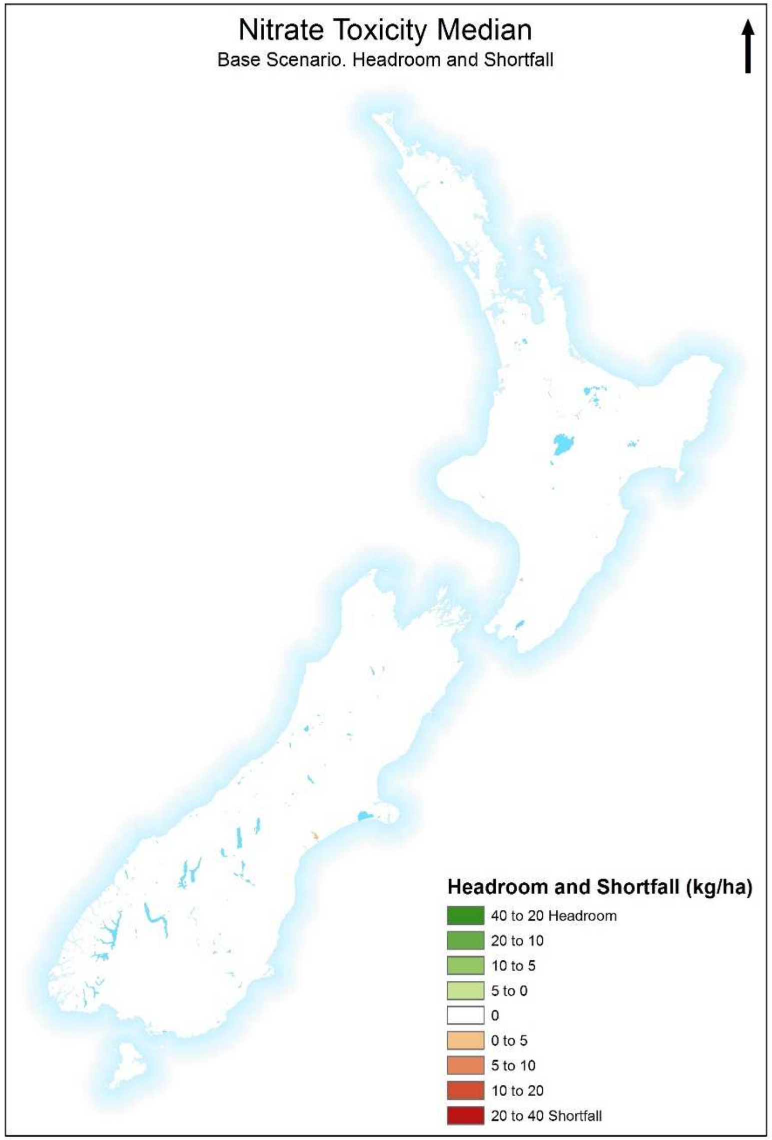

E. coli Secondary Contact
Scenario M1. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


E. coli Secondary Contact
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (peta/km²)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

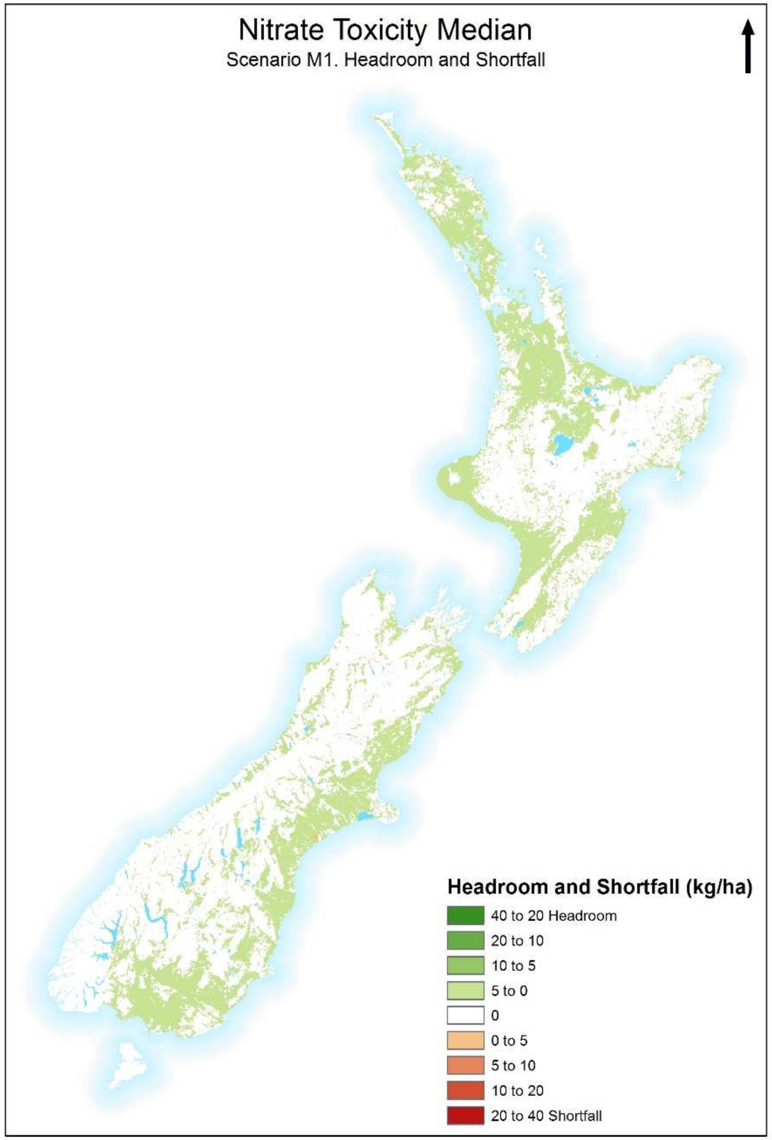
Nitrate toxicity median

Results for nitrate toxicity 95th percentile are very similar to those for nitrate toxicity median, and so are not shown.

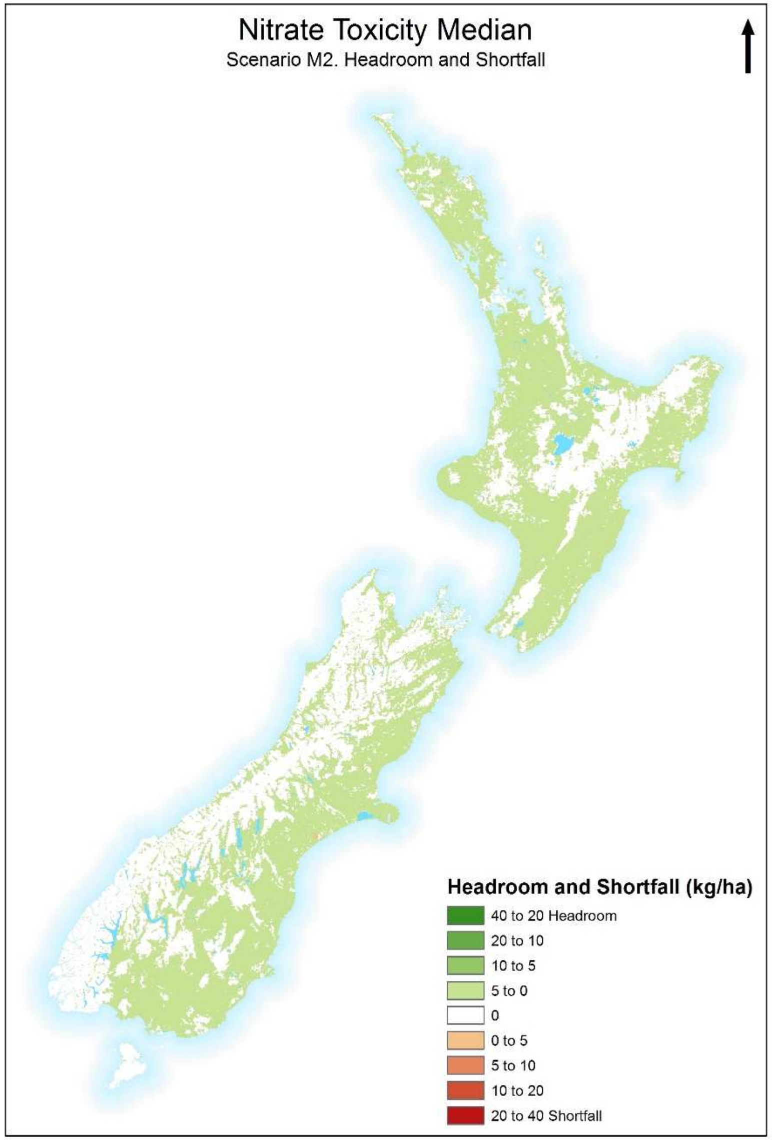

Nitrate Toxicity Median
Base Scenario. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Nitrate Toxicity Median
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

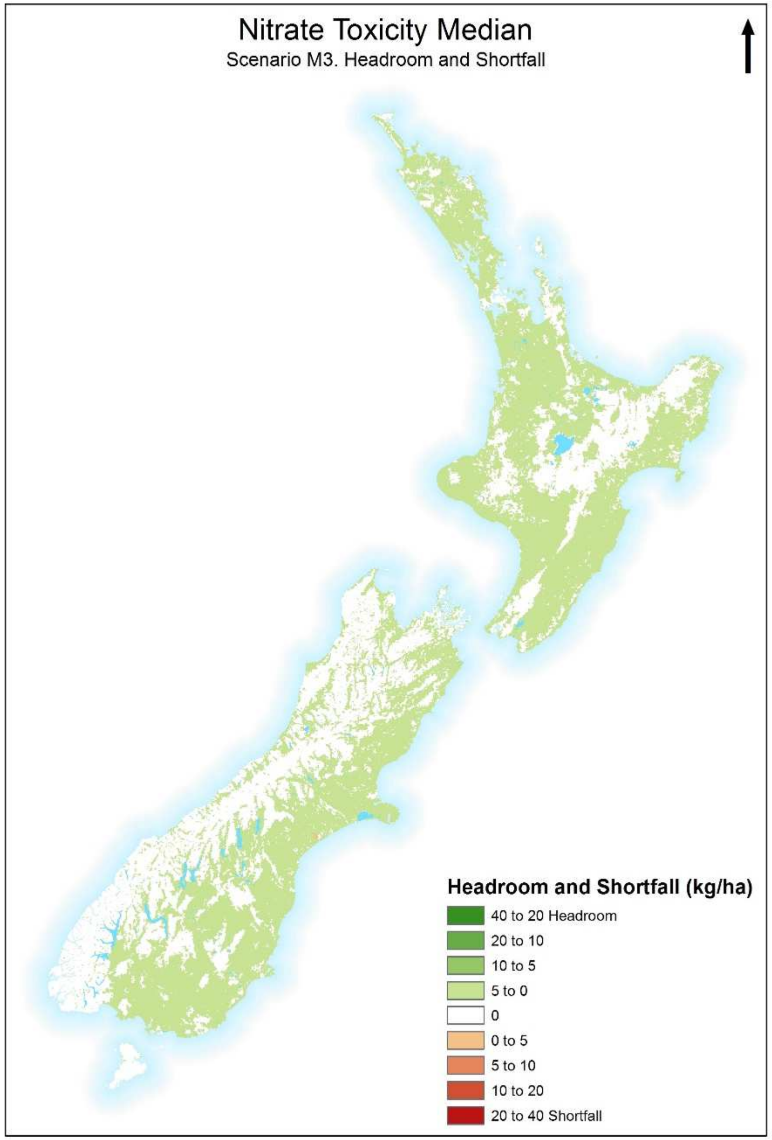

Nitrate Toxicity Median
Scenario M1. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Nitrate Toxicity Median
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall


Nitrate Toxicity Median
Scenario M2. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

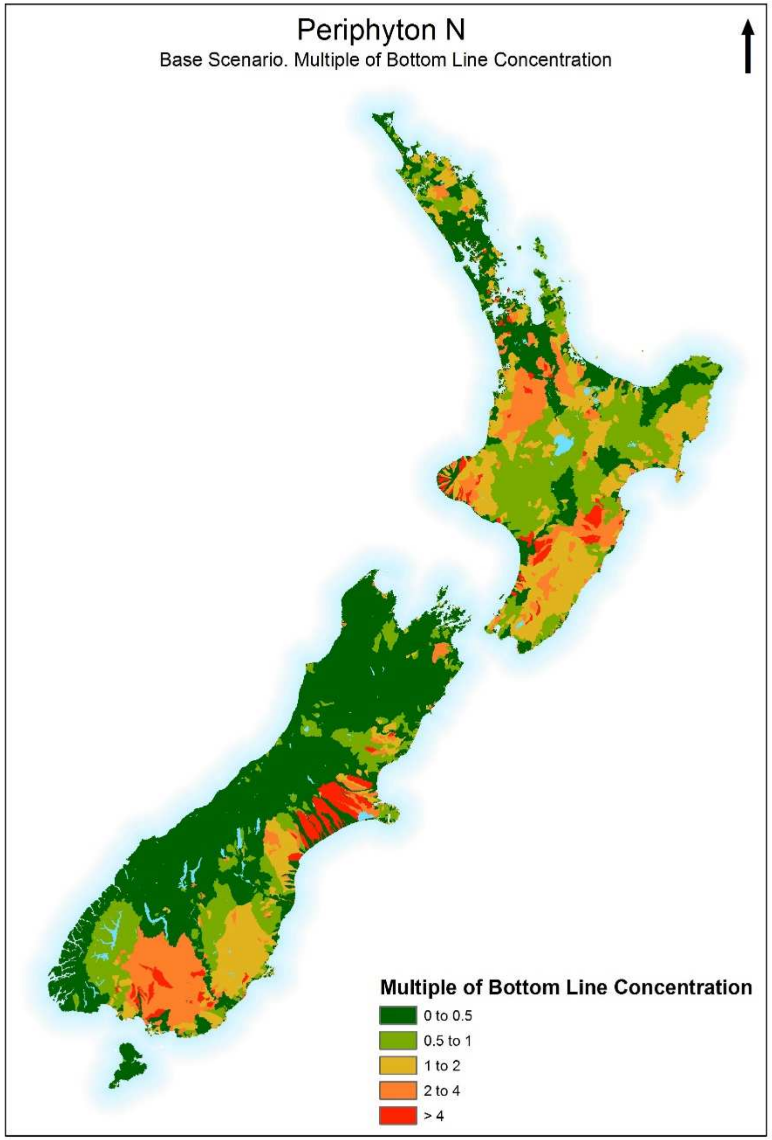

Nitrate Toxicity Median
Scenario M2. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

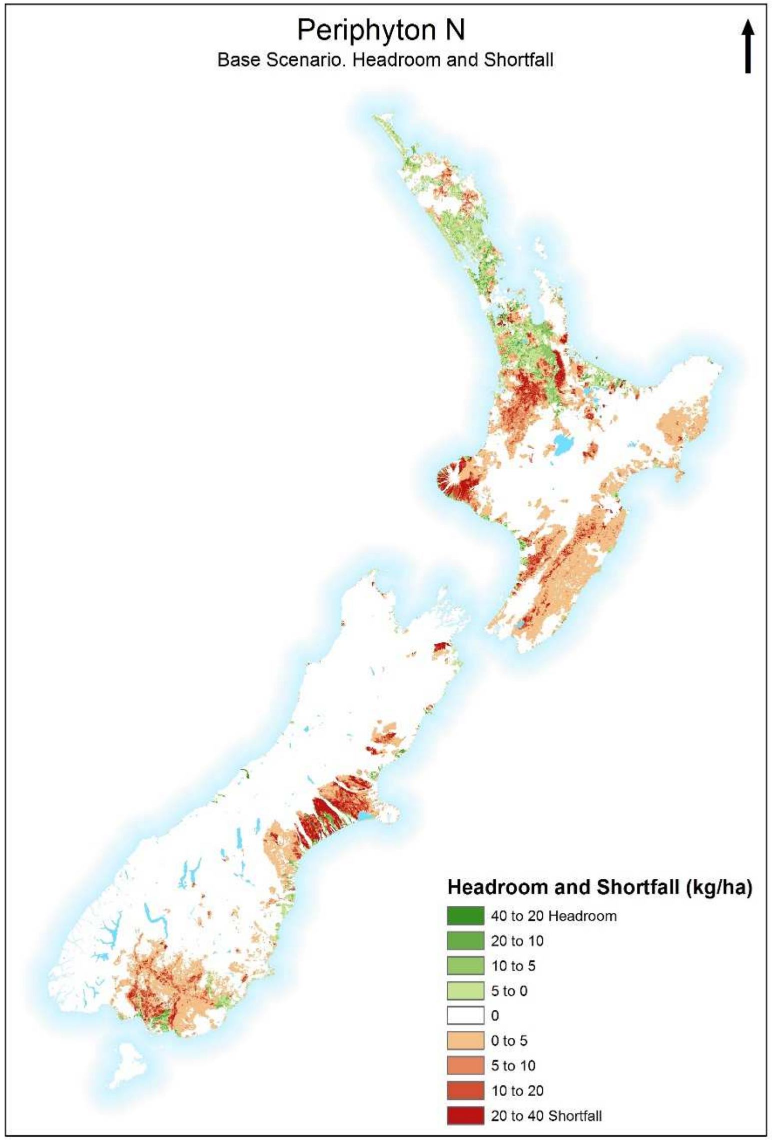

Nitrate Toxicity Median
Scenario M3. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

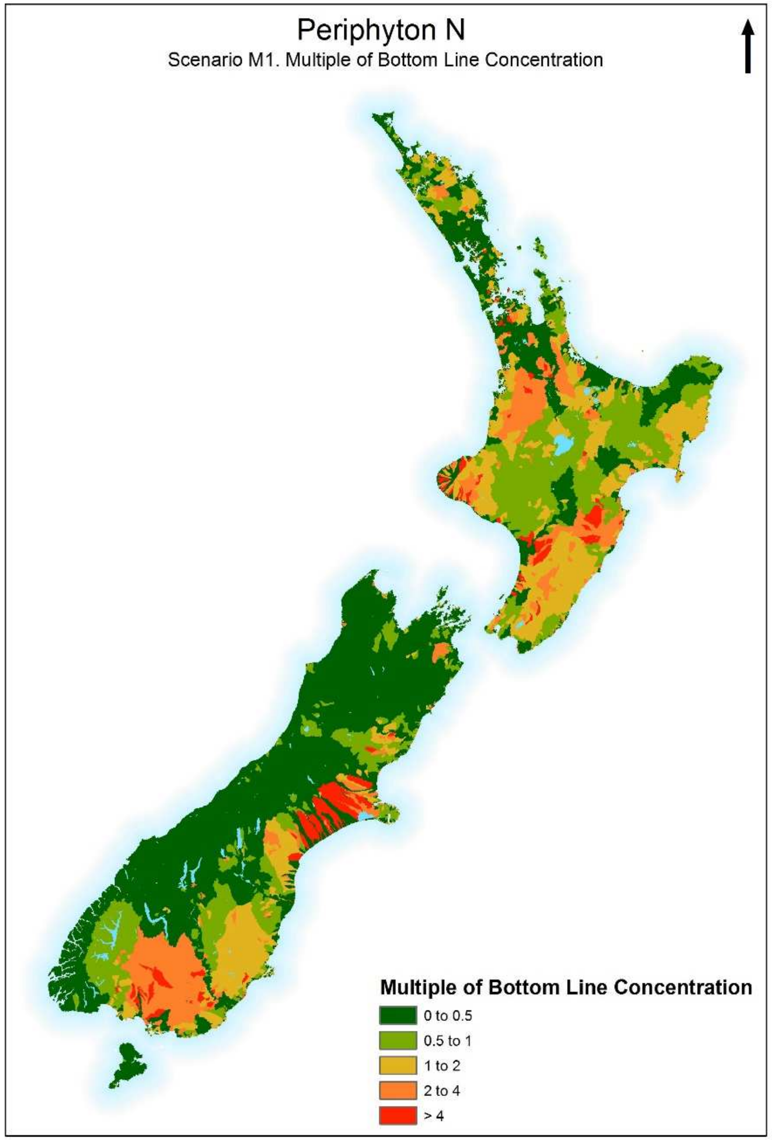

Nitrate Toxicity Median
Scenario M3. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

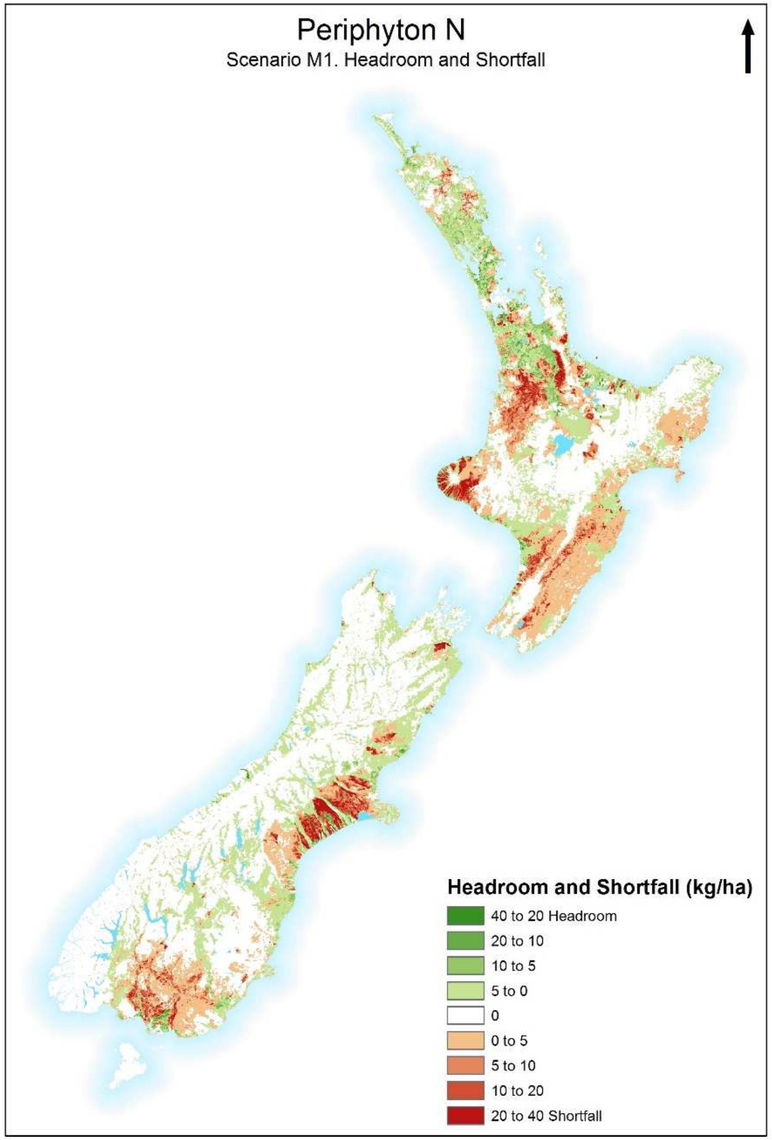
Periphyton N

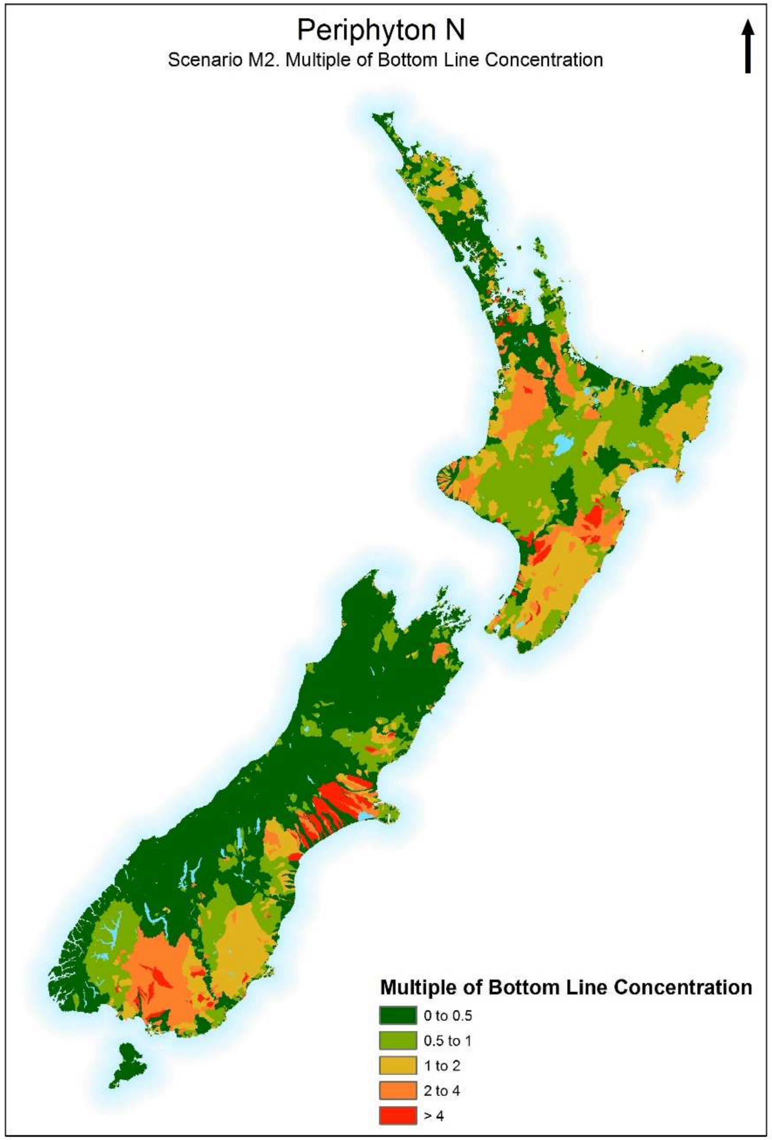
Note that if there are no bottom lines in nodes downstream, the areas are shown as green.

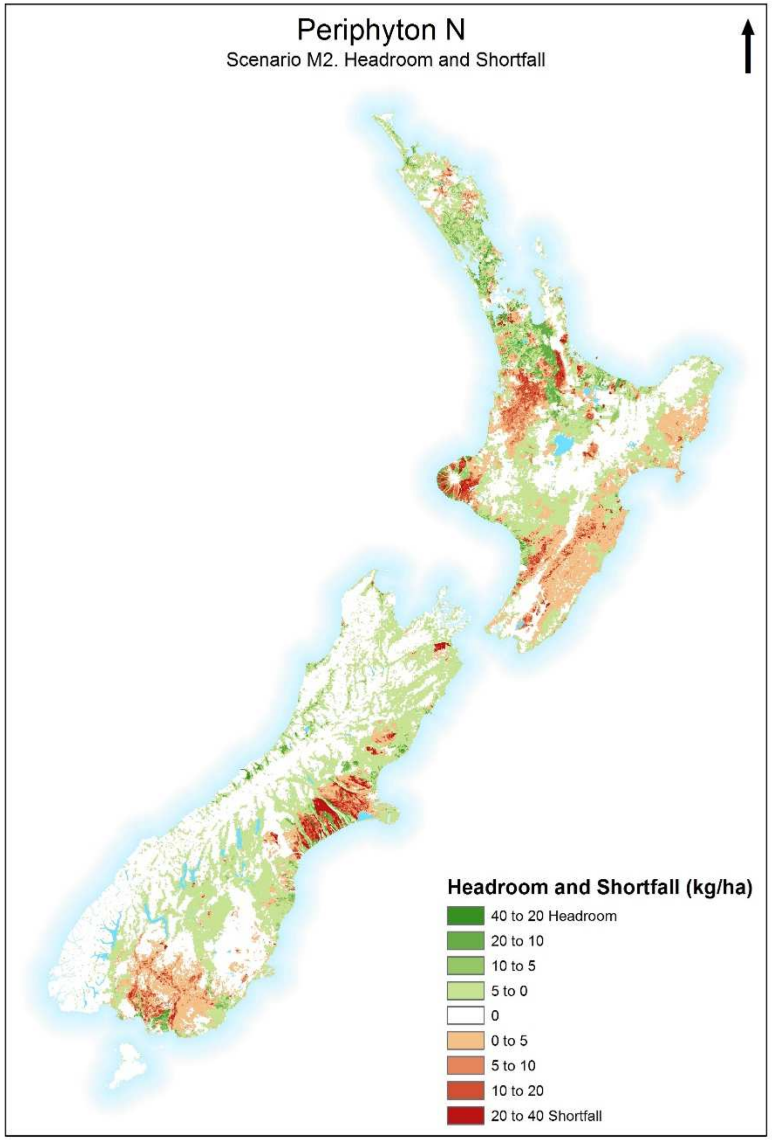

Periphyton N
Base Scenario. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

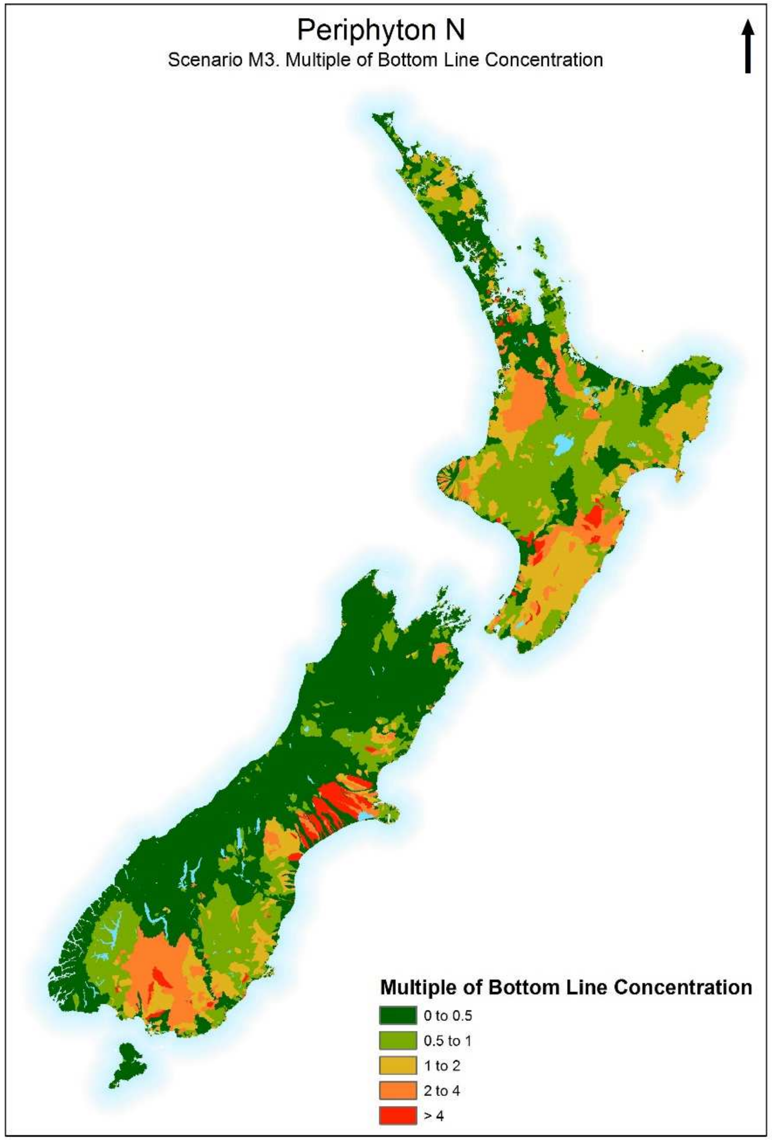

Periphyton N
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

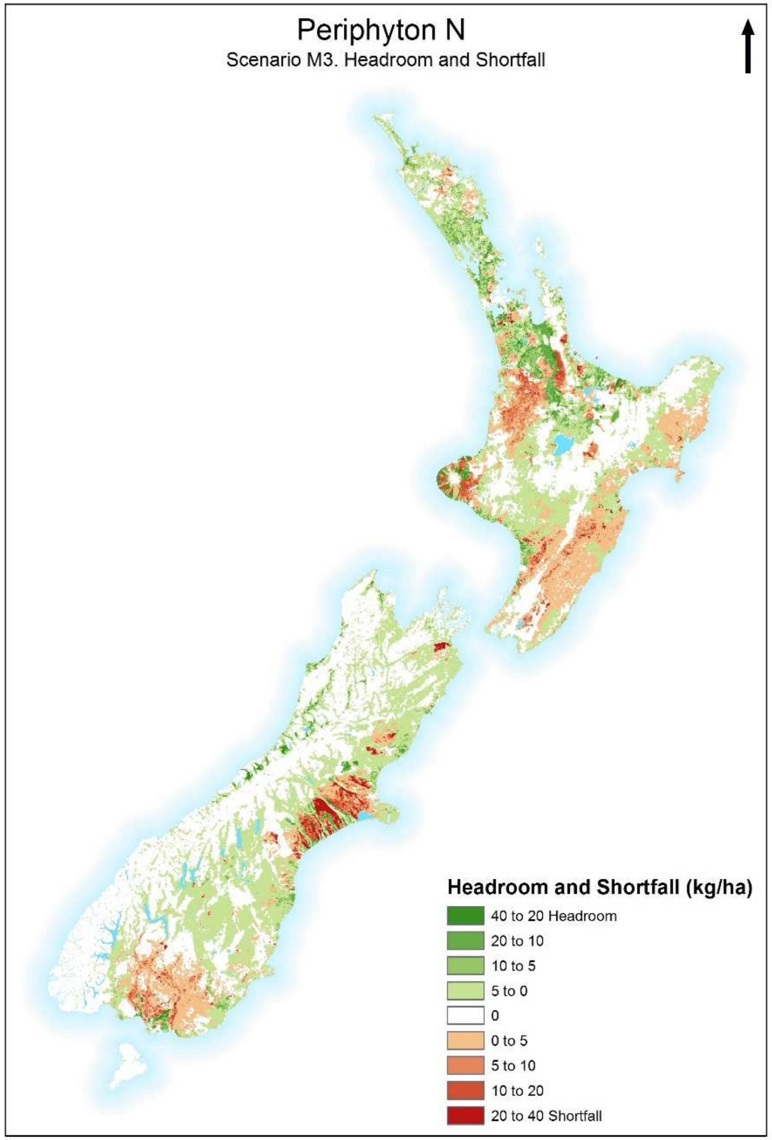

Periphyton N
Scenario M1. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Periphyton N
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

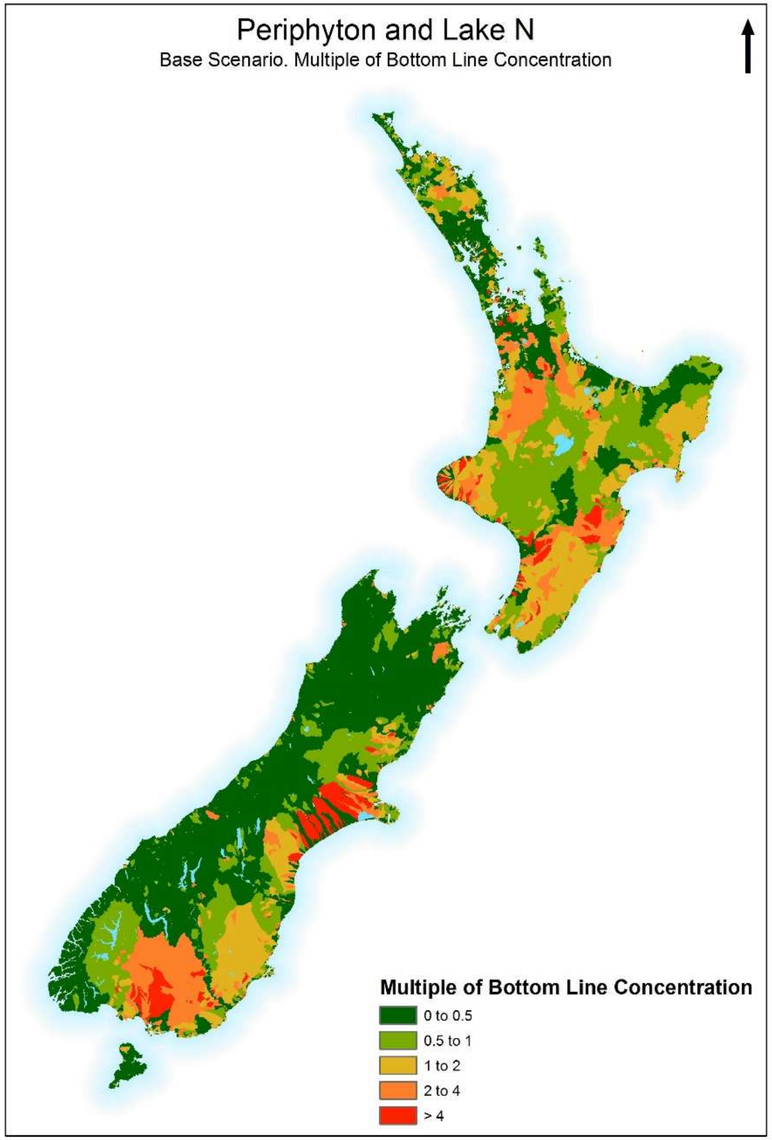

Periphyton N
Scenario M2. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

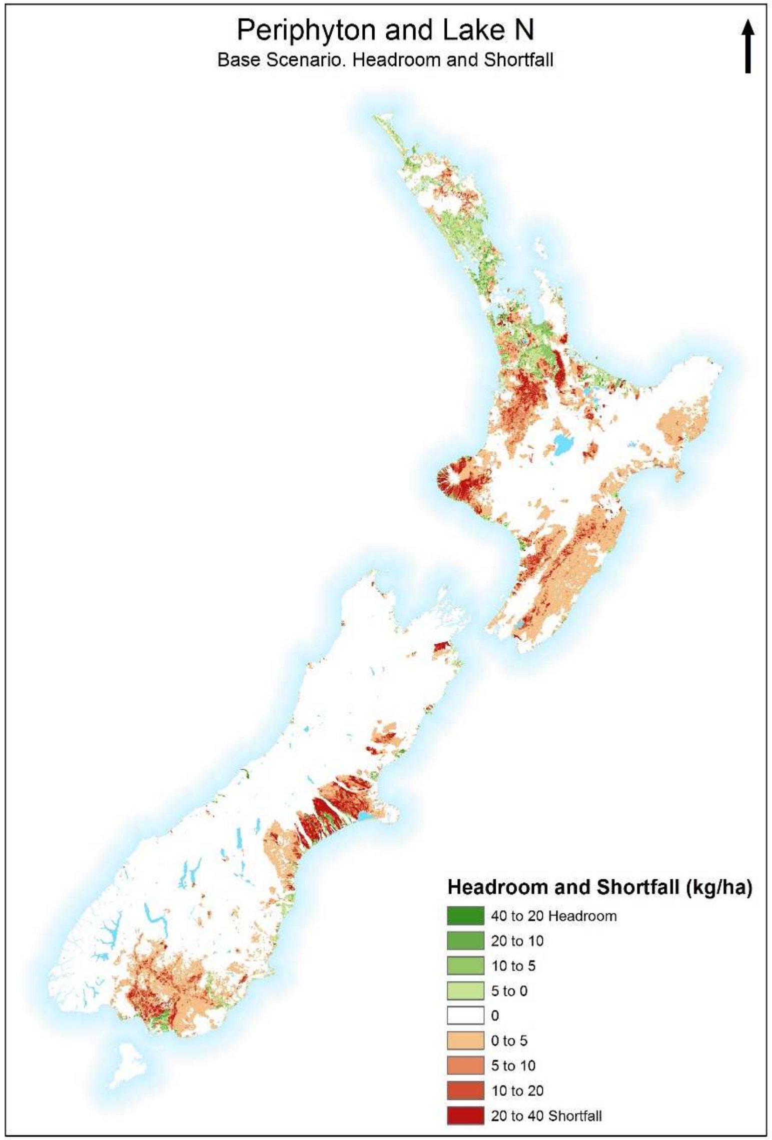

Periphyton N
Scenario M2. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

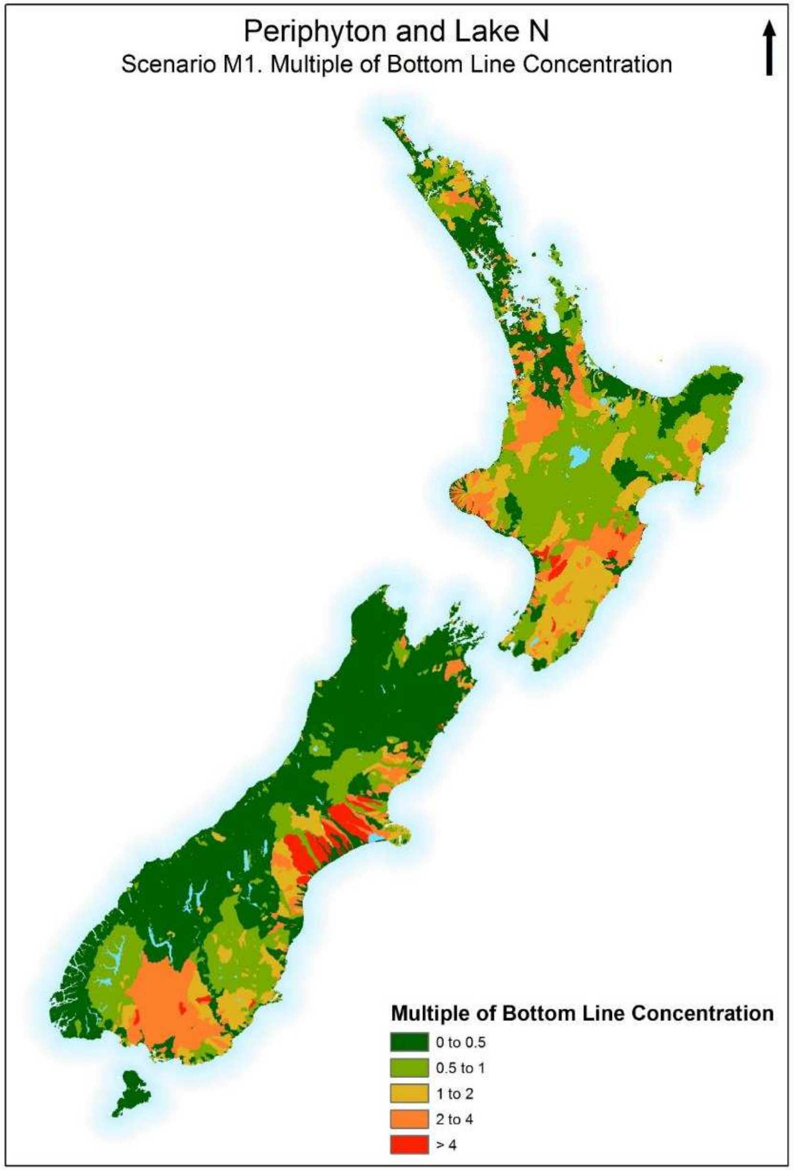

Periphyton N
Scenario M3. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

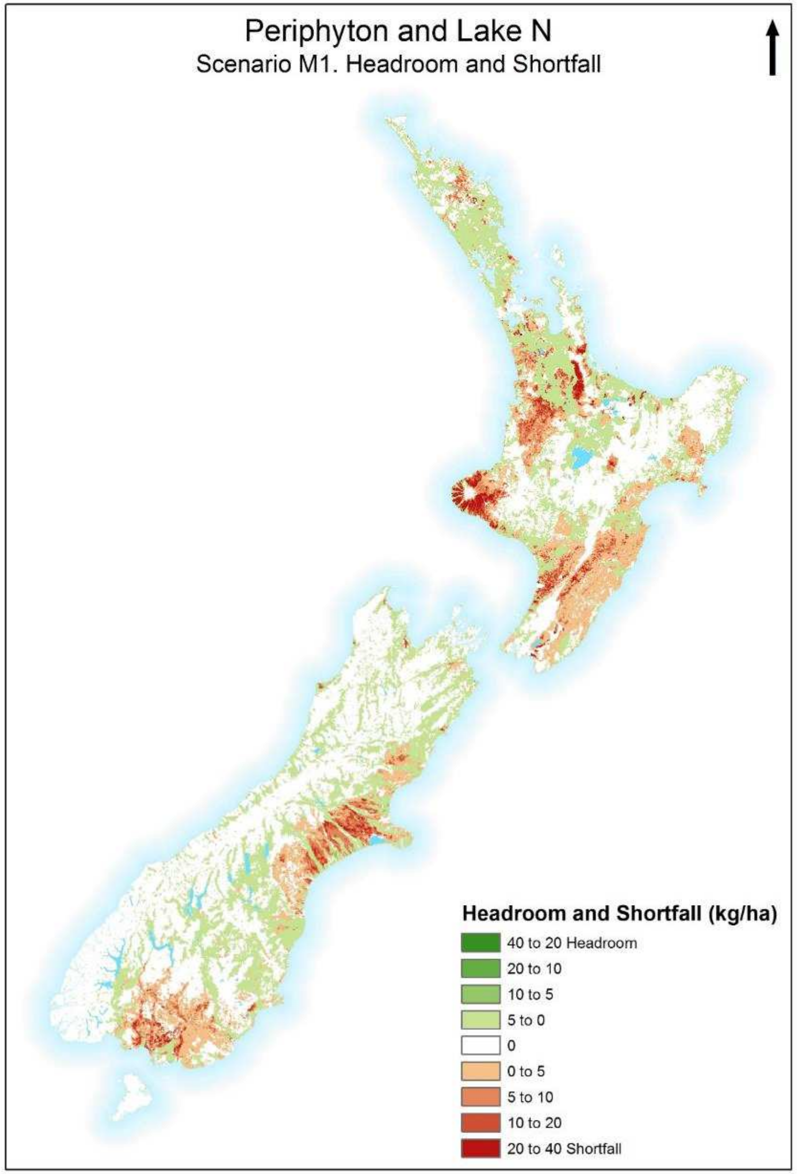

Periphyton N
Scenario M3. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

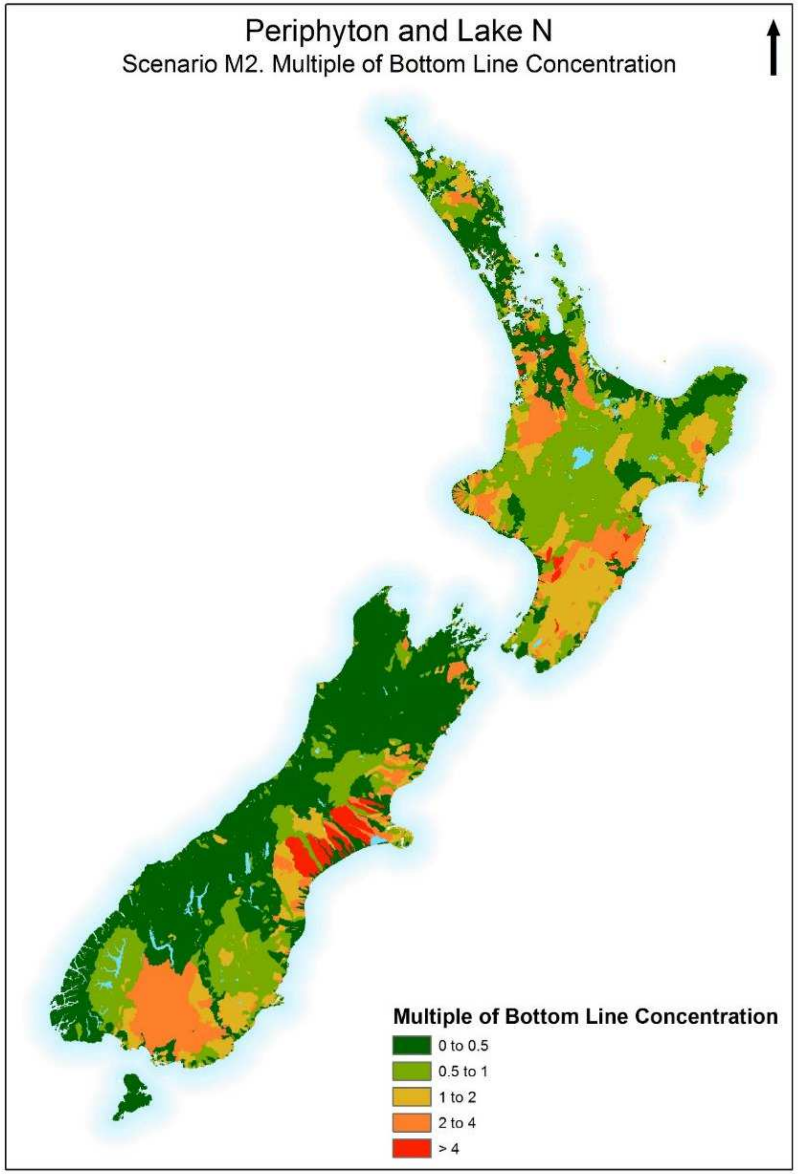
Periphyton and lake N


Periphyton and Lake N
Base Scenario. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

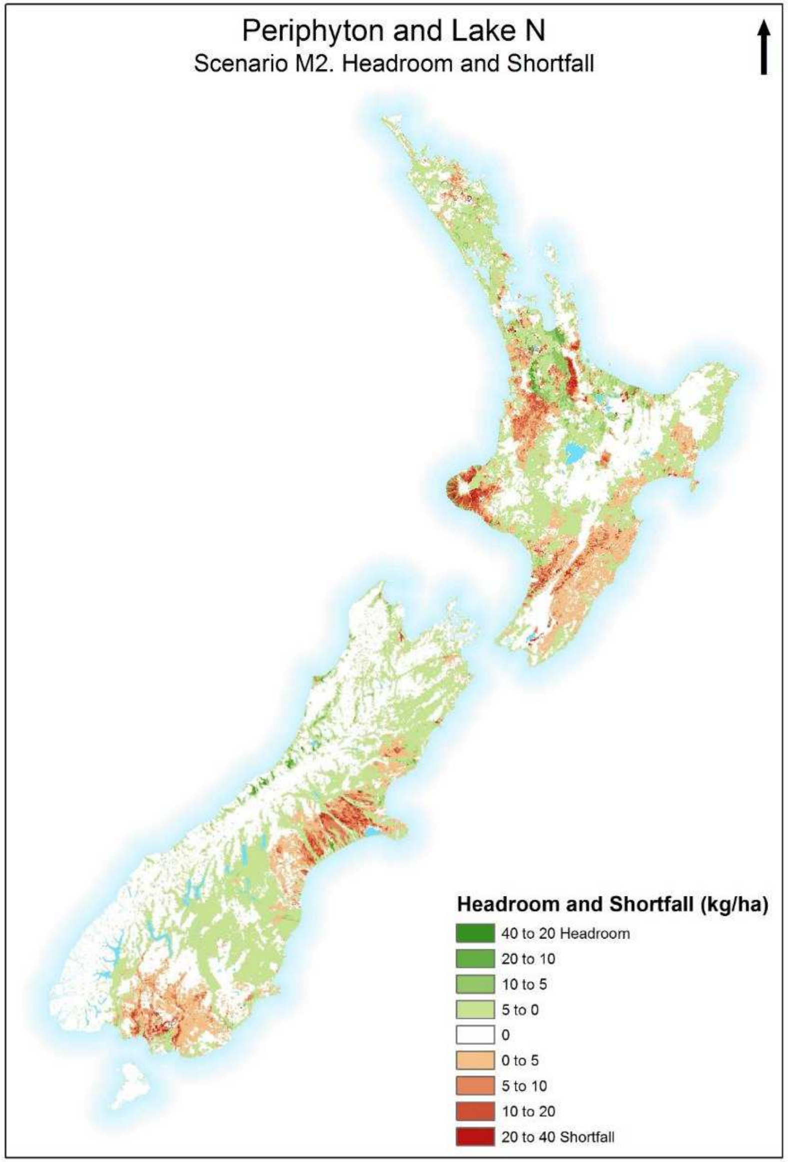

Periphyton and Lake N
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall


Periphyton and Lake N
Scenario M1. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

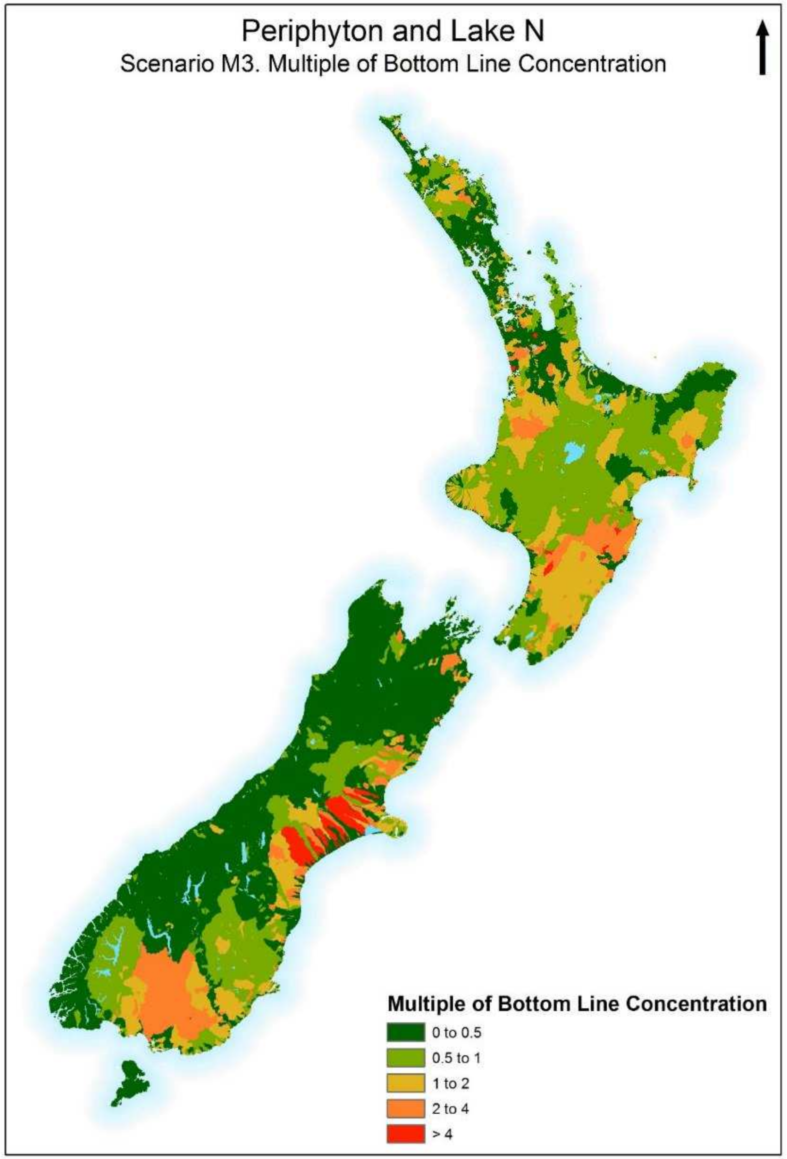

Periphyton and Lake N
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

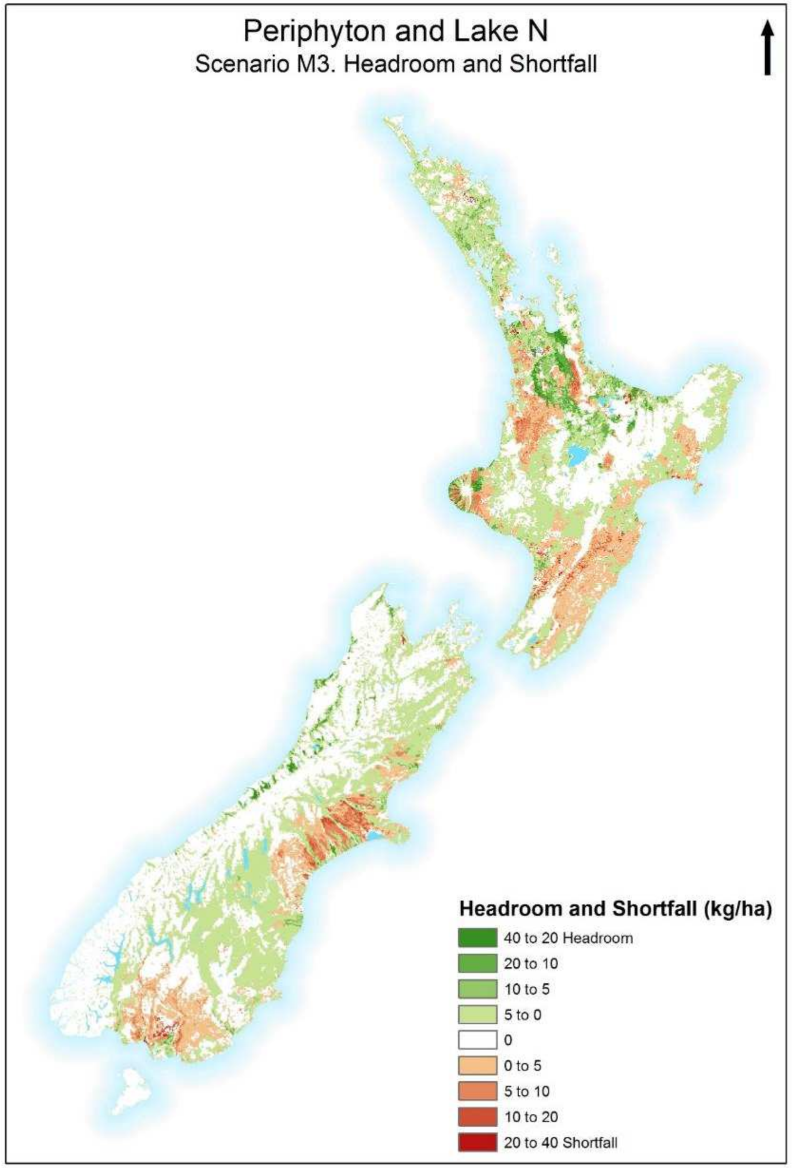


Periphyton and Lake N
Scenario M2. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4



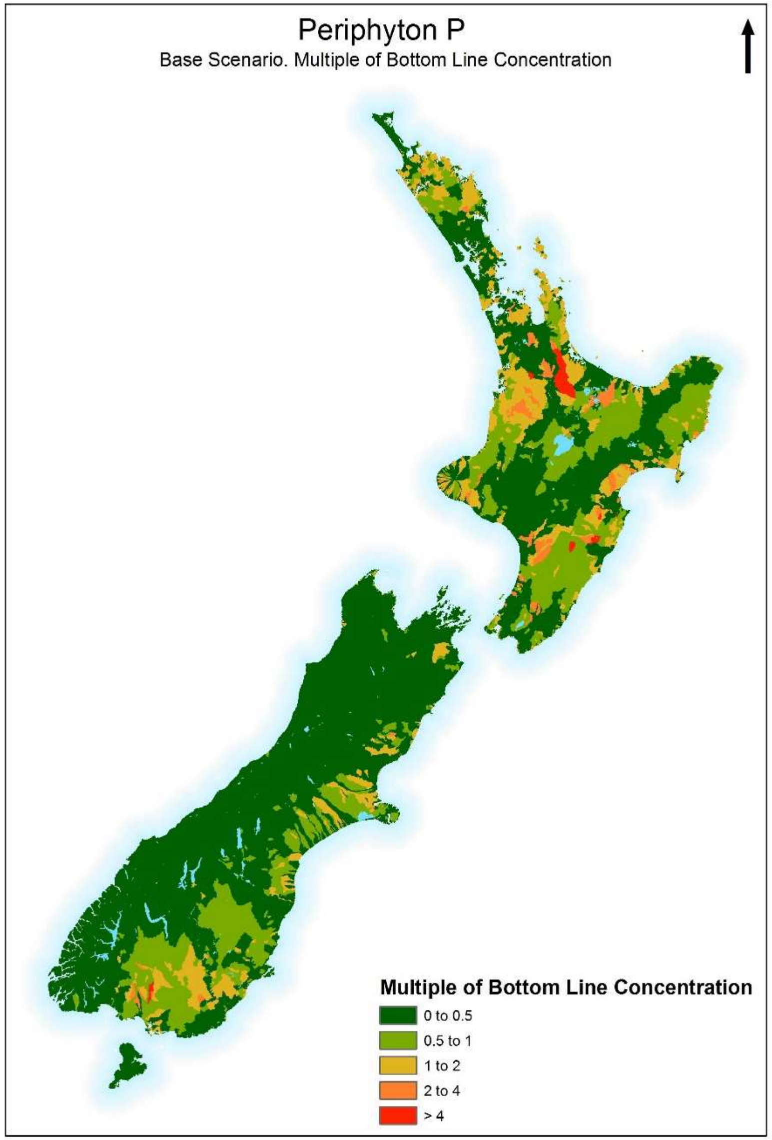
Periphyton and Lake N
Scenario M2. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

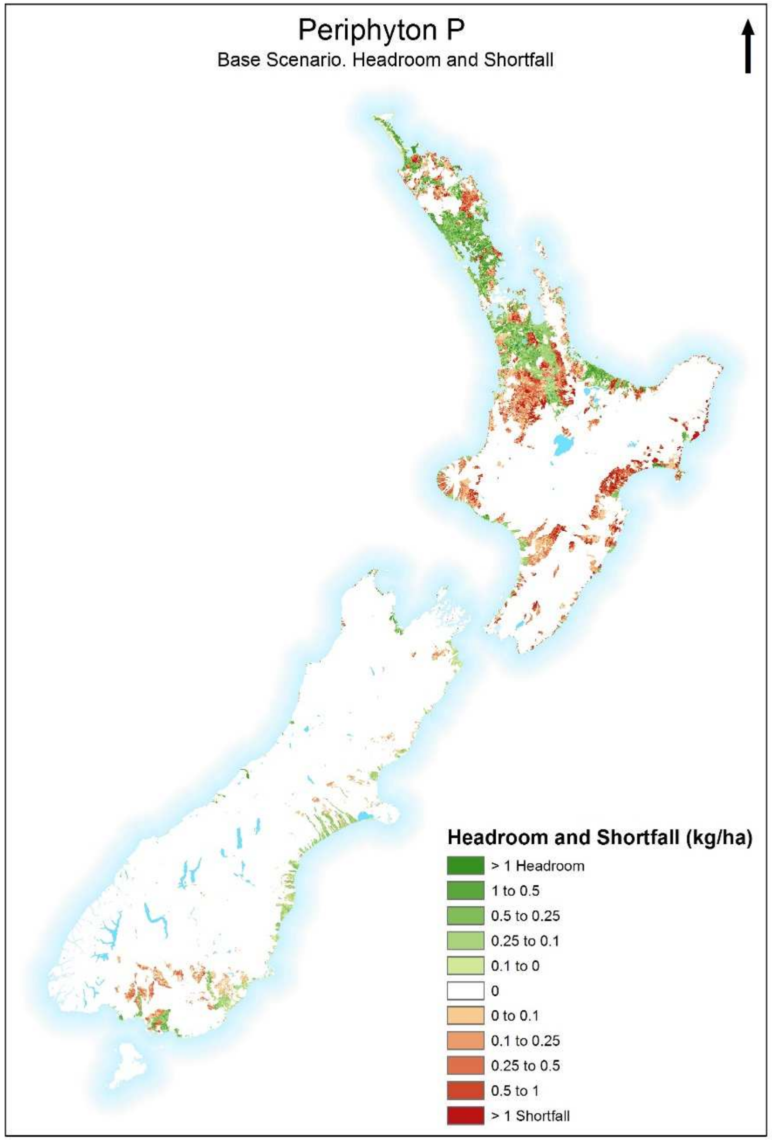

Periphyton and Lake N
Scenario M3. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

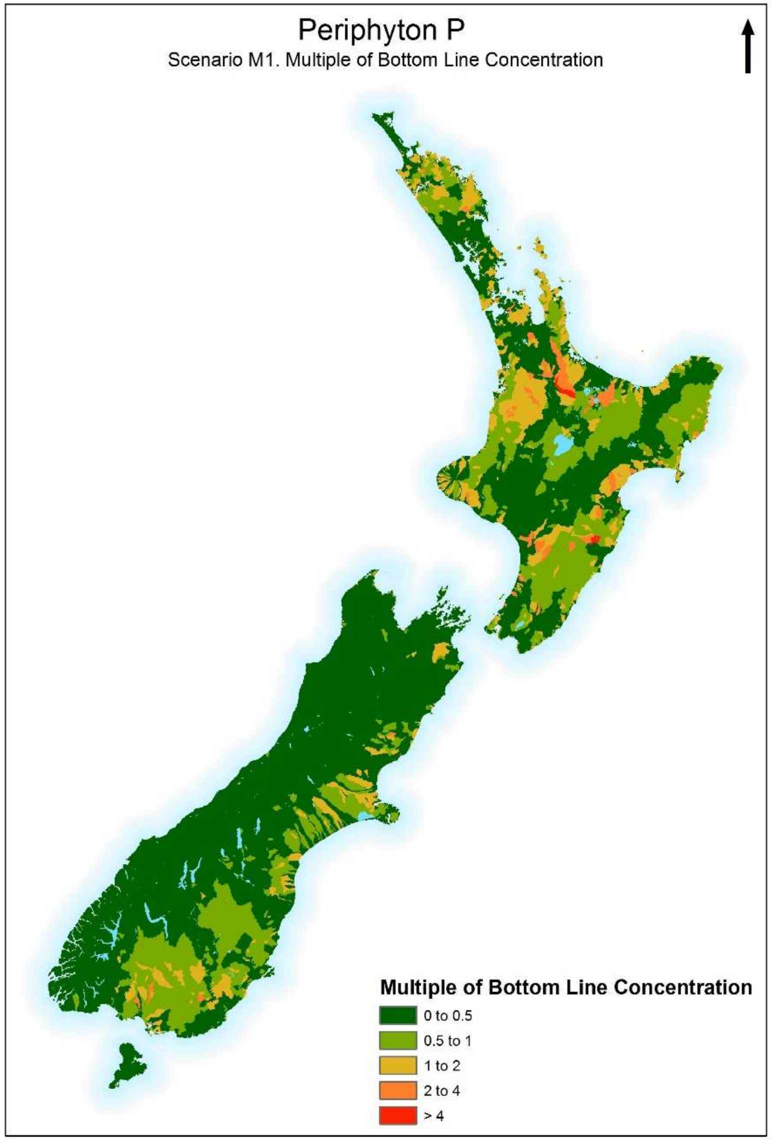

Periphyton and Lake N
Scenario M3. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
40 to 20 Headroom
20 to 10
10 to 5
5 to 0
0
0 to 5
5 to 10
10 to 20
20 to 40 Shortfall

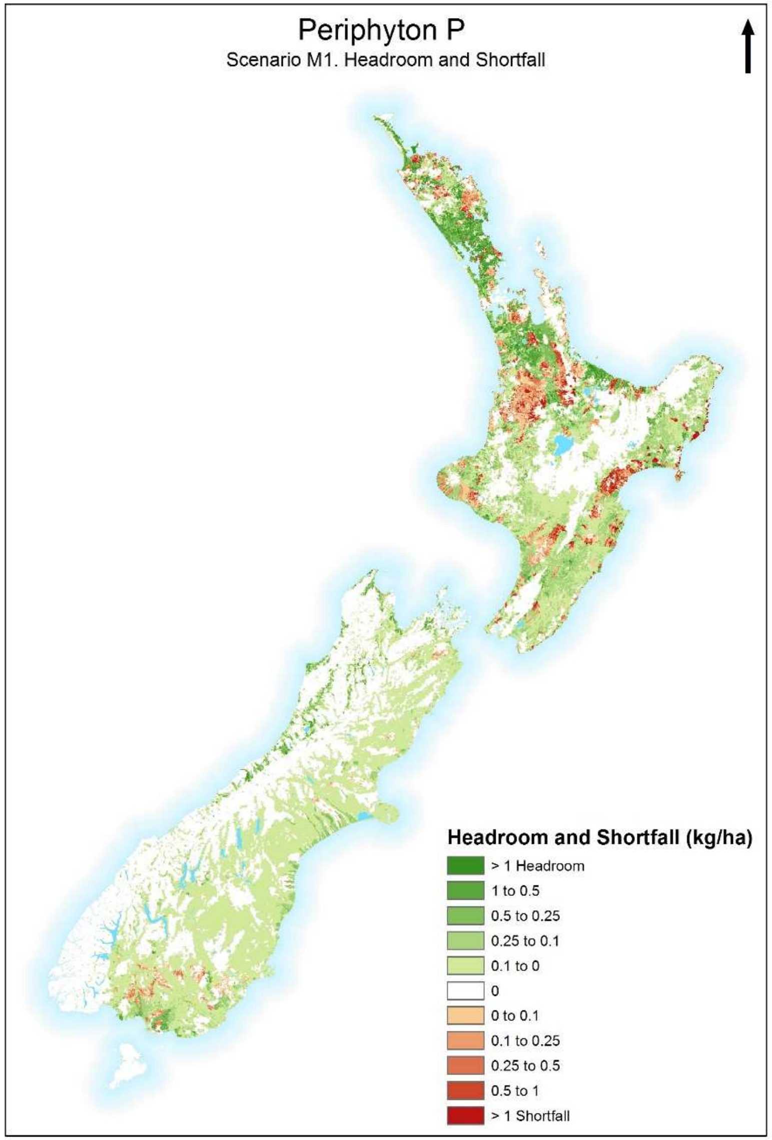
Periphyton P

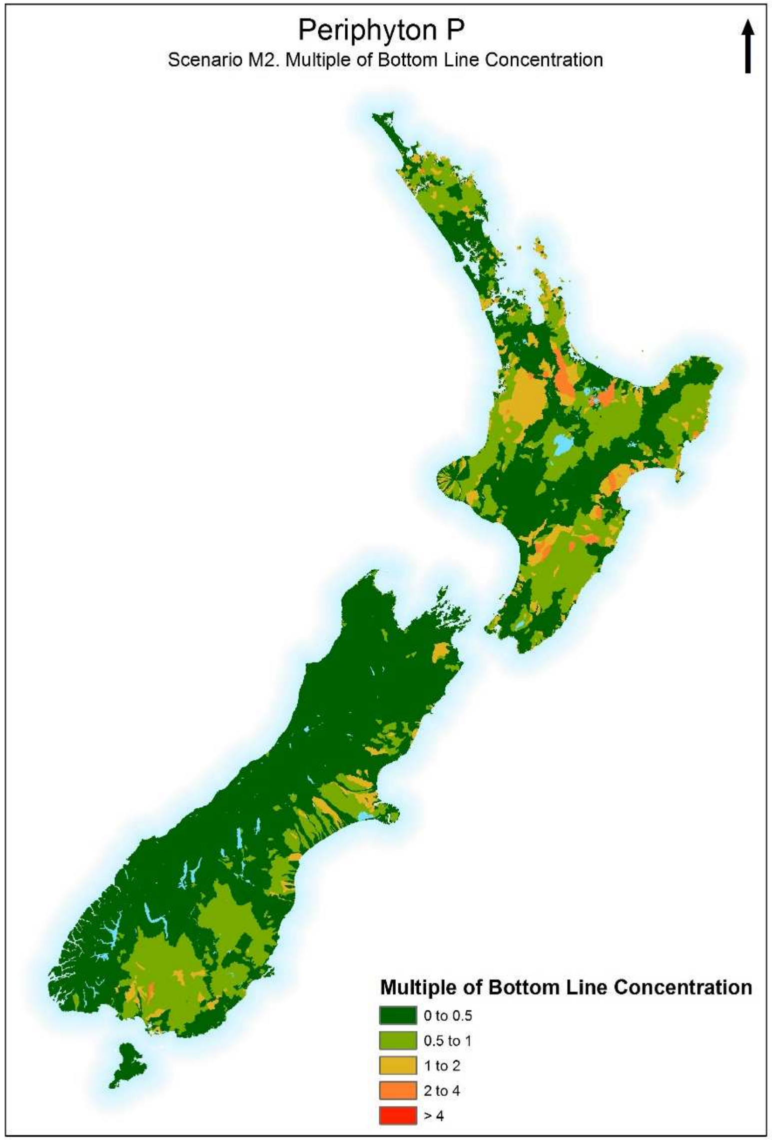
Note that if there are no bottom lines in nodes downstream, the areas are shown as green.

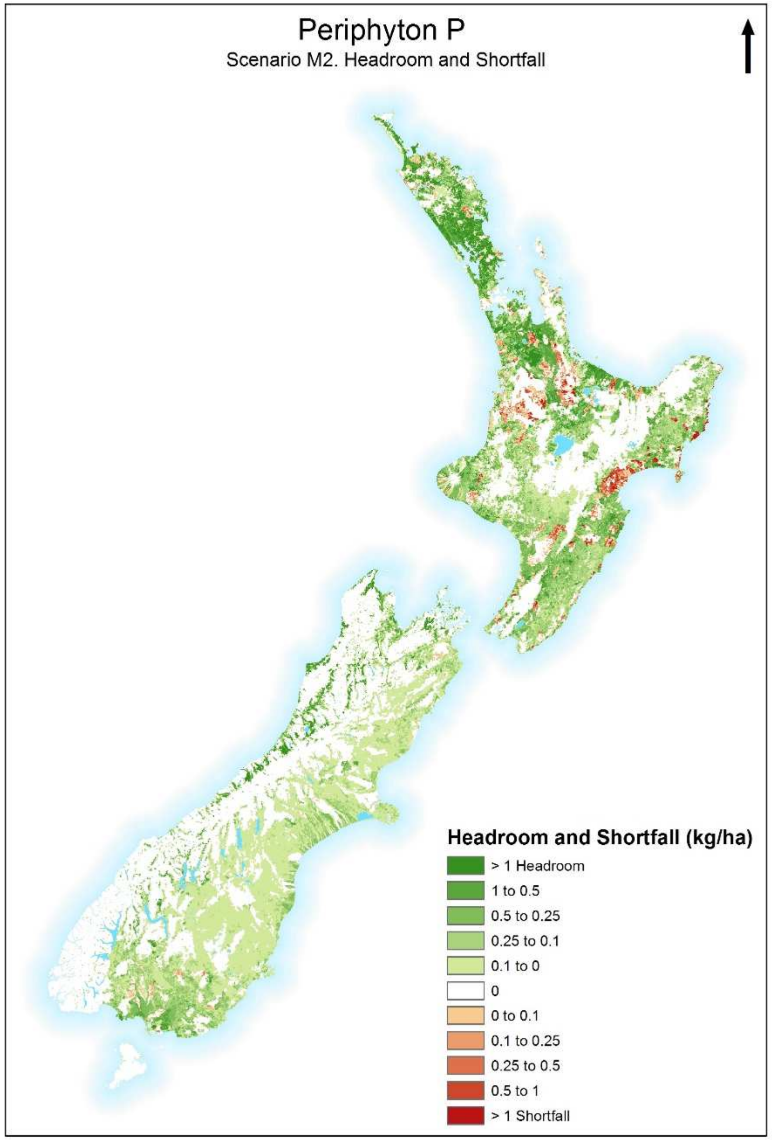

Periphyton P
Base Scenario. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Periphyton P
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

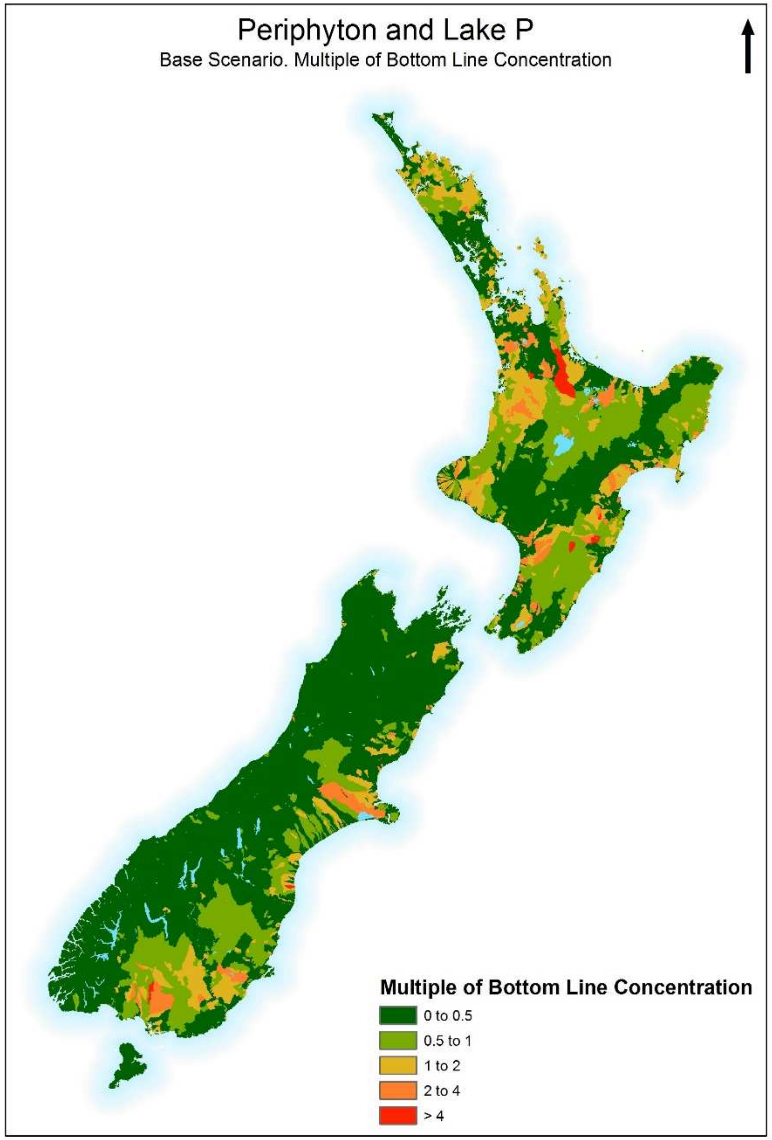

Periphyton P
Scenario M1. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

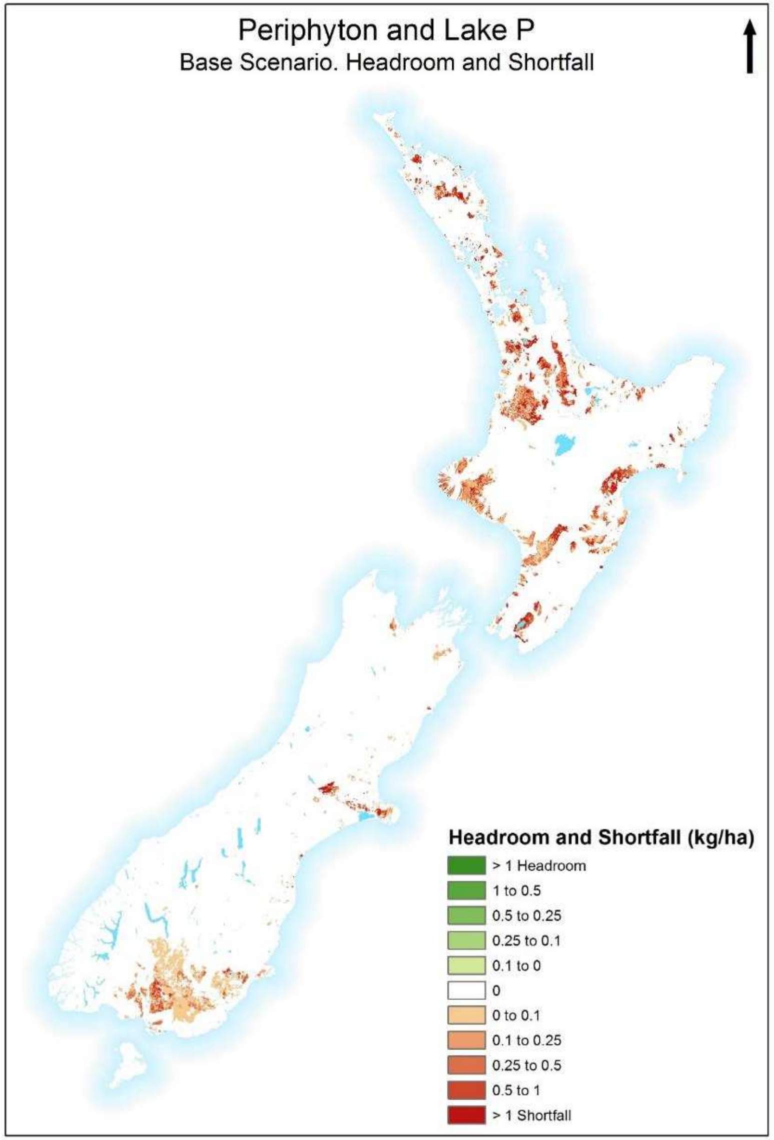

Periphyton P
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

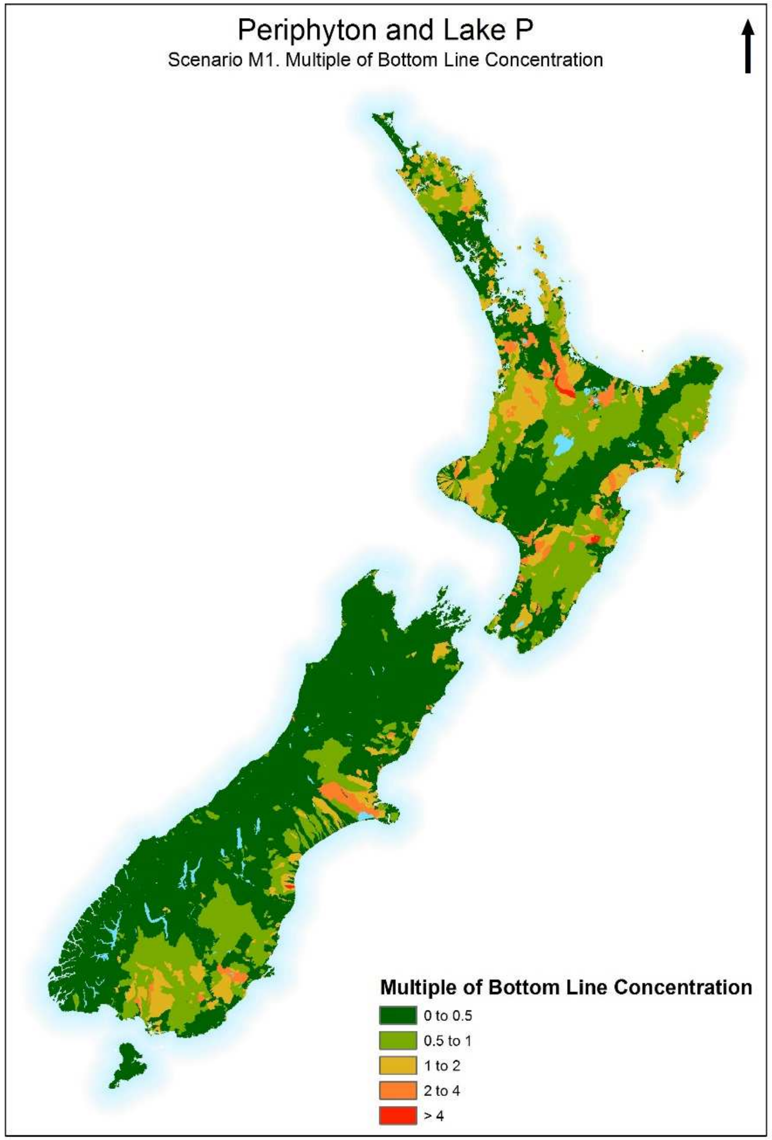

Periphyton P
Scenario M2. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

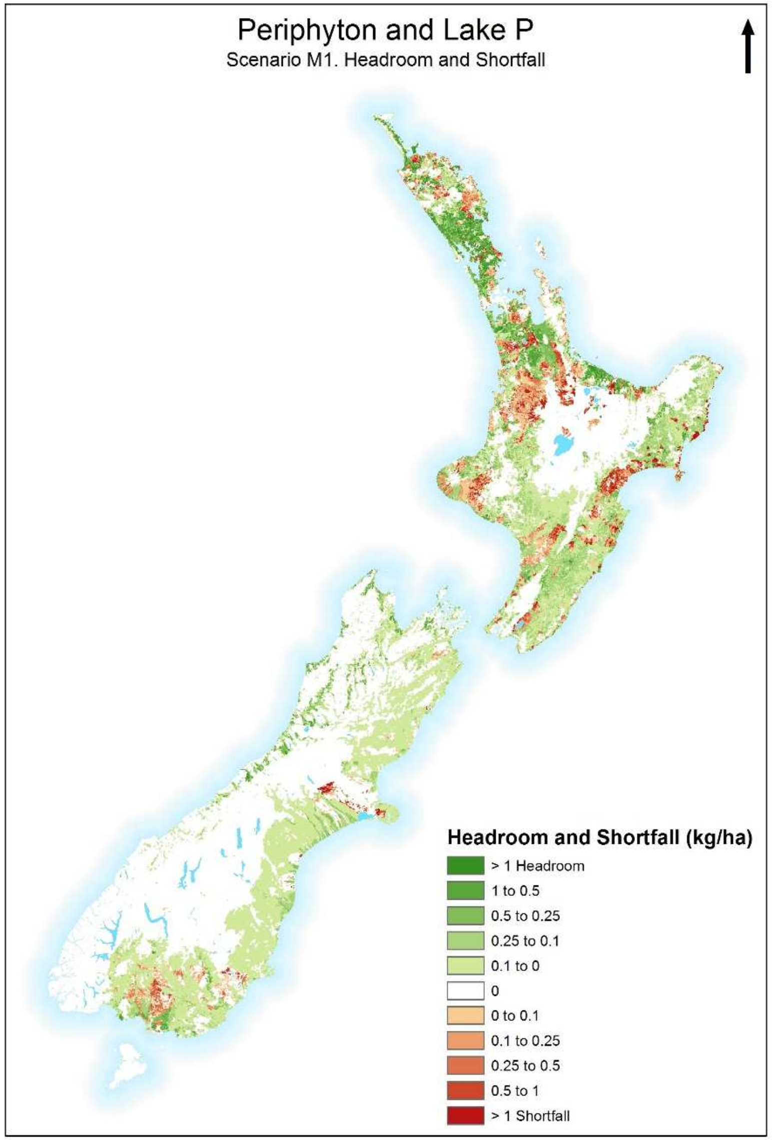

Periphyton P
Scenario M2. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

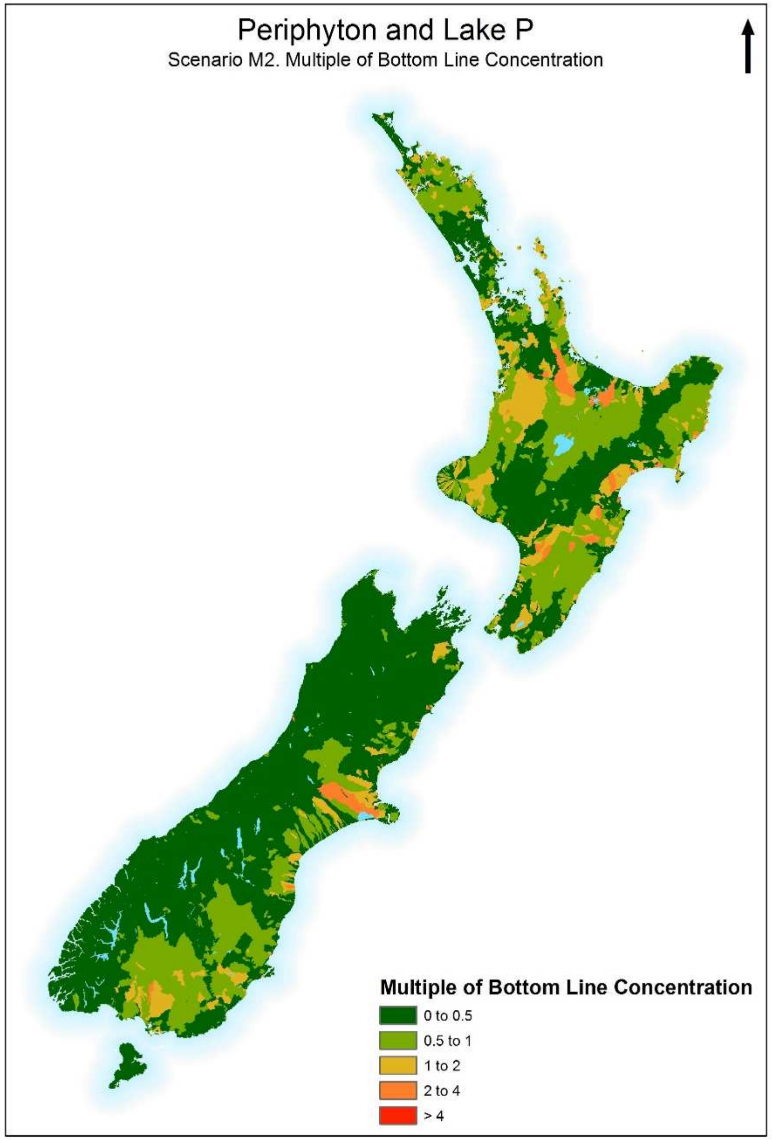
Periphyton and lake P

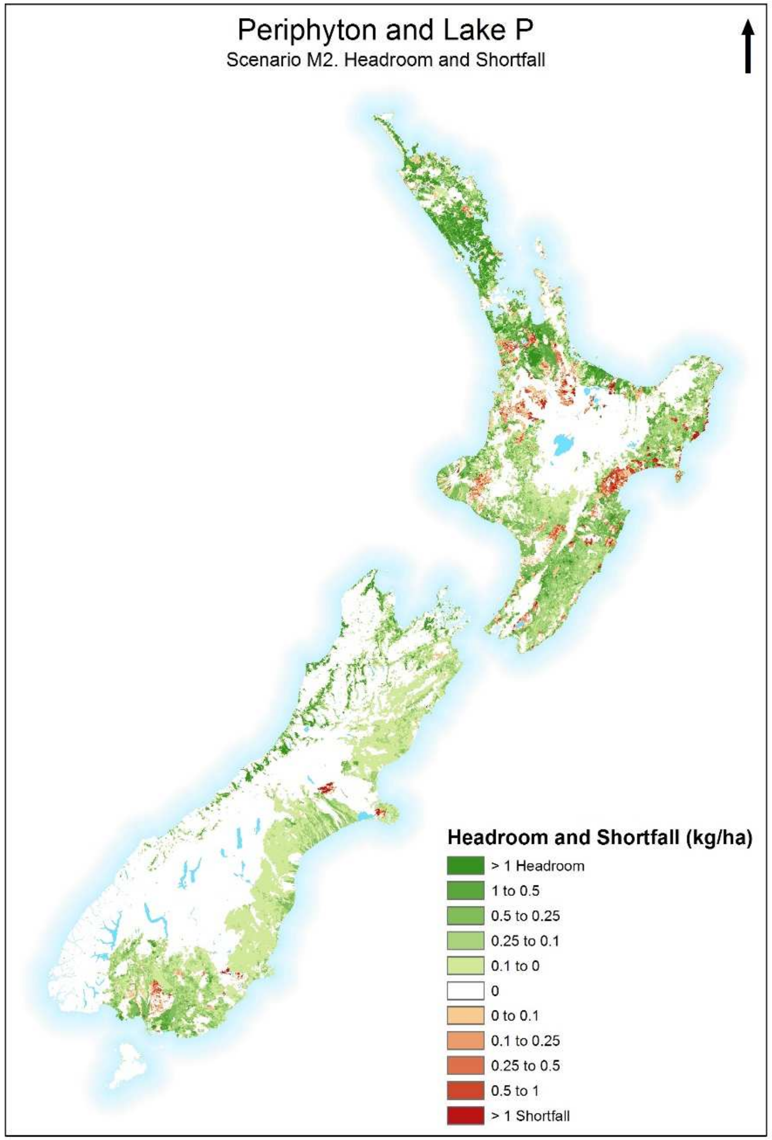

Periphyton and Lake P
Base Scenario. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4

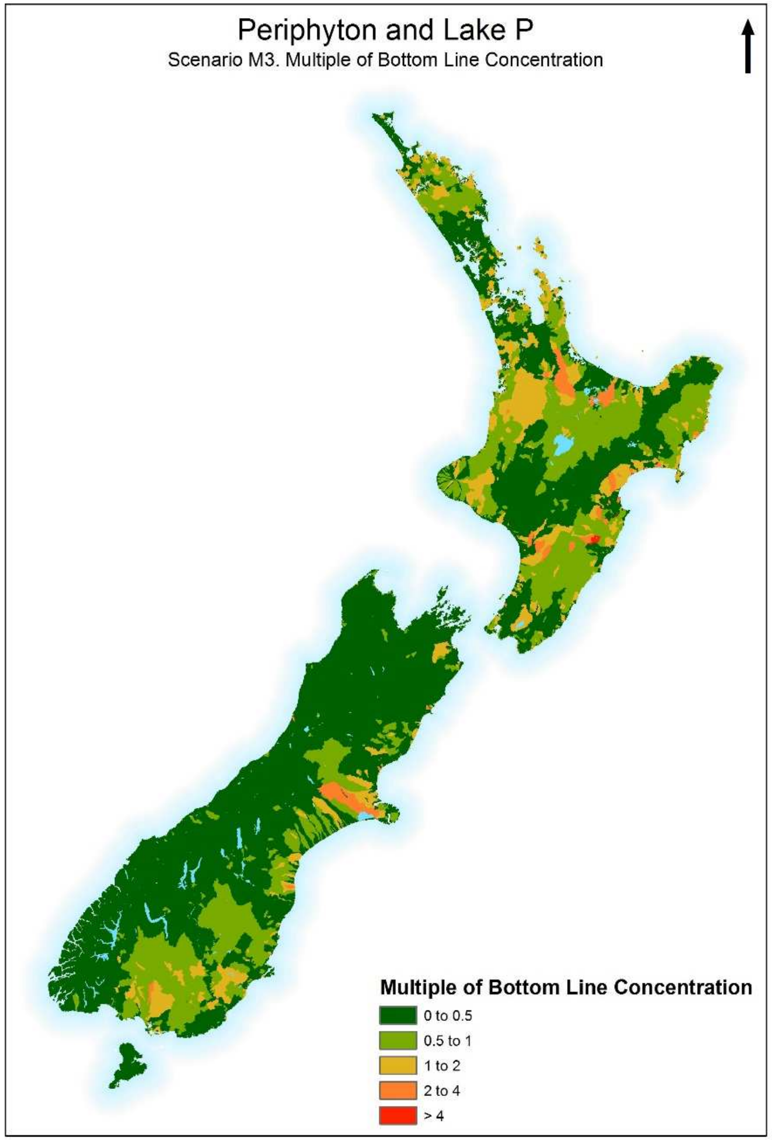

Periphyton and Lake P
Base Scenario. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall

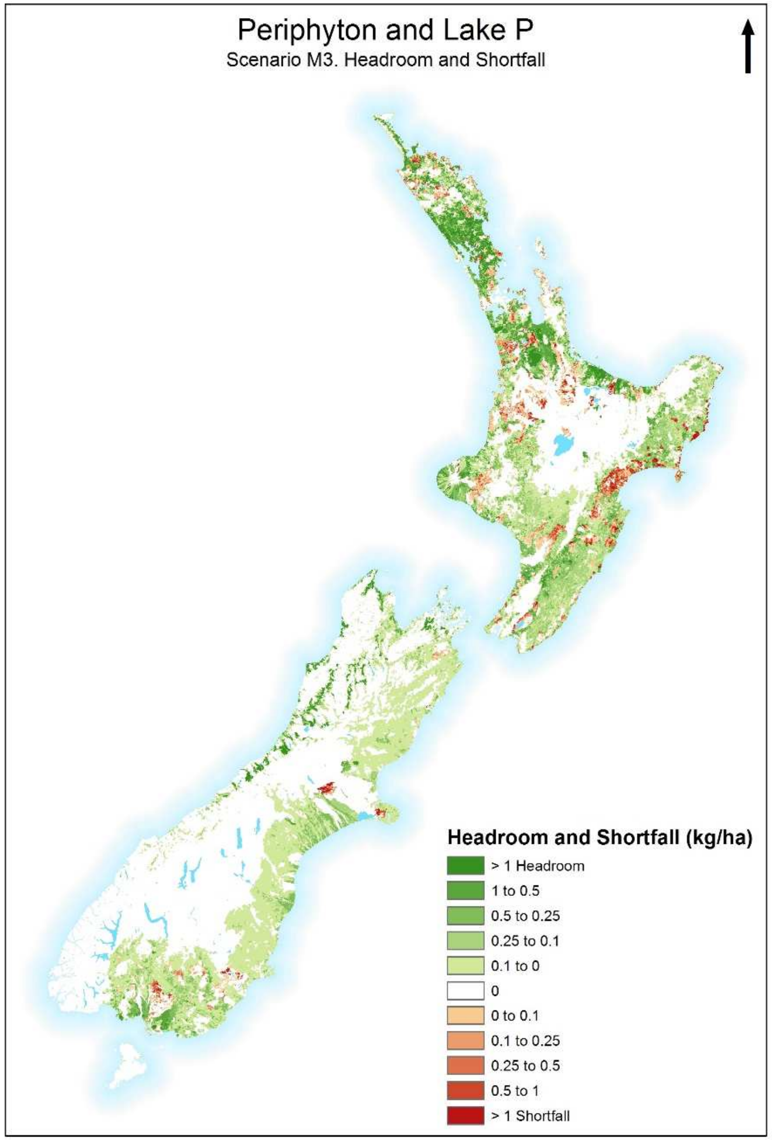

Periphyton and Lake P
Scenario M1. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Periphyton and Lake P
Scenario M1. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall


Periphyton and Lake P
Scenario M2. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Periphyton and Lake P
Scenario M2. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall


Periphyton and Lake P
Scenario M3. Multiple of Bottom Line Concentration
Multiple of Bottom Line Concentration
0 to 0.5
0.5 to 1
1 to 2
2 to 4
> 4


Periphyton and Lake P
Scenario M3. Headroom and Shortfall
Headroom and Shortfall (kg/ha)
> 1 Headroom
1 to 0.5
0.5 to 0.25
0.25 to 0.1
0.1 to 0
0
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1 Shortfall