NIWA
Taihoro Nukurangi

Effects of land and water management on ecological aspects of major rivers

in the Ruamahanga River catchment

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Executive summary

Greater Wellington Regional Council (GWRC) has initiated a series of community led collaborative planning processes to address land and water management issues and to carry out its obligations under the National Policy Statement for Freshwater Management (NPS). The first of these relates to the Ruamahanga whaitua[1], the catchment of the Ruamahanga River.

The collaborative group, called the Ruamahanga Whaitua Committee (RWC), requires tools to support decision making in an environment with many diverse values and complex biophysical processes. The Bayesian Network presented in this report is designed as a decision-support tool. It shows the expected consequences of various possible management and policy decisions on values related to large gravel-bed rivers. The values include ecological values (three species and one index of native fish, periphyton (attached algae), *Phormidium* (toxic algae), macroinvertebrate community index and river birds), recreational values (trout size/abundance) and natural character.

This report describes the structure of the Bayesian network, the "states" of the key variables (nodes) and the predictive relationships between them, including comments on the assumptions, limitations and appropriate application of the network. It references the sources of information used to derive the network to allow the assumptions to be tested. The report is intended as a companion to the Bayesian network itself, which runs on Netica™ software. A free evaluation version of Netica™ is available from www.norsys.com.

The Bayesian network was designed to be used in association with other models that predict water quality and quantity resulting from policy/management decisions. This network uses results of those models as input and predicts their consequences for the suite of ecological, recreational and aesthetic values listed above.

The RWC has outlined three possible future scenarios to be tested with the various models that support their decision-making. The first, Business as Usual (BAU), extends existing policy, practice and investment into the future. The second, Silver, corresponds to a moderate effort for making water quality improvements across the whaitua. The third, Gold, represents the highest and most aspirational effort for making water quality improvements across a broad range of activities and issues in the whaitua. The Bayesian network outputs for each of these scenarios will be used by the RWC to inform their ongoing discussions and ultimately to develop recommendations for managing land in water for their Whaitua Implementation Programme.

Outputs are presented here for 10 reporting reaches, each 6-9 km long: two on the Ruamahanga River and eight on major (fourth-order or larger) tributaries. According to the Bayesian network, by 2080, periphyton growth decreases by 30-40% in Silver and Gold relative to baseline and BAU at three sites; MCI score improves by ~3-4 points in Silver and Gold relative to baseline at two sites and relative to BAU at four sites; probability of a *Phormidium* bloom decreases in Silver and Gold relative to BAU at one site, but increases significantly relative to baseline at two sites and it increases significantly in BAU, Silver and Gold relative to baseline at one site; trout size and abundance does not change in any scenario relative to baseline; Fish IBI score increases in Silver and Gold relative to BAU and baseline at one site; the probability of presence for eels, redfin bullies and inanga shows the same patterns as Fish IBI; the probability of wading bird abundance being OK increases in Silver and

[1] The Maori word whaitua means a designated space or catchment. Greater Wellington Regional Council has divided the Greater Wellington region into five whaitua with a committee in each making decisions on the future of land and water management in that whaitua

Gold relative to BAU and baseline at one site, but decreases in BAU, Silver and Gold relative to baseline at one site; natural character shows only a small increase at each site under Silver and Gold relative to BAU.

The main drivers of change in these attributes are reduced concentrations of dissolved nutrients, and suspended solids, increased riparian tree cover and a shift from river discharge to land-based dispersal of sewage treatment plant effluent. However, some of the changes in drivers are minor, and some other important drivers of ecological outcomes, such as flow regime, change very little or not at all among the scenarios. In addition, the reporting reaches are all on moderately large rivers (mostly fourth-order or larger), which are relatively insensitive to changes in factors such as riparian vegetation. For these reasons, overall only a few attributes showed more than minor changes in any of the three scenarios compared to baseline. Silver and Gold scenarios showed some differences in outcomes compared to BAU, but there were no differences between Silver and Gold by 2080; the only differences between these two scenarios were that some attributes changed a little earlier in Gold than in Silver.

1 Introduction

1.1 The Ruamahanga Whaitua process

Greater Wellington Regional Council (GWRC) has initiated a series of community led collaborative planning processes to address land and water management issues and to carry out its obligations under the National Policy Statement for Freshwater Management (NPS). The first of these relates to the catchment of the Ruamahanga River. This catchment, known as the Ruamahanga Whaitua, is the first of five whaitua comprising the Greater Wellington region, to undergo this process. The aim of the planning process is to setting policies on water quality and quantity in rivers, streams, wetlands, lakes and groundwater in an area of 3300 km^2. Recommendations on these policies are made by a collaborative group called the Ruamahanga Whaitua Committee (RWC) comprised of about 14 members of the community as well as representatives of iwi and territorial authorities.

The planning process is conducted within the legal framework of New Zealand resource management law. In particular, it must give effect to the Resource Management Act and the National Policy Statement on Freshwater Management (NPS-FM 2017). The NPS-FM specifies that regional councils must "make or change regional plans to the extent needed to ensure the plans:

a) establish freshwater objectives in accordance with Policies CA1-CA4 and set freshwater quality limits for all freshwater management units in their regions…., and

b) establish methods (including rules) to avoid over-allocation."

With respect to water quantity, the NPS-FM specifies a similar requirement for "setting environmental flows and/or levels for all freshwater management units in its region."

Through the National Objectives Framework (NOF), the NPS-FM identifies ecosystem health and human health for recreation as "compulsory national values" that must be maintained in regional plans. Within these two values it specifies condition bands for several attributes with the lowest band representing a national "bottom line" that regional plans must equal or exceed.

To deliver appropriate recommendations, the RWC must base their decisions on robust information including scientific information. However, the science for such a large area with diverse values is highly complex. Different components of a river system interact in complex ways such that a single decision has effects on multiple values. RWC members need decision-support tools that enable them to determine and compare the effects of different management or policy options on a wide range of values. They are also required to provide transparency regarding their decision-making process.

1.2 Bayesian networks

Bayesian networks (BNs) are a tool particularly well-suited for supporting decisions on environmental resource management. Their strength in helping to resolve complex environmental problems lies in their ability to incorporate the effects of multiple influences on a wide range of values (economic, social, cultural and ecological) and to include information from a variety of sources, including empirical data, scientific theory, various types of models and expert opinion (Quinn et al. 2013).

BNs represent the components of a river system in the form of "nodes" (shown as boxes or circles), with the cause-effect relationships (linkages) between them shown by arrows. Each node in a BN has two or more possible states, and the BN represents outcomes as a probability distribution between the possible states. The effect of the causative (parent) nodes on another (child) node is quantified in a "conditional probability table" (CPT). The CPT shows the probability of each state in the child node, given each combination of states in the parent nodes. In a causative chain with multiple linkages, a change in the state of the top node propagates through the entire network to all the "descendant" nodes. In the context of resource management, the top nodes typically represent either management decisions or variables that are specified by either monitoring data or outputs of external models. The final descendant nodes represent components of the system, such as species, aspects of the environment, economic indicators, etc., that are valued by the community. In this way, BNs condense complex scientific information into an intuitive form that is appropriate for guiding stakeholder deliberations and supporting decision-making.

BNs allow users to visualise the interacting components of a river system and run "what-if" scenarios with different management options. Thus, they are useful in group situations where a shared understanding of the system is important, and where all members need to see the effects of different management options. BNs provide transparency to decision-making, whether those decisions are made by councils or stakeholder groups.

BNs are not intended to replace mechanistic models. Rather, they summarise the key outputs of mechanistic models and integrate them with other sources of information. Because they describe outputs in terms of probabilities, BNs can incorporate highly precise forms of knowledge with other forms that are inherently less precise or subject to a range of influences outside the BN.

Bayesian networks are intended to reflect our best estimate regarding the state of different components in a system, based on what we know of the factors affecting them. They are intended to be updated with more precise knowledge as it becomes available, or to be amended to reflect locations where ecological relationships differ from the general pattern.

1.3 Scope of this report

1.3.1 Description of the Bayesian network

This report outlines a Bayesian network (BN) that was developed to support decision-making by the RWC. It does this by showing the consequences of different possible policy options for key ecological attributes. This BN was developed from a generic BN applicable to large gravel-bed New Zealand rivers (Storey 2015). In the Ruamahanga River catchment, it is applicable to the Ruamahanga River itself and the lower reaches of its major tributaries. This report first describes the rationale, methods and assumptions underlying the BN so that it can be applied appropriately for decision-making in the rivers of the Ruamahanga catchment. To avoid unnecessary repetition, readers are referred to Storey (2015) for some details of the methods and assumptions.

The Bayesian Network is capable of predicting responses to land use changes (particularly with regard to agricultural intensification) and increases in water abstraction that result in a significant decrease in the river's flow.

The focus of this BN is on ecological values (invertebrates, periphyton, *Phormidium*, native fish and river birds), recreational values (trout fishing) and aesthetic values (natural character). We acknowledge the importance of other values, such as Maori cultural values (including mahinga kai, taonga species and the mauri of the river), uses such as drinking water and industrial processing, specific recreational values, such as whitewater kayaking or rafting, economic and tourism values. All these values are important, and could be incorporated into future extensions of the BN.

In some parts of the BN (e.g., effects on trout size and abundance) many quantitative studies and models are available and outcomes can be determined relatively precisely. In other parts (e.g., effects on river birds), the effects of influential factors are known only in general terms and outcomes can only be known in general terms. In some areas the science is developing rapidly. This BN incorporates the most recent thinking in most areas, but in a few (e.g., trout), very recent developments may not be captured.

1.3.2 Outputs of the Bayesian network

The report outlines the BN results for the current state (called Baseline) and three scenarios that the RWC is considering. These three scenarios are referred to as Business as Usual (BAU), Silver and Gold.

The BAU scenario extends existing policy, practice and investment into the future. Key changes in resource management under this scenario include wastewater treatment plants progressively discharging to land and stock exclusion from water bodies in accordance with the Proposed Natural Resources Plan rule. This scenario is drawn from existing information and is not designed by the RWC.

The management options in the Silver scenario correspond to a moderate effort for making water quality improvements across the whaitua. In general, management actions occur in longer timeframes than the Gold Scenario. For example, space planting on steep slopes is completed by 2040.

The Gold scenario represents the highest and most aspirational effort for making water quality improvements across a broad range of activities and issues in the whaitua. It envisages actions to manage sediment, wastewater, water allocation, wetlands and on-farm practices. Management options happen in the shortest timeframes of the three integrated scenarios – for example, all wastewater treatment plants discharge only to land by 2025.

For each scenario, results have been generated at three time steps (2025, 2040 and 2080) that represent progressive implementation of the three scenarios as well as gradual response of the environment to scenario implementation. Results are specified for 10 reaches (each 6-9 km long), two located on the Ruamahanga River mainstem and the other eight on its major tributaries, (from north to south): Kopuaranga, Waipoua, Waingawa, Waiohine, Taueru, Mangatarere, Huangarua and Tauherenikau (Figure 1).

To apply the BN to the “reporting reaches” required determining location-specific values for many of the nodes. For current state, many of these values were derived from State of Environment monitoring data provided by Greater Wellington Regional Council. Nodes that required this user input values are shown in light blue. For future states under the three scenarios, values for several of these nodes were generated by external models. Nodes specified by modelled data are shown in green.

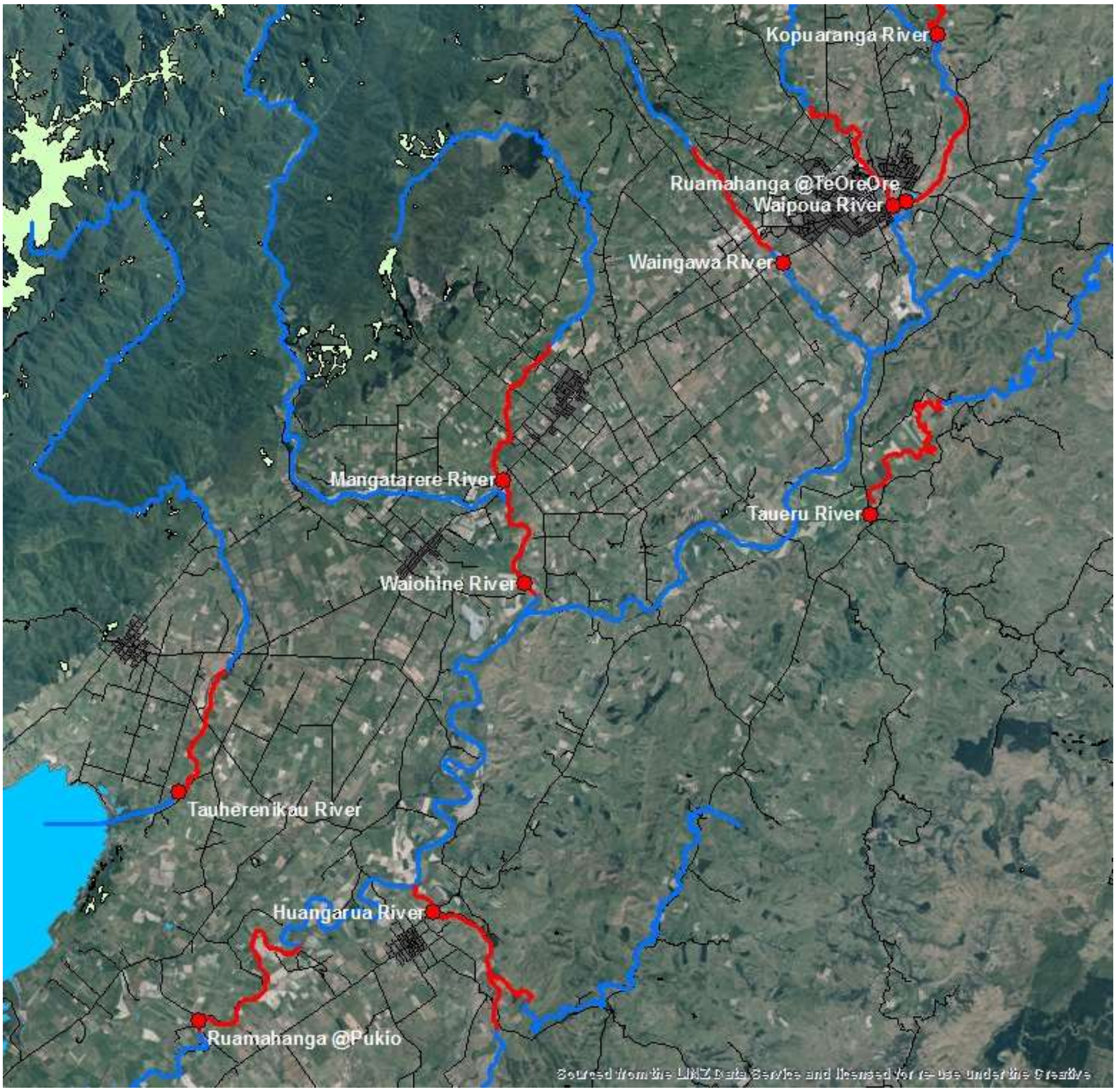

Figure 1: Ruamahanga River catchment showing locations of the ten reporting reaches.

2 Methods

The Bayesian network was developed using the software package Netica 5.24 (Norsys, 2016). The structure, node definitions, states and cause-effect relationships of the BN were developed by drawing on a variety of information sources. The specific sources are cited in the relevant subsections of the Results section. Generally, they included published papers, reports, expert evidence related to recent Environment Court cases, large datasets from regional council State of Environment and NIWA National Rivers Water Quality Network monitoring, and expert opinion from scientists at NIWA, Cawthron Institute, universities and Greater Wellington Regional Council.

The method for developing each node and its probabilistic relationships with adjacent nodes is described in the Results section, but some general procedures are described here.

To make this BN as relevant as possible to planning under the NPS-FM, variables specified in the National Objectives Framework were assigned states that correspond to the condition bands in the NOF.

Parent nodes include only the most influential drivers, those that are likely to change under the scenarios being considered by the RWC and those whose relationship with the child node are known with at least some degree of precision. Therefore, this Bayesian network does not represent all the ecological relationships that influence a particular variable or organism, and it may or may not include the same set of factors that have been shown to influence that variable in another situation or at another scale. This is because the BNs are designed to be decision support tools, showing expected outcomes from certain management decisions, rather than detailed ecosystem models. In general, factors are excluded if they are not expected to change under different scenarios. However, in some cases, non-varying factors have been retained so that the BNs can be used in future with different scenarios or in other planning processes (e.g., other whaitua in the Wellington region).

Nodes are colour-coded to aid usability and interpretation. Yellow nodes are those representing key values. These include periphyton (attached algae), Macroinvertebrate Community Index (a measure of stream ecological health based on the invertebrate assemblage inhabiting the river bed, Boothroyd and Stark 2000), *Phormidium* (attached cyanobacteria), trout biomass (a combination of fish abundance and size), abundance of river birds, natural character, fish Index of Biotic Integrity (IBI), individual species of native fish (longfin and shortfin eels, inanga and redfin bullies). Green nodes are values that can only be calculated with the use of other models, such as RHYHABSIM (Jowett 1989) for % protection of trout habitat, or SOURCE (e-water) for increases in nutrient input with change in land use. Light blue nodes are variables requiring the user to set values or states. Generally, they are characteristics of the river or its catchment that are unlikely to change under different planning scenarios. Dark blue nodes are nodes where values can be specified by the user if data are available, otherwise they will be calculated by the Bayesian network. Pink nodes represent management decisions that are made by the user. Purple nodes are those calculated by other parts of the Bayesian network. Pale nodes (of various shades) are intermediate nodes that are calculated by the Bayesian network. Note, however, that a user may set the value of any node if it is known. The relationships between nodes are such that setting the state of a child node affects the state of a parent node as well as the reverse (for this reason, the state of a parent and child node cannot both be set to values that are incompatible with each other given the relationship defined between them).

In the figures showing the Bayesian network, the different possible states of each node are listed vertically down the left hand side of the node box. The number to the right of each state is the percent probability of being in that state, and the black bar shows the probability graphically. A bar with a black line on either side has been specified by the user, whereas a bar without these lines has been calculated by the network. The number at the bottom of the node box is a numerical value calculated by the average of the different states, weighted by their probabilities.

3 Results: predictive Bayesian network

3.1 Periphyton biomass

3.1.1 Node description and states

Node name: Periphyton. *Units:* mg Chlorophyll *a* /m$^{2.}$

Periphyton biomass is one of the nodes in this Bayesian Network that is an attribute of Ecosystem Health in the National Objectives Framework. NOF condition bands for periphyton biomass as mg of chlorophyll *a* per m^2 (Chl. *a*) were used to define the states for the periphyton node. Periphyton is classified in a particular state provided that its biomass does not exceed the upper bound for that state in more than 8% of monthly samples.

3.1.2 Node parents

Periphyton biomass results from a balance between its rate of growth and the frequency of biomass loss events (Snelder et al. 2014; Matheson et al. 2015; Hoyle et al. 2017). Rate of growth is controlled primarily by nutrient supply, light, and temperature, whereas biomass loss is primarily due to grazing by macroinvertebrates and high flow events that scour periphyton from the substrate.

The drivers of periphyton biomass are shown in Appendix A Figure 1. Relationships between periphyton and its drivers (in particular, the values of the drivers that result in a change of state in periphyton) were determined for a New Zealand-wide dataset (Matheson et al. 2012, 2015). A New Zealand-wide dataset was expected to yield more robust relationships than a smaller local dataset, and there were no obvious reasons why periphyton in the Ruamahanga rivers should have different relationships than in other New Zealand rivers.

The conditional probability table for periphyton is quite long (432 rows) because each of the five parent states has between 2 and 4 states. Therefore, in this section we describe the relationship between each parent and periphyton, and the method for combining these relationships. The entire table is in Appendix B.

Light

Node name: Light at river bed. *Units:* µmol PAR /m^2/s.

Like all plants, periphyton requires light for photosynthesis, and hence growth. Light at the riverbed is determined by shading of the water surface (by topographic features and riparian vegetation), and by the visual clarity, coloured dissolved organic matter (CDOM) and depth of the water (which together control how much of the light at the water surface reaches the river bed). We used summer (Dec-March) values of clarity, depth and shading as this is the period when excessive periphyton growths may occur. The factors that may change under future development scenarios include water clarity (due to changes in fine sediment runoff from land), water depth (due to changes in water abstractions) and shading (due to changes in riparian vegetation).

The function linking light at the bed with daily solar radiation, clarity, CDOM, shade and depth was taken from Davies-Colley and Nagels (2008).

Matheson et al. (2012) found that among 65 sites in the National River Water Quality Network, those with >300 μmol m^{-2} s^{-1} at the bed showed no indication of light limitation, whereas below this threshold, periphyton growth appeared to be increasingly limited by light. The relationship they proposed between light at the river bed and the probability of nuisance periphyton growth is shown in Table 1.

Table 1: Relationship between light at the river bed and probability of nuisance periphyton growths.

Light at bed (μmol PAR m^{-2} s^{-1}) [a]	Probability of nuisance periphyton
>300	0.95
50-300	0.65
<50	0.10

[a] average daily radiation.

Nuisance periphyton growth was defined by Matheson et al. (2012) as 30% cover by filamentous periphyton, which roughly corresponds to 120 mg/m^2 periphyton biomass, i.e., the threshold between bands B and C in the current periphyton node. Therefore, in the current BBN the probabilities of periphyton biomass >120 mg/m^2 (bands C and D) are reduced at the lower light levels by multiplying by the factors in Table 1. The reduction in band D (>200 mg/m^2) is twice as great as that in band C (120-200 mg/m^2). Probabilities of periphyton biomass in bands A and B (0-50 mg/m^2 and 50-120 mg/m^2) are increased by the same amounts as the reductions in bands C and D.

Summer water temperature

Node name: Mean summer water temp. *Units:* °C.

Definition: average water temperature during mid-summer months January-February.

Many metabolic activities in living organisms proceed more rapidly with increasing temperature, thus periphyton growth rates increase with water temperature (Snelder et al. 2014). Matheson et al.'s (2015) dataset includes several measures of water temperature, at different numbers of months prior to the date of periphyton sampling, as well as temperatures averaged over these time periods. Matheson et al. (2015) found that the strongest correlation between periphyton biomass and water temperature was for water temperatures averaged over 12 months prior to sampling. Logically, however, water temperatures closer to the time of sampling should have a stronger influence on periphyton biomass, since biomass is "re-set" several times per year by scouring floods. Since nuisance periphyton blooms typically develop in late summer, water temperature averaged over the two months prior to sampling was used as an estimate of summer water temperature. This also made the water temperature node for periphyton consistent with that for macroinvertebrates and trout. In Matheson et al.'s (2015) dataset, the proportion of samples with periphyton in the higher biomass categories increased with increasing summer water temperature (Table 2).

Table 2: Frequency of periphyton biomass in NOF categories with different summer water temperatures in Matheson et al.'s (2015) dataset.

	Chl. *a* <50 mg/m^2	Chl. *a* 50-120 mg/m^2	Chl. *a* 120-200 mg/m^2	Chl. *a* >200 mg/m^2
Temp <11 °C	89%	3%	1%	7%
<11-16.4 °C	83%	5%	4%	7%
16.4-21 °C	79%	8%	5%	9%
>21 °C	62%	14%	7%	17%

Water temperature depends on a number of factors including air temperature, shading (by topographic features and riparian vegetation) and contribution of groundwater. The amount by which water temperature changes depends on amount by which riparian shading changes, the river length over which shading changes occur, and the proportion of flow that is contributed by groundwater. Therefore, determining changes in water temperature under different future scenarios is complex. We derived a simple relationship between change in riparian shading and change in mean summer water temperature (Table 2) by comparing equilibrium temperatures for different levels of riparian shading in Fig. 41 of Rutherford et al. (1999) assuming:

1. All reaches are far enough from areas with different riparian management that water temperatures will reach equilibrium.
2. Within the range of river sizes being considered here, river size makes little difference to the amount of temperature change. In Fig. 41, the temperature difference between the three levels of shading is about 4 °C for both third and fifth order streams.
3. Changes in mean daily temperature are about half as great as changes in maximum daily temperature (based on comparing these two statistics in monitoring data among sites).

Only two sites showed a change in mean summer water temperature of more than 0.5 °C under any scenario (Taueru, 3.2 °C and Kopuaranga 1.0 °C).

Table 3: Change in mean summer water temperature with change in % riparian shade.

Change in riparian shade (%)	Change in mean summer water temperature (°C)
12.5	1
25	2
37.5	3
50	4

Dissolved nutrients

Node names: DIN conc, DRP conc. *Units:* mg/m$^{3.}$

Periphyton requires dissolved nutrients from the surrounding water, in particular dissolved inorganic nitrogen (DIN; consisting of ammonia, nitrate and nitrite) and dissolved reactive phosphorus (DRP), in order to grow (Biggs 2000a). Therefore, provided light is not limiting, and growth is not impeded by frequent floods, periphyton biomass is strongly correlated with the concentration of dissolved nutrients in river water (Snelder et al. 2014). Periphyton typically requires DIN and DRP in a concentration ratio of 15:1, therefore where the ratio is higher than this, growth is limited by availability of DRP and when lower than this it is limited by availability of DIN. Therefore, DRP and DIN were combined into an intermediate node called “nutrient sufficiency” which recognises that the nutrient that is in least supply will limit periphyton growth. Nutrient sufficiency takes on the state that is the lower of DIN and DRP.

Values of DIN and DRP concentration that result in periphyton biomass in each of the four NOF condition bands were determined from Matheson et al. (2015). In this summer-focused dataset, 85% of samples had periphyton biomass equalling the boundaries between NOF condition bands A-B, B-C and C-D at annual mean DIN concentrations of 98, 631 and 1122 mg/m^3, respectively. The 85%iles of the Matheson et al. (2015) summer-focused data were assumed to correspond approximately to the permissible 8% exceedance level for the NOF bands, because including winter data, when periphyton cover is typically low, would likely increase the 85%ile to close to 92%. In addition, 85% of samples had periphyton biomass corresponding to B-C and C-D boundaries at annual mean DRP concentrations of 10.3 and 18 mg/m^3, respectively. An additional DRP concentration of 5 mg/m^3 was added to approximate a likely boundary between A and B bands. In Matheson et al.’s (2015) dataset, the proportion of samples with periphyton in the higher biomass categories increased with increasing concentration of DIN and DRP (Table 4 and Table 5).

Table 4: Frequency of periphyton biomass in NOF categories with different concentrations of annual mean dissolved inorganic nitrogen (DIN) in summer - focused dataset of Matheson et al. (2015).

	Chl. *a* **<50 mg/m^2**	**Chl. *a*** **50-120 mg/m^2**	**Chl. *a*** **120-200 mg/m^2**	**Chl. *a*** **>200 mg/m^2**
DIN low (<98 mg/m^3)	90%	7%	2%	1%
Low-med (98-631 mg/m^3)	65%	23%	6%	6%
Med-high (631-1122 mg/m^3)	53%	22%	10%	14%
High (>1122 mg/m^3)	61%	21%	7%	12%

Table 5: Frequency of periphyton biomass in NOF categories with different concentrations of annual mean dissolved reactive phosphorus (DRP) in summer. - focused dataset of Matheson et al. (2015).

	Chl. *a* <50 mg/m²	**Chl. *a* 50-120 mg/m²**	**Chl. *a* 120-200 mg/m²**	**Chl. *a* >200 mg/m²**
DRP low (<5 mg/m³)	76%	16%	4%	5%
Low-med (5-10.8 mg/m³)	73%	16%	6%	5%
Med-high (10.8-18 mg/m³)	53%	24%	12%	11%
High (>18 mg/m³)	57%	22%	11%	11%

Density of macroinvertebrate grazers

Node name: Grazer density. *Units:* per $m^{2.}$

A number of aquatic macroinvertebrate species graze on periphyton and previous studies (Jacoby 1985, Welch et al. 1992, 2000, Holomuzki et al. 2006) have shown that high densities of macroinvertebrate grazers are capable of reducing the accrual rate of periphyton biomass. In the dataset of Matheson et al. (2015), 85% of samples had periphyton biomass equalling the boundaries between NOF condition bands C-D and B-C when the densities of selected macroinvertebrate grazers were 100 and 708 individuals per m^2, respectively. The proportion of samples with periphyton in the higher biomass categories decreased with increasing densities of macroinvertebrate grazers (Table 6).

Table 6: Frequency of periphyton biomass in NOF categories with different densities of selected macroinvertebrate grazers Matheson et al.'s (2015) dataset.

	Chl. *a* <50 mg/m²	**Chl. *a* 50-120 mg/m²**	**Chl. *a* 120-200 mg/m²**	**Chl. *a* >200 mg/m²**
Grazers <100 m^{-2}	39%	33%	10%	18%
100 – 708 m^2	59%	19%	14%	9%
>708 m^{-2}	66%	21%	8%	4%

Although the density of macroinvertebrate grazers is clearly linked to other macroinvertebrate nodes (Macroinvertebrate Community Index and Trout Prey Index, which is a measure of macroinvertebrate density), grazer density was left as a separate node to be entered by the user. The reasons are that a) this is an absolute measure (number per m^2), whereas Trout Prey Index is relative to reference, b) MCI and Trout Prey Index are influenced by periphyton, so linking these with grazer density would create a circularity which is prohibited in Bayesian networks; and c) grazer density includes only a subset of macroinvertebrate taxa that are known to graze on periphyton. The criteria for selecting which taxa to include in calculations of Grazer density are described in Matheson et al. (2015).

Days of accrual

Node name: Days of accrual. *Units:* days.

High flow events reduce periphyton biomass to very low levels, from which the periphyton regrows over time. Hoyle et al. (2017) showed that the probability of a site experiencing recurrent nuisance periphyton growths is related to the frequency of flows that mobilise sand on the river bed. The size of this flow (Q_{pr}, the discharge that removes periphyton) differs among rivers and among sites within rivers due to differences in slope and riverbed materials. Hoyle et al. (2017) provide a method for calculating Q_{pr} for an individual site by plotting periphyton biomass against the size of the maximum flow in the last 7 days. Once Q_{pr} is known, the frequency of Q_{pr} events (the percentage of days with flushing flows) for the site can be calculated from the site flow record. Since high flow events are less frequent during summer (the period when nuisance periphyton growths are more likely), the percentage of days with flushing flows is calculated from only the summer months of the flow record.

If data for calculating Q_{pr} are not available, Q_{pr} can be approximated as flow three times the median. Clausen and Biggs (1997) and Matheson et al. (2015) showed that FRE3, the number times per year that river flow equals or exceeds three times the median flow, is the best general (non-site specific) hydrological metric for predicting the probability of nuisance periphyton. As for Q_{pr}, the percent of days with flows three times the median needs seasonal adjustment to relate to the peak summer growth period.

Days of accrual (the number of days since a flushing event) is the inverse of the frequency of flushing flow events. Using a dataset consisting of State of Environment monitoring from several regional councils and National River Water Quality Network monitoring by NIWA, Matheson et al. (2015) described a quantile regression relationship between periphyton cover and days of accrual (DA). The value of DA that most clearly separated low from high periphyton biomass was about 14 days. The frequencies of periphyton biomass in the four NOF condition bands above and below DA=14 were determined using Matheson et al.'s dataset (Table 7).

Table 7: Frequency of periphyton biomass in NOF categories with greater or less than 14 days since a flood 3x median flow. Numbers in parentheses represent change relative to DA_3 <14.

	Chl. *a* **<50 mg/m²**	**Chl. *a*** **50-120mg/m²**	**Chl. *a*** **120-200 mg/m²**	**Chl. *a*** **>200 mg/m²**
DA_3 <14	85%	7%	3%	4%
DA_3 >14	70% (-15%)	15% (+8%)	5% (+2%)	7% (+3%)

3.1.3 Combining parents of periphyton biomass

Netica is able to learn predictive cause-effect relationships between nodes by applying "Bayesian inference" to a dataset that includes the child and one or more parent nodes. To do this, Netica was presented with a dataset from Matheson et al. (2015) that included periphyton biomass, summer water temperature, nutrient sufficiency and macroinvertebrate grazer densities. For the learning process cause-effect arrows from periphyton were directed to the causative variables to prevent Netica from inferring interactions between the causative variables. Such interactions complicate the Bayesian inference process and were leading to nonsensical results in preliminary trials. Interactions among the causative variables were assumed to be minor compared to the main effect of each variable on periphyton. After the initial learning process the cause-effect arrows were reversed one by one, deleting any cross-links among causative variables formed during the reversal process, so that all arrows were directed from the causative variables to the periphyton node. The probabilistic relationships described by the arrows are symmetrical, therefore reversing them should not alter the effect of each variable on the other (Netica v 4.16 help file).

The dataset linking days of accrual with periphyton biomass was separate to that for the other variables. Therefore, the effect of days of accrual was incorporated by calculating the change in probability of periphyton being in each biomass category with a change in days of accrual from <14 to >14. These changes in probability (Table 7 values in parentheses) were applied to the conditional probability table for periphyton biomass for days of accrual >14.

3.1.4 Periphyton biomass at baseline

Bayesian networks produce results as a probability distribution across all states defined for a node. The results reported here are "expected values", which represent the average of all states (NOF bands) in the periphyton biomass node, weighted by their probabilities. It is important to remember that behind each expected value is a probability distribution, and that states other than the one represented by the expected value are possible.

At baseline, the Bayesian Network predicts that the expected value of periphyton biomass is in band B for most sites (50-120 mg/m^2), with two sites (Huangarua and Kopuaranga) in band C and one site (Mangatarere) in band D (Figure 2, Table 8, Figure 3). Kopuaranga and Mangatarere have med-high concentrations of DRP and/or DIN, while Huangarua has med-low concentrations of nutrients but warm water temperatures and a low density of grazers. Although the Bayesian network was not calibrated to the Ruamahanga rivers, there is a reasonably good correlation (Pearson r=0.71) between BN predictions and actual values from RSOE monitoring among the 10 reporting sites (monthly visual % cover estimates from 2013-2016, converted to biomass using the equation in Matheson et al. (2015) Appendix I). The Bayesian network tends to overestimate low values and underestimate high values of periphyton biomass among these sites. One likely reason for the underestimation of high values is that the Bayesian Network may underestimate the contribution of *Phormidium* to periphyton biomass because it is based on a national dataset. Rivers in the Ruamahanga catchment appear to be more vulnerable than the national average to *Phormidium* blooms. The *Phormidium* predictions cannot simply be added to periphyton results as they are expressed in different terms (probabilities rather than biomass). Instead, users are advised to give greater attention to the relative values of periphyton biomass among sites and among scenarios rather than to the absolute value of any particular site or scenario. The relative values among sites agree well between the Bayesian network and RSOE data (which includes *Phormidium* biomass), with the exception of Mangatarere for which the BN overestimates periphyton biomass.

3.1.5 Effects of three development scenarios on periphyton biomass

Expected values of periphyton biomass under the three scenarios are shown in Table 8 and Figure 3. In Gold and Silver 2080, periphyton biomass is predicted to be in the B band for all except two sites (Kopuaranga and Mangatarere) which were in C and D bands respectively. The greatest changes relative to baseline occur in

a. Huangarua: decreases of about 30% (from 170 mg/m^2 to 114 mg/m^2 average during the summer period December to March) in Silver (by 2080) and in Gold (by 2040). This is the only site to show a change in NOF band (from C to B).
b. Taueru decreases of about 40% (from 92 mg/m^2 to 57 mg/m^2) in Silver and Gold (each by 2040).
c. Waingawa: decreases of about 35% (from 81 mg/m^2 to 53 mg/m^2) in Silver and Gold (each by 2040).

The main cause of the decreases in periphyton biomass is decreases in "nutrient sufficiency", which represents the most limiting of dissolved inorganic nitrogen (DIN) and dissolved reactive phosphate (DRP). Although DIN and DRP concentrations decrease at all sites in Gold and Silver scenarios, changes in nutrient sufficiency occur only in these three rivers at the timestep described.

Sensitivity analysis shows that periphyton biomass is also sensitive to water temperature and light at river bed. In the Taueru river, declines in water temperature in Silver and Gold scenarios may contribute to decreases in periphyton biomass. However, the Huangarua and Waingawa rivers show only very small decreases in water temperature.

Light at the riverbed increases over time at these three sites and most other sites in Silver and Gold scenarios, due to increasing water clarity (and despite increasing shade). Increases in light could promote greater periphyton growth, but this effect is evidently outweighed by the decrease in dissolved nutrient concentrations.

3.1.6 Possible further decreases in periphyton biomass

Most of the drivers of periphyton biomass in this BN would be difficult to improve further than predicted under the Silver and Gold scenarios. Light at the bed and water temperature depend on riparian shading, which is already at a maximum under the Silver and Gold scenarios. Reducing days of accrual would require increasing the frequency of high flows beyond the natural regime. Increasing the density of invertebrate grazers may be possible by improving general stream health, but it is difficult to predict what improvements would be required and how much grazer densities may increase. Therefore, the only means for further reducing periphyton biomass discussed here is reductions in dissolved nutrients. Table 9 shows the concentrations of DRP and DIN in Silver and Gold 2080, and the periphyton biomass predicted if one or both nutrients were reduced to the Low category (<5 ppb DRP or <98 ppb DIN). If dissolved nutrient concentrations could be reduced to this low level, periphyton biomass could be reduced by >50% in Kopuaranga and Mangatarere, and smaller reductions could occur in Ruamahanga, Waiohine and Taueru.

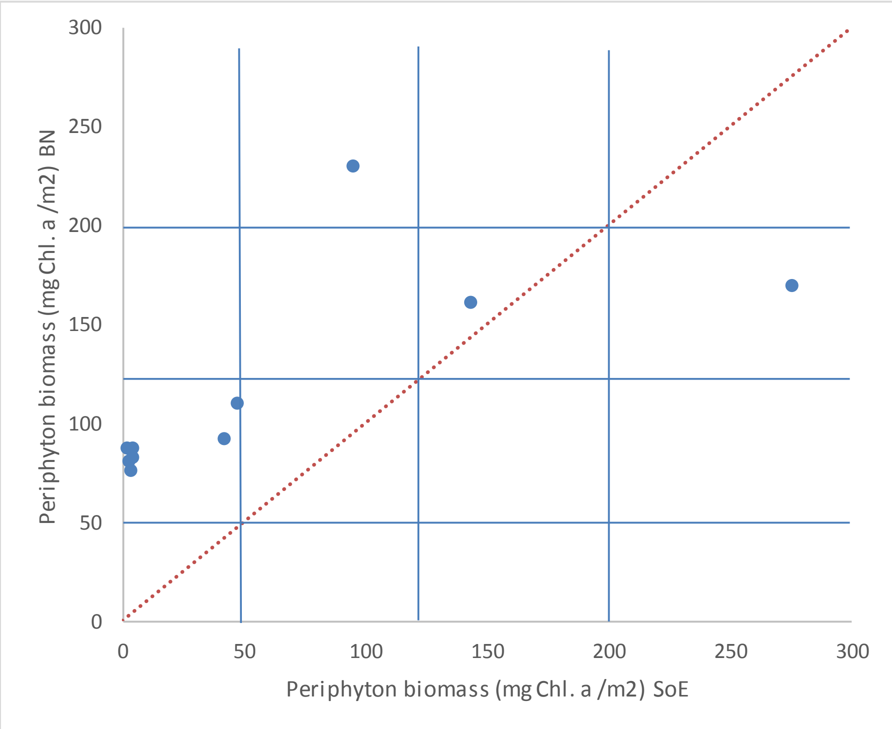

Figure 2: Expected values of periphyton biomass (mg/m²) predicted by BN at baseline compared with actual RSoE data from GWRC (2013-2016, with highest biomass value in each year removed from dataset, in accordance with definition of NOF bands). Red line indicates 1:1 relationship. Blue lines indicate thresholds of NOF bands A-D.

Table 8: Expected values of periphyton biomass (mg Chl. a / m²) at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	170	170	170	170	170	170	114	170	114	114
Kopuaranga	162	162	162	162	162	162	162	162	162	162
Mangatarere	230	230	230	230	230	230	230	230	230	230
Ruamahanga @Pukio	88	88	88	88	88	88	88	88	88	88
Ruamahanga @TeOreOre	88	88	88	88	88	88	88	88	88	88
Taueru	92	92	92	92	92	57	57	92	57	57
Tauherenikau	76	76	76	76	76	76	76	76	76	76
Waingawa	81	81	81	81	53	53	53	53	53	53
Waiohine	83	83	83	83	83	83	83	83	83	83
Waipoua	110	110	110	110	110	110	110	110	110	110

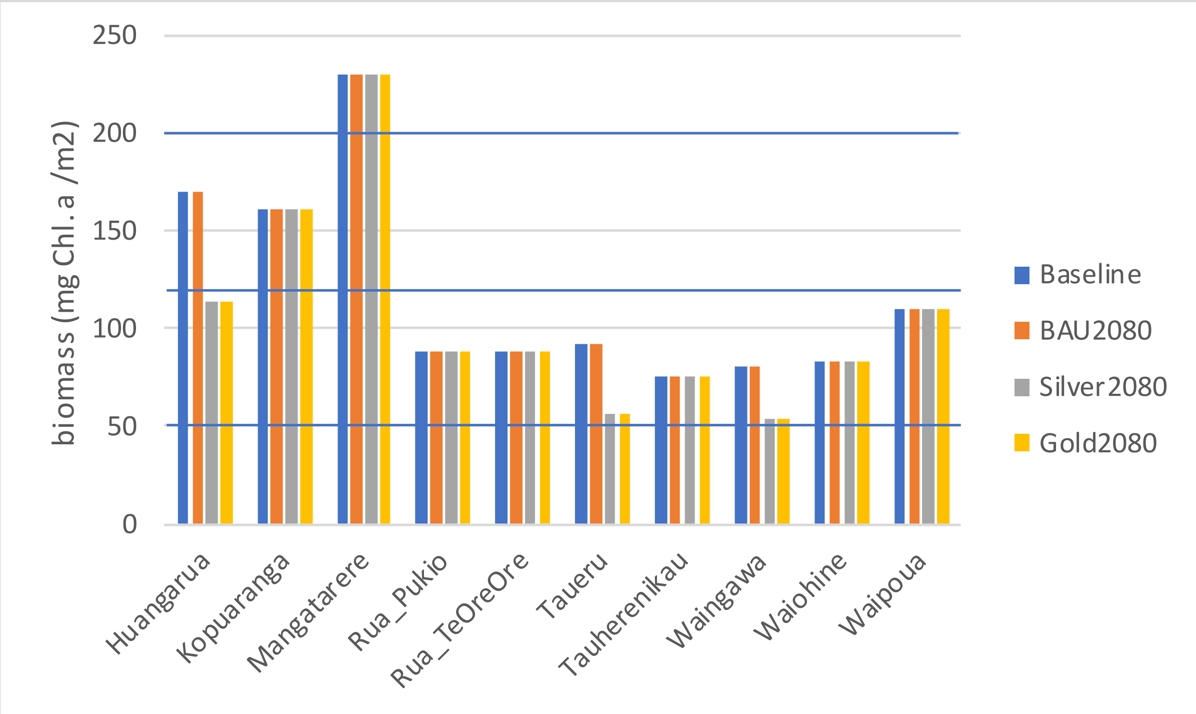

Figure 3: Expected values of periphyton biomass (mg Chl.a / m²) at baseline and BAU, Silver and Gold scenarios in 2080.

Table 9: Potential responses in periphyton biomass to further reductions in dissolved nutrients. Abbreviations: DRP = dissolved reactive phosphorus. DIN = dissolved inorganic nitrogen. In columns 2-4, Low DRP is <5 ppb, Low DIN is <98 ppb. For values of other categories, see Table 4. In columns 4 and 5, periphyton biomass is in units of mg Chl. a / m².

	DRP in Gold or Silver 2080	DIN in Gold or Silver 2080	Periphyton biomass with low DRP or DIN	Change in periphyton biomass
Huangarua	Low	Med	114	0
Kopuaranga	Med-high	Med-high	79	-83
Mangatarere	High	Med-high	108	-122
Ruamahanga @ Pukio	Low-med	Med	57	-31
Ruamahanga @Te OreOre	Low-med	Med	57	-31
Taueru	Low-med	Med-high	40	-17
Tauherenikau	Low	Low	76	0
Waingawa	Low	Low-med	53	0
Waiohine	Low-med	Med	56	27
Waipoua	Low	Med-high	110	0

3.2 Macroinvertebrate Community Index

3.2.1 Node description and states

Node name: MCI. *Units:* MCI units.

The condition of the macroinvertebrate community is one of the main indicators used internationally and in New Zealand to assess the overall ecological health of a stream or river (Boothroyd and Stark 2000). The Macroinvertebrate Community Index (MCI; Stark and Maxted 2007) is one of the main indices used by regional councils across New Zealand to measure the health of the macroinvertebrate community (Davies-Colley et al. 2012). MCI was considered the most appropriate performance measure for macroinvertebrate community condition in this Bayesian network because a) it responds to several stressors associated with land use intensification (Collier 2008); and b) it is used and understood widely across New Zealand, therefore several studies and datasets were available to determine the key drivers of change in MCI and to quantify the cause-effect relationships between them.

The states chosen for MCI in this Bayesian network correspond to the condition bands for Excellent, Good, Fair and Poor ecological health defined by Stark and Maxted (2007). Note that the numeric thresholds of these bands are slightly different to those used by GWRC in a regional MCI classification of streams in the Wellington region.

3.2.2 Node parents

The main factors determining MCI (and/or its quantitative variant QMCI) have been described in several recent publications and reports, e.g., Clapcott et al. (2013); Booker et al. (2015); Death et al. (2015). Our choice of the primary factors influencing MCI was based on the causative factors described in these publications and on our opinions as freshwater ecologists. These factors are shown in Appendix A Figure 1.

As for periphyton, instead of showing the entire conditional probability table for MCI, we describe the relationship between each parent and MCI, and the method for combining these relationships.

We added the effect of each parent node on MCI sequentially in the order they are described below. We began with a basic distribution of MCI scores among the four condition bands (the “prior distribution” in Bayesian terms), which was taken from the dataset of Matheson et al. (2015). This dataset included 1783 sites from Canterbury, Southland, Hawke’s Bay, Manawatu, Greater Wellington and the National Rivers Water Quality Network. According to this dataset, 26% of sites were in “excellent” condition (MCI >119), 40% were in “good” condition (MCI 100-119), 28% were classed as “fair” (MCI 80-99) and 6% were classed as “poor” (MCI <80). To quantify the effect of each parent, we multiplied the probabilities in the four MCI condition bands by a set of factors for each level (state) of the parent node, as described in Tables 9-12.

Mean summer water temperature

Node name: mean summer water temp. *Units:* °C.

Clapcott et al. (2013) identified summer (January) temperature as one of the four variables in the FENZ (Freshwater Ecosystems of New Zealand) database that is most strongly correlated with MCI value in a national database of 1033 sites. The database of Clapcott et al. (2013) was used to determine the proportional frequencies (probabilities) of MCI scores in the different condition bands in the categories of mean summer temperature defined by the 25th, 50th and 75th percentiles in the dataset, adjusted slightly to convert air temperature (a FENZ variable) to water temperature and to harmonise these categories with the categories used for predicting periphyton and trout growth. The basic probability distribution among the four MCI condition bands were modified according to the factors in Table 10. At low temperatures (<16.4 °C) macroinvertebrates were considered to be unstressed, and the probabilities were not altered. At higher temperatures, macroinvertebrates became progressively more stressed, thus the probabilities of high MCI scores (100-119 and >119) became progressively lower while the probabilities of low MCI scores (80-99 and <80) became progressively higher (Table 10).

As described in the Periphyton section (3.1), water temperature itself is determined by a number of factors that may change with river management. Because the main management factor changing under the scenarios BAU, Silver and Gold was riparian shade, we used changes in % shade as the sole predictor of changes in water temperature, as in Table 3.

Table 10: Multiplication factors applied to the basic (prior) probability distribution in MCI condition bands at different levels of water temperature.

	MCI >119	MCI 100-119	MCI 80-99	MCI <80
Prior probabilities	26%	40%	28%	6%
Temp <16.4 °C	1	1	1	1
16.4 to 17.3 °C	-1.19	-1.1	-1.5	1.63
17.3 to 19 °C	-1.26	-1.19	1.04	2.05
>19°C	-1.74	-1.17	1.41	2.68

Deposited fine sediment

Node name: Deposited fine sediment. *Units:* % cover.

Deposition of fine sediment (silt) is widely recognised as a major impact of changing land use on river ecosystem health (Clapcott et al. 2011). Clapcott et al. (2011) determined a relationship between % cover of fine sediment (assessed visually from bankside) and MCI for 454 sites across New Zealand. They defined a threshold of 20% to separate healthy from unhealthy rivers based on MCI. We used their scatterplot (Fig. 4-21 in Clapcott et al. 2011) to calculate the proportional frequencies (probabilities) of MCI scores in the different condition bands above the 20 % threshold, relative to those at <20% sediment cover (Table 11). Although the Deposited fine sediment node has additional states (0-1%, 1-10%, 10-20%, 20-30%), Clapcott et al. (2011) describe only a single threshold (from <20% to >20% cover) relating to change in MCI. Therefore, in this BN, MCI changes only with a shift in deposited fine sediment across that threshold.

Table 11: Multiplication factors applied to the probability in each MCI condition band at different levels of deposited fine sediment,based on data in Clapcott et al. (2011).

	MCI >119	MCI 100-119	MCI 80-99	MCI <80
Sediment <20%	1	1	1	1
Sediment >20%	-1.64	-1.02	1.52	2.23

Intuitively, deposited fine sediment would be expected to increase with increasing load of fine sediment entering a river from its catchment. However, in available datasets, this relationship is very weak, with wide uncertainty intervals (Hicks et al. 2016). In explaining the weakness of this relationship, Hicks et al. (2016) noted that most sediment delivery is likely to occur at periods of high flow that would effectively flush the sediment through the river network until a receiving environment is reached. They, and Naden et al. (2016), concluded that sediment deposition is influenced more by stream power (a product of river slope and flow) and median annual flood than by upstream sediment load. Consistent with this view, Booker (NIWA, pers. comm.) identified the strongest predictors of deposited fine sediment as upstream particle size, FRE3, source of flow and specific mean flow (all as defined in Freshwater Ecosystems of NZ) in a New Zealand-wide dataset. In this Bayesian Network, these are the factors used to predict deposited fine sediment, and the conditional probability table relating these factors to deposited fine sediment was learned by Netica from Booker's dataset.

Change in mean annual low flow

Node name: % change in MALF. *Units:* % change.

Booker et al. (2015) found that the hydrological variable most strongly predicting MCI among 1075 river sites across New Zealand was specific MALF, i.e., the mean annual low flow divided by catchment area. Since the catchment area of a river will not change with development, a % change in specific MALF is equal to a % change in MALF, thus we represented Booker et al.'s data as % change in MALF. Only a weak relationship was found, MCI decreasing from an average of 105 at specific MALF of 0.04 to an average of 101.5 at specific MALF of 0.0025. A weak relationship between invertebrate communities and low flow level was also found by Suren and Jowett (2006). The probability distribution among MCI condition bands at each level of % decrease in MALF was determined by multiplying the probabilities by the factors in Table 12 (additional details in Storey 2015).

Table 12: Multiplication factors applied to the probability in each MCI condition band at different levels of % decrease in MALF.

% MALF decrease	MCI >119	MCI 100-119	MCI 80-99	MCI <80
0-5%	1	1	1	1
5-50%	-1.03	1	1.01	1.01
50-90%	-1.04	1.01	1.02	1.02
>90%	-1.05	1	1.03	1.03

Periphyton biomass

Node name: Periphyton. *Units:* mg Chl. *a* per m^2.

The main effects of pastoral land use on macroinvertebrates in rural streams (not considering changes to the riparian zone) are via increased inputs of silt, nutrients and organic matter. Nutrient inputs affect macroinvertebrates mainly through their effects on increased periphyton biomass, which can alter the type and quantity of food available to macroinvertebrates and change the physical habitat. A small increase in periphyton biomass can be beneficial to the macroinvertebrate community as it represents an increase in available food. However, the main effect of this subsidy is on macroinvertebrate densities, whereas MCI is based on presence-absence only. Accordingly, we found that a small increase in periphyton biomass did not change the distribution of MCI scores, and a large increase reduced proportional frequencies in the higher MCI states. The probabilities of different MCI condition bands changed with increases in periphyton biomass according to the multiplication factors in Table 13 (further details in Storey 2015).

Table 13: Multiplication factors applied to the probability in each MCI condition band at different levels of periphyton biomass. based on data in Matheson et al. (2015).

	MCI >119	MCI 100-119	MCI 80-99	MCI <80
Chl. *a* <50 mg/m^2	1	1	1	1
50 to 120 mg/m^2	-1.71	1.06	1.88	1.63
120 to 200 mg/m^2	-1.90	1.06	2.02	2.38
>200 mg/m^2	-1.94	-1.40	2.98	2.30

3.2.3 Macroinvertebrate Community Index at baseline

The Bayesian network predicts that at baseline, MCI at all sites is “fair” (MCI 80-100) (Figure 4, Table 14, Figure 5). Overall, there is a fairly good correlation (Pearson r=0.53) between the BN predictions and RSOE monitoring data from 2013-16. The BN tends to underestimate MCI scores by 10-15 units. However, the relative values among sites agree well between the Bayesian network and RSOE data, with the exception of Kopuaranga and Taueru for which the BN estimates are high relative to other sites. Therefore, greater attention should be given to the relative values among sites and among scenarios than to the absolute value of any particular site and scenario.

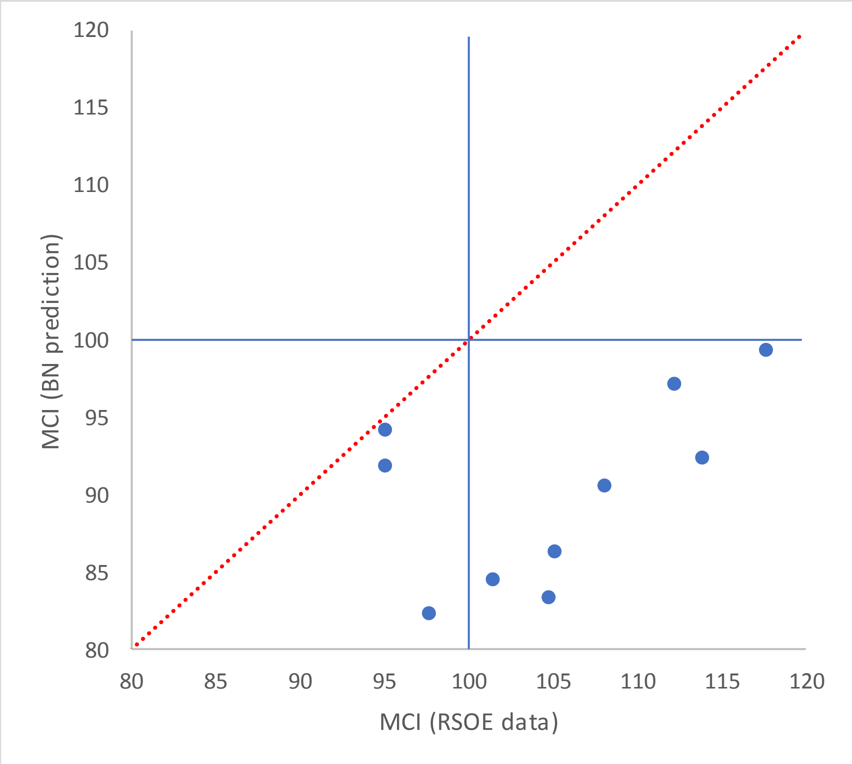

Figure 4: Expected values of MCI predicted by BN compared with actual RSoE data from GWRC (2013-2016). Red line indicates 1:1 relationship.

Table 14: Expected values MCI at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	85	84	84	84	84	84	85	84	85	85
Kopuaranga	92	92	92	92	92	92	92	92	92	92
Mangatarere	91	91	91	91	91	91	91	91	91	91
Ruamahanga @ Pukio	83	83	83	83	83	83	83	83	83	83
Ruamahanga @ TeOreOre	86	86	86	86	86	86	86	86	86	86
Taueru	94	93	93	93	93	94	94	93	94	94
Tauherenikau	97	96	96	96	96	96	96	96	96	96
Waingawa	92	92	92	92	94	94	94	94	94	94
Waiohine	99	99	99	99	99	99	99	99	99	99
Waipoua	82	82	82	82	82	86	86	86	86	86

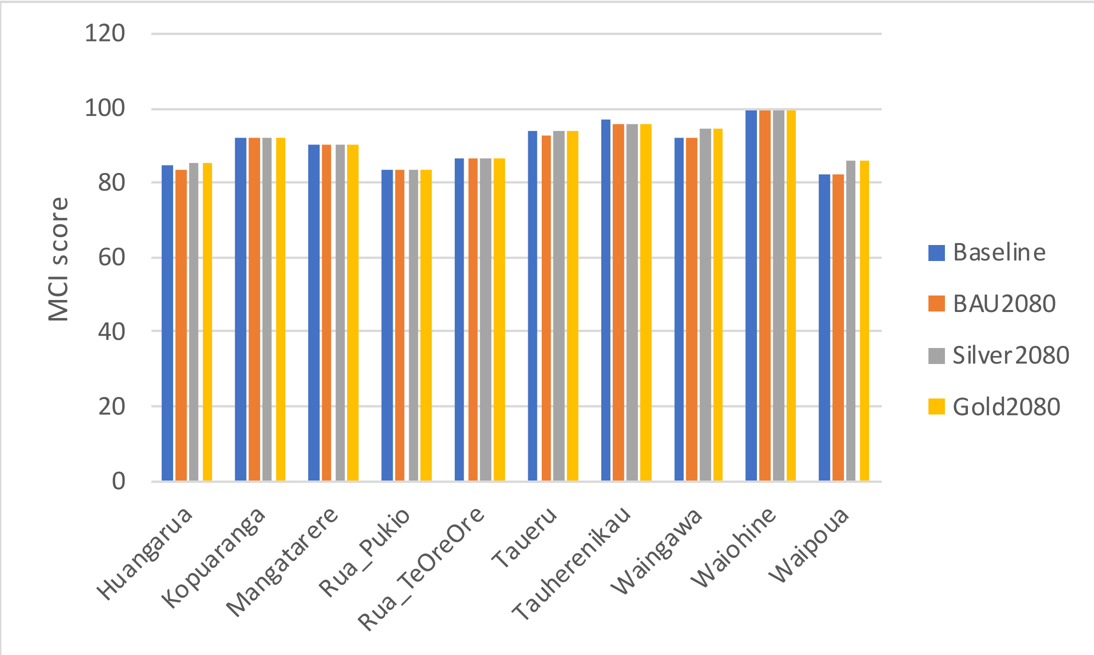

Figure 5: Expected values of MCI score at baseline and in BAU, Silver and Gold in the year 2080.

3.2.4 Effects of three development scenarios on Macroinvertebrate Community Index

MCI shows only very small changes in any scenario. The greatest increase is in the Waipoua River (4 MCI points between BAU and Silver/Gold); the greatest decrease in the Tauherenikau River (1.5 MCI points between baseline and all scenarios). Only changes of 10 MCI points or more are typically considered ecologically significant (Stark and Maxted 2007).

The reasons why differences in MCI are so small between scenarios are as follows. MCI depends on deposited fine sediment, % change in mean annual low flow (MALF), mean summer water temperature and periphyton biomass.

a) Deposited fine sediment does not change at any site under any scenario because it is controlled primarily by the flood regime of rivers, which does not change under any of the three scenarios. One may expect deposited fine sediment to be determined, at least in part, by suspended sediment which decreases under all scenarios. However, there is very weak empirical evidence for such a relationship, so this BN shows no link between suspended sediment and deposited fine sediment.

b) % change in MALF is <5% for most sites under most scenarios. Exceptions are Huangarua, Taueru and Tauherenikau which all show a 5-50% decline in MALF relative to baseline in all scenarios. However, change in MALF has only a weak effect on MCI score.

c) Mean summer water temperature stays unchanged in almost all sites under almost all scenarios. Only Waipoua shows a change in mean summer water temperature state (declining from 19-21 °C to 17.3-19 °C in Silver 2040 Gold 2025, due to riparian planting).

d) Periphyton changes in only three sites (see above).

3.3 *Phormidium* (toxic algae)

3.3.1 Node description and states

Node name: Phormidium % cover *Units:* % cover.

Phormidium is the main genus of toxic cyanobacteria (commonly known as toxic algae) that form expansive mats (blooms) attached to benthic substrates in rivers (Heath and Greenfield 2016, McAllister et al. 2016). *Phormidium* is considered a nuisance mainly due to the neurotoxins produced by some species that have resulted in numerous dog deaths (70 between 2003 and 2013; Heath 2013) and raise concerns for human health risk during contact recreation (although cases of health impacts are not proven) and via drinking water supply (Wood et al. 2014, Heath and Greenfield 2016, McAllister et al. 2016).

Nationally, the rivers with observed *Phormidium* issues are primarily non-alpine rivers on the lower-lying parts of the dry, eastern side of New Zealand. These are also often areas with shallow aquifers that are part of an increasingly allocated water supply, often used to support intensive agriculture (McAllister et al. 2016). In the Wellington region, the most expansive and frequent *Phormidium* blooms tend to occur in the large gravel bed rivers of the Kapiti, Hutt and Ruamahanga catchments, with the Waipoua River and the Hutt River experiencing the worst blooms (Heath and Greenfield 2016). Blooms have also been recorded since 2004 in the Huangarua, Ruamahanga (at Te Ore Ore), and Waingawa rivers (Heath and Greenfield 2016). Over the past decade there has been an increase in the frequency and extent of *Phormidium* blooms in some New Zealand rivers (McAllister et al. 2016), indicating that *Phormidium* is likely to represent an increasingly important issue in the future.

Phormidium blooms are typically defined as mats that cover more than 20% of the river bed (Wood et al. 2014, Heath and Greenfield 2016, McAllister et al. 2016). Therefore, in this BN we defined two states for *Phormidium* of <20% and >20% cover.

3.3.2 Node parents

The factors determining the probability of *Phormidium* blooms (>20% cover) were identified by S. Wood (Cawthron Institute) and are consistent with those in published reports (e.g., Heath and Greenfield 2016, Wood et al. 2017a) and peer-reviewed articles (e.g., Wood et al. 2017b, review in McAllister et al. 2016). They are shown in Appendix A Figure 1. The conditional probability tables were quantified by S. Wood. Both the network structure and the probability tables were based on knowledge from numerous rivers across New Zealand, and should be applicable to any large gravel-bed river in New Zealand. Year-to-year variability in *Phormidium* blooms is observed in many rivers, and this variability is not fully explained by statistical models or experimental work (Heath and Greenfield 2016). The probability tables reflect this uncertainty in predicting *Phormidium* blooms.

Dissolved reactive phosphorus concentration

Node name: DRP conc. *Units:* ppb.

According to McAllister et al. (2016) and Wood et al. (2014a), *Phormidium* blooms are most likely when DRP concentration in the water column is less than 0.01 mg/L (10 ppb). These authors do not identify a lower DRP limit. The reason that *Phormidium* blooms can occur at low DRP concentrations is probably due to nutrient dynamics within the *Phormidium* mats. *Phormidium* appears able to trap fine sediment and extract phosphorus from these fines by altering the pH and redox conditions within the mat so that phosphorus is mobilised (Wood et al. 2015). Thus, the amount of DRP available for growth is largely independent of DRP concentrations in the overlying water, allowing *Phormidium* to bloom in rivers with low DRP where other algae struggle to bloom.

We define the DRP node with 2 states: <10 ppb and >10 ppb, with the former associated with higher probability of *Phormidium* blooms. After accrual period, DRP concentration has the strongest influence on *Phormidium* growth. At >10 ppb, the chance of a *Phormidium* bloom does not exceed 5%, unless downstream of a sewage treatment plant and >7 days since a flushing flow, in which case it can be as high as 85%.

Dissolved inorganic nitrogen concentration

Node name: DIN conc. *Units:* ppb.

Several studies (Wood et al. 2014a, 2015a) suggest that water column nutrient concentrations during the initial colonisation phase strongly influence whether *Phormidium* can establish and subsequently form mats. Once mats are formed, the relationship between *Phormidium* blooms and water column nitrogen concentration becomes more complicated, as processes within the mat (e.g., nitrogen-fixation by bacteria) begin to influence the amount of biologically available nitrogen (McAllister et al. 2016). Nevertheless, in the data analysed by McAllister et al. (2016), most *Phormidium* blooms occurred at dissolved inorganic nitrogen concentrations of >0.1 mg/L (100 ppb).

This node is defined as the average DIN concentration over the accrual period (as in Wood et al. 2014a cited in McAllister et al. 2016). We define 2 states for the node DIN conc: <100 ppb and >100 ppb. Higher DIN concentrations increase the probability of a *Phormidium* bloom by up to 40%, the greater increases occurring when the site is not downstream of a sewage treatment plant and other conditions are not ideal (e.g., electrical conductivity is low, water velocity and deposited fine sediment are not ideal).

Deposited fine sediment

Node name: deposited fine sediment. *Units:* % cover.

A common feature of most *Phormidium*-dominated mats is a thin layer of fine sediment at the substrate/mat interface. Fine-grained sediment particles that are washed across the mat surface stick to the mat and are incorporated into the mat matrix. As described above, biogeochemical conditions within the mat can mobilise sediment-bound phosphorus, which is then available for growth.

Wood et al. (2015a) and Wood et al. (2015b) found that river sites with *Phormidium* blooms had higher deposition of fine sediment (<63 μm), and higher concentrations of biologically available phosphorus within the sediments. These studies suggest that fine sediment, provided it contains biologically available phosphorus, is an important factor promoting *Phormidium* blooms once mats are established. Wood (pers. comm.) describes fine sediment as probably the most important variable that can be managed to control *Phormidium* blooms.

In regard to *Phormidium* blooms, three levels of deposited fine sediment are functional: <1%, 1-30% and >30% cover. These levels were chosen based on expert opinion, as there is very little empirical evidence relating levels of fine sediment to *Phormidium* blooms. The 1-30% state is optimal for growth, and this state increases the probability of a *Phormidium* bloom by up to 45% compared to lower or higher levels of deposited fine sediment. The greater increases occur when other variables are not optimal. When all other variables are optimal, the probability of a bloom is 10% higher at 1-30% fine sediment cover than at <1% or >30% cover.

Electrical conductivity

Node name: Conductivity. *Units:* μS/cm.

Phormidium growth also appears responsive to various other dissolved chemicals that may represent essential elements for metabolism. While no correlations between *Phormidium* blooms and any single element have yet been found (McAllister et al. 2016), blooms appear more likely where a variety of elements are in higher concentration. The electrical conductivity of the water represents this variety of elements, and field data show a linear correlation between *Phormidium* blooms and conductivity between 150 and 400 μS/cm (S. Wood, pers. comm.).

Two states are defined for electrical conductivity: <150 μS/cm and >150 μS/cm. Higher conductivity is associated with an increase in the chance of a *Phormidium* bloom of up to 45%, the greater increases occurring at low DIN concentrations or sub-optimal (low or high) levels of deposited fine sediment.

Accrual period

Node name: More than 7 days since flushing flow. *Units:* categories TRUE, FALSE.

Phormidium mats, like all periphyton growths, are removed from river substrate in elevated flows due to increased shear stress, abrasion by mobilised fine particles and physical turn-over of substrates. These flows are known as 'flushing flows' and their frequency is a key variable regulating *Phormidium* abundance (Heath and Greenfield 2016). Generally, the less frequent flushing flows are, the more abundant *Phormidium* will be (Heath et al. 2011). A flow three times the median has been widely used to represent a flushing flow (Clausen & Biggs 1997). *Phormidium* blooms covering greater than 20% of the riverbed, as well as other periphyton species, can persist in much higher flows (Wood et al. 2017b), depending on factors including substrate size, river/stream order and stage of mat development (Wood et al. 2014). In this Bayesian network, we leave the definition of a flushing flow open and recommend the method of Hoyle et al. (2017) to calculate the size of flow that will remove periphyton and *Phormidium* growths.

The accrual period (the length of time available between flushing events for *Phormidium* mats to develop) is the inverse of the frequency of flushing events. The node "More than seven days since flushing flow" is inserted between the "% of days with flushing flows" and "*Phormidium* % cover" nodes to represent this inverse relationship. The relationship between "% of days with flushing flows" and the probability of being within 7 days of a flushing flow was derived by randomly generating a large number of hypothetical years with different percentages of days with flushing flows, then for each percentage, calculating the probability of any one day being within 7 days of a flushing flow. A trend line was then fitted between these two variables as follows:

$$\mathrm{Log}(y+1) = -0.0371x + 1.9996$$

Where x = % of days with flushing flows and y = probability of being within 7 days of a flushing flow. Since *Phormidium* blooms typically only occur during warm summer months, the procedure was repeated for a 3-month (90 day) period. However, the equation for 90 days was almost identical to that for a full year (365 days).

An accrual period of seven days was chosen as this is the period over which *Phormidium* can increase from 0% to >20% cover, i.e., is able to form a bloom (Wood et al. 2014). This is a simplification, as growth rate depends on several factors, including the initial inoculum (i.e., the amount of material remaining after the previous flushing event), temperature, nutrient concentrations and photosynthetically active radiation (Wood et al. 2014).

The node has two states, >7 days and <7 days since flushing flow. The accrual period has an overriding influence on *Phormidium* growth. At <7 days, the probability of a *Phormidium* bloom is 5% for all combinations of states in other variables.

Water velocity

Node name: Water velocity. *Units:* m/s.

As noted above, increased river velocities can greatly reduce benthic algal communities through elevated shear stress, abrasion by mobilized sediments and grinding action of tumbling gravel/cobble substrata (Heath et al. 2015). Reduced water velocities may also reduce *Phormidium* growth in low nutrient waters, as the supply of nutrients to the growing *Phormidium* is related to water velocity. Therefore, Heath et al. (2015) found that *Phormidium* cover was highest in river velocities between 0.6 m/s and 1.1 m/s, with optimal velocity being greater at sites with larger substrate sizes. Susie Wood (29/7/16) estimated that optimal *Phormidium* growth would occur at approximately 0.5 times the median flow, and would reduce where flows drop below 0.2-0.3 times median flow.

In this Bayesian network, we define three states in the water velocity node: <0.3 m/s, 0.3-1.1 m/s and >1.1 m/s based on Heath et al. (2015). The middle state (0.3-1.1 m/s) represents the optimal growth conditions for *Phormidium*, and increases the probability of blooms by up to 40% compared with the lower and higher velocity states. The influence of optimal water velocity is greater when nutrients or dissolved essential elements are limiting, i.e., low DIN concentration, conductivity or deposited fine sediment.

Influence of sewage treatment plant

Node name: Downstream of sewage treatment plant. *Units:* categories yes, no.

Most cases where *Phormidium* respond in an atypical way to the above drivers were downstream of sewage treatment plants (McAllister et al. 2016). The reason that *Phormidium* responds differently below a sewage treatment plant is not well understood (Wood et al. 2017b). In this Bayesian network, the presence of a sewage treatment plant allows *Phormidium* blooms at DRP concentrations >10 ppb (whereas in the absence of a STP, blooms are very unlikely to occur at high DRP concentrations), and reduces the probability of *Phormidium* blooms by 5-30% where other conditions are ideal.

3.3.3 Probability of *Phormidium* blooms at baseline

Results are reported here as the probability of a *Phormidium* bloom (covering >20% of the river bed).

At baseline, the probability of a *Phormidium* bloom predicted by the Bayesian network varies from 5% to 54% average probability on any day of the year (Table 15, Figure 6). As found in RSOE monitoring, the BN predicts that blooms are most likely in the Waipoua River (54%). Other rivers where the probability of a bloom is predicted to be relatively high include Mangatarere (45%) and Tauherenikau (37%), though blooms have not been recorded to date at these sites in RSOE monitoring. Mangatarere has a high probability in the BN because of the presence of a sewage treatment plant upstream of the reporting reach. In this BN, a sewage treatment plant increases the uncertainties related to predictions, but does not necessarily raise the chance of a bloom, therefore the BN may be over-estimating the probability in this case. Other rivers where blooms have been observed (Huangarua, Waingawa and Ruamahanga @ Te Ore Ore) had moderate to low chances of a bloom according to the BN (27%, 25% and 5%, respectively). The reasons for the discrepancy between the observed and predicted probability of *Phormidium* bloom in the Ruamahanga @ Te Ore reporting reach are not known, but note that this probability does increase dramatically in Silver and Gold scenarios (see below), which implies that conditions in terms of most water quality and flow variables are conducive to blooms.

Table 15: Expected probability of a *Phormidium* bloom (>20% cover) at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	27	27	27	27	27	27	27	27	27	27
Kopuaranga	5	5	5	5	5	5	5	5	5	5
Mangatarere	45	5	5	5	5	5	5	5	5	5
Ruamahanga @Pukio	5	5	25	25	25	25	25	25	25	25
Ruamahanga @TeOreOre	5	5	5	5	44	44	44	44	44	44
Taueru	5	5	5	5	5	27	27	5	27	27
Tauherenikau	37	37	37	37	30	30	30	30	30	30
Waingawa	25	25	25	25	25	25	25	25	25	25
Waiohine	24	5	5	5	25	25	25	25	25	25
Waipoua	54	54	54	54	54	54	54	54	54	54

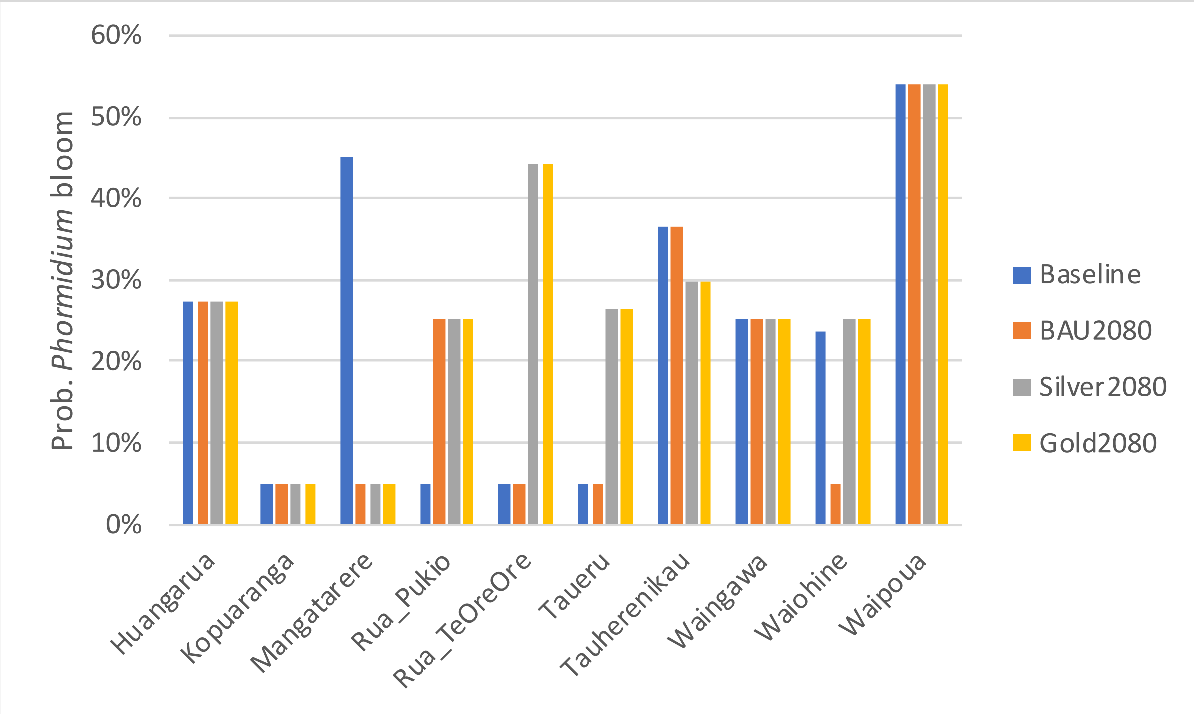

Figure 6: Expected probability of *Phormidium* bloom (>20% cover) at baseline and under BAU, Silver and Gold scenarios in the year 2080.

3.3.4 Effects of three development scenarios on *Phormidium*

The probability of a *Phormidium* bloom does not change significantly in Huangarua, Kopuaranga, Tauherenikau, Waingawa and Waipoua rivers under any scenario (Table 15, Figure 6).

The probability of a bloom decreases significantly in the Mangatarere River (45% at baseline to 5% in all scenarios by 2025) and in the Waiohine River (24% at baseline to 5% in BAU by 2025). These decreases are due to a switch from river discharge to land discharge of sewage treatment plant effluent. Sewage treatment plants cause *Phormidium* to act in unpredictable ways, and therefore *Phormidium* blooms become more predictable when sewage effluent is kept out of these rivers.

The probability of a *Phormidium* bloom increases in Ruamahanga at Pukio (5% at baseline increases to 25% by 2080 in Gold and Silver scenarios), Ruamahanga at Te Ore (5% at baseline increases to 44% by 2080 in Gold and Silver scenarios), Taueru (5% at baseline increases to 27% by 2040 in Gold and Silver scenarios) and Waiohine (5% in BAU increases to 25% by 2025 in Gold and Silver scenarios). The increased probability of a bloom in these four sites is due to declines in dissolved reactive phosphate to <10.8 ppb. *Phormidium* competes for habitat space more successfully when DRP concentrations are low than when they are higher, thus the probability of a *Phormidium* bloom can be inversely related to DRP concentration.

The probability of *Phormidium* bloom also depends on DIN concentration, deposited fine sediment, electrical conductivity, water velocity and number of growing days since a flood (flushing) event. Flow velocity doesn't change significantly in any scenario at any site, because of only minor changes in mean annual flow. Frequency of high flow events and deposited fine sediment do not change, as discussed above. Changes in electrical conductivity could not be predicted by the collaborative modelling group, therefore are represented as unchanging (note that changes in conductivity due to modelled changes in DIN concentration would be < 1μS/cm at all sites under all scenarios).

3.4 Trout size and abundance

3.4.1 Node description and states

Node name: Trout size abund. *Units:* categories good, medium, poor.

The trout node attempts to estimate the state of the trout population in a way that relates to its value for angling. Angler surveys show that both trout abundance and trout size are relevant to angling, as rivers supporting large numbers of small trout are not favoured (John Hayes, Cawthron Institute, pers. comm.). Therefore, this node represents the product of abundance and size. Jowett (1990) used the product of size and abundance to estimate trout biomass, the measure by which he separated river sites into different classes on the basis of their trout populations. Unlike Jowett (1990) we did not distinguish between brown trout and rainbow trout, in order to keep our model relatively simple.

The state categories of good, medium and poor are defined in terms of trout biomass as >2.0 g/m^2, 0.5-2 g/m^2 and <0.5 g/m^2. These are the thresholds use by Jowett (1990) to distinguish rivers with "high"' "medium" and "low" trout biomass. They separate the upper 15%, the middle 45th to 85th percentile and the lower 45% of the 157 sites surveyed by Jowett (1990), a collection of sites that represents a wide geographic spread across New Zealand and a wide range of catchment and channel conditions (Jowett 1992).

3.4.2 Network structure

The factors affecting trout size and abundance are shown in Appendix A Figure 2. Trout abundance is influenced by a different set of factors to trout size, therefore they are each shown by a separate branch of the Bayesian network. Trout abundance is mainly a function of habitat area and recruitment from spawning (Jowett 1992, John Hayes pers. comm.) whereas trout size is influenced primarily by temperature, density of prey (drifting invertebrates) and the ability of trout to see their prey. The importance of habitat area and macroinvertebrate prey abundance were highlighted by Jowett (1992) who showed that among 89 river sites across New Zealand, 64.4% of variability in the abundance of large (>200 mm) brown trout was explained by habitat area and benthic macroinvertebrate biomass.

Dissolved oxygen is an over-riding factor that may cause mortality if it reaches very low levels, or retard growth and development at sub-lethal levels (Davies-Colley et al. 2013). The following subsections describe these nodes and associated branches of the network.

Trout habitat area % protected

Node name: Trout habitat area %. *Units:* % of natural extent.

Since different trout species and life stages have different habitat requirements (different habitat suitability curves), a clear definition of trout habitat area is needed. For the purpose of this Bayesian network, an appropriate definition for trout habitat area is the area of drift feeding habitat for adult brown trout at MALF (mean annual low flow). This is the definition used by Young and Hayes (1999) for trout bioenergetics modelling and by Jowett (1992) in his model of brown trout abundance.

Using this definition, changes in trout habitat area resulting from changes in flow can be predicted using RHYHABSIM. RHYHABSIM modelling requires data on the morphology of specific river reaches, which usually involves field surveys. However, GIS databases now contain sufficiently accurate data on river morphology that the effect of flow changes on habitat area can be predicted accurately enough for the purposes of the Bayesian network. Changes in trout habitat area were predicted from changes in flow by Jan Diettrich (NIWA) using Environmental Flows Strategic Allocation Platform (EFSAP) (Booker 2016).

It is assumed here that a percent change in trout habitat area results in the same percent change in trout abundance. Jowett (1992) found a linear correlation between habitat area and the logarithm of brown trout abundance. Given the broad categories we use in the trout size and abundance node, the difference between raw abundance and log abundance is probably minor.

Trout spawning

Node name: trout spawning. *Units:* categories good, medium, poor.

Many New Zealand rivers are recruitment-limited, however in most large river systems spawning occurs mainly in tributaries rather than the mainstem (John Hayes, Cawthron Institute, pers. comm.). Therefore, development scenarios that reduce the spawning potential of the mainstem but not tributaries may not have a large impact on trout abundance in the mainstem. The mainstem may be an important site for spawning if it has very stable flows, e.g., lake- or spring-fed rivers. In this Bayesian network we allow the user to determine whether the mainstem is important for spawning by choosing “yes” or “no” for the node “Important for spawning”. If “no” is selected, the state of the “trout spawning” node will not affect trout size and abundance. The user may select “yes” if a development scenario being considered affects the key spawning tributaries as well as the mainstem.

Jowett (1992) found that brown trout were absent from rivers with poor spawning habitat. Therefore in this Bayesian network we set trout spawning as a “minimum operator”, i.e., trout size and abundance cannot be in a better state than trout spawning (assuming that “yes” is selected for “important for spawning”). Provided other factors are ideal, trout size and abundance will assume the same state as trout spawning.

Changes in trout spawning with abstraction and land use intensification

Trout spawning is affected primarily by water temperature, dissolved oxygen and clogging of river beds by silt (Hay et al. 2006). These aspects of water and habitat quality are similar to those affecting adult trout. The differences are that successful spawning requires lower water temperatures, higher dissolved oxygen and “cleaner” gravels than adult trout do, and that these requirements are during the winter spawning period rather than during the summer growth period. Jowett (1992) noted that trout were rare or absent from New Zealand rivers with minimum annual (i.e., winter) water temperatures >10 °C, and attributed this to inability to spawn. He defined three levels of spawning preference as <10 °C, 10-11 °C and >11 °C. We have equated these levels to good, medium and poor trout spawning.

Trout spawning also requires high concentrations of dissolved oxygen within the gravels that eggs are laid in. Maintaining high dissolved oxygen among the gravels requires maintaining even higher oxygen concentrations in the overlying water. Davies-Colley et al. (2013) cite a USEPA study that describes no, slight, moderate and severe impairment of production of early life-stage trout at dissolved oxygen concentrations of 11, 9, 8 and 7 mg/L, respectively. A concentration of 6 mg/L marks the limit to avoid acute mortality. We used these values to define the effect of winter dissolved oxygen on trout spawning (Table 16).

Table 16: Probabilities of trout spawning being in good, medium or poor state as a function of winter dissolved oxygen concentration in the overlying water.

	Trout spawning Good	Trout spawning Medium	Trout spawning Poor
oxygen <5 mg/L	0%	0%	100%
5-7 mg/L	0%	0%	100%
7-8 mg/L	0%	20%	80%
8-11 mg/L	20%	80%	0%
>11 mg/L	100%	0%	0%

Spawning trout appear to be more sensitive to clogging of river beds by fine silt than macroinvertebrates are. According to Crisp & Carling (1989), greater than 20% sediment is generally seen as a threshold for suitable spawning habitat, 10-20% sediment provides adequate to poor spawning habitat (embryo survival will be affected), less than 10% is good and no sediment is optimal. In this Bayesian network, ranges of 0-10%, 10-20% and >20% sediment cover correspond to good, medium and poor trout spawning.

The three factors influencing trout spawning interact as "minimum operators", i.e., the state of trout spawning corresponds to the lowest state among the three causative factors.

Trout maximum size

Node name: trout max size. *Units:* % of maximum size expected in a reference stream

The maximum size that trout can attain is a direct function of their growth rate, thus we use maximum size and growth rate inter-changeably here. This enables us to use experimental data on growth rates to inform the relationships between nodes, while using a measure that is meaningful to anglers. In addition, because much data on trout size are gathered from fishing spots, but few data on growth rates are collected from field situations, using growth rate and maximum size interchangeably allows us to validate the results of this Bayesian network.

Since experiments by Elliott (1976), it has been commonly recognised that trout growth rates are primarily influenced by temperature, food supply and visual clarity of the water (Hayes et al. 2000). Food supply is defined here as the density of drifting macroinvertebrates. Drift feeding (c.f. benthic feeding on food items on the river bed) is by far the most energy-efficient form of feeding for trout, and large invertebrates provide a much higher energy return per unit effort than small invertebrates (Hayes et al. 2000). Therefore trout growth rates depend strongly on the density of drifting large invertebrates.

Water temperature exerts a strong influence on trout energetics (hence growth rate). Efficiency of energy uptake reduces at low water temperatures (Elliott 1976). Meanwhile trout metabolic rate, and hence energy demand, increases exponentially with temperature (Hayes et al. 2000). As a result of these two patterns, brown trout show optimal growth rates at about 13 °C, and steep declines as temperature increases or decreases away from this value. Temperature and food intake interact in complex ways. Growth rates for different combinations of temperature and food intake (expressed as a percentage of full rations) used in this Bayesian network (Table 17) were derived from growth curves in Elliott (1976).

Table 17: Trout growth rates as percentages of maximum growth rate for different combinations of water temperature and prey abundance. (Expressed as % of full rations).

	5-11 °C	11-16.4 °C	16.4-19 °C	19-21 °C	>21 °C
100%	44%	100%	28%	0%	0%
75%	44%	91%	13%	0%	0%
50%	44%	56%	9%	0%	0%
25%	37%	11%	-28%	-44%	-44%
10%	0%	-28%	-61%	-67%	-67%

The actual availability of drifting invertebrates as prey depends on the visual clarity of the water as well as invertebrate density. This is because decreases in visual clarity allow invertebrates further from the trout to escape unseen. Hay et al. (2006) state that if clarity is maintained above 1.4 m, the foraging area for small prey should not be substantially reduced. However, large prey can be seen from further away, and these may form a significant part of diet. Therefore, to maintain optimal foraging for large (60 cm) fish on large (30 mm) prey, water clarity must be maintained above 3.75 m.

Despite evidence that visual clarity has a strong effect on trout bioenergetics, very little data are available that quantify the effect of reduced visual clarity on trout growth rates. We scaled growth rates by a factor of 0.8 for visual clarity <1.4 m and 0.95 for visual clarity of 1.4-3.75 m relative to values at clarity >3.75 m. These factors were conservative estimates based on a) the prediction of Hayes et al. (2000) that maximum trout weight would decline by 19 and 44%, respectively, when maximum prey size was reduced from 39 to 12 and 9 mm, and b) the following figure (Figure 7) taken from Hay et al. (2006):

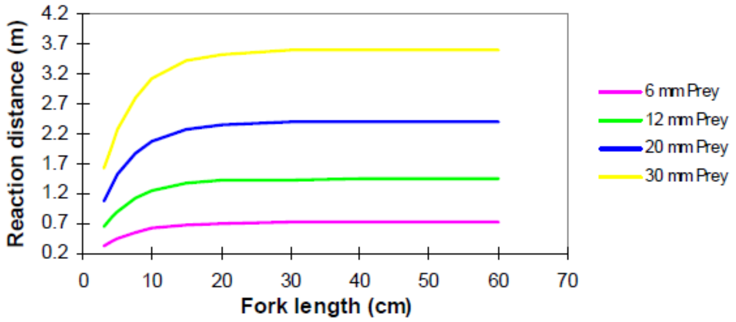

Figure 7: Reaction distance to drifting invertebrate prey relative to fish size, and on Hughes and Dill's (1990) drift foraging model for a range of sizes of invertebrate prey. Referenced in Hay et al. (2006) Figure 1.

Changes in visual clarity

Changes in suspended sediment concentration were estimated by Jacobs Ltd. using Source™ (e-Water). The relationship between visual clarity and suspended sediment concentration differs among river catchments (Davies-Colley and Close 1990), so was specified in this BN using RSOE data for rivers in the Ruamahanga catchment that included both variables.

Trout prey index

Node name: trout prey index. *Units:* % of value expected in a reference site.

Trout prey index (TPI; Hayes et al. unpubl. data) is defined here as the density of large drifting macroinvertebrates. As the TPI was still under development at the time of developing this BN, there are other possible definitions for it, including definitions based on presence/absence rather than density, or based on benthic or cruise feeding. Trout may feed on benthic (bottom-dwelling) as well as drifting macroinvertebrates, but at much greater energy cost, therefore trout growth rate (hence maximum size) strongly depends on the density of drifting invertebrates. This is the reason for our choice of definition.

Since different invertebrate taxa grow to different size, and have different propensities to drift, some taxa contribute much more than others to the energy intake of trout. The trout prey index takes these factors into account, assigning weightings to different taxa according to their potential contribution to trout diet. Because of these weightings, TPI is a somewhat different measure to total invertebrate density or total invertebrate biomass. It also differs from MCI because it is based on abundance rather than presence/absence and has different weightings to MCI. Despite these differences we considered that the main factors that may cause change in TPI with water abstraction and land use intensification would be similar to those causing change in MCI. However relationships may be somewhat different because TPI is a density measure.

Using the taxa weighting scores for drift feeding, Matheson et al. (2015) calculated changes in TPI with different levels of periphyton biomass. TPI shows a “hump-shaped” relationship with periphyton biomass (Table 18), reaching a maximum at biomass of 120-200 mg Chl. *a* /m^2. Up to this level, periphyton represents a food subsidy, whereas above this level it represents a disruption to invertebrate habitat.

Table 18: Percent changes in Trout prey index (measured as density of large drifting invertebrates) with changes in periphyton biomass. Percent changes are relative to TPI at 120-200 mg Chl. a / m^2.

Chl. *a*	% change compared to optimal
<50 mg/m^2	-25%
50 to 120 mg/m^2	-16%
120 to 200 mg/m^2	0%
>200 mg/m^2	-32%

Floods scour macroinvertebrates from riverbeds, and population densities take time to recover following such events. Clausen and Biggs (1997) combined data for FRE3 (number of floods >3x median flow per year) and macroinvertebrate density for 83 river sites across New Zealand. From their dataset we calculated that macroinvertebrate density is about 10% less at sites with <14 days of accrual (FRE3=26) compared to sites with >14 days of accrual.

Generally, taxa providing the bulk of the diet for trout tend to be mayflies, stoneflies and caddisflies, also known as EPT taxa. The proportion of an invertebrate community comprised of EPT taxa (%EPT abundance) is a common measure of stream ecosystem health, and we used %EPT abundance as a surrogate for TPI to determine the effects of fine sediment deposition and water temperature. Clapcott et al. (2011) showed that %EPT abundance declined by 8% and 38% respectively, as cover of deposited fine sediment increased from 0-10% to 10-20% and from 0-10% to >20%, respectively. Data from NIWA's National River Water Quality Network show percent changes in %EPT abundance with water temperature as summarised in Table 19.

Table 19: %EPT abundance and % change in EPT abundance in different categories of summer water temperature. % change is relative to that at optimal temperature of <11 °C.

Summer water temperature	Average % EPT abundance	% change in %EPT abundance relative to optimal (0 to 11 °C)
0 to 11 °C	39.2	0%
11 to 16.4 °C	39.2	0%
16.4 to 17.3 °C	33.4	-15%
17.3 to 19 °C	20	-49%
19 to 21 °C	5	-87%
>21 °C	0	-100%

A value for Trout prey index for each combination of states in each of the four causative factors was calculated as the product of the % change for the corresponding state in each factor. Values of trout prey index were then discretised into categories of 0-10%, 10-25%, 25-50%, 50-75% and 75-100%.

Dissolved oxygen

Node name: Dissolved oxygen. *Unit*s: mg/L

Dissolved oxygen is one of the compulsory attributes described in the National Objectives Framework. The states represented in this Bayesian network correspond to the condition bands specified in the NOF. Therefore, dissolved oxygen concentrations used here are defined as 7-day mean minimum values (i.e., the mean value of 7 consecutive daily minimum values) during summer. The narrative attribute states in the NOF state that dissolved oxygen of ≥8.0 mg/L represents no stress on aquatic organisms, 7.0-8.0 mg/L represents occasional minor stress on aquatic organisms including risk of reduced abundance of sensitive fish, 5.0-7.0 mg/L represents moderate stress on aquatic organisms including risk of sensitive fish species being lost, and <5.0 mg/L represents significant persistent stress on a range of aquatic organisms. Studies by the USEPA (cited in Davies-

Colley et al. 2013) indicate that low dissolved oxygen can reduce the growth rate of salmonid fish. Using these two sources of information, we considered that at concentrations >8 mg/L dissolved oxygen has no effect on trout size and abundance, at concentrations of 7-8 mg/L trout size and abundance is reduced by a factor of 0.9, at concentrations of 5-7 mg/L trout size and abundance is reduced by a factor of 0.75, and at concentrations <5 mg/L trout size and abundance is reduced to zero.

3.4.3 Combining parents of trout size and abundance

A value for "trout size and abundance" was calculated as the product of trout maximum size and habitat area % protected (which is equivalent to trout abundance). This value was then modified by the scaling factors described above for dissolved oxygen. Values >0.85 were designated as "good", values between 0.45 and 0.85 were designated as "medium" and values <0.45 were designated as "poor" according to the percentiles in Jowett's (1990) dataset for high, medium and low biomass. Finally, trout spawning was incorporated by providing an upper limit to the state for trout size and abundance (i.e., if trout spawning was medium, trout size and abundance could only achieve a maximum state of medium, if trout spawning was poor, trout size and abundance could only achieve a maximum state of poor).

3.4.4 Trout size and abundance at baseline

Trout size and abundance is described as poor to medium among the reporting reaches at current state (**Table 20**, Figure 8). This is mainly because of low water clarity at all sites (<1.4 m average daily clarity during the summer period December to March) and because of generally poor trout prey index (e.g., <10% at Waiohine and Ruamahanga at Pukio; 10-20% at Ruamahanga at Te Ore Ore). However, since data were not available to calibrate the BN at baseline, more attention should be given to relative values among the different scenarios rather than to absolute values.

Table 20: Expected values of trout size/abundance at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080. Values are on a scale of 0 (poor) to 3 (good).

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	0	0	0	0	0	0	0	0	0	0
Kopuaranga	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Mangatarere	1	1	1	1	1	1	1	1	1	1
Ruamahanga @Pukio	0	0	0	0	0	0	0	0	0	0
Ruamahanga @TeOreOre	0	0	0	0	0	0	0	0	0	0
Taueru	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Tauherenikau	0	0	0	0	0	0	0	0	0	0
Waingawa	0	0	0	0	0	0	0	0	0	0
Waiohine	1	1	1	1	1	1	1	1	1	1
Waipoua	0	0	0	0	0	0	0	0	0	0

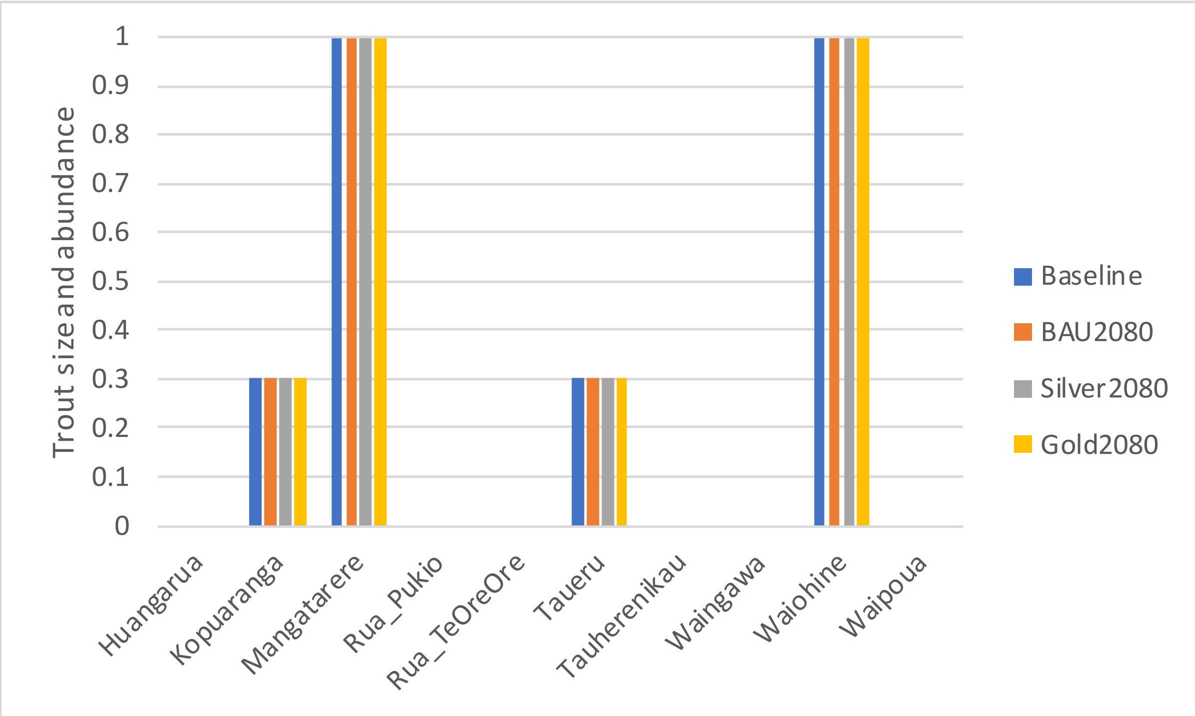

Figure 8: Expected values of trout size/abundance at baseline and under BAU, Silver and Gold scenarios in the year 2080. Values are on a scale of 0 (poor) to 2 (good).

3.4.5 Effects of development scenarios on trout size and abundance

Trout size and abundance does not change at any site under any scenario, relative to baseline (**Table 20**, Figure 8).

The reasons that no differences seen among scenarios are as follows. Trout size/abundance is based on % weighted usable habitat area protected (a function of % change in MALF), deposited fine sediment, summer and winter dissolved oxygen, winter mean temperature, water clarity and trout prey index (which is a function of summer water temperature, accrual period between floods, periphyton biomass and deposited fine sediment).

A. % habitat area is >90% in all sites under all scenarios except in Huangarua (where it decreases to 63% in all scenarios compared with baseline). However, because trout size/abundance is already poor at this site, a decrease in habitat area makes no difference.

B. Visual water clarity is <1.4 m at all sites under all scenarios, because suspended solids is >7.7 g/m^3 under all scenarios. To achieve visual water clarity of >1.4 m would require suspended sediment concentration of 6 g/m^3 or less. Note that visual water clarity appears to be one of the main factors limiting trout size and abundance. For example, improving clarity to 2 m could raise trout size/abundance to 20-80% probability of being “good” at some sites that are currently medium, e.g., Kopuaranga, Mangatarere, Taueru, and Waiohine. Achieving 2 m water clarity would require TSS to be less than about 2 g/m^3.

C. Trout prey index does not vary among the scenarios at any site except Waipoua where it increases from 6% (baseline) to 28% (all other scenarios) due to a decrease in temperature.

3.5 River bird abundance

3.5.1 Node description and states

Node names: Wading bird abundance, Black-billed gull abundance. *Units:* categories OK, reduced.

Several species of native bird depend largely or entirely on gravel bed rivers for nesting and feeding. Bird species in the Ruamahanga River and its tributaries include banded dotterel, black-fronted dotterel, pied stilt, black-backed gull, and black-billed gull (K. Hughey, Lincoln University, pers. comm.).

Each of these species has its own preferences regarding nesting and feeding, however the wading birds (pied stilts, banded and black-fronted dotterels) have enough in common that a single node of a Bayesian network can be used to summarise the condition of all three species. Black-billed gulls appear to feed more widely than stilts and dotterels, their diet consisting more of terrestrial invertebrates from nearby agricultural areas than of aquatic invertebrates (McClellan 2009). Therefore, in this BN their abundance is determined separately, being not dependent on "Feeding OK".

The two states of these nodes represent ends of a spectrum, and the probability distribution between them indicates how far along this spectrum the condition of the bird community is. An increase in the probability of "reduced" relative to "OK" should be interpreted as a decline in abundance of wading birds or black-billed gulls.

3.5.2 Network design

The network for river bird abundance (Appendix A Figure 3) was based on the schema in Hughey (2012), and the threats described by McArthur and Lawson (2013) for river birds in the Ruamahanga catchment. Hughey (2012) describes threats to two aspects of river bird ecology, nesting success and foods/feeding. In this situation, threats to nesting success were given greater weight than threats to foods/feeding. Although the ecological relationships described in this BN are understood in general terms, most of them cannot be quantified due to lack of data. Even the relative strength of the different causal factors may vary from one site to another, and is not known for sites in the TANK catchments. Therefore, while results from different scenarios can be interpreted relative to one another, the probabilities generated for any one scenario should not be interpreted too closely.

Nesting success

River birds typically nest on open gravel bars, a habitat that is naturally highly dynamic due to floods that cover gravel bars and shift their locations. Nesting is naturally at risk from unpredictable flows, but nesting success on many gravel bed rivers is also subject to three main human-derived threats. These include predation by introduced mammals, physical disturbance of nests (by humans, dogs, recreational vehicles, stock or flood protection works) and vegetation encroachment on gravel banks which forces birds to nest at lower levels on gravel banks where they are more frequently disturbed by floods (McArthur and Lawson 2013). Predation is known to be less on open gravels than on those covered in vegetation, and on gravel islands than on gravel banks connected to the mainland.

Therefore, changes to river flow regimes that alter vegetation encroachment and river braidedness potentially have an indirect effect on river birds.

Food and feeding

Food supply is believed to affect bird population sizes, as nesting densities of some bird species are highest where habitat conditions provide the greatest feeding opportunities (Hughey 1998, 2012). Adequate feeding opportunities requires both an abundance of food (mainly aquatic invertebrates) and suitable habitat for harvesting this food (typically shallow areas with slow flow).

The relative importance of predator impact vs. food/feeding vs. disturbance of nesting sites is likely to be different in different river systems (Hughey 2012), and is not known for the TANK rivers. Therefore, we have not attempted to distinguish the relative importance of predator impact vs. feeding OK, but have given both of these double the weighting of bird disturbance. The final outcome for bird abundance is the product of multiplying the three factors, with the optimal state in each factor being assigned a 1, and the degraded state being assigned 0.25 for predator impact and feeding OK, and 0.5 for bird disturbance. The resulting conditional probability table is shown in Table 21.

Black billed gull abundance is determined in the same way as wading bird abundance, except without the influence of feeding, as black billed gulls typically depend more on terrestrial invertebrates than aquatic ones. The conditional probability table for black billed gulls is shown in Table 22.

Table 21: Conditional probability table for wading bird abundance as a function of bird disturbance, predator impact and Feeding OK.

			Wading bird abundance	
Bird disturbance	**Predator impact**	**Feeding OK**	**OK**	**Reduced**
FALSE	low	FALSE	25%	75%
FALSE	low	TRUE	100%	0%
FALSE	high	FALSE	6%	94%
FALSE	high	TRUE	25%	75%
TRUE	low	FALSE	13%	88%
TRUE	low	TRUE	50%	50%
TRUE	high	FALSE	3%	97%
TRUE	high	TRUE	13%	88%

Table 22: Conditional probability table for black billed gull abundance as a function of bird disturbance and predator impact.

		Black billed gull abundance	
Bird disturbance	Predator impact	OK	reduced
FALSE	low	100%	0%
FALSE	high	25%	75%
TRUE	low	50%	50%
TRUE	high	13%	88%

3.5.3 Node parents

Impact of predators

Node name: impact of predators. *Units:* categories high, low.

The impact of mammalian predators on river birds is related to two factors. The first is the "braidedness" of a river, i.e., the number and size of gravel islands that are separated from the mainland. This is because mammalian predators visit bird nests on islands much less frequently than nests on connected gravel banks, despite the fact that many predators can swim (Hughey 2012). Pressure from mammalian predators is also increased where weeds encroach on gravel banks. This is because weeds tend to attract rabbits, which then attract predators, and because the weeds provide cover for predators. Unfortunately, these relationships are only poorly understood (Hughey 2012). Therefore, the conditional probability table for impact of predators are set more conservatively, i.e., the probabilities are distributed more evenly between "low" and "high" states of predator impact, than would be the case if there were higher certainty regarding the effects of weed encroachment and river braidedness (Table 23).

Table 23: Conditional probability table relating river braidedness and weed encroachment to impact of predators.

		Impact of predators	
River braidedness	Weed encroachment	Low	High
high	low	80	20
high	high	60	40
low	low	30	70
low	high	20	80

Weed encroachment

Weed encroachment onto gravel bars is naturally reduced by large floods that overtop the bars and have the energy to scour vegetation (Hughey 2012). The size of flood expected to remove weeds in rivers of the Ruamahanga catchment is estimated as Q5, the five-year ARI (average return interval) flood (David Boone, GWRC, pers. comm.). The natural rate of removal by floods is not necessarily sufficient to prevent weed encroachment, and in the Ruamahanga rivers, weed encroachment has had an impact on river birds (Philippa Crisp, GWRC, pers. comm.). Flood frequency and magnitude can be reduced by a dam on the mainstem or a major tributary, or by harvesting of high flows.

Regional councils often reduce weed encroachment on gravel bars for the purpose of flood protection, using herbicides and mechanical removal. This work, which is regarded as having a positive effect on river birds (McArthur et al. 2013), may have greater effect on weed encroachment that natural removal processes (David Boone, GWRC, pers. comm.).

The effects of Q5 and GWRC weed removal on weed encroachment are shown in Table 24.

Table 24: Conditional probability table relating Q5 (the size of the five-year ARI flood) and council weed removal to weed encroachment.

		Weed encroachment	
Council weed removal	Q5	Low	High
current	current	100	0
current	reduced 50%	100	0
none	current	50	50
none	reduced 50%	0	100

River braidedness

Node name: river braidedness. *Units:* categories high, low.

River braidedness is defined for the purpose of river bird habitat as the number of islands per km of river length. High braiding is defined here as >2 islands per river km, and low as <0.2 islands per river km, based on the number of islands recorded in the reporting rivers. In the Ruamahanga catchment, only the Waingawa River has naturally high braiding, while the Tauherenikau and Ruamahanga @ Te Ore have medium braiding, i.e., these rivers have enough islands to provide important nesting habitat for river birds.

The number of islands is affected by three main factors. First is the balance between supply of sediment (gravel) from upper reaches and the capacity of the river to remove that gravel. River braiding is a result of large volumes of gravel carried from upper reaches by high energy flows that deposit the gravel when they lose energy (Mosely 2004). The gravels are typically transported along the riverbed rather than in suspension. Sediment supply from upper reaches may be reduced or completely halted by a dam on a major tributary or the mainstem. Conversely, the capacity of a river to remove gravel may be reduced by abstraction of flow. The critical element is Q2, the discharge of the two-year ARI (average return interval) flood.

The effect of the sediment supply:transport capacity ratio on river braidedness can be determined with some accuracy using models such as MIWA (Morphological Impacts of Water Allocation; Hicks et al. 2009). However, as this requires detailed work using site-specific information, only a generalised relationship has been developed here.

The second factor is encroachment of gravel banks and braids by exotic vegetation (the node here called “weed encroachment”). Encroaching vegetation stabilises gravel bars and banks, and as a result, wide, braided rivers tend to become narrow and single-thread (Mosley 2004). As with sediment supply and transport capacity, a generalised relationship between vegetation encroachment on river braidedness inferred from observations (Mosley 2004) is used here.

The third factor is the flow at mean annual low flow (MALF). Reductions in MALF by water abstraction may lower water levels so that shallow channels dry up and gravel bars formerly isolated from the mainland become connected (Hughey 2012). Mosley (1983), Hicks et al. (2003), Duncan (2010) and Hicks and Bind (2015) showed that for several braided rivers there is a relationship between increasing flow and the number of braids. Hughey (2012) concludes that “Any reduction in the low to medium flows is thus likely… to increase vulnerability to predation.” Because braiding can only decrease in rivers that have some amount of braiding, “Natural river braidedness” is included as a parent node of river braidedness. The relationship between MALF and river braidedness was developed for the Waingawa River in the Ruamahanga catchment. A visual count using satellite images on Google Earth shows that of the number of islands >0.25 ha in area has a roughly linear relationship with flow above MALF, but below MALF the rate of island disappearance with decreasing flow increases.

The relationships between river braidedness and all its drivers are shown in Table 25.

Table 25: Conditional probability table relating change in mean annual low flow (MALF), ratio of sediment supply:transport capacity and weed encroachment to river braidedness.

				River braidedness	
Natural braidedness	%change in MALF	Sediment supply:transport capacity ratio	Weed encroachment	High	Low
high	0 to 5	one or more	low	1	0
high	0 to 5	one or more	high	0.5	0.5
high	0 to 5	less than one	low	0.5	0.5
high	0 to 5	less than one	high	0.25	0.75
high	5 to 50	one or more	low	0.75	0.25
high	5 to 50	one or more	high	0.375	0.625
high	5 to 50	less than one	low	0.375	0.625
high	5 to 50	less than one	high	0.1875	0.8125
high	50 to 90	one or more	low	0.25	0.75
high	50 to 90	one or more	high	0.125	0.875
high	50 to 90	less than one	low	0.125	0.875
high	50 to 90	less than one	high	0.0625	0.9375
high	90 to 100	one or more	low	0	1
high	90 to 100	one or more	high	0	1
high	90 to 100	less than one	low	0	1
high	90 to 100	less than one	high	0	1
low	0 to 5	one or more	low	0	1
low	0 to 5	one or more	high	0	1
low	0 to 5	less than one	low	0	1
low	0 to 5	less than one	high	0	1
low	5 to 50	one or more	low	0	1
low	5 to 50	one or more	high	0	1
low	5 to 50	less than one	low	0	1
low	5 to 50	less than one	high	0	1

				River braidedness	
Natural braidedness	%change in MALF	Sediment supply:transport capacity ratio	Weed encroachment	High	Low
low	50 to 90	one or more	low	0	1
low	50 to 90	one or more	high	0	1
low	50 to 90	less than one	low	0	1
low	50 to 90	less than one	high	0	1
low	90 to 100	one or more	low	0	1
low	90 to 100	one or more	high	0	1
low	90 to 100	less than one	low	0	1
low	90 to 100	less than one	high	0	1

Disturbance of bird nesting sites

Node name: bird disturbance. *Units:* categories true, false.

Hughey (2012) and McArthur and Lawson (2013) list several human activities (four-wheel driving, movement across gravel banks for fishing or camping) that may cause disturbance to river bird nests, thus reducing nesting success. In addition, dogs or stock allowed to wander freely over gravel banks may crush nests, as can heavy machinery brought to extract gravel or rake beaches for flood protection (Stephenson 2011). Such disturbances can be reduced or prevented by policies on the activities causing disturbance, and by reducing access, e.g., by fencing out stock. According to D. Boone (GWRC), flood protection works in the Ruamahanga catchment are now conducted mainly outside of bird breeding season, and in conjunction with bird surveys, to minimise direct disturbance of breeding birds. Therefore, flood protection works are not included in this BN.

Food and feeding

Node name: Feeding OK. *Units:* categories true, false.

Among the main wading birds of conservation concern (listed above), most feeding is on aquatic invertebrates (Hughey 2012). Food supply is believed to affect population sizes, as nesting densities of some bird species are highest where habitat conditions provide the greatest feeding opportunities. This is where the amount of river braiding is greatest (Hughey 1998, 2012). Hughey (2012) concludes that “birds, like other animals require sufficient and appropriate food supply to maintain the energy levels required for breeding.” Hughey (2012) identifies the main threats to feeding habitat and food supply as:

1. reduction of low flows to the point where minor channels dry up and food supplies are lost – for territorial species this can lead to an increase in energy needed to expand and defend their territories, and

2. factors which reduce food supply (i.e., the density of benthic or drifting invertebrates).

The first point relates to the area of suitable feeding habitat, which is represented by the node “Bird feeding habitat area %”. Changes in this node for an altered flow regime (relative to a flow regime without water abstraction) can, in theory, be predicted using RHYHABSIM. Habitat suitability curves are available for feeding of black fronted terns and wrybills (Duncan and Bind 2009, Booker 2010), and we can assume that water depth and velocity preferences for other bird species are similar enough that curves for these two species can be used to represent all wading birds. However, Booker (2010) states that a key factor determining habitat suitability for wading birds is distance from the shoreline. This is not currently included in RHYHABSIM, and until it is, we are not able to accurately predict changes in bird feeding habitat area with changes in flow regime. However, since changes in river flow (and trout habitat area) are minimal at all sites except Huangarua, we assumed that bird feeding habitat area remained within the 80-100% state and at Huangarua, reduced to 60-80% (based on trout habitat area, which declined to 63%).

The second point relates to the density of invertebrate populations. This is represented by the node Trout prey index. Trout prey index relates primarily to drifting invertebrates. Some bird species (e.g., black fronted terns) feed on drift, while others are benthic feeders (Hughey 2012), however the Trout prey index node is affected by factors driving benthic populations as well as drift density, therefore is considered an appropriate measure of invertebrate food supply for birds.

The node Feeding OK is simply the product of invertebrate food density (measured as Trout prey index) and Bird feeding habitat area. The percent probability of Feeding OK being in the “true” state is the percent of the food supply * feeding area that is retained in a modified flow regime relative to an unmodified one.

3.5.4 Abundance of wading birds and black billed gulls at baseline

Given the uncertainties in the BN for river birds, the absolute probabilities of black billed bull abundance or wading bird abundance being “OK” should not be interpreted too literally. Instead, the focus should be on changes in these probabilities under different scenarios.

Sites scoring highly for abundance of wading birds and black billed gulls needed to have both extensive braiding for protection against predators and relatively high abundances of aquatic invertebrate food (shown by the trout prey index). Two sites, Tauherenikau and Waingawa, scored more highly than the others (Table 26 and Table 27, Figure 9 and Figure 10). Low-scoring sites, which included Ruamahanga @ Pukio, Waipoua and Huangarua, had relatively low Trout Prey Index scores. Note, however, that the river birds BN is not designed for comparing sites, as various habitat factors not included in the BN may affect the suitability of a reach for supporting river bird populations.

Table 26: Probability of wading bird abundance being "OK" at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	12%	11%	11%	11%	11%	11%	11%	11%	11%	11%
Kopuaranga	24%	24%	24%	24%	24%	24%	24%	24%	24%	24%
Mangatarere	24%	24%	24%	24%	24%	24%	24%	24%	24%	24%
Ruamahanga @Pukio	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Ruamahanga @TeOreOre	17%	17%	17%	17%	17%	17%	17%	17%	17%	17%
Taueru	18%	18%	18%	18%	18%	18%	18%	18%	18%	18%
Tauherenikau	33%	31%	31%	31%	31%	31%	31%	31%	31%	31%
Waingawa	32%	32%	32%	32%	32%	32%	32%	32%	32%	32%
Waiohine	24%	24%	24%	24%	24%	24%	24%	24%	24%	24%
Waipoua	10%	10%	10%	10%	10%	18%	18%	18%	18%	18%

Table 27: Probability of black-billed gull abundance being "OK" at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Kopuaranga	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Mangatarere	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Ruamahanga @Pukio	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Ruamahanga @TeOreOre	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Taueru	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Tauherenikau	50%	46%	46%	46%	46%	46%	46%	46%	46%	46%
Waingawa	64%	64%	64%	64%	64%	64%	64%	64%	64%	64%
Waiohine	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Waipoua	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%

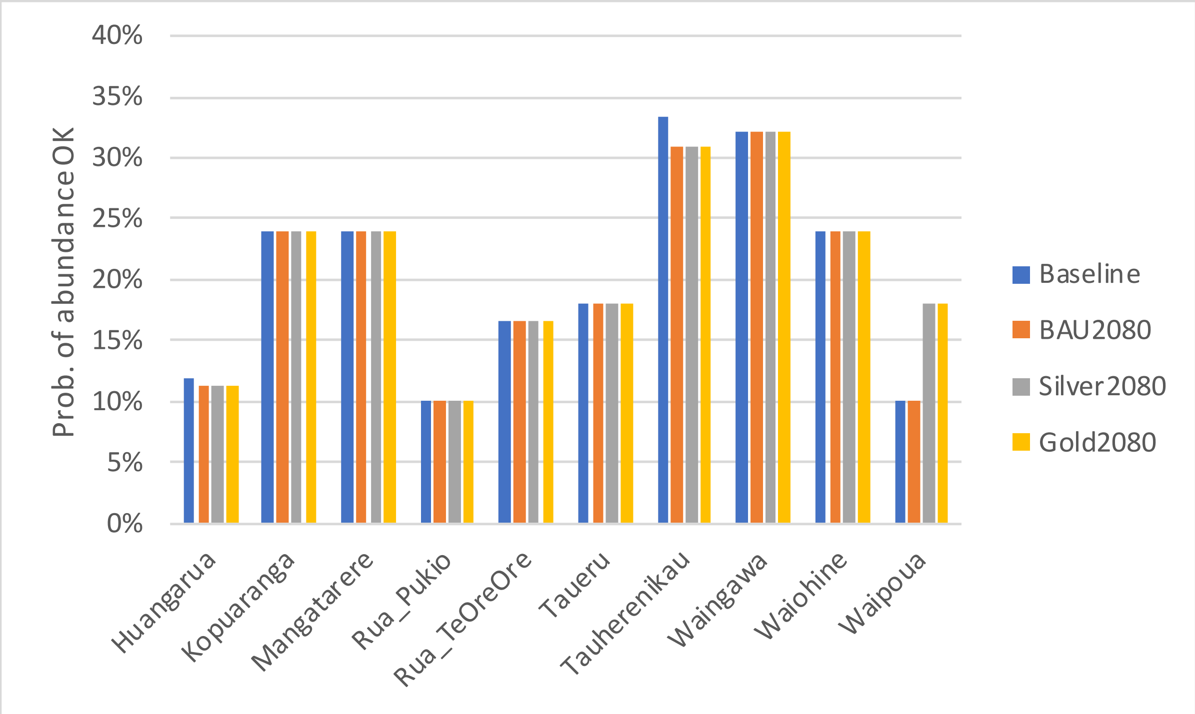

Figure 9: **Probability of wading bird abundance being "OK" at baseline and under scenarios BAU, Silver and Gold in the year 2080.**

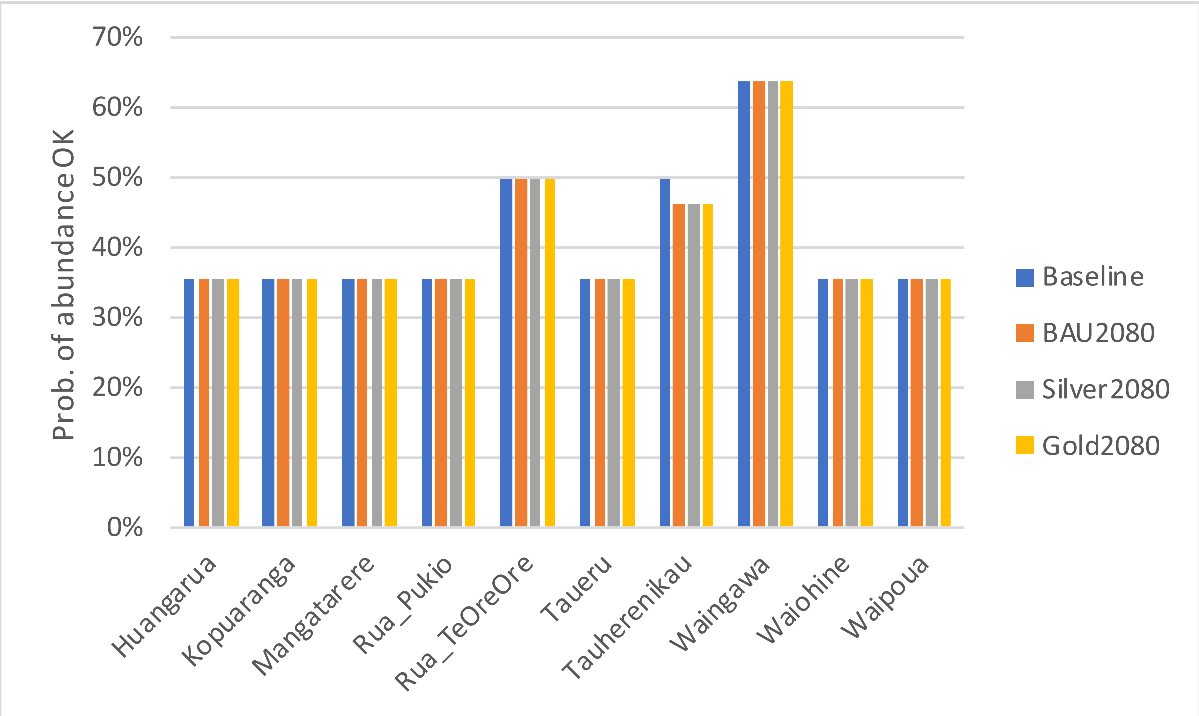

Figure 10: **Probability of black-billed gull bird abundance being "OK" at baseline and under scenarios BAU, Silver and Gold in the year 2080.**

3.5.5 Effects of three development scenarios on abundance of wading birds and black-billed gulls

No change to these values occurs under any scenario at any site except Waipoua (where there is an increase of 6% in Silver and Gold by 2080), Tauherenikau (where there is a decrease of 2% in BAU, Silver and Gold by 2080) and Huangarua (where there is a decrease of 1% in BAU, Silver and Gold relative to baseline) (Table 26).

The Wading birds OK node depends on sufficient feeding resources (Feeding OK), predator impact and human disturbance. Changes to human disturbance were considered outside the scope of the plan change and were not modelled in these scenarios. Predator impact does not change in any reporting reach except the Tauherenikau river (a decrease of 2% in all scenarios compared to baseline). This change is due to slight drop in MALF, which reduces river braidedness and hence gives predators greater access to chicks. Similar decreases in MALF in the Taueru and Huangarua rivers do not cause increases in predator impact because natural braiding is low in these rivers.

The Feeding OK node depends on Bird feeding habitat and Trout Prey Index. Bird feeding habitat does not decline in any scenario for any site except Huangarua, where it drops to 60-80%. The trout prey index does not change significantly in any scenario at any reporting reach except Waipoua (where it increases due to a decrease in mean summer temperature). Therefore, the node "Feeding OK" changes only at Huangarua and Waipoua.

Gulls OK does not change under any scenario at any site except Tauherenikau (where there is a decrease of 3.5% in BAU, Gold and Silver by 2080) (Table 27).

3.6 Native fish: community condition

3.6.1 Node description and states

Node name: Fish IBI. *Units:* IBI scale.

The performance measure for the overall condition of the native fish community is the Fish Index of Biotic Integrity, or Fish IBI (Joy and Death 2004). The Fish IBI is a multimetric index combining six metrics that include total (native) taxonomic richness, richness of native taxa in three habitat guilds (riffle, benthic pool and pelagic pool), richness of native species intolerant of degraded habitat conditions and the ratio of native to exotic species. It is based on presence/absence only and does not indicate shifts in the abundance of any fish species. To calculate scores, the Fish IBI compares the species found at a site with those expected to be at a site, taking into account natural changes in species diversity that occur with distance inland and elevation (Joy & Death 2004). The IBI was chosen as the performance indicator for overall fish community condition as it has been widely used across New Zealand and is a recognised index for assessing the condition of the freshwater fish community.

The identification of key drivers, definition of node states and quantification of the conditional probability tables for the Fish IBI and individual freshwater species in this Bayesian network were all done by Alton Perrie (Greater Wellington Regional Council) in consultation with Dr Mike Joy (Massey University) and Richard Storey (NIWA). They were developed specifically for the Ruamahanga River and its major tributaries. The factors affecting Fish IBI are shown in Appendix A Figure 4.

IBI scores can range from 0 to 60. For this BN, we defined three states based on IBI scores calculated from existing fish survey records for the Wellington Region in the NZ Freshwater Fish Database. This range of IBI scores was split into equal thirds producing the following three states: poor <22, fair 22-32 and good >32.

3.6.2 Node parents

The IBI state that would result from each combination of drivers was decided by the expert judgement of Alton Perrie (Greater Wellington Regional Council). To help facilitate this judgement process a "typical fish community" of the Ruamahanga River (and its main tributaries) was considered in relation to the drivers. This typical fish community is presented in Table 28 (column 1), along with an indication of where each species is mostly likely to occur within the catchment (column 2) and the relative importance of each driver to that species (columns 3-7).

Table 28: The "typical fish community" of the Ruamahanga River catchment considered for generating IBI scores. Impact classes: No impact; + = minimal impact; ++ = likely some impact; +++ = potential for significant impact. Full descriptions of drivers described below.

Species	Locations in catchment	Migration barrier		Percent deep habitat[1]	Bank edge cover	Fine sediment cover
		"stop swimmers"	"stop climbers"			
N.D. bully	Throughout	No impact	No impact	+	+	++
Common bully	mid-lower reaches mostly	+++	+++	+	+	+
Redfin bully	Throughout	+ (but still pass)	+++	+++	++	+++
Torrentfish	Throughout	+++	+++	+++	+	+++
Inanga	mid-lower reaches mostly	+++	+++	+++	++	No impact
Common smelt	mid-lower reaches mostly	+++	+++	+++	++	No impact
Longfin eel	Throughout	+ (but still pass)	+++	+++	+++	++
Shortfin eel	Throughout	+ (but still pass)	+++	+++	+++	++

[1]Note if this is impacted it is also considered to cause a decline in the quality of riffle habitat.

Barriers to migration

Node name: Barriers to migration. *Units:* categories none, stop swimmers, stop climbers.

Many of New Zealand's native freshwater fish species are diadromous, i.e., every generation migrates between freshwater bodies and the sea. A variety of human structures and modifications to rivers can create barriers preventing fish from passing upstream, downstream or both. Barriers to migration represent one of the major impacts reducing fish occurrence and abundance in New Zealand rivers.

Different species have different abilities to overcome potential migration barriers. Some can climb vertical wet surfaces using attachment structures on their fins. These are referred to here as "climbers." They include the eels, redfin bullies and some galaxiids (in Table 28, those species that are minimally affected by a "stop swimmers" barrier). Other species do not have this ability, and are referred to here as "swimmers." They include common bullies, smelt and certain galaxiids such as inanga (in Table 28, those species significantly affected by a "stop swimmers" barrier).

The barrier node has three states:

- No barrier: fish passage is not impeded in any way.
- Stop swimmers: the barrier inhibits passage for species classified as swimmers.
- Stop climbers: the barrier inhibits passage for all diadromous species (both “swimmers” and “climbers”).

Bank edge cover

Node name: Bank edge cover. *Units:* percent of channel length.

Most New Zealand freshwater fish, even pelagic species, require some form of instream cover. Cover can be provided by benthic substrate (such as boulders, cobbles, large wood and aquatic macrophytes), undercut banks or bank/riparian vegetation interaction with the wetted channel of the river. The latter factors (undercut banks and bank/riparian vegetation interaction with the wetted channel) were considered very important in the Ruamahanga River catchment. Therefore this Bayesian network focuses on bank edge features, quantifying them in the node “Bank edge cover”. We assume that if such features occur along 20% or more of the channel length, the habitat requirements of fish have been met. Between 5 and 20% cover is considered to provide a “medium” amount of cover, and <5% cover is considered poor.

The amount of bank edge cover may be reduced if riparian vegetation or contact between the wetted channel and the banks are reduced. We assume that riparian vegetation extent (measured as the % of bank length with riparian trees or shrubs) is directly proportional to the amount of bank edge cover. We also assume that riparian shrubs provide half of the cover benefits of riparian trees, and this effect is represented by the node “riparian vegetation type (% as trees)”.

Channel contact with the banks is defined as the % of channel length that is in contact with one bank or the other. Channel contact with banks may be reduced by a reduction in flow that reduces the wetted channel width (such that the wetted channel shrinks away from the banks) or by flood protection works that shift the wetted channel away from the river banks (thus reducing the influence of overhanging banks, riparian vegetation shading, riparian root mats and riparian wood fallen into the channel). We assume that flood protection works are only done where the river is in contact with the bank (because this is where it is needed), therefore the % of river with flood protection works results in a decline of channel contact with bank by the same %. The relationship between the node “wetted width:bankfull width ratio” and channel contact with banks was determined empirically using measured cross-sections on 5 km-long reaches on each of nine fourth- to seventh-order rivers in the Ruamahanga catchment in Google Earth.

Bank edge cover is related to its parent nodes by the equation:

Bank edge cover =
100*((Rip_veg/100)*(Contact_bank/100)*(0.5+(0.5*(Ripveg_type/100)))+(0.5*((100-Rip_veg)/100)*(Contact_bank/100)))

Mesohabitat diversity

Node name: Percent deep pools and runs. *Units:* percent of channel length.

Different fish species have different habitat needs. Rivers that have a natural morphology and maintain pool, riffle, run sequences, they tend to maintain a diverse range of habitats and hence a more likely to contain a more diverse fish community. In order to provide a univariate measure of mesohabitat diversity we focus on deep pools and runs, as these are key habitats required by some fish species and are most at risk of loss. We also believe that the occurrence of deep pool and run habitat is linked with the quality of shallow riffle habitat and that a decrease in the occurrence of deep habitat will result in poorer riffle habitat being present; and hence a decline in riffle dwelling fish species (ie, our measure of deep pool and run habitat also relates to the quality of riffle habitat). We measure the occurrence of deep pools and runs as percent of channel length. We estimated that the habitat needs of freshwater fish would be met when deep pools and runs occupy >20% of the channel length. Deep pool and run habitat was considered to be severely limiting when it occupies <10% of channel length. Therefore, three states were defined for this node: <10%, 10-20% and >20%.

Deep pools may be reduced or lost by channel modifications and sedimentation. In the Ruamahanga catchment, the former was considered more likely to result in loss of deep habitat than the latter, and flood protection works were considered to represent the main form of channel modification. We assumed that in the absence of human influence, deep pool and run habitat would occupy 30-40% of channel length. We considered that flood protection works would focus on deep pool and run habitats, as these tend to occur near the river banks where bank erosion during floods is most likely. Allowing for some uncertainty in these assumptions, the probability table relating flood protection works to deep pool and run habitat is shown in Table 29.

Table 29: Conditional probability table showing the effect of flood protection works on deep pool and run habitat.

	Deep pool and run habitat (% of channel length)		
Flood protection works (% of channel length)	**<10%**	**10-20%**	**>20%**
0-10%	0	0	100
10-20%	0	5	95
20-30%	0	40	60
30-40%	5	55	40
40-50%	40	55	5
50-60%	60	40	0
60-70%	95	5	0
70-80%	100	0	0
80-90%	100	0	0
90-100%	100	0	0

Deposited fine sediment

Node name: Deposited fine sediment. *Units:* % cove.

A large number of freshwater fish species, including bullies, torrentfish and eel species, are benthic (i.e., live on the river bed). Deposited fine sediment cover can smother larger substrates such as cobbles, infilling the spaces between them that fish use for habitat and feeding (Clapcott et al. 2011). Deposited fine sediment therefore reduces the suitability or quality of habitat for these fish species, reducing the likelihood that they will be present. No studies have directly tested the mortality of New Zealand native fishes in response to deposited sediments (Clapcott et al. 2011). Therefore, to set thresholds for deposited fine sediment, we relied on expert judgment guided by international literature in which salmonid spawning shows some impairment at fine sediment cover >10% and significant impairment at cover >20% (Clapcott et al. 2011). We assume that rivers will naturally have some deposited fine sediment, and therefore define <10% cover as natural or not harmful to fish. Conversely, we consider that >50% cover of fine sediment causes major impacts on fish. Thus, for predicting Fish IBI and presence of individual fish species, we define three states of deposited fine sediment: <10%, 10-50% and >50% cover.

The parents (predictors) of deposited fine sediment are the same as described in section 3.2.2.

Other influential factors

Several other environmental factors may influence the fish community (and hence alter Fish IBI scores) at certain places and times. Elevated water temperature can be stressful for fish, leading to lethal and sub-lethal effects. Water temperatures can reach stressful levels in the Ruamahanga River and its main tributaries. Dissolved oxygen may cause lethal or sub-lethal stress when depleted. Finally, macrophytes may alter habitat and cause extreme fluctuations in dissolved oxygen and pH when growth is excessive. These factors may influence fish community composition at certain times and places. However, in terms of the wider riverscape, the drivers included in the Bayesian network were considered to be the primary ones.

3.6.3 Combining parents of Fish IBI

The combined effects of migration barriers, bank edge cover, mesohabitat diversity and deposited fine sediment are shown in Table 30. The key features (reference points) of this table are:

- With all variables in optimal state, we expect (with 90% confidence) an IBI score of 50–60.
- With all variables in optimal state except no deep pools or runs, we expect an IBI score of not more than 30.
- With all variables in optimal state except no instream cover, we expect an IBI score of not more than 40.
- With all variables in optimal state except high deposition of fine sediment, we expect an IBI score of not more than 35.
- With all variables in optimal state except barrier to climbers and swimmers, we expect an IBI score of not more than 20.
- With all variables in optimal state except barrier to swimmers, we expect an IBI score of not more than 40.

Table 30: Conditional probability table for Fish IBI showing the combined effects of migration barriers, bank edge cover, mesohabitat diversity and deposited fine sediment.

				Fish IBI score		
Migration barriers	**% deep pools/runs**	**Bank edge cover**	**Fine sediment**	**<22**	**22-32**	**>32**
none	<10%	<5%	<10%	60	40	0
none	<10%	<5%	10-50%	62	38	0
none	<10%	<5%	>50%	65	35	0
none	<10%	5-20%	<10%	40	50	10
none	<10%	5-20%	10-50%	50	45	5
none	<10%	5-20%	>50%	55	40	5
none	<10%	>20%	<10%	30	40	30
none	<10%	>20%	10-50%	35	40	25
none	<10%	>20%	>50%	40	45	15
none	10-20%	<5%	<10%	30	45	25
none	10-20%	<5%	10-50%	35	45	20
none	10-20%	<5%	>50%	45	45	10
none	10-20%	5-20%	<10%	20	40	40
none	10-20%	5-20%	10-50%	20	45	35
none	10-20%	5-20%	>50%	25	50	25
none	10-20%	>20%	<10%	0	40	60
none	10-20%	>20%	10-50%	5	40	55
none	10-20%	>20%	>50%	10	45	45
none	>20%	<5%	<10%	20	20	60
none	>20%	<5%	10-50%	20	25	55
none	>20%	<5%	>50%	25	30	45
none	>20%	5-20%	<10%	0	25	75
none	>20%	5-20%	10-50%	0	30	70
none	>20%	5-20%	>50%	10	30	60
none	>20%	>20%	<10%	0	10	90

				Fish IBI score		
Migration barriers	% deep pools/runs	Bank edge cover	Fine sediment	<22	22-32	>32
none	>20%	>20%	10-50%	0	15	85
none	>20%	>20%	>50%	0	25	75
stop swimmers	<10%	<5%	<10%	63	37	0
stop swimmers	<10%	<5%	10-50%	68	32	0
stop swimmers	<10%	<5%	>50%	70	30	0
stop swimmers	<10%	5-20%	<10%	50	50	0
stop swimmers	<10%	5-20%	10-50%	53	47	0
stop swimmers	<10%	5-20%	>50%	56	44	0
stop swimmers	<10%	>20%	<10%	50	45	5
stop swimmers	<10%	>20%	10-50%	52	46	2
stop swimmers	<10%	>20%	>50%	54	46	0
stop swimmers	10-20%	<5%	<10%	55	40	5
stop swimmers	10-20%	<5%	10-50%	57	41	2
stop swimmers	10-20%	<5%	>50%	59	41	0
stop swimmers	10-20%	5-20%	<10%	40	45	15
stop swimmers	10-20%	5-20%	10-50%	42	46	12
stop swimmers	10-20%	5-20%	>50%	44	47	9
stop swimmers	10-20%	>20%	<10%	30	50	20
stop swimmers	10-20%	>20%	10-50%	32	51	17
stop swimmers	10-20%	>20%	>50%	34	52	14
stop swimmers	>20%	<5%	<10%	50	45	5
stop swimmers	>20%	<5%	10-50%	52	46	2
stop swimmers	>20%	<5%	>50%	53	47	0
stop swimmers	>20%	5-20%	<10%	30	45	25
stop swimmers	>20%	5-20%	10-50%	32	46	22
stop swimmers	>20%	5-20%	>50%	34	47	19
stop swimmers	>20%	>20%	<10%	10	50	40

Migration barriers	% deep pools/runs	Bank edge cover	Fine sediment	Fish IBI score <22	22-32	>32
stop swimmers	>20%	>20%	10-50%	12	51	37
stop swimmers	>20%	>20%	>50%	14	52	34
stop climbers	<10%	<5%	<10%	85	15	0
stop climbers	<10%	<5%	10-50%	86	14	0
stop climbers	<10%	<5%	>50%	87	13	0
stop climbers	<10%	5-20%	<10%	80	20	0
stop climbers	<10%	5-20%	10-50%	81	19	0
stop climbers	<10%	5-20%	>50%	82	18	0
stop climbers	<10%	>20%	<10%	75	25	0
stop climbers	<10%	>20%	10-50%	76	24	0
stop climbers	<10%	>20%	>50%	77	23	0
stop climbers	10-20%	<5%	<10%	80	20	0
stop climbers	10-20%	<5%	10-50%	81	19	0
stop climbers	10-20%	<5%	>50%	82	18	0
stop climbers	10-20%	5-20%	<10%	74	25	1
stop climbers	10-20%	5-20%	10-50%	75	25	0
stop climbers	10-20%	5-20%	>50%	76	24	0
stop climbers	10-20%	>20%	<10%	70	25	5
stop climbers	10-20%	>20%	10-50%	71	25	4
stop climbers	10-20%	>20%	>50%	72	25	3
stop climbers	>20%	<5%	<10%	75	24	1
stop climbers	>20%	<5%	10-50%	76	24	0
stop climbers	>20%	<5%	>50%	77	23	0
stop climbers	>20%	5-20%	<10%	70	25	5
stop climbers	>20%	5-20%	10-50%	71	25	4
stop climbers	>20%	5-20%	>50%	72	25	3
stop climbers	>20%	>20%	<10%	70	20	10

				Fish IBI score		
Migration barriers	% deep pools/runs	Bank edge cover	Fine sediment	<22	22-32	>32
stop climbers	>20%	>20%	10-50%	70	21	9
stop climbers	>20%	>20%	>50%	70	22	8

3.7 Native fish: individual species

Node names: LF and SF eels, redfin bullies, inanga. *Units:* categories present, absent.

A range of species considered as taonga species by Maori and valued by the public were recommended by the Ruamahanga Whaitua Committee for inclusion into the Bayesian network. These included kanakana (lamprey), longfin tuna (eel), shortfin tuna (eel), inanga, patiki (black flounder), kakahi (freshwater mussel) and koura (freshwater crayfish). Of these, we considered we had enough information on ecology and sensitivity to different anthropogenic factors only for longfin and shortfin eel and inanga, so only these taonga species were included in the BN. In addition, we included redfin bully because the eel species and inanga are all considered to be relatively tolerant to a range of anthropogenic factors. Redfin bullies have more sensitive relationships with the drivers in the BN than eels and inanga do, and are intended to represent a range of more sensitive species.

As described in Table 28, each of these species has somewhat different habitat requirements and different levels of tolerance to sub-optimal conditions. Further details are given below. The Bayesian network showing the factors affecting the individual fish species is in Appendix A Figure 4.

3.7.1 Longfin and shortfin eels

Longfin and shortfin eel were combined into one node as both species are considered to respond similarly to the key drivers that are included in the BN. The following considerations were applied when determining the probability of eel presence within a reach:

- Both species are expected to be present (in low numbers) even when habitat is severely degraded. Therefore, to account for this, the lowest likelihood of an eel being present was set at 50% and ranged from 50 to 100%.
- Deep pool and run hydraulic habitat and instream and riparian cover were considered to be the most important drivers for eels and of about equal importance in determining the probability of eel presence. Deposited sediment was considered to be less influential. Based on these assessments, the change in probability of eel presence with a shift in state of each driver was calculated according to the values in Table 31.

3.7.2 Redfin bully

The following considerations were applied when determining the probability of redfin bully presence:

- In the Ruamahanga River catchment, redfin bullies can be found in the in the mainstems of the main tributaries and are regularly encountered far inland in the headwater reaches of these rivers. However, this species is not very common anywhere in the Ruamahanga riverscape, and even where ideal habitat is present there is the chance that this species will not be present. Therefore, in this BN the maximum probability of Redfin bully presence was set at 90%.

- Redfin bullies are considered relatively good at overcoming instream migration barriers so they were classed as "climbers". Hence their probability of occurrence is not reduced by "barriers to swimmers" but is reduced to 0% by "barriers to climbers".
- Within the Ruamahanga River catchment, redfin bullies tend to be associated with well-developed riffle habitat that contains large boulder/cobbley substrate, or in close proximity to this type of habitat (i.e., immediately downstream of the riffle). Well-developed riffle habitat tends to be associated with deep pool and run habitat, therefore redfin bully presence declines with a decline in deep pools and runs.
- "Percent deep pools and runs" was considered the strongest driver of the probability of redfin bully presence. The next most important driver was "fine sediment cover". This reflects that redfin bully are benthic and tend to be associated with larger substrate. "Bank edge cover" was considered of negligible importance for determining the presence of this species. Based on these assessments, the change in probability of eel presence with a shift in state of each driver was calculated according to the values in Table 31.

3.7.3 Inanga

The following considerations were applied when allocating the probability of inanga presence:

- Although it is considered a "lowland species", in the Ruamahanga River catchment inanga can still be present in reasonable numbers up to 70 km inland. However, the likelihood of encountering them decreases with distance inland. Recognising that at inland sites inanga might not be recorded in surveys even where habitat conditions are ideal, the maximum probability of presence was set at 90%.
- inanga were classed as "swimmers", hence barriers to "swimmers" or "climbers" reduced the probability of finding inanga to 0%. Among the other drivers, "deep pools and runs" were considered the most important, followed by "bank edge cover". Fine sediment cover was considered to be of negligible importance. Based on these assessments, the change in probability of inanga presence with a shift in state of each driver was calculated according to the values in Table 31.

Table 31: Change in probability of presence for longfin and shortfin eels, redfin bullies and inanga with a change in state of various habitat factors. Numbers refer to the change in probability of presence resulting from a shift of one state in the corresponding habitat variable, e.g., for the habitat variable "percent deep pools and runs", a shift of one state means a shift from <10% to 10-20%, or from 10-20% to >20%. Larger values indicate greater sensitivity to the corresponding habitat variable.

	LF & SF eels	Redfin bullies	Inanga
barriers: stop swimmers	0	0	-100%
barriers: stop climbers	-100%	-100%	-100%
% deep pools and runs	+10%	+40%	+25%
bank edge cover	+10%	+15%	+15%
deposited fine sediment % cover	-5%	-2%	-2%

3.7.4 Fish IBI and presence of three native fish species at baseline

At baseline, Fish IBI scores range from 49 to 55, which places all reporting reaches in the "good" category (>32) (Table 32, Figure 11). The probability of eels being present is 85-97%, the probability of redfin bullies 67-79% and the probability of inanga 68-85% (Table 33, Table 34 and Table 35, Figure 12, Figure 13 and Figure 14).

Table 32: Expected values Fish IBI at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	54	54	54	54	54	54	54	54	54	54
Kopuaranga	54	54	54	54	54	54	54	54	54	54
Mangatarere	54	54	54	54	54	54	54	54	54	54
Ruamahanga @Pukio	55	55	55	55	55	55	55	55	55	55
Ruamahanga @TeOreOre	55	55	55	55	55	55	55	55	55	55
Taueru	54	54	54	54	54	54	54	54	54	54
Tauherenikau	55	55	55	55	55	55	55	55	55	55
Waingawa	49	49	49	49	50	50	50	50	50	50
Waiohine	55	55	55	55	55	55	55	55	55	55
Waipoua	55	55	55	55	55	55	55	55	55	55

Table 33: Expected probabilities of longfin and shortfin eels being present at baseline and under scenarios BAU, Silver and Gold in years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%
Kopuaranga	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%
Mangatarere	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%
Ruamahanga @Pukio	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%
Ruamahanga @TeOreOre	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%
Taueru	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%
Tauherenikau	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%
Waingawa	85%	85%	85%	85%	86%	87%	87%	86%	87%	87%
Waiohine	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%
Waipoua	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%

Table 34: Expected probabilities of redfin bullies being present at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	69%	69%	69%	69%	69%	69%	69%	69%	69%	69%
Kopuaranga	67%	67%	67%	67%	67%	67%	67%	67%	67%	67%
Mangatarere	68%	68%	68%	68%	68%	68%	68%	68%	68%	68%
Ruamahanga @Pukio	71%	71%	71%	71%	71%	71%	71%	71%	71%	71%
Ruamahanga @TeOreOre	71%	71%	71%	71%	71%	71%	71%	71%	71%	71%
Taueru	67%	67%	67%	67%	67%	67%	67%	67%	67%	67%
Tauherenikau	79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Waingawa	76%	76%	76%	76%	76%	76%	77%	76%	77%	77%
Waiohine	79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Waipoua	71%	71%	71%	71%	71%	71%	71%	71%	71%	71%

Table 35: Expected probabilities of inanga being present at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%
Kopuaranga	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%
Mangatarere	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%
Ruamahanga @Pukio	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%
Ruamahanga @TeOreOre	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%
Taueru	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%
Tauherenikau	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%
Waingawa	68%	68%	68%	68%	69%	70%	71%	70%	71%	71%
Waiohine	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%
Waipoua	84%	84%	84%	84%	84%	84%	84%	84%	84%	84%

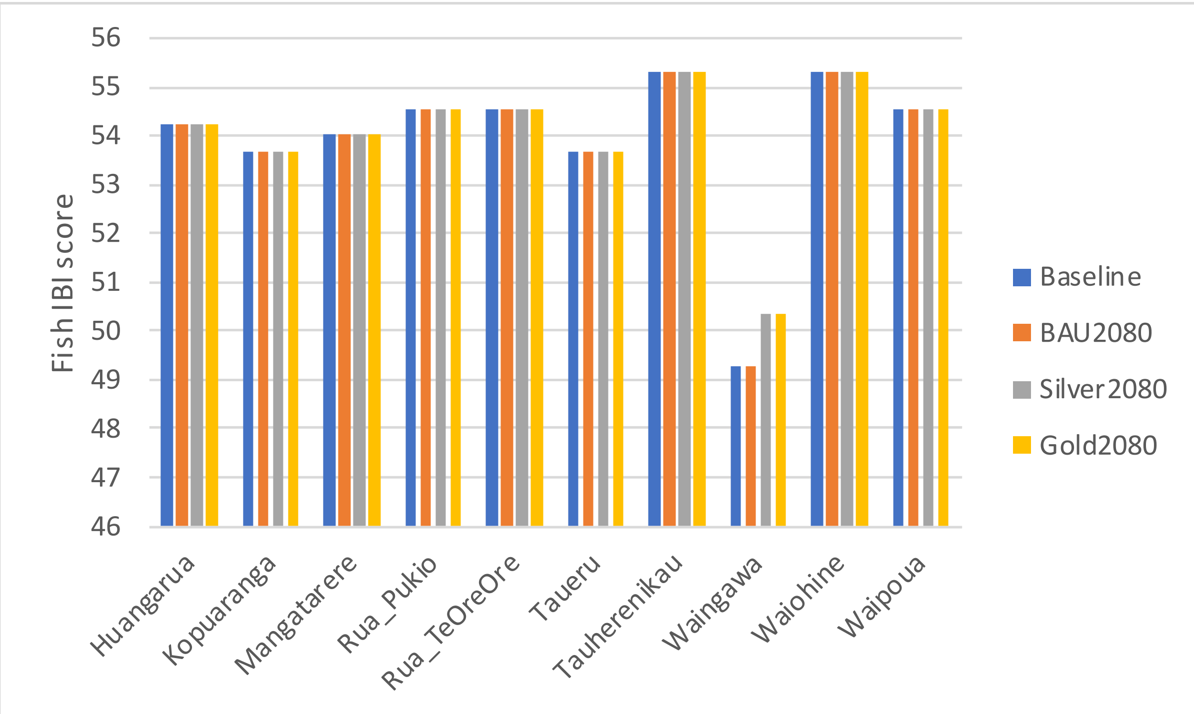

Figure 11: Expected values Fish IBI at baseline and under scenarios BAU, Silver and Gold in the year 2080.

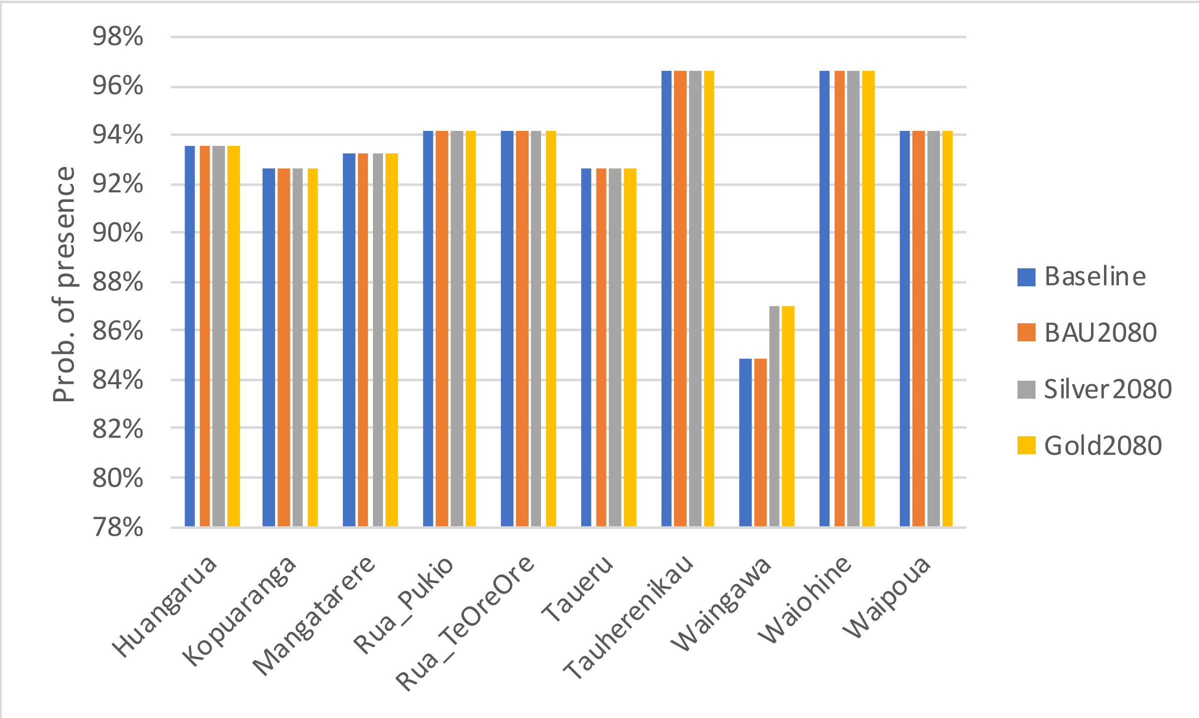

Figure 12: **Expected probabilities of longfin and shortfin eels being present at baseline and under scenarios BAU, Silver and Gold in the year 2080.**

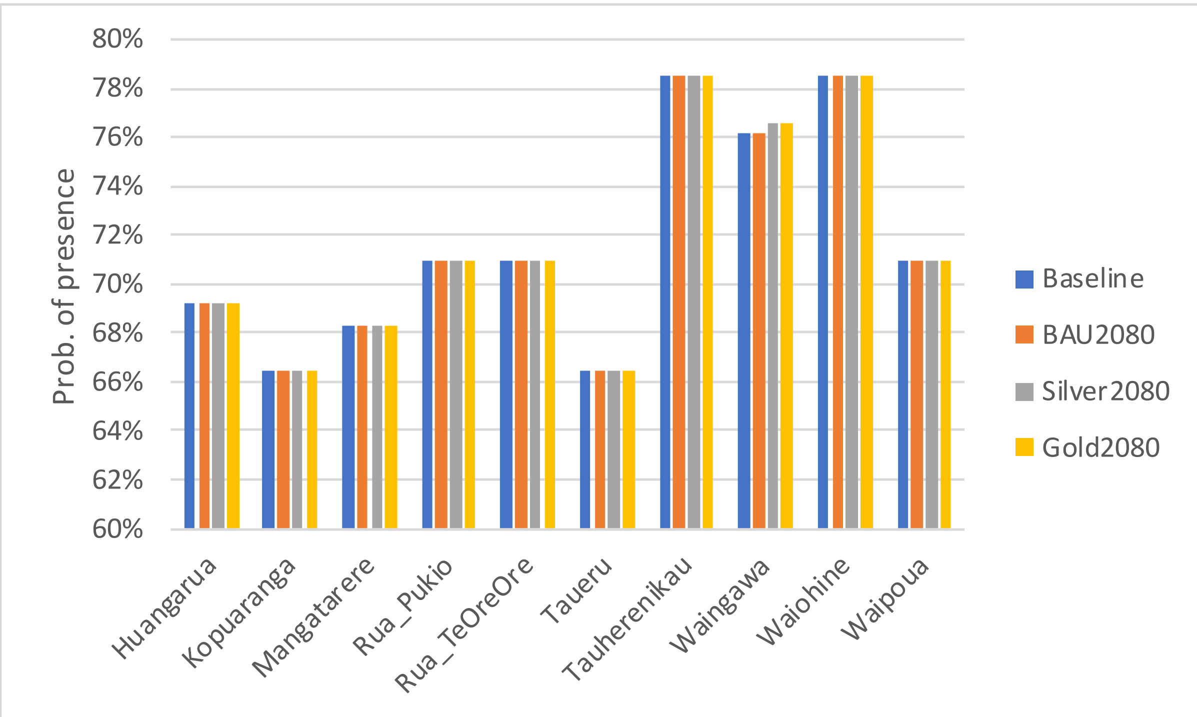

Figure 13: **Expected probabilities of redfin bullies being present at baseline and under scenarios BAU, Silver and Gold in the year 2080.**

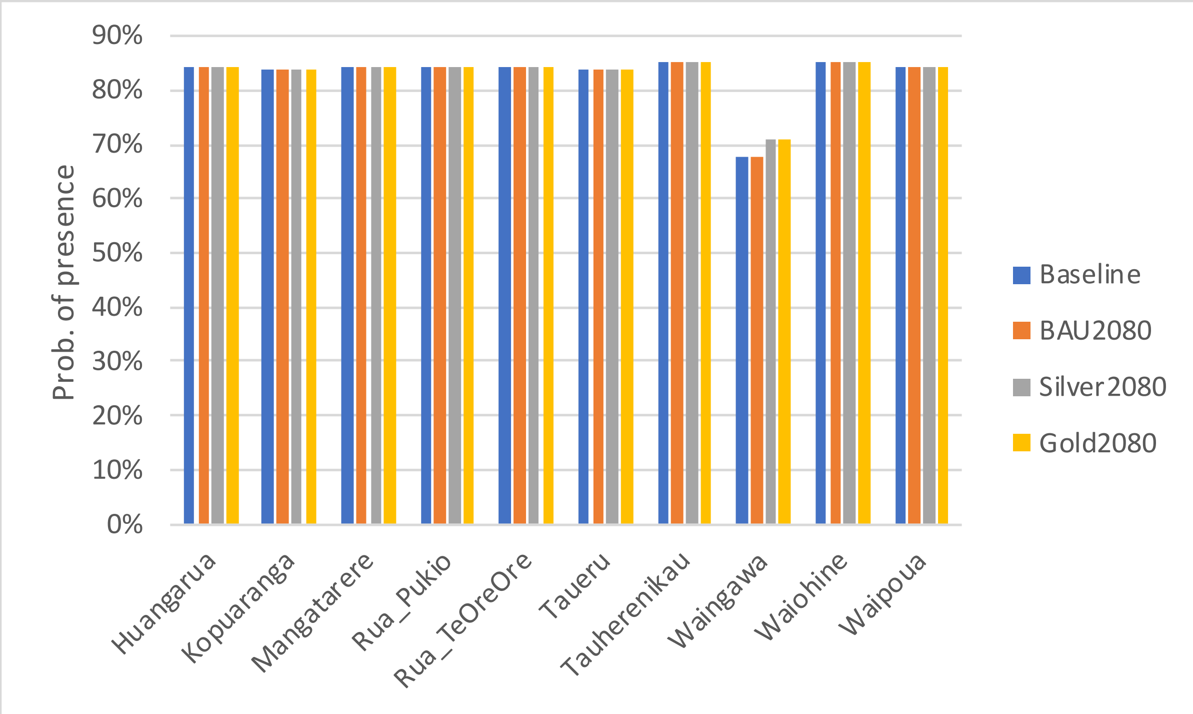

Figure 14: Expected probabilities of inanga being present at baseline and under scenarios BAU, Silver and Gold in the year 2080.

3.7.5 Effects of three development scenarios on Fish IBI and presence of three native species

There is no change in Fish IBI score or probability of occurrence among the three fish taxa under any scenario at any site, except Waingawa which shows an increase in IBI score of 1 point and an increase in eel, redfin bully and inanga probability of 2%, 1% and 3%, respectively between baseline and Silver (2080) and Gold (2080). These improvements are due to a small increase in bank edge cover that results from planted riparian vegetation. Since the fish nodes are based on presence/absence, not abundance, a change in state would not be expected except with a major change in habitat.

Fish IBI and probability of occurrence among the three fish taxa depend on deposited fine sediment, barriers to migration, abundance of deep pools and runs (in this BN, a function only of flood protection works) and bankside cover (a function of wetted width and riparian vegetation extent).

The extent of riparian vegetation increases significantly in a number of reporting reaches under Silver and Gold scenarios. However, bank edge cover needs only to exceed 20% of bank length to provide sufficient habitat for fish, and this is achieved at baseline in all reporting reaches except Waingawa. Therefore, the increase in riparian vegetation does not increase the state of the bank edge cover node in any reporting reach except Waingawa.

3.8 Natural character

3.8.1 Node description and states

Node name: Natural character. *Units:* modified RiVAS scale (range 7-21).

Many of New Zealand's large gravel bed rivers are greatly valued for their natural character, and natural character is recognised in the Resource Management Act (Mosley 2004). In the Resource Management Act natural character is defined as "the natural or physical qualities or characteristics of an area that contribute to people's appreciation of its pleasantness, aesthetic coherence and cultural and recreational attributes" (Mosley 2004). Braided rivers in particular are valued for the unique "riverscape" they provide (Stephenson 2011; Booth 2012).

The degree or level of natural character within an area depends on:

1. the extent to which natural elements, patterns and processes occur, and
2. the nature and extent of modifications to the ecosystems and landscape/ riverscape.

The highest degree of natural character (the greatest naturalness) occurs where there is least modification. The effect of different types of modification upon the natural character of an area varies with the context and may be perceived differently by different parts of the community (Booth 2012). For this reason, natural character is inherently subjective, and the attributes that contribute to an overall measure of natural character may differ from place to place and according to different members of the community.

In this Bayesian network (Appendix A Figure 5), natural character is composed of a number of attributes that were identified as important in rivers of the Ruamahanga catchment by the Ruamahanga Whaitua Committee (Table 36). In order to make the natural character measure more objective and widen its applicability, this list of attributes was fit into a RiVAS framework for natural character that was developed for Hawke's Bay rivers by Booth (2012) in consultation with a Hawke's Bay expert panel. All except two of the RWC attributes (deposited fine sediment and primary senses – smell, sound, air temperature) could be mapped into corresponding RiVAS categories (Table 36), and all except two RiVAS categories (Structures and human modifications in the riparian edge, and character modifications in the wider landscape) were identified by the RWC (Table 37). This provides confidence that the attributes comprising natural character in this Bayesian network are mostly agreed on by a diversity of people.

Table 36: Attributes of natural character identified as important by the Ruamahanga Whaitua Committee and the corresponding category in RiVAS (Booth 2012). Entries in parentheses refer to RiVAS categories that are relevant but were not used as a node in the Bayesian network. New categories are nodes that were not included in Booth (2012). The final attribute, with no corresponding RiVAS category or new category, was not included in this Bayesian network.

RWC Attribute	RiVAS category	New category
Braidedness	channel shape	
Sinuosity	channel shape	
channel shrinkage	channel shape	
mechanical modifications to shape or appearance (for flood control)	channel shape	
Baseflow	flow regime	
flow variability	flow regime	
water clarity	water quality	
macrophytes	(Exotic aquatic flora and fauna)	riverbed condition
vegetation encroaching on gravel bars	(Extent of exotic riparian flora)	
structures/mechanical modification (e.g., dams, groynes, railway irons)	Human structures and modifications within channel	
riparian vegetation extent	Riparian vegetation	
riparian vegetation diversity of heights	Riparian vegetation	
riparian vegetation type (native/exotic/invasive)	Riparian vegetation	
periphyton cover	(Exotic aquatic flora and fauna)	riverbed condition
deposited fine sediment		riverbed condition
primary senses (smell, sound, air temperature)		

Table 37: RiVAS categories and the attributes identified by the Ruamahanga Whaitua Committee that relate to each.

RiVAS category cluster	RiVAS category	RWC attributes included
River channel	flow regime	base flow, flow variability
	channel shape	braidedness, sinuosity, channel shrinkage
	water quality	water clarity
	Exotic aquatic flora and fauna within river channel	macrophytes, periphyton
	Human structures and modifications within river channel	dams, groynes, railway irons
Riparian edge	Vegetation cover in the riparian edge	riparian vegetation extent, type, diversity of heights
	Extent of exotic flora	weed encroachment, riparian vegetation type
	Structures and human modifications in the riparian edge	
Wider landscape character	Character modifications	

The scoring system for natural character in this Bayesian network is based on the RiVAS system (Booth 2012). The attributes are combined into categories, most of which were derived from RiVAS (Table 36 and Table 37). In each of these categories, three states were defined as in Booth (2012), highly modified (score=1), modified (score=2) and near natural (score=3). The criteria for each state were defined to be as similar as possible to those in Booth (2012) (see Appendix C). As in RiVAS, natural character itself was calculated as the sum of all the category scores (i.e., equal weighting was given to each category). In this Bayesian network, which has seven component categories each with scores between 1 and 3, natural character had a range between 7 and 21.

As for the component categories, three states were defined for natural character: highly modified (scores between 7 and 12), modified (scores between 13 and 19) and near-natural (scores between 20 and 21). These thresholds were set such that natural character is classified as modified if two or more categories are modified, or any category is highly modified. Natural character is classified as highly modified if two or more components are highly modified while others are modified. This is similar to Booth (2012), where on a scale of 8-24, scores of 20 or lower are classified as “moderate natural character” and scores <16 are classified as “low natural character”.

Riparian condition

Node name: Riparian condition. *Units:* categories highly modified (score=1), modified (score=2), near natural (score=3).

The RWC considered three aspects of riparian vegetation to be relevant to natural character: the extent of woody riparian vegetation (as % of bank length with woody vegetation), whether the vegetation is native, exotic or invasive (weedy), and diversity in the height of vegetation. In regard to the first aspect, more was regarded as better, up to 100% of bank length. In regard to the second aspect, native plants were regarded as retaining natural character more than exotic, and exotic plants more than invasive. In these respects, the RWC judgments were consistent with the RiVAS narrative descriptions of riparian condition states, so RiVAS descriptions were used to assign probabilities to the three states of riparian condition (highly modified, modified and near natural).

RiVAS states do not consider the diversity of riparian vegetation height, therefore this aspect was incorporated using weighting factors to modify the probabilities. Diversity in vegetation height was measured as the % of vegetation as trees. The optimum state was regarded as a mixture of trees and shrubs, therefore factors of 0.4, 0.6, 1 and 0.9 were assigned to the categories 0-25%, 25-50%, 50-75% and 75-100% trees, respectively. For each combination of the riparian vegetation extent and vegetation nativeness, the probability of near-natural state was multiplied by the weighting factor for vegetation diversity. The resulting probability table is shown below (Table 38).

Table 38: Conditional probability table for riparian condition, based on states of riparian vegetation extent, nativeness and % as trees.

			Riparian condition		
Riparian vegetation extent (%)	Riparian nativeness	Vegetation % as trees	highly modified	modified	near natural
0 to 25	weedy	0 to 25	100	0	0
0 to 25	weedy	25 to 50	100	0	0
0 to 25	weedy	50 to 75	100	0	0
0 to 25	weedy	75 to 100	100	0	0
0 to 25	exotic	0 to 25	100	0	0
0 to 25	exotic	25 to 50	100	0	0
0 to 25	exotic	50 to 75	100	0	0
0 to 25	exotic	75 to 100	100	0	0
0 to 25	native	0 to 25	80	20	0
0 to 25	native	25 to 50	70	30	0
0 to 25	native	50 to 75	50	50	0
0 to 25	native	75 to 100	55	45	0

Riparian vegetation extent (%)	Riparian nativeness	Vegetation % as trees	Riparian condition		
			highly modified	modified	near natural
25 to 50	weedy	0 to 25	100	0	0
25 to 50	weedy	25 to 50	100	0	0
25 to 50	weedy	50 to 75	100	0	0
25 to 50	weedy	75 to 100	100	0	0
25 to 50	exotic	0 to 25	90	10	0
25 to 50	exotic	25 to 50	85	15	0
25 to 50	exotic	50 to 75	75	25	0
25 to 50	exotic	75 to 100	77.5	22.5	0
25 to 50	native	0 to 25	0	80	20
25 to 50	native	25 to 50	0	70	30
25 to 50	native	50 to 75	0	50	50
25 to 50	native	75 to 100	0	55	45
50 to 75	weedy	0 to 25	100	0	0
50 to 75	weedy	25 to 50	100	0	0
50 to 75	weedy	50 to 75	100	0	0
50 to 75	weedy	75 to 100	100	0	0
50 to 75	exotic	0 to 25	70	30	0
50 to 75	exotic	25 to 50	55	45	0
50 to 75	exotic	50 to 75	25	75	0
50 to 75	exotic	75 to 100	32.5	67.5	0
50 to 75	native	0 to 25	0	60	40
50 to 75	native	25 to 50	0	40	60
50 to 75	native	50 to 75	0	0	100
50 to 75	native	75 to 100	0	10	90
75 to 100	weedy	0 to 25	100	0	0

Riparian vegetation extent (%)	Riparian nativeness	Vegetation % as trees	Riparian condition		
			highly modified	modified	near natural
75 to 100	weedy	25 to 50	100	0	0
75 to 100	weedy	50 to 75	100	0	0
75 to 100	weedy	75 to 100	100	0	0
75 to 100	exotic	0 to 25	60	40	0
75 to 100	exotic	25 to 50	40	60	0
75 to 100	exotic	50 to 75	0	100	0
75 to 100	exotic	75 to 100	10	90	0
75 to 100	native	0 to 25	0	60	40
75 to 100	native	25 to 50	0	40	60
75 to 100	native	50 to 75	0	0	100
75 to 100	native	75 to 100	0	10	90

Flow regime

Node name: Flow regime. *Units:* categories highly modified (score=1), modified (score=2), near natural (score=3).

Two aspects of flow regime were considered important for natural character: the amount of water in the river, and natural variation in flows. Assuming that reduction in flow (the amount of water) would be most likely and most noticeable at low flow, we used % reduction in MALF (mean annual low flow) to capture this aspect. As a measure of flow variability, we used % reduction in FRE3 (the frequency of flows three-times the median flow).

To define states and assign probabilities for the "flow regime" node, we used RiVAS narrative descriptions. RiVAS only considers reduction in flow, not in flow variability, therefore we assigned initial probabilities using % reduction in MALF, then reduced the probability of higher flow regime scores in cases where flow variability was reduced. The resulting probabilities are shown in Table 39.

Table 39: Conditional probability table relating % change in MALF. (mean annual low flow) and % change in FRE3 (frequency of flows three times the median) with the RiVAS category "Flow regime".

		Flow regime		
% change in MALF	% reduction in FRE3	highly modified	modified	near natural
0 to 5	0 to 20	0	0	100
0 to 5	20 to 50	0	50	50
0 to 5	50 to 100	0	100	0
5 to 50	0 to 20	0	100	0
5 to 50	20 to 50	25	75	0
5 to 50	50 to 100	50	50	0
50 to 100	0 to 20	100	0	0
50 to 100	20 to 50	100	0	0
50 to 100	50 to 100	100	0	0

Channel shape

Node name: Channel shape. *Units:* categories highly modified (score=1), modified (score=2), near natural (score=3).

Three aspects of channel shape were regarded as being important to natural character: channel sinuosity, river braidedness and reduction in the width of the wetted channel.

For sinuosity and river braidedness we defined three states using the same descriptors and scores (near-natural=3, modified=2 and highly modified=1) as for RiVAS attributes. Sinuosity and river braidedness may be reduced by changes in flow regime caused by water abstractions, diversions or a dam that alter the balance between sediment supply and sediment transport capacity in a river. The effect of these modifications on sinuosity and braidedness requires a model such as MIWA (Hicks et al. 2009) and the specifications of the water diversion, dam, etc. Such modelling is beyond the scope of this Bayesian network. Sinuosity is also directly reduced by flood protection works that recontour the river bed to straighten the wetted channel and shift it into the centre of the river. Guided by the RiVAS descriptions of indicator thresholds for channel shape, we chose thresholds of <10%, 10-20% and >20% of channel length modified by bed recontouring to correspond to near-natural, modified and highly modified sinuosity, respectively.

Channel wetted width is reduced mainly by reductions in flow. We considered that reductions in wetted width would be most noticeable at low flow, therefore we used % change in MALF to predict change in wetted width. For rivers in the Ruamahanga catchment, rating curves provided by Greater Wellington Regional Council showed roughly linear relationships between river discharge and wetted width at flows below MALF. Therefore, we used a 1:1 relationship between % reduction in MALF and % reduction in wetted width.

To combine the three aspects above into a single measure of channel shape, we assumed that channel shape is equally affected by each. Therefore, we calculated product of scores in all 3 parent nodes, then defined equal-sized bins for the channel shape node over the range of values of the product.

Riverbed condition

Node name: Riverbed condition. *Units:* categories highly modified (score=1), modified (score=2), near natural (score=3).

Riverbed condition is a category we developed to summarise attributes that affect the appearance of the river bed: macrophyte and periphyton growth and deposited fine sediment. RiVAS (Booth 2012) does not have a category for riverbed condition, as it does not include deposited fine sediment and incorporates macrophytes and periphyton under "exotic aquatic flora and fauna". We felt the appearance of the river bed is a distinct aspect of natural character that should be recognised in a scoring system. Also, nuisance macrophytes and periphyton growths are not necessarily "exotic flora" as they can be due to native species.

Macrophyte growth can be quantified in terms of volume or surface area occupied (Matheson et al. 2015). We chose % channel water surface area as the most relevant measure for natural character, and defined four states corresponding to the condition bands for angler acceptability in Matheson et al. (2015) (Table 40).

Table 40: Four states of macrophyte growth, and the corresponding percent of anglers who regarded each level as "acceptable" in a survey by Matheson et al. (2015).

Macrophyte % water surface area occupied	Angler acceptability rate
<5%	>70%
5-10%	60-70%
10-20%	50-60%
>20%	<50%

For periphyton growth we defined two states, <120 mg/m^2 and >120 mg/m^2 chl. *a*, corresponding to the New Zealand guideline for aesthetics and recreation (Biggs 2000b).

For deposited fine sediment we defined two states, <20% cover and >20% cover, which correspond as closely as possible to the guideline for amenity value (<25% cover) in Clapcott et al. (2011) while remaining compatible with the categories of fine sediment cover used elsewhere in this Bayesian network.

To combine the three attributes of riverbed condition into a single measure, we assigned numerical values on a 1-3 scale, consistent with other attributes of natural character. For sediment cover and periphyton, which have only two states, we assigned values of 1 and 3 to states below and above the guideline value, respectively. For macrophytes, which have four states, we assigned values of 1, 1.67, 2.33 and 3. We then assigned each combination of the three attributes to a state of riverbed condition based on the sum of their scores (Table 41).

Table 41: Conditional probability table relating deposited fine sediment periphyton cover and macrophyte cover to states of riverbed condition.

			Riverbed condition		
Sediment cover	Periphyton biomass (mg/m²)	Macrophyte cover	highly modified	modified	near natural
>25%	>120	>20%	100	0	0
>25%	>120	10-20%	100	0	0
>25%	>120	5-10%	100	0	0
>25%	>120	<5%	100	0	0
>25%	<120	>20%	100	0	0
>25%	<120	10-20%	0	100	0
>25%	<120	5-10%	0	100	0
>25%	<120	<5%	0	100	0
<25%	>120	>20%	100	0	0
<25%	>120	10-20%	0	100	0
<25%	>120	5-10%	0	100	0
<25%	>120	<5%	0	100	0
<25%	<120	>20%	0	100	0
<25%	<120	10-20%	0	100	0
<25%	<120	5-10%	0	0	100
<25%	<120	<5%	0	0	100

Visual water clarity

Node name: Water clarity. *Units:* m.

RiVAS includes the category Water Quality (Table 36). Since natural character relates only to properties that can be perceived, water quality refers primarily to clarity and colour (though smell and surface scums could also be included). In the Ruamahanga catchment, changes in water colour are probably unlikely, therefore, we considered that for the purpose of the Bayesian network, water quality can be represented largely by visual clarity.

We defined two states for water clarity, <1.6 m and >1.6 m, based on the New Zealand guideline value for swimming (MfE 1994). For calculating the natural character score, clarity <1.6 m was given a score of 1 and clarity >1.6 m was given a score of 3. Visual water clarity can be calculated from suspended sediment as described in section 3.4.2.

Weed encroachment

Node name: Weed encroachment. *Units:* categories high (score=1), low (score=3).

We defined two states for weed encroachment: high and low.

Human structures and modifications

Node name: Human structures and modifications. *Units:* categories highly modified (score=1), modified (score=2), near natural (score=3).

Human structures and modifications include stopbanks, bridges, rock groynes, rail groynes, dams, diversions, gravel extraction works, etc. This range of features was identified by both the Ruamahanga Whaitua Committee and Booth (2012). Because of the close alignment between these two groups, we used the narrative descriptions in RiVAS (Appendix C) to determine the state of different rivers. Information on human structures and modifications can be gained from Google Earth and records held by various departments (e.g., Flood Protection) of the regional council.

3.8.2 Natural character at baseline

At baseline, natural character varies between 14.2 and 17.0, on a scale between 7 (highly modified) and 21(near natural) (Table 42, Figure 15). The lowest scoring site is Taueru and the highest Huangarua. Factors lowering natural character at the lower-scoring sites include channel modifications (six sites have modified channels), bed condition (Taueru scores low because of macrophyte growth, Mangatere scores low because of periphyton growth and several other sites score low because of deposited fine sediment) and riparian vegetation (Taueru, Ruamahanga @ Pukio and Waingawa score low because of lack of riparian vegetation).

Table 42: Expected values of natural character at baseline and under scenarios BAU, Silver and Gold in the years 2025, 2040 and 2080.

	Baseline	BAU 2025	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Huangarua	17.0	16.0	16.0	16.0	16.3	16.6	17.0	16.5	17.0	17.0
Kopuaranga	16.5	16.5	16.5	16.5	17.1	17.4	17.7	17.2	17.7	17.7
Mangatarere	15.8	15.8	15.8	15.8	16.1	16.5	16.8	16.3	16.8	16.8
Ruamahanga @Pukio	16.5	16.5	16.5	16.5	17.4	17.8	18.2	17.6	18.2	18.2
Ruamahanga @TeOreOre	16.1	16.1	16.1	16.1	16.4	16.7	17.1	16.6	17.1	17.1
Taueru	14.2	13.2	13.2	13.2	13.9	14.8	15.2	14.5	15.2	15.2
Tauherenikau	16.6	15.6	15.6	15.6	15.9	16.3	16.6	16.1	16.6	16.6
Waingawa	15.9	15.9	15.9	15.9	16.8	17.3	17.6	17.0	17.6	17.6
Waiohine	17.4	17.4	17.4	17.4	17.9	18.3	18.6	18.1	18.6	18.6
Waipoua	16.0	16.0	16.0	16.0	16.4	16.7	17.0	16.5	17.0	17.0

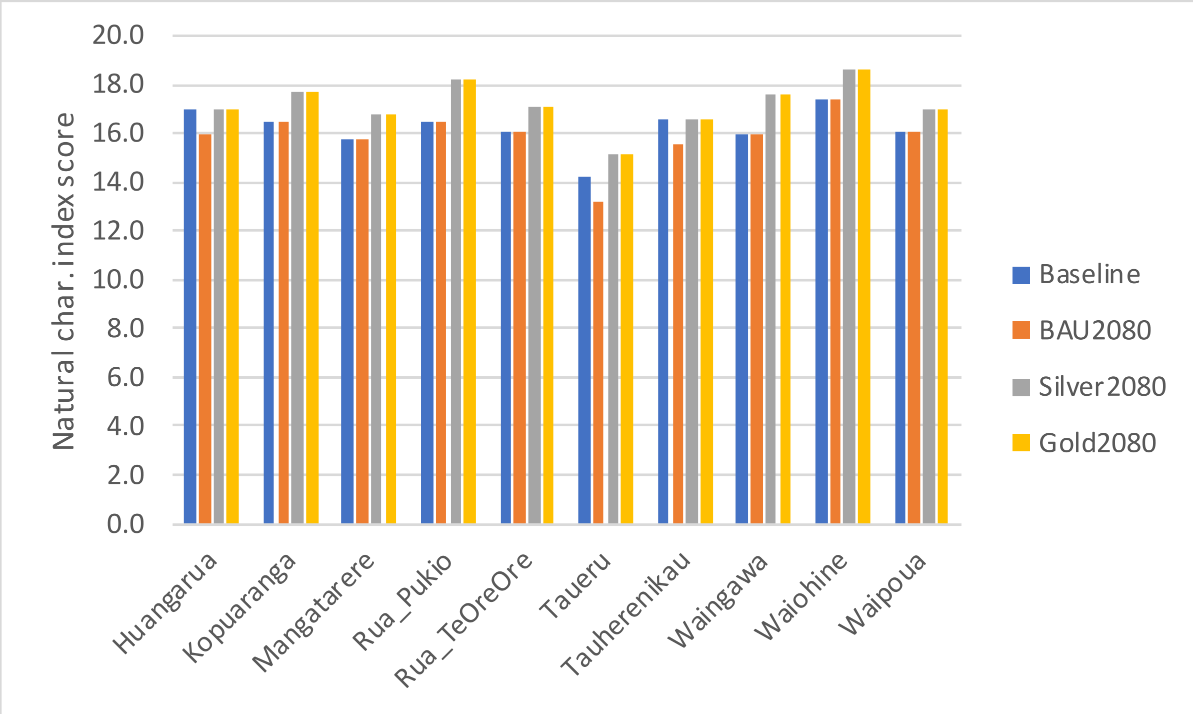

Figure 15: Expected values of natural character at baseline and under scenarios BAU, Silver and Gold in the year 2080.

3.8.3 Effects of three development scenarios on natural character

The three scenarios were run twice, the first time assuming that all riparian willows would be replaced by native trees, and the second time assuming that willows remain (native trees are planted between existing stands of willows).

Assuming that willows are replaced by native trees, natural character increased by up to 1.7 points between baseline and Gold 2080 on the 14-point scale (min 7 to max 21) (Table 42, Figure 15). Three sites (Huangarua, Taueru and Tauherenikau) show a small decrease in natural character between baseline and BAU, due to declines in flow. The natural character scores at these sites are restored in Silver and Gold (compared to baseline) due to improvements in riparian vegetation condition.

Riparian vegetation condition changes are relatively small at all sites because most sites (except Taueru, Ruamahanga at Pukio and Waingawa) have riparian trees covering >60% of bank length at baseline. Therefore, the riparian condition node is already at 1.7-1.9 (on a scale of 1 to 3) for most sites. Most of the riparian trees are willows, and if these are replaced by native trees, then the riparian condition score increases to 2.9 in all reporting reaches in Silver and Gold scenarios. These increases in riparian vegetation condition are the main reason that natural character score recovers in Huangarua, Taueru and Tauherenikau, and increases in the remaining sites, in Silver and Gold compared to baseline.

Riverbed condition shows little or no change under any scenario in any reporting reach. Riverbed condition is a function of periphyton biomass, macrophyte cover and deposited fine sediment. Some changes in periphyton occur at three sites (see Section 3.1.5). Macrophyte cover is >0% in only two reporting reaches, and changes in only one of these (Taueru; decrease from 40% to 28%). Deposited fine sediment does not change in any reporting reach, for reasons discussed in previous sections.

Flow regime changes in the Huangarua, Taueru and Tauherenikau rivers due to decreases in MALF relative to baseline under all scenarios (see previous sections: decrease of 33% in Huangarua, decreases of 5.8 and 5.3% in Taueru and Tauherenikau, respectively). Flow regime changes are the reason for the decline in natural character at Huangarua, Taueru and Tauherenikau in BAU compared to baseline.

No changes in human structures and channel modifications were modelled in this BN, as they were considered outside the scope of the plan change. Similarly, there were no changes in channel shape, because there were no changes in flood control works or flood regime and only minimal changes in MALF.

Overall, the main changes in natural character were due to an increase in the extent of riparian vegetation and the replacement of exotic willows by native species. In the second model run, where willows were not replaced, and native trees were planted only in the gaps between them, natural character scores increased by a smaller amount (between 0.1 and 0.9 points less) than when assuming replacement, but the overall patterns among sites and scenarios were similar.

4 Conclusions

This report describes a Bayesian Network designed to show the expected outcomes of different decisions on land and water management for selected ecological, recreational and aesthetic attributes of large gravel-bed rivers. It has been developed specifically with respect to several development scenarios being considered by the Ruamahanga Whaitua Committee and their effects on the mainstem of the Ruamahanga River and its major tributaries. The report provides the definition of each attribute (or node), the different outcomes (states) that each node can take on, the dependent relationships that together determine the outcome of each node, and the rationale and assumptions behind each of those aspects.

Overall only a few attributes show more than minor changes in any of the three scenarios compared to baseline. Silver and Gold scenarios show some differences in outcomes compared to BAU. There are no differences between Silver and Gold by 2080, but some attributes change earlier in Gold than in Silver. There are several reasons why the changes in attributes are relatively small.

The main drivers of change in the attributes are reduced concentrations of dissolved nutrients, and suspended solids, increased riparian tree cover and a shift from river discharge to land-based dispersal of sewage treatment plant effluent. Some of these drivers change by only a small amount in each of the scenarios. Other important drivers of ecological outcomes, such as flow regime, change even less or not at all among the scenarios. In addition, the reporting reaches are all on moderately large rivers (mostly fourth-order or larger), which are relatively insensitive to changes in factors such as riparian vegetation.

The Bayesian network is designed to assist the RWC in selecting a particular scenario by showing the ecological outcomes likely to result from each. The value of the BN approach is that it provides a transparent summary of knowledge about the land-water system interactions and how key values are likely to change with various management actions and mitigations.

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Appendix A Bayesian networks for the ecological, recreational and aesthetic attributes.

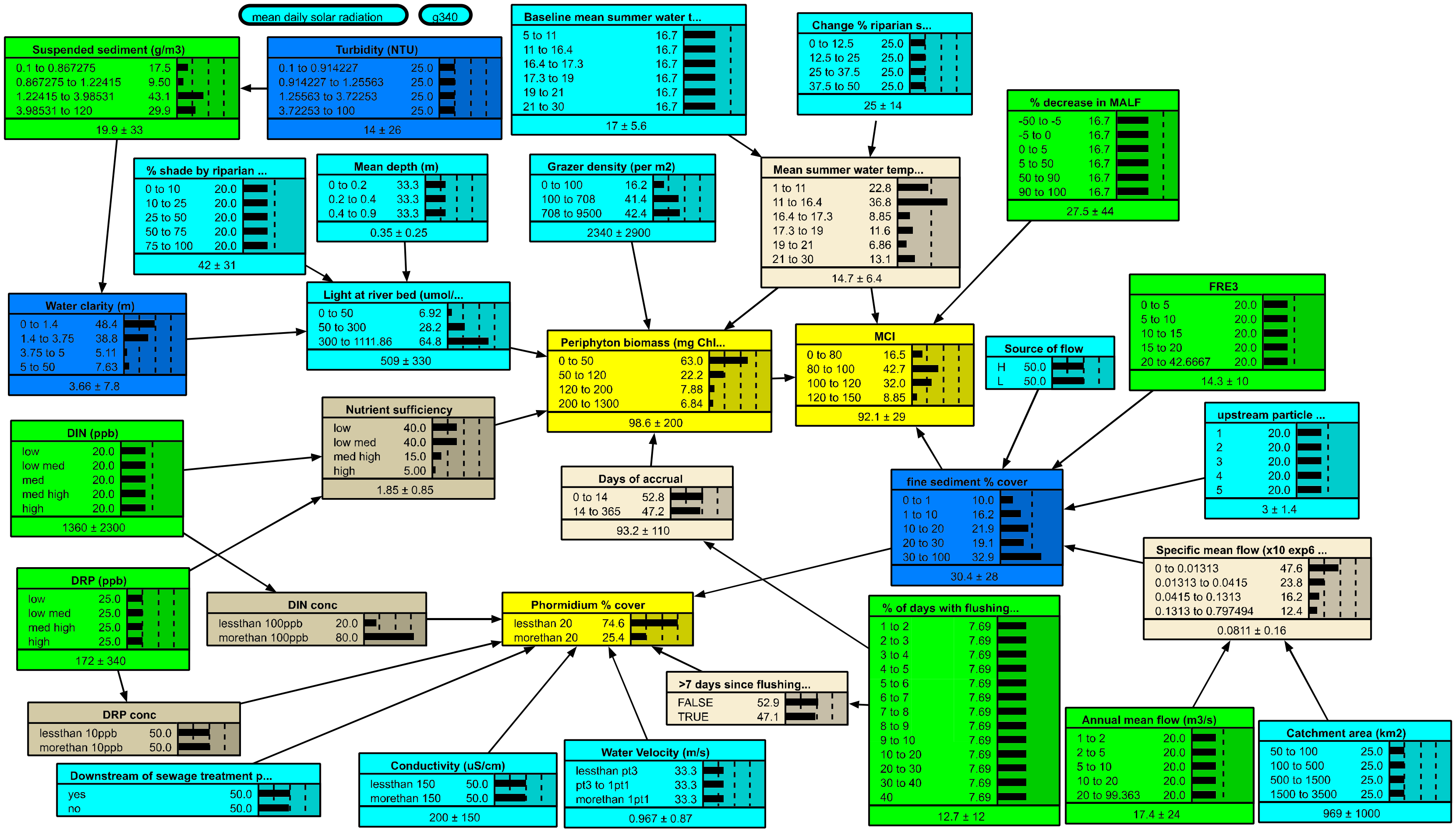

Figure 1: **Bayesian network for periphyton biomass, Macroinvertebrate Community Index (MCI) and *Phormidium*.**

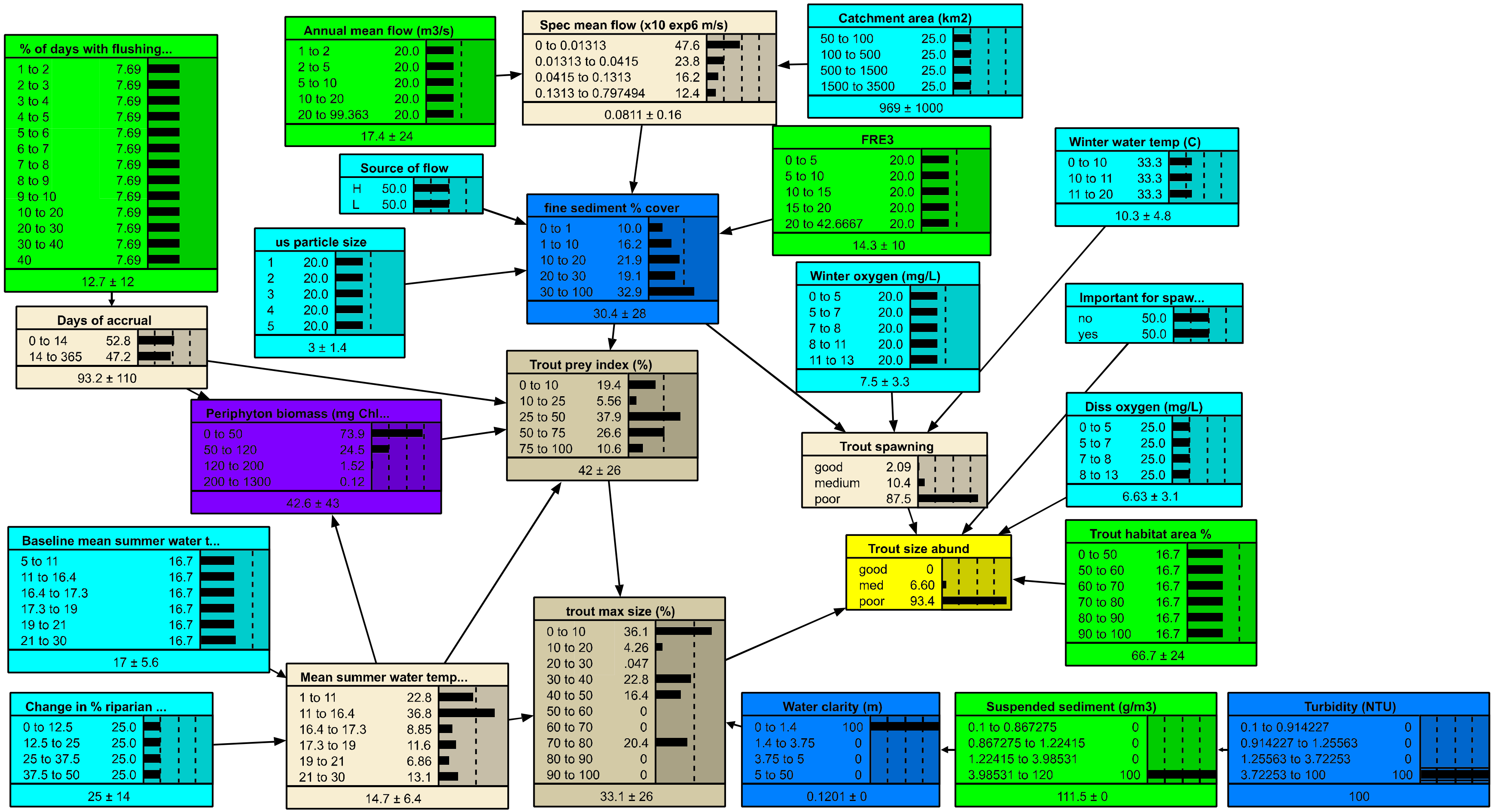

Figure 2: **Bayesian network for trout size and abundance.**

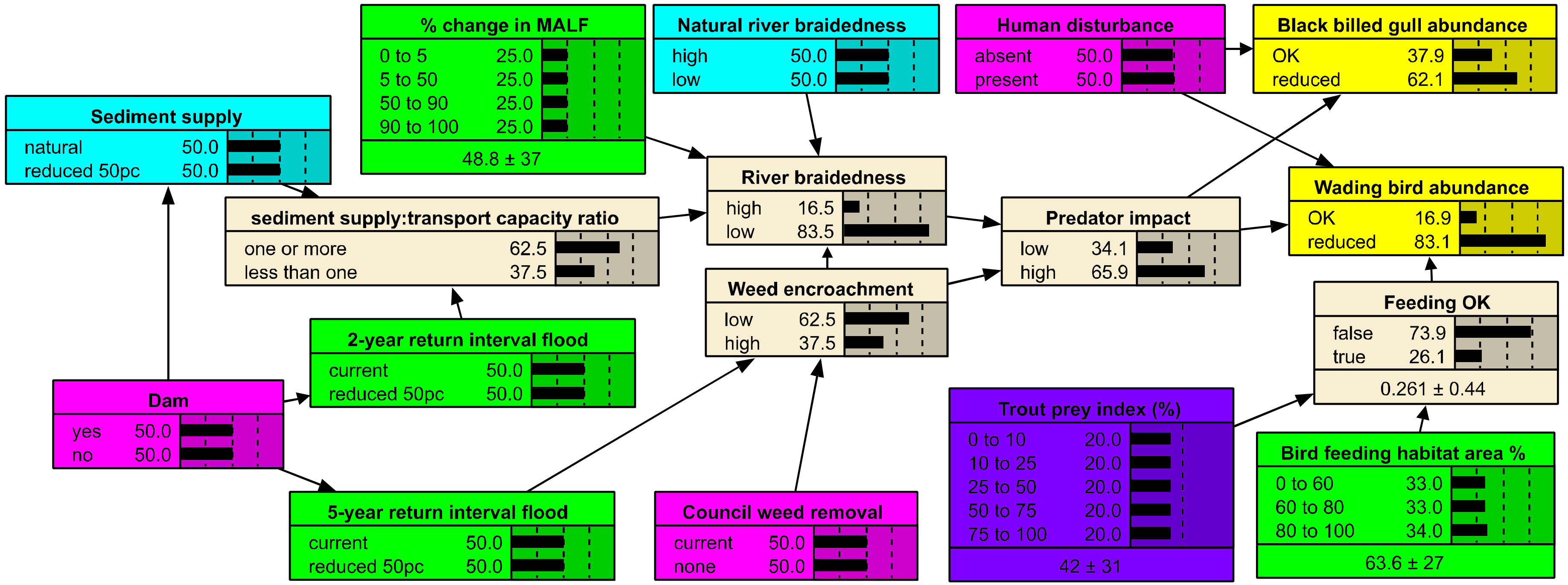

Figure 3: **Bayesian network for probability of wading bird and black-billed gull abundances being "OK".**

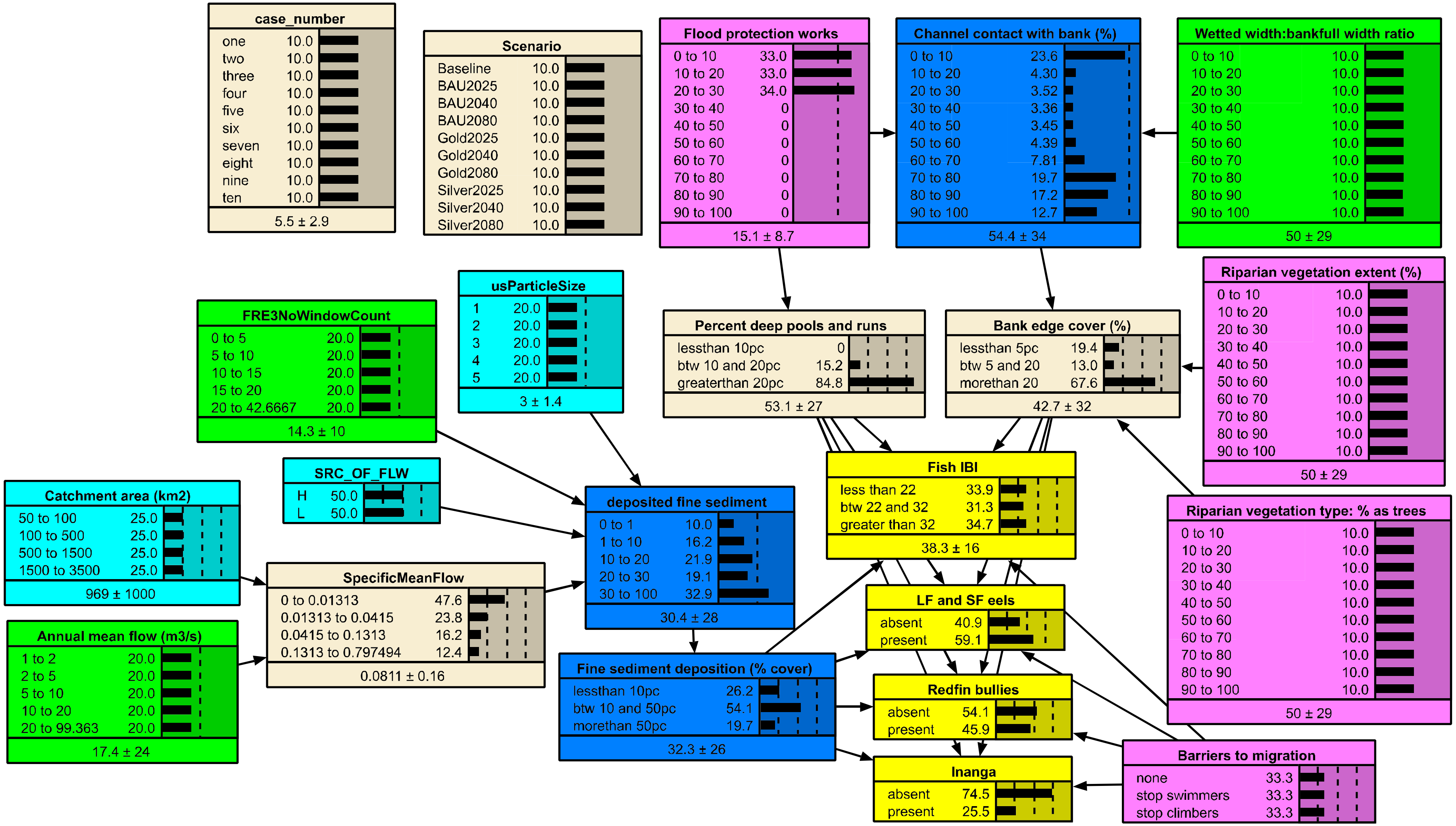

Figure 4: Bayesian network for Fish IBI and the probability of eels (longfin and shortfin), redfin bullies and inanga being present.

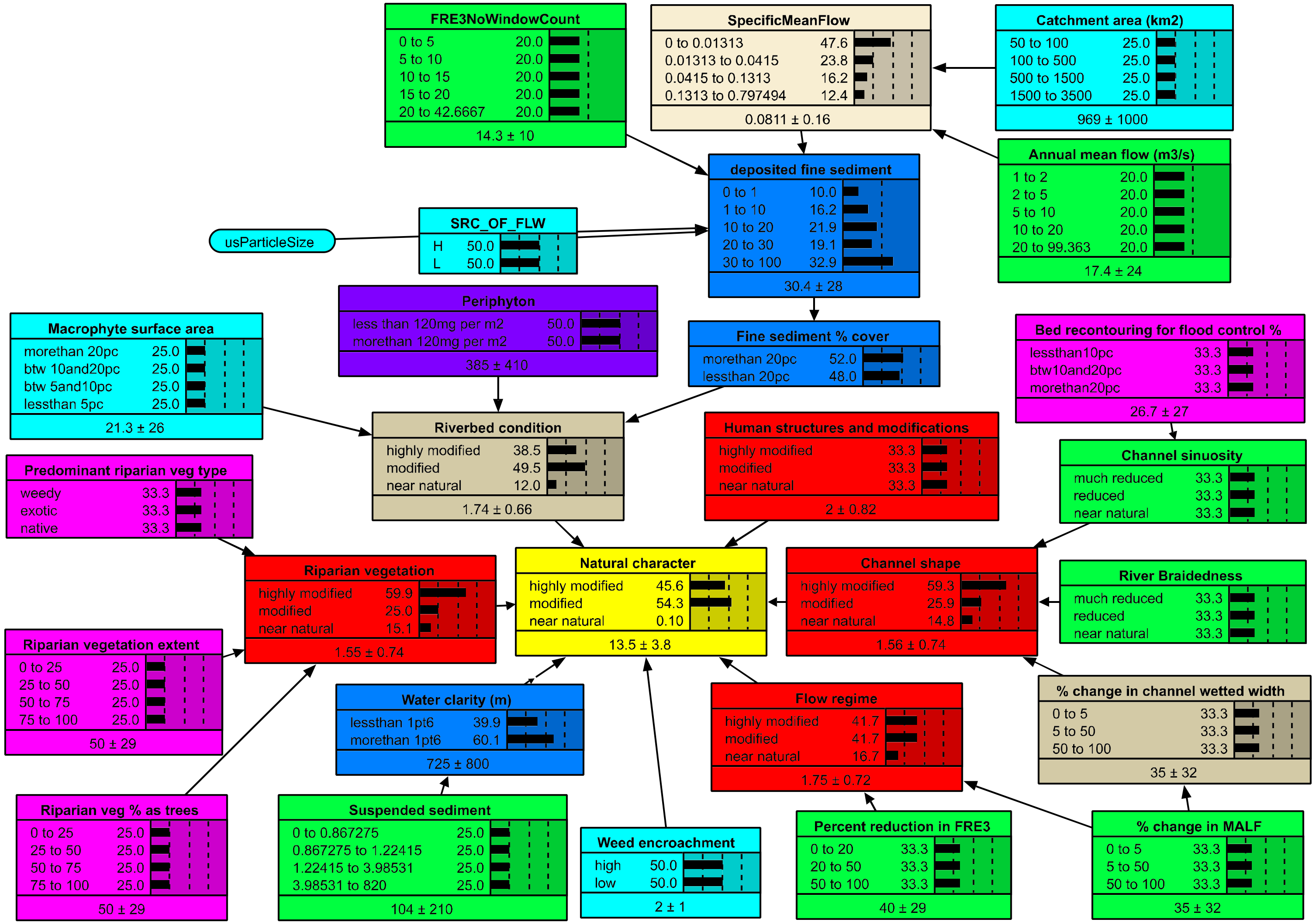

Figure 5: **Bayesian network for river natural character.**

Appendix B Conditional Probability Table for Periphyton biomass

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
<50	0 to 14	0 to 11	low	0 to 100	85.2	14.3	0.5	0
<50	0 to 14	0 to 11	low	100 to 708	91.8	7.8	0.4	0
<50	0 to 14	0 to 11	low	708 to 9500	92.4	7.4	0.2	0
<50	0 to 14	0 to 11	low med	0 to 100	68.6	30.4	0.9	0
<50	0 to 14	0 to 11	low med	100 to 708	80.9	18.4	0.7	0
<50	0 to 14	0 to 11	low med	708 to 9500	81.6	18.0	0.4	0
<50	0 to 14	0 to 11	med high	0 to 100	60.8	37.1	0.3	1.8
<50	0 to 14	0 to 11	med high	100 to 708	73.8	24.7	1.6	0
<50	0 to 14	0 to 11	med high	708 to 9500	74.9	24.2	0.8	0
<50	0 to 14	0 to 11	high	0 to 100	62.0	36.2	0	1.8
<50	0 to 14	0 to 11	high	100 to 708	75.0	23.6	1.4	0
<50	0 to 14	0 to 11	high	708 to 9500	76.1	23.2	0.7	0
<50	0 to 14	11 to 16.4	low	0 to 100	81.5	17.5	1.0	0
<50	0 to 14	11 to 16.4	low	100 to 708	89.0	10.2	0.8	0
<50	0 to 14	11 to 16.4	low	708 to 9500	90.2	9.4	0.4	0
<50	0 to 14	11 to 16.4	low med	0 to 100	64.2	34.1	1.7	0
<50	0 to 14	11 to 16.4	low med	100 to 708	76.6	22.0	1.4	0
<50	0 to 14	11 to 16.4	low med	708 to 9500	77.8	21.4	0.8	0
<50	0 to 14	11 to 16.4	med high	0 to 100	57.4	39.4	3.3	0
<50	0 to 14	11 to 16.4	med high	100 to 708	69.0	28.2	2.8	0
<50	0 to 14	11 to 16.4	med high	708 to 9500	70.4	28.0	1.6	0
<50	0 to 14	11 to 16.4	high	0 to 100	58.3	38.8	2.7	0.3
<50	0 to 14	11 to 16.4	high	100 to 708	70.3	27.3	2.4	0
<50	0 to 14	11 to 16.4	high	708 to 9500	71.7	26.9	1.4	0
<50	0 to 14	16.4 to 17.3	low	0 to 100	75.0	23.5	1.0	0.5
<50	0 to 14	16.4 to 17.3	low	100 to 708	84.8	14.1	1.1	0
<50	0 to 14	16.4 to 17.3	low	708 to 9500	86.2	13.3	0.6	0
<50	0 to 14	16.4 to 17.3	low med	0 to 100	56.4	41.3	0.6	1.7
<50	0 to 14	16.4 to 17.3	low med	100 to 708	69.6	28.5	1.9	0
<50	0 to 14	16.4 to 17.3	low med	708 to 9500	70.6	28.4	1.0	0
<50	0 to 14	16.4 to 17.3	med high	0 to 100	51.8	43.9	0	4.2
<50	0 to 14	16.4 to 17.3	med high	100 to 708	62.3	34.1	3.2	0.4
<50	0 to 14	16.4 to 17.3	med high	708 to 9500	62.8	35.1	2.1	0
<50	0 to 14	16.4 to 17.3	high	0 to 100	52.3	43.7	0	3.9
<50	0 to 14	16.4 to 17.3	high	100 to 708	63.3	33.4	1.7	1.6
<50	0 to 14	16.4 to 17.3	high	708 to 9500	64.0	34.2	1.9	0

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
<50	0 to 14	17.3 to 19	low	0 to 100	75.0	23.5	1.0	0.5
<50	0 to 14	17.3 to 19	low	100 to 708	84.8	14.1	1.1	0
<50	0 to 14	17.3 to 19	low	708 to 9500	86.2	13.3	0.6	0
<50	0 to 14	17.3 to 19	low med	0 to 100	56.4	41.3	0.6	1.7
<50	0 to 14	17.3 to 19	low med	100 to 708	69.6	28.5	1.9	0
<50	0 to 14	17.3 to 19	low med	708 to 9500	70.6	28.4	1.0	0
<50	0 to 14	17.3 to 19	med high	0 to 100	51.8	43.9	0	4.2
<50	0 to 14	17.3 to 19	med high	100 to 708	62.3	34.1	3.2	0.4
<50	0 to 14	17.3 to 19	med high	708 to 9500	62.8	35.1	2.1	0
<50	0 to 14	17.3 to 19	high	0 to 100	52.3	43.7	0	3.9
<50	0 to 14	17.3 to 19	high	100 to 708	63.3	33.4	1.7	1.6
<50	0 to 14	17.3 to 19	high	708 to 9500	64.0	34.2	1.9	0
<50	0 to 14	19 to 21	low	0 to 100	75.0	23.5	1.0	0.5
<50	0 to 14	19 to 21	low	100 to 708	84.8	14.1	1.1	0
<50	0 to 14	19 to 21	low	708 to 9500	86.2	13.3	0.6	0
<50	0 to 14	19 to 21	low med	0 to 100	56.4	41.3	0.6	1.7
<50	0 to 14	19 to 21	low med	100 to 708	69.6	28.5	1.9	0
<50	0 to 14	19 to 21	low med	708 to 9500	70.6	28.4	1.0	0
<50	0 to 14	19 to 21	med high	0 to 100	51.8	43.9	0	4.2
<50	0 to 14	19 to 21	med high	100 to 708	62.3	34.1	3.2	0.4
<50	0 to 14	19 to 21	med high	708 to 9500	62.8	35.1	2.1	0
<50	0 to 14	19 to 21	high	0 to 100	52.3	43.7	0	3.9
<50	0 to 14	19 to 21	high	100 to 708	63.3	33.4	1.7	1.6
<50	0 to 14	19 to 21	high	708 to 9500	64.0	34.2	1.9	0
<50	0 to 14	21 to 30	low	0 to 100	70	26.6	3.4	0
<50	0 to 14	21 to 30	low	100 to 708	79.1	18.2	2.7	0
<50	0 to 14	21 to 30	low	708 to 9500	82.0	16.4	1.6	0
<50	0 to 14	21 to 30	low med	0 to 100	55.5	40	4.5	0
<50	0 to 14	21 to 30	low med	100 to 708	65.3	30.7	4.0	0
<50	0 to 14	21 to 30	low med	708 to 9500	66.6	30.9	2.5	0
<50	0 to 14	21 to 30	med high	0 to 100	54.0	39.5	0.9	5.7
<50	0 to 14	21 to 30	med high	100 to 708	60.1	33.8	6.1	0
<50	0 to 14	21 to 30	med high	708 to 9500	60.1	35.6	4.3	0
<50	0 to 14	21 to 30	high	0 to 100	54.0	39.7	0	6.3
<50	0 to 14	21 to 30	high	100 to 708	60.7	33.6	5.7	0
<50	0 to 14	21 to 30	high	708 to 9500	61.0	35.1	3.9	0
<50	14 to 365	0 to 11	low	0 to 100	74.3	24.6	1.1	0
<50	14 to 365	0 to 11	low	100 to 708	80.9	18.1	1.0	0

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²) 0 to 50	50 to 120	120 to 200	200 to 1300
<50	14 to 365	0 to 11	low	708 to 9500	81.5	17.7	0.8	0
<50	14 to 365	0 to 11	low med	0 to 100	57.7	40.7	1.6	0
<50	14 to 365	0 to 11	low med	100 to 708	70	28.7	1.3	0
<50	14 to 365	0 to 11	low med	708 to 9500	70.7	28.3	1.0	0
<50	14 to 365	0 to 11	med high	0 to 100	49.9	47.4	1.0	1.7
<50	14 to 365	0 to 11	med high	100 to 708	62.9	35.0	2.2	0
<50	14 to 365	0 to 11	med high	708 to 9500	64.0	34.5	1.4	0
<50	14 to 365	0 to 11	high	0 to 100	51.1	46.5	0.3	2.1
<50	14 to 365	0 to 11	high	100 to 708	64.1	33.9	2.0	0
<50	14 to 365	0 to 11	high	708 to 9500	65.2	33.5	1.3	0
<50	14 to 365	11 to 16.4	low	0 to 100	70.6	27.8	1.6	0
<50	14 to 365	11 to 16.4	low	100 to 708	78.1	20.5	1.4	0
<50	14 to 365	11 to 16.4	low	708 to 9500	79.3	19.7	1.0	0
<50	14 to 365	11 to 16.4	low med	0 to 100	53.3	44.4	2.3	0
<50	14 to 365	11 to 16.4	low med	100 to 708	65.7	32.3	2.0	0
<50	14 to 365	11 to 16.4	low med	708 to 9500	66.9	31.7	1.4	0
<50	14 to 365	11 to 16.4	med high	0 to 100	46.5	49.7	3.9	0
<50	14 to 365	11 to 16.4	med high	100 to 708	58.1	38.5	3.4	0
<50	14 to 365	11 to 16.4	med high	708 to 9500	59.5	38.3	2.2	0
<50	14 to 365	11 to 16.4	high	0 to 100	47.4	49.1	3.4	0.2
<50	14 to 365	11 to 16.4	high	100 to 708	59.4	37.6	3.0	0
<50	14 to 365	11 to 16.4	high	708 to 9500	60.8	37.2	2.0	0
<50	14 to 365	16.4 to 17.3	low	0 to 100	64.1	33.8	1.7	0.4
<50	14 to 365	16.4 to 17.3	low	100 to 708	73.9	24.4	1.7	0
<50	14 to 365	16.4 to 17.3	low	708 to 9500	75.3	23.6	1.2	0
<50	14 to 365	16.4 to 17.3	low med	0 to 100	45.5	51.6	1.3	1.6
<50	14 to 365	16.4 to 17.3	low med	100 to 708	58.7	38.8	2.5	0
<50	14 to 365	16.4 to 17.3	low med	708 to 9500	59.7	38.7	1.6	0
<50	14 to 365	16.4 to 17.3	med high	0 to 100	40.9	54.2	0	4.8
<50	14 to 365	16.4 to 17.3	med high	100 to 708	51.4	44.4	3.9	0.3
<50	14 to 365	16.4 to 17.3	med high	708 to 9500	51.9	45.4	2.7	0
<50	14 to 365	16.4 to 17.3	high	0 to 100	41.4	54.0	0	4.5
<50	14 to 365	16.4 to 17.3	high	100 to 708	52.4	43.7	2.4	1.5
<50	14 to 365	16.4 to 17.3	high	708 to 9500	53.1	44.5	2.5	0
<50	14 to 365	17.3 to 19	low	0 to 100	64.1	33.8	1.7	0.4
<50	14 to 365	17.3 to 19	low	100 to 708	73.9	24.4	1.7	0
<50	14 to 365	17.3 to 19	low	708 to 9500	75.3	23.6	1.2	0
<50	14 to 365	17.3 to 19	low med	0 to 100	45.5	51.6	1.3	1.6

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
<50	14 to 365	17.3 to 19	low med	100 to 708	58.7	38.8	2.5	0
<50	14 to 365	17.3 to 19	low med	708 to 9500	59.7	38.7	1.6	0
<50	14 to 365	17.3 to 19	med high	0 to 100	40.9	54.2	0	4.8
<50	14 to 365	17.3 to 19	med high	100 to 708	51.4	44.4	3.9	0.3
<50	14 to 365	17.3 to 19	med high	708 to 9500	51.9	45.4	2.7	0
<50	14 to 365	17.3 to 19	high	0 to 100	41.4	54.0	0	4.5
<50	14 to 365	17.3 to 19	high	100 to 708	52.4	43.7	2.4	1.5
<50	14 to 365	17.3 to 19	high	708 to 9500	53.1	44.5	2.5	0
<50	14 to 365	19 to 21	low	0 to 100	64.1	33.8	1.7	0.4
<50	14 to 365	19 to 21	low	100 to 708	73.9	24.4	1.7	0
<50	14 to 365	19 to 21	low	708 to 9500	75.3	23.6	1.2	0
<50	14 to 365	19 to 21	low med	0 to 100	45.5	51.6	1.3	1.6
<50	14 to 365	19 to 21	low med	100 to 708	58.7	38.8	2.5	0
<50	14 to 365	19 to 21	low med	708 to 9500	59.7	38.7	1.6	0
<50	14 to 365	19 to 21	med high	0 to 100	40.9	54.2	0	4.8
<50	14 to 365	19 to 21	med high	100 to 708	51.4	44.4	3.9	0.3
<50	14 to 365	19 to 21	med high	708 to 9500	51.9	45.4	2.7	0
<50	14 to 365	19 to 21	high	0 to 100	41.4	54.0	0	4.5
<50	14 to 365	19 to 21	high	100 to 708	52.4	43.7	2.4	1.5
<50	14 to 365	19 to 21	high	708 to 9500	53.1	44.5	2.5	0
<50	14 to 365	21 to 30	low	0 to 100	59.1	36.9	4.0	0
<50	14 to 365	21 to 30	low	100 to 708	68.2	28.5	3.3	0
<50	14 to 365	21 to 30	low	708 to 9500	71.1	26.7	2.2	0
<50	14 to 365	21 to 30	low med	0 to 100	44.6	50.3	5.1	0
<50	14 to 365	21 to 30	low med	100 to 708	54.4	41.0	4.6	0
<50	14 to 365	21 to 30	low med	708 to 9500	55.7	41.2	3.1	0
<50	14 to 365	21 to 30	med high	0 to 100	43.1	49.7	1.6	5.6
<50	14 to 365	21 to 30	med high	100 to 708	49.2	44.1	6.7	0
<50	14 to 365	21 to 30	med high	708 to 9500	49.2	45.9	4.9	0
<50	14 to 365	21 to 30	high	0 to 100	43.1	50	0	6.9
<50	14 to 365	21 to 30	high	100 to 708	49.8	43.9	6.3	0
<50	14 to 365	21 to 30	high	708 to 9500	50.1	45.4	4.5	0
50 to 300	0 to 14	0 to 11	low	0 to 100	83.2	13.4	1.7	1.7
50 to 300	0 to 14	0 to 11	low	100 to 708	90.5	7.2	1.8	0.6
50 to 300	0 to 14	0 to 11	low	708 to 9500	91.7	7.1	1.0	0.2
50 to 300	0 to 14	0 to 11	low med	0 to 100	65.2	28.7	2.7	3.5
50 to 300	0 to 14	0 to 11	low med	100 to 708	78.3	17.1	3.1	1.4
50 to 300	0 to 14	0 to 11	low med	708 to 9500	80.3	17.3	1.9	0.5

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m^2)			
					0 to 50	50 to 120	120 to 200	200 to 1300
50 to 300	0 to 14	0 to 11	med high	0 to 100	53.2	33.3	4.1	9.4
50 to 300	0 to 14	0 to 11	med high	100 to 708	68.0	21.8	5.5	4.7
50 to 300	0 to 14	0 to 11	med high	708 to 9500	71.9	22.7	3.5	2.0
50 to 300	0 to 14	0 to 11	high	0 to 100	55.2	32.8	3.0	9.0
50 to 300	0 to 14	0 to 11	high	100 to 708	70.1	21.1	4.2	4.6
50 to 300	0 to 14	0 to 11	high	708 to 9500	73.5	21.9	2.7	1.9
50 to 300	0 to 14	11 to 16.4	low	0 to 100	77.7	15.5	4.7	2.1
50 to 300	0 to 14	11 to 16.4	low	100 to 708	86.1	8.7	4.8	0.4
50 to 300	0 to 14	11 to 16.4	low	708 to 9500	88.6	8.6	2.8	0
50 to 300	0 to 14	11 to 16.4	low med	0 to 100	57.9	30.9	7.0	4.2
50 to 300	0 to 14	11 to 16.4	low med	100 to 708	71.3	19.4	8.0	1.3
50 to 300	0 to 14	11 to 16.4	low med	708 to 9500	74.9	20	4.9	0.3
50 to 300	0 to 14	11 to 16.4	med high	0 to 100	45.4	33.4	10.2	11.0
50 to 300	0 to 14	11 to 16.4	med high	100 to 708	58.7	23.1	13.3	4.9
50 to 300	0 to 14	11 to 16.4	med high	708 to 9500	64.4	24.9	8.8	1.9
50 to 300	0 to 14	11 to 16.4	high	0 to 100	47.5	33.4	8.0	11.0
50 to 300	0 to 14	11 to 16.4	high	100 to 708	61.4	22.8	10.6	5.2
50 to 300	0 to 14	11 to 16.4	high	708 to 9500	66.7	24.4	6.9	2.1
50 to 300	0 to 14	16.4 to 17.3	low	0 to 100	69.4	20.7	3.8	6.1
50 to 300	0 to 14	16.4 to 17.3	low	100 to 708	80.8	12.2	4.4	2.6
50 to 300	0 to 14	16.4 to 17.3	low	708 to 9500	84.1	12.2	2.7	1.0
50 to 300	0 to 14	16.4 to 17.3	low med	0 to 100	47.8	37.0	4.9	10.3
50 to 300	0 to 14	16.4 to 17.3	low med	100 to 708	62.8	25.1	6.8	5.3
50 to 300	0 to 14	16.4 to 17.3	low med	708 to 9500	66.9	26.5	4.4	2.2
50 to 300	0 to 14	16.4 to 17.3	med high	0 to 100	36.3	36.2	5.6	21.9
50 to 300	0 to 14	16.4 to 17.3	med high	100 to 708	49.2	27.6	9.8	13.5
50 to 300	0 to 14	16.4 to 17.3	med high	708 to 9500	55.1	31.2	7.1	6.6
50 to 300	0 to 14	16.4 to 17.3	high	0 to 100	37.8	36.5	4.1	21.6
50 to 300	0 to 14	16.4 to 17.3	high	100 to 708	51.5	27.5	7.6	13.4
50 to 300	0 to 14	16.4 to 17.3	high	708 to 9500	57.2	30.8	5.5	6.5
50 to 300	0 to 14	17.3 to 19	low	0 to 100	69.4	20.7	3.8	6.1
50 to 300	0 to 14	17.3 to 19	low	100 to 708	80.8	12.2	4.4	2.6
50 to 300	0 to 14	17.3 to 19	low	708 to 9500	84.1	12.2	2.7	1.0
50 to 300	0 to 14	17.3 to 19	low med	0 to 100	47.8	37.0	4.9	10.3
50 to 300	0 to 14	17.3 to 19	low med	100 to 708	62.8	25.1	6.8	5.3
50 to 300	0 to 14	17.3 to 19	low med	708 to 9500	66.9	26.5	4.4	2.2
50 to 300	0 to 14	17.3 to 19	med high	0 to 100	36.3	36.2	5.6	21.9
50 to 300	0 to 14	17.3 to 19	med high	100 to 708	49.2	27.6	9.8	13.5

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
50 to 300	0 to 14	17.3 to 19	med high	708 to 9500	55.1	31.2	7.1	6.6
50 to 300	0 to 14	17.3 to 19	high	0 to 100	37.8	36.5	4.1	21.6
50 to 300	0 to 14	17.3 to 19	high	100 to 708	51.5	27.5	7.6	13.4
50 to 300	0 to 14	17.3 to 19	high	708 to 9500	57.2	30.8	5.5	6.5
50 to 300	0 to 14	19 to 21	low	0 to 100	69.4	20.7	3.8	6.1
50 to 300	0 to 14	19 to 21	low	100 to 708	80.8	12.2	4.4	2.6
50 to 300	0 to 14	19 to 21	low	708 to 9500	84.1	12.2	2.7	1.0
50 to 300	0 to 14	19 to 21	low med	0 to 100	47.8	37.0	4.9	10.3
50 to 300	0 to 14	19 to 21	low med	100 to 708	62.8	25.1	6.8	5.3
50 to 300	0 to 14	19 to 21	low med	708 to 9500	66.9	26.5	4.4	2.2
50 to 300	0 to 14	19 to 21	med high	0 to 100	36.3	36.2	5.6	21.9
50 to 300	0 to 14	19 to 21	med high	100 to 708	49.2	27.6	9.8	13.5
50 to 300	0 to 14	19 to 21	med high	708 to 9500	55.1	31.2	7.1	6.6
50 to 300	0 to 14	19 to 21	high	0 to 100	37.8	36.5	4.1	21.6
50 to 300	0 to 14	19 to 21	high	100 to 708	51.5	27.5	7.6	13.4
50 to 300	0 to 14	19 to 21	high	708 to 9500	57.2	30.8	5.5	6.5
50 to 300	0 to 14	21 to 30	low	0 to 100	57.5	20.4	11.1	11.0
50 to 300	0 to 14	21 to 30	low	100 to 708	69.2	13.3	13.2	4.3
50 to 300	0 to 14	21 to 30	low	708 to 9500	76.2	13.5	8.7	1.6
50 to 300	0 to 14	21 to 30	low med	0 to 100	38.8	31.6	12.8	16.7
50 to 300	0 to 14	21 to 30	low med	100 to 708	50.5	23.3	17.9	8.3
50 to 300	0 to 14	21 to 30	low med	708 to 9500	57.3	26.3	12.8	3.6
50 to 300	0 to 14	21 to 30	med high	0 to 100	29.8	27.4	13.0	29.8
50 to 300	0 to 14	21 to 30	med high	100 to 708	37.7	22.6	21.4	18.3
50 to 300	0 to 14	21 to 30	med high	708 to 9500	44.2	27.6	18.1	10.1
50 to 300	0 to 14	21 to 30	high	0 to 100	30.9	28.2	10.2	30.6
50 to 300	0 to 14	21 to 30	high	100 to 708	39.7	23.1	17.7	19.4
50 to 300	0 to 14	21 to 30	high	708 to 9500	46.6	27.9	14.7	10.8
50 to 300	14 to 365	0 to 11	low	0 to 100	70.1	22.6	3.5	3.8
50 to 300	14 to 365	0 to 11	low	100 to 708	77.4	16.4	3.6	2.7
50 to 300	14 to 365	0 to 11	low	708 to 9500	78.6	16.3	2.8	2.3
50 to 300	14 to 365	0 to 11	low med	0 to 100	52.1	37.9	4.5	5.6
50 to 300	14 to 365	0 to 11	low med	100 to 708	65.2	26.3	4.9	3.5
50 to 300	14 to 365	0 to 11	low med	708 to 9500	67.2	26.5	3.7	2.6
50 to 300	14 to 365	0 to 11	med high	0 to 100	40.1	42.5	5.9	11.5
50 to 300	14 to 365	0 to 11	med high	100 to 708	54.9	31.0	7.3	6.8
50 to 300	14 to 365	0 to 11	med high	708 to 9500	58.8	31.9	5.3	4.1
50 to 300	14 to 365	0 to 11	high	0 to 100	42.1	42.0	4.8	11.1

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
50 to 300	14 to 365	0 to 11	high	100 to 708	57.0	30.3	6.0	6.7
50 to 300	14 to 365	0 to 11	high	708 to 9500	60.4	31.1	4.5	4.0
50 to 300	14 to 365	11 to 16.4	low	0 to 100	64.6	24.7	6.5	4.2
50 to 300	14 to 365	11 to 16.4	low	100 to 708	73.0	17.9	6.6	2.5
50 to 300	14 to 365	11 to 16.4	low	708 to 9500	75.5	17.8	4.6	2.1
50 to 300	14 to 365	11 to 16.4	low med	0 to 100	44.8	40.1	8.8	6.3
50 to 300	14 to 365	11 to 16.4	low med	100 to 708	58.2	28.6	9.8	3.4
50 to 300	14 to 365	11 to 16.4	low med	708 to 9500	61.8	29.2	6.7	2.4
50 to 300	14 to 365	11 to 16.4	med high	0 to 100	32.3	42.6	12.0	13.1
50 to 300	14 to 365	11 to 16.4	med high	100 to 708	45.6	32.3	15.1	7.0
50 to 300	14 to 365	11 to 16.4	med high	708 to 9500	51.3	34.1	10.6	4.0
50 to 300	14 to 365	11 to 16.4	high	0 to 100	34.4	42.6	9.8	13.1
50 to 300	14 to 365	11 to 16.4	high	100 to 708	48.3	32.0	12.4	7.3
50 to 300	14 to 365	11 to 16.4	high	708 to 9500	53.6	33.6	8.7	4.2
50 to 300	14 to 365	16.4 to 17.3	low	0 to 100	56.3	29.9	5.6	8.2
50 to 300	14 to 365	16.4 to 17.3	low	100 to 708	67.7	21.4	6.2	4.7
50 to 300	14 to 365	16.4 to 17.3	low	708 to 9500	71.0	21.4	4.5	3.1
50 to 300	14 to 365	16.4 to 17.3	low med	0 to 100	34.7	46.2	6.7	12.4
50 to 300	14 to 365	16.4 to 17.3	low med	100 to 708	49.7	34.3	8.6	7.4
50 to 300	14 to 365	16.4 to 17.3	low med	708 to 9500	53.8	35.7	6.2	4.3
50 to 300	14 to 365	16.4 to 17.3	med high	0 to 100	23.2	45.4	7.4	24.0
50 to 300	14 to 365	16.4 to 17.3	med high	100 to 708	36.1	36.8	11.6	15.6
50 to 300	14 to 365	16.4 to 17.3	med high	708 to 9500	42.0	40.4	8.9	8.7
50 to 300	14 to 365	16.4 to 17.3	high	0 to 100	24.7	45.7	5.9	23.7
50 to 300	14 to 365	16.4 to 17.3	high	100 to 708	38.4	36.7	9.4	15.5
50 to 300	14 to 365	16.4 to 17.3	high	708 to 9500	44.1	40	7.3	8.6
50 to 300	14 to 365	17.3 to 19	low	0 to 100	56.3	29.9	5.6	8.2
50 to 300	14 to 365	17.3 to 19	low	100 to 708	67.7	21.4	6.2	4.7
50 to 300	14 to 365	17.3 to 19	low	708 to 9500	71.0	21.4	4.5	3.1
50 to 300	14 to 365	17.3 to 19	low med	0 to 100	34.7	46.2	6.7	12.4
50 to 300	14 to 365	17.3 to 19	low med	100 to 708	49.7	34.3	8.6	7.4
50 to 300	14 to 365	17.3 to 19	low med	708 to 9500	53.8	35.7	6.2	4.3
50 to 300	14 to 365	17.3 to 19	med high	0 to 100	23.2	45.4	7.4	24.0
50 to 300	14 to 365	17.3 to 19	med high	100 to 708	36.1	36.8	11.6	15.6
50 to 300	14 to 365	17.3 to 19	med high	708 to 9500	42.0	40.4	8.9	8.7
50 to 300	14 to 365	17.3 to 19	high	0 to 100	24.7	45.7	5.9	23.7
50 to 300	14 to 365	17.3 to 19	high	100 to 708	38.4	36.7	9.4	15.5
50 to 300	14 to 365	17.3 to 19	high	708 to 9500	44.1	40	7.3	8.6

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
50 to 300	14 to 365	19 to 21	low	0 to 100	56.3	29.9	5.6	8.2
50 to 300	14 to 365	19 to 21	low	100 to 708	67.7	21.4	6.2	4.7
50 to 300	14 to 365	19 to 21	low	708 to 9500	71.0	21.4	4.5	3.1
50 to 300	14 to 365	19 to 21	low med	0 to 100	34.7	46.2	6.7	12.4
50 to 300	14 to 365	19 to 21	low med	100 to 708	49.7	34.3	8.6	7.4
50 to 300	14 to 365	19 to 21	low med	708 to 9500	53.8	35.7	6.2	4.3
50 to 300	14 to 365	19 to 21	med high	0 to 100	23.2	45.4	7.4	24.0
50 to 300	14 to 365	19 to 21	med high	100 to 708	36.1	36.8	11.6	15.6
50 to 300	14 to 365	19 to 21	med high	708 to 9500	42.0	40.4	8.9	8.7
50 to 300	14 to 365	19 to 21	high	0 to 100	24.7	45.7	5.9	23.7
50 to 300	14 to 365	19 to 21	high	100 to 708	38.4	36.7	9.4	15.5
50 to 300	14 to 365	19 to 21	high	708 to 9500	44.1	40	7.3	8.6
50 to 300	14 to 365	21 to 30	low	0 to 100	44.4	29.6	12.9	13.1
50 to 300	14 to 365	21 to 30	low	100 to 708	56.1	22.5	15.0	6.4
50 to 300	14 to 365	21 to 30	low	708 to 9500	63.1	22.7	10.5	3.7
50 to 300	14 to 365	21 to 30	low med	0 to 100	25.7	40.8	14.6	18.8
50 to 300	14 to 365	21 to 30	low med	100 to 708	37.4	32.5	19.7	10.4
50 to 300	14 to 365	21 to 30	low med	708 to 9500	44.2	35.5	14.6	5.7
50 to 300	14 to 365	21 to 30	med high	0 to 100	16.8	36.5	14.8	31.9
50 to 300	14 to 365	21 to 30	med high	100 to 708	24.6	31.8	23.2	20.4
50 to 300	14 to 365	21 to 30	med high	708 to 9500	31.1	36.8	19.9	12.2
50 to 300	14 to 365	21 to 30	high	0 to 100	17.8	37.4	12.0	32.7
50 to 300	14 to 365	21 to 30	high	100 to 708	26.6	32.3	19.5	21.5
50 to 300	14 to 365	21 to 30	high	708 to 9500	33.5	37.1	16.5	12.9
>300	0 to 14	0 to 11	low	0 to 100	82.0	12.7	2.3	2.9
>300	0 to 14	0 to 11	low	100 to 708	89.6	6.8	2.2	1.4
>300	0 to 14	0 to 11	low	708 to 9500	91.3	6.9	1.2	0.6
>300	0 to 14	0 to 11	low med	0 to 100	62.9	27.6	3.8	5.7
>300	0 to 14	0 to 11	low med	100 to 708	76.7	16.3	3.9	3.1
>300	0 to 14	0 to 11	low med	708 to 9500	79.4	16.9	2.3	1.4
>300	0 to 14	0 to 11	med high	0 to 100	48.4	30.9	6.5	14.2
>300	0 to 14	0 to 11	med high	100 to 708	64.3	19.9	7.4	8.4
>300	0 to 14	0 to 11	med high	708 to 9500	69.9	21.7	4.5	3.9
>300	0 to 14	0 to 11	high	0 to 100	50.9	30.6	5.2	13.3
>300	0 to 14	0 to 11	high	100 to 708	66.9	19.5	5.8	7.8
>300	0 to 14	0 to 11	high	708 to 9500	71.9	21.0	3.5	3.6
>300	0 to 14	11 to 16.4	low	0 to 100	75.2	14.3	5.9	4.5
>300	0 to 14	11 to 16.4	low	100 to 708	84.3	7.8	5.7	2.2

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
>300	0 to 14	11 to 16.4	low	708 to 9500	87.6	8.1	3.3	1.0
>300	0 to 14	11 to 16.4	low med	0 to 100	53.9	28.9	9.0	8.2
>300	0 to 14	11 to 16.4	low med	100 to 708	68.0	17.7	9.7	4.6
>300	0 to 14	11 to 16.4	low med	708 to 9500	73.0	19.0	5.8	2.1
>300	0 to 14	11 to 16.4	med high	0 to 100	37.8	29.6	14.0	18.6
>300	0 to 14	11 to 16.4	med high	100 to 708	52.2	19.8	16.6	11.4
>300	0 to 14	11 to 16.4	med high	708 to 9500	60.5	23.0	10.7	5.7
>300	0 to 14	11 to 16.4	high	0 to 100	40.7	30	11.4	17.8
>300	0 to 14	11 to 16.4	high	100 to 708	55.8	20	13.4	10.9
>300	0 to 14	11 to 16.4	high	708 to 9500	63.4	22.7	8.5	5.3
>300	0 to 14	16.4 to 17.3	low	0 to 100	65.8	18.9	5.6	9.6
>300	0 to 14	16.4 to 17.3	low	100 to 708	78.3	10.9	5.7	5.1
>300	0 to 14	16.4 to 17.3	low	708 to 9500	82.8	11.6	3.4	2.3
>300	0 to 14	16.4 to 17.3	low med	0 to 100	42.3	34.3	7.6	15.8
>300	0 to 14	16.4 to 17.3	low med	100 to 708	58.4	22.9	9.0	9.7
>300	0 to 14	16.4 to 17.3	low med	708 to 9500	64.5	25.4	5.5	4.6
>300	0 to 14	16.4 to 17.3	med high	0 to 100	26.4	31.2	10.6	31.8
>300	0 to 14	16.4 to 17.3	med high	100 to 708	40.8	23.4	13.9	21.8
>300	0 to 14	16.4 to 17.3	med high	708 to 9500	50.1	28.8	9.6	11.5
>300	0 to 14	16.4 to 17.3	high	0 to 100	28.6	31.9	8.7	30.8
>300	0 to 14	16.4 to 17.3	high	100 to 708	43.9	23.7	11.4	21.0
>300	0 to 14	16.4 to 17.3	high	708 to 9500	52.9	28.6	7.7	10.9
>300	0 to 14	17.3 to 19	low	0 to 100	65.8	18.9	5.6	9.6
>300	0 to 14	17.3 to 19	low	100 to 708	78.3	10.9	5.7	5.1
>300	0 to 14	17.3 to 19	low	708 to 9500	82.8	11.6	3.4	2.3
>300	0 to 14	17.3 to 19	low med	0 to 100	42.3	34.3	7.6	15.8
>300	0 to 14	17.3 to 19	low med	100 to 708	58.4	22.9	9.0	9.7
>300	0 to 14	17.3 to 19	low med	708 to 9500	64.5	25.4	5.5	4.6
>300	0 to 14	17.3 to 19	med high	0 to 100	26.4	31.2	10.6	31.8
>300	0 to 14	17.3 to 19	med high	100 to 708	40.8	23.4	13.9	21.8
>300	0 to 14	17.3 to 19	med high	708 to 9500	50.1	28.8	9.6	11.5
>300	0 to 14	17.3 to 19	high	0 to 100	28.6	31.9	8.7	30.8
>300	0 to 14	17.3 to 19	high	100 to 708	43.9	23.7	11.4	21.0
>300	0 to 14	17.3 to 19	high	708 to 9500	52.9	28.6	7.7	10.9
>300	0 to 14	19 to 21	low	0 to 100	65.8	18.9	5.6	9.6
>300	0 to 14	19 to 21	low	100 to 708	78.3	10.9	5.7	5.1
>300	0 to 14	19 to 21	low	708 to 9500	82.8	11.6	3.4	2.3
>300	0 to 14	19 to 21	low med	0 to 100	42.3	34.3	7.6	15.8

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
>300	0 to 14	19 to 21	low med	100 to 708	58.4	22.9	9.0	9.7
>300	0 to 14	19 to 21	low med	708 to 9500	64.5	25.4	5.5	4.6
>300	0 to 14	19 to 21	med high	0 to 100	26.4	31.2	10.6	31.8
>300	0 to 14	19 to 21	med high	100 to 708	40.8	23.4	13.9	21.8
>300	0 to 14	19 to 21	med high	708 to 9500	50.1	28.8	9.6	11.5
>300	0 to 14	19 to 21	high	0 to 100	28.6	31.9	8.7	30.8
>300	0 to 14	19 to 21	high	100 to 708	43.9	23.7	11.4	21.0
>300	0 to 14	19 to 21	high	708 to 9500	52.9	28.6	7.7	10.9
>300	0 to 14	21 to 30	low	0 to 100	49.6	16.5	15.0	18.9
>300	0 to 14	21 to 30	low	100 to 708	63.0	10.1	16.3	10.6
>300	0 to 14	21 to 30	low	708 to 9500	72.6	11.7	10.5	5.3
>300	0 to 14	21 to 30	low med	0 to 100	28.2	26.3	18.1	27.3
>300	0 to 14	21 to 30	low med	100 to 708	41.1	18.6	22.6	17.7
>300	0 to 14	21 to 30	low med	708 to 9500	51.4	23.3	15.8	9.5
>300	0 to 14	21 to 30	med high	0 to 100	14.5	19.7	20.6	45.2
>300	0 to 14	21 to 30	med high	100 to 708	23.4	15.5	28.6	32.5
>300	0 to 14	21 to 30	med high	708 to 9500	34.0	22.5	23.2	20.3
>300	0 to 14	21 to 30	high	0 to 100	16.2	20.9	17.6	45.3
>300	0 to 14	21 to 30	high	100 to 708	26.4	16.5	24.4	32.7
>300	0 to 14	21 to 30	high	708 to 9500	37.4	23.3	19.3	19.9
>300	14 to 365	0 to 11	low	0 to 100	67.5	21.2	4.8	6.4
>300	14 to 365	0 to 11	low	100 to 708	75.1	15.3	4.7	4.9
>300	14 to 365	0 to 11	low	708 to 9500	76.8	15.4	3.7	4.1
>300	14 to 365	0 to 11	low med	0 to 100	48.4	36.1	6.3	9.2
>300	14 to 365	0 to 11	low med	100 to 708	62.2	24.8	6.4	6.6
>300	14 to 365	0 to 11	low med	708 to 9500	64.9	25.4	4.8	4.9
>300	14 to 365	0 to 11	med high	0 to 100	33.9	39.4	9.0	17.7
>300	14 to 365	0 to 11	med high	100 to 708	49.8	28.4	9.9	11.9
>300	14 to 365	0 to 11	med high	708 to 9500	55.4	30.2	7.0	7.4
>300	14 to 365	0 to 11	high	0 to 100	36.4	39.1	7.7	16.8
>300	14 to 365	0 to 11	high	100 to 708	52.4	28.0	8.3	11.3
>300	14 to 365	0 to 11	high	708 to 9500	57.4	29.5	6.0	7.1
>300	14 to 365	11 to 16.4	low	0 to 100	60.7	22.8	8.4	8.0
>300	14 to 365	11 to 16.4	low	100 to 708	69.8	16.3	8.2	5.7
>300	14 to 365	11 to 16.4	low	708 to 9500	73.1	16.6	5.8	4.5
>300	14 to 365	11 to 16.4	low med	0 to 100	39.4	37.4	11.5	11.7
>300	14 to 365	11 to 16.4	low med	100 to 708	53.5	26.2	12.2	8.1
>300	14 to 365	11 to 16.4	low med	708 to 9500	58.5	27.5	8.3	5.6

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
>300	14 to 365	11 to 16.4	med high	0 to 100	23.3	38.1	16.5	22.1
>300	14 to 365	11 to 16.4	med high	100 to 708	37.7	28.3	19.1	14.9
>300	14 to 365	11 to 16.4	med high	708 to 9500	46.0	31.5	13.2	9.2
>300	14 to 365	11 to 16.4	high	0 to 100	26.2	38.5	13.9	21.3
>300	14 to 365	11 to 16.4	high	100 to 708	41.3	28.5	15.9	14.4
>300	14 to 365	11 to 16.4	high	708 to 9500	48.9	31.2	11.0	8.8
>300	14 to 365	16.4 to 17.3	low	0 to 100	51.3	27.4	8.1	13.1
>300	14 to 365	16.4 to 17.3	low	100 to 708	63.8	19.4	8.2	8.6
>300	14 to 365	16.4 to 17.3	low	708 to 9500	68.3	20.1	5.9	5.8
>300	14 to 365	16.4 to 17.3	low med	0 to 100	27.8	42.8	10.1	19.3
>300	14 to 365	16.4 to 17.3	low med	100 to 708	43.9	31.4	11.5	13.2
>300	14 to 365	16.4 to 17.3	low med	708 to 9500	50	33.9	8.0	8.1
>300	14 to 365	16.4 to 17.3	med high	0 to 100	11.9	39.7	13.1	35.3
>300	14 to 365	16.4 to 17.3	med high	100 to 708	26.3	31.9	16.4	25.3
>300	14 to 365	16.4 to 17.3	med high	708 to 9500	35.6	37.3	12.1	15.0
>300	14 to 365	16.4 to 17.3	high	0 to 100	14.1	40.4	11.2	34.3
>300	14 to 365	16.4 to 17.3	high	100 to 708	29.4	32.2	13.9	24.5
>300	14 to 365	16.4 to 17.3	high	708 to 9500	38.4	37.1	10.2	14.4
>300	14 to 365	17.3 to 19	low	0 to 100	51.3	27.4	8.1	13.1
>300	14 to 365	17.3 to 19	low	100 to 708	63.8	19.4	8.2	8.6
>300	14 to 365	17.3 to 19	low	708 to 9500	68.3	20.1	5.9	5.8
>300	14 to 365	17.3 to 19	low med	0 to 100	27.8	42.8	10.1	19.3
>300	14 to 365	17.3 to 19	low med	100 to 708	43.9	31.4	11.5	13.2
>300	14 to 365	17.3 to 19	low med	708 to 9500	50	33.9	8.0	8.1
>300	14 to 365	17.3 to 19	med high	0 to 100	11.9	39.7	13.1	35.3
>300	14 to 365	17.3 to 19	med high	100 to 708	26.3	31.9	16.4	25.3
>300	14 to 365	17.3 to 19	med high	708 to 9500	35.6	37.3	12.1	15.0
>300	14 to 365	17.3 to 19	high	0 to 100	14.1	40.4	11.2	34.3
>300	14 to 365	17.3 to 19	high	100 to 708	29.4	32.2	13.9	24.5
>300	14 to 365	17.3 to 19	high	708 to 9500	38.4	37.1	10.2	14.4
>300	14 to 365	19 to 21	low	0 to 100	51.3	27.4	8.1	13.1
>300	14 to 365	19 to 21	low	100 to 708	63.8	19.4	8.2	8.6
>300	14 to 365	19 to 21	low	708 to 9500	68.3	20.1	5.9	5.8
>300	14 to 365	19 to 21	low med	0 to 100	27.8	42.8	10.1	19.3
>300	14 to 365	19 to 21	low med	100 to 708	43.9	31.4	11.5	13.2
>300	14 to 365	19 to 21	low med	708 to 9500	50	33.9	8.0	8.1
>300	14 to 365	19 to 21	med high	0 to 100	11.9	39.7	13.1	35.3
>300	14 to 365	19 to 21	med high	100 to 708	26.3	31.9	16.4	25.3

Light at bed	Days of accrual	mean summer water temp	nutrient sufficiency	grazer density	Periphyton biomass (mg/m²)			
					0 to 50	50 to 120	120 to 200	200 to 1300
>300	14 to 365	19 to 21	med high	708 to 9500	35.6	37.3	12.1	15.0
>300	14 to 365	19 to 21	high	0 to 100	14.1	40.4	11.2	34.3
>300	14 to 365	19 to 21	high	100 to 708	29.4	32.2	13.9	24.5
>300	14 to 365	19 to 21	high	708 to 9500	38.4	37.1	10.2	14.4
>300	14 to 365	21 to 30	low	0 to 100	35.1	25.0	17.5	22.4
>300	14 to 365	21 to 30	low	100 to 708	48.5	18.6	18.8	14.1
>300	14 to 365	21 to 30	low	708 to 9500	58.1	20.2	13.0	8.8
>300	14 to 365	21 to 30	low med	0 to 100	13.7	34.8	20.6	30.8
>300	14 to 365	21 to 30	low med	100 to 708	26.6	27.1	25.1	21.2
>300	14 to 365	21 to 30	low med	708 to 9500	36.9	31.8	18.3	13.0
>300	14 to 365	21 to 30	med high	0 to 100	0	28.2	23.1	48.7
>300	14 to 365	21 to 30	med high	100 to 708	8.9	24.0	31.1	36.0
>300	14 to 365	21 to 30	med high	708 to 9500	19.5	31.0	25.7	23.8
>300	14 to 365	21 to 30	high	0 to 100	1.7	29.4	20.1	48.8
>300	14 to 365	21 to 30	high	100 to 708	11.9	25.0	26.9	36.2
>300	14 to 365	21 to 30	high	708 to 9500	22.9	31.8	21.8	23.4

Appendix C RiVAS attributes and indicator thresholds developed for Hawke's Bay rivers by Booth (2012)

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
flow regime	Hydrological information on a river's low, median and mean flows assist in determining natural character. Substantial flow that appears to fit the nature and scale of the channel may suggest a higher degree of natural character. Dewatered bed or 'misfit' flows suggest upstream diversions, which reduce natural character.	Very highly modified or diverted flow/ water-take (e.g., large-scale dams; take averaging 50% or more of median flow).	1	1
		Highly modified or diverted flow (e.g., small-scale dams, irrigation or flood channels).	2	1
		Moderately modified or diverted flow (e.g., several irrigation takes taking a moderate proportion of MALF).	3	2
		Relatively low levels of modified or diverted flow (e.g., few irrigation takes taking minor proportion (<5%) of low flow).	4	3
		Highly natural flow regime with no modifications to the flow pattern.	5	3

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
channel shape	Modification to cross section (e.g., slope-banks) and long section (e.g., cut through meanders) .This also includes changes to a river bed width (e.g., narrowing of the channel), which is commonly undertaken in modified rivers with valuable land adjacent. Changes to the bed sediment should also be taken account of in this attribute.	Very Highly modified river, (i.e., straightened and channelised, often with concrete or rock fill banks) often within an urban context.	1	1
		A highly modified channel shape or width but with semi natural reaches or channel shapes in some areas.	2	1
		A river displaying a patchwork with moderate natural channel shape in places together with many human influences such as long stretches of stopbanks, groynes.	3	2
		A highly natural river displaying occasional pockets or individual minor modifications to its channel shape (i.e., small stopbanks or groynes).	4	3
		A very highly natural river with no modifications to its channel shape.	5	3

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
water quality	Perception of the water quality, especially its clarity, colour, etc.	Very highly contaminated or permanently discoloured water displaying very high levels of human-induced changes to the water quality with limited life supporting capacity (e.g., within polluted urban/ industrialised areas or intensive farming).	1	1
		Water usually displaying high levels of contamination mainly from adjacent diffuse sources from land use activities (agricultural leaching, etc.).	2	1
		Water displaying reasonable levels of naturalness although contains occasional high-moderate levels of human induced changes to part of the waterway or at some times.	3	2
		Water displaying relatively high levels of water quality with small or rare amounts of impurities caused further upstream (e.g., by occasional stock crossing or forest harvesting).	4	3
		Highly natural water quality displaying no human induced changes.	5	3

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
Exotic aquatic flora and fauna	Presence of aquatic flora and fauna within the river channel (including waterweeds, pest fish (which include trout and salmon), the eggs and fry of pest fish, and the invasive alga, e.g., didymo) can reduce the natural character of the river. This does not include vegetation on 'islands' within the river channel. This is contained under 'riparian vegetation'. Algal bloom may be evident in some rivers due to seasonal low flows. Expert ecological judgement will be required to assess extent and may have a bearing on the degree of naturalness of this primary attribute.	River system choked with exotic aquatic flora and fauna.	1	1
		Large areas of introduced flora and fauna (including pest fish) evident (in approximately 75% of river).	2	1
		Occasional stretches (some quite long) of introduced flora and fauna evident within waterway (approx. 50% of river).	3	2
		Small, often isolated pockets of introduced flora and fauna evident(less than 20% of total river), however river displaying very high levels of naturalness.	4	3
		No evidence of introduced flora or fauna within the water channel.	5	3

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
Human structures and modifications within channel	Including dams, groynes, stopbanks, diversions, gravel extractions which may affect the level of natural character of the river channel.	River channel completely modified or artificial (i.e., dam/ weir/ flood defence structure).	1	1
		Significant parts of the river channel have been affected or encroached upon by human intervention (i.e., a suburban/ highly managed agricultural land, including: gravel workings, part-channelisation).	2	1
		Occasional 'reaches' of human modifications (i.e., a settled rural landscape with bridge/ aqueduct supports, pylon footing).	3	2
		Limited human intervention (i.e., occasional bridge abutments/ power pole within the river channel).	4	3
		Overwhelmingly natural with no/ very limited evidence of human interference.	5	3

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
Riparian vegetation	Dominance of native communities in natural patterns (the presence of exotic species in natural patterns will reduce natural character but is of higher naturalness than the absence of such vegetation (unless this is natural) or the presence of planted vegetation). This includes all bankside vegetation as well as vegetation within 'islands', such as those within braided river systems. Vegetation comprises all types, including grasses, remnant scrub, shrubs and trees. In some instances, the natural elements and patterns indicate limited vegetation (i.e., high country rivers), where native grasses or herbs are the only form of vegetation in the area.	Complete absence of vegetation due to human-induced changes (or limited presence (in pockets) of exotic vegetation such as occasional willow, gorse or buddleia).	1	1
		Exotic vegetation with complete absence of native species within a pastoral/ semi urban setting.	2	1
		Predominantly exotic vegetation in natural patterns (i.e., willows/ gorse) and/ or patches of remnant indigenous vegetation.	3	2
		Fragmented areas of native and exotic vegetation in natural patterns. Predominance of native vegetation.	4	3
		Overwhelmingly indigenous vegetation with no or few introduced species.	5	3
Extent of exotic flora	Proliferation of exotic flora.			

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
Modifications of riparian edge	Include bridges, roads. All potentially impact on the naturalness of a river. An absence of human modifications. However minor, structures particularly if constructed from natural or local materials may not influence natural character greatly, but will have a localised effect. The scale and nature of modifications will influence the effect on natural character.	Major modification to the riparian edge (i.e., dam/ weir/ flood defence structure).	1	1
		Significant parts of the riparian edge have been affected by human intervention (i.e., a suburban/ highly managed agricultural land, including: gravel workings, part-channelisation, marinas).	2	1
		Occasional 'pockets' of human modifications (i.e., a settled rural landscape with bridge/ aqueduct supports, boathouses).	3	2
		Limited human intervention (i.e., occasional bridge/ power pole/ jetty).	4	3
		Overwhelmingly natural with no/ very limited evidence of human interference.	5	3

RiVAS attribute	Attribute description	Indicator thresholds	Score (1-5 scale)	Score (1-3 scale)
Wider landscape character modifications	Broader scale landscape modification beyond the immediate river margin, leaching from agricultural land, intensification of land use all impact on natural character. Protected natural areas such as reserves, parks and estates managed by DoC indicate a higher natural character. Catchment modifications if ecologically or visually linked to the waterway.	Heavily modified landscape (urban or highly intensive setting) with limited vegetation.	1	1
		Suburban/ highly managed agricultural landscape.	2	1
		Settled pastoral landscape with areas of commercial forestry and pockets of indigenous vegetation.	3	2
		Fragmented indigenous and rural landscape including a few areas of commercial exotic forestry.	4	3
		Overwhelmingly indigenous landscape with no or very little human modification.	5	3