# Horizons Regional Council science plan

## To inform objective and limit setting process

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## Executive Summary

Horizons Regional Council (HRC) require a science plan to position council with appropriate scientific information to support objective and limit setting as part of its process to develop a new regional water plan that implements the National Policy Statement – Freshwater Management (NPS-FM). The aim of the science plan is to set out the role of science and the tasks to be undertaken by HRC's science team in the objective and limit setting process. The science plan will also identify work that should be undertaken in the immediate future to ensure that the science team and information systems are well prepared for the regional planning process.

The NPS-FM promulgates the active involvement of tangata whenua in freshwater management, the identification of Māori freshwater values and the application of a diversity of knowledge systems including mātauranga Māori. While we acknowledge the fundamental importance of these elements, the incorporation of mātauranga Māori is outside the scope of this report. In our view this is best resolved through direct engagement with iwi and hapū, firstly during the up-front design of the policy development process and then subsequently when implementing that process, including during the objective and limit-setting part of the process. Ideally the biophysical and economic science described in this report will, through careful design of the process, be brought together to complement mātauranga Māori and other knowledge. This report provides advice concerning the design of the process and our first recommendation is for HRC to establish a process design team and a process structure that ensures strong and on-going lines of communication between that team, the science, policy, and Te ao Māori teams, and other relevant contributors.

Identifying freshwater objectives and associated limits involves making decisions that give effect to Te Mana o te Wai, satisfy the three ordered priorities laid out in the objective of the NPS-FM, and thereby find an acceptable balance between resource uses and multiple other values. Because there are potentially many ways that the tension between resource use and other values can be resolved, finding the most acceptable solution involves exploration of options. In our view, the role of science in objective and limit-setting processes is to support and inform this exploration by building a model of the land-water-social system, which we refer to as an analytical framework. This analytical framework is used to make predictions about the consequences of a range of scenarios that comprise different configurations of, for example, land use and management, alternative approaches to the management of point source discharges and water takes. The analytical framework is used to evaluate outcomes under each scenario for agreed indicators that represent environmental, economic, social, cultural and Māori values. This process is referred to as scenario assessment, the purpose of which is to help find an acceptable intensity and spatial distribution of resource use and to formulate an appropriate management regime to achieve this.

The relatively technical and quantitative nature of the NOF process can suggest that it can be performed with a high degree of technical detail and accuracy. In this report, we highlight that there are large uncertainties associated with all science tasks. It is our opinion that these uncertainties are largely irreducible in the context of objective and limit setting processes, which are always subject to regulatory time frames and resource limitations. This means that while science is critical to objective and limit-setting, scientific information is always subject to technical limitations and uncertainty which should be accepted and then explicitly managed. It is tempting for scientists to employ complicated models that promise greater accuracy or insight. In our opinion, this temptation should be resisted, at least initially, for at least two reasons. First, descriptions of most characteristics and processes associated with the land-water-social system are uncertain, including even the current state of important system

variables such as water quality measures and contaminant loads. Second, experience has shown that the development and use of complicated models is likely to be unsatisfactory given the timeframes and resources available.

In our opinion, scientific input to policy and planning should be approached as problem solving using existing knowledge, data and models. Areas of uncertainty and unknowns should be treated as information that needs to be communicated to decision makers to inform rather than delay decisions. We argue this approach gives effect to the new NPS-FM (2020) explicit requirement to use the best information available and avoid delaying decisions because of uncertainty.

Given the irreducible uncertainties and time and resource constraints outlined above, we recommend that relatively simple modelling approaches are justifiable and should be used in the first instance. In this report, we recommend component models for a simple analytical framework that can be used to simulate the impacts of resource use and management on four key water quality contaminants: nitrogen (N), phosphorus (P), sediment (S) and microbes (M). We consider that objective and limit setting processes will at least need to explicitly consider these contaminants because they determine environmental outcomes for NPS-FM attributes and existing One Plan water quality targets.

In our view, a simple analytical framework that addresses N, P, S and M can be assembled from existing tools and data and we consider that this would be a fit-for-purpose starting point for HRC's implementation of NPS-FM policy and planning process. We stress that there may be circumstances where more complex component models in the analytical framework are justified or needed but they should not be used in the first instance. In our opinion, more complicated modelling should only be considered in the case that there is a well-defined question that decision-makers need answered and for which the more sophisticated model has a demonstrable advantage.

We consider that HRC science has adequate biophysical information with which to implement the NPS-FM. There are some new NPS-FM (2020) attributes for which current information is quite limited and that we think will need to be handled qualitatively at this stage while data gathering is initiated to inform plan reviews well beyond the current process. We do not consider there are whole-region biophysical science gaps that could be filled such that this would significantly improve the information that can be provided to decision makers within the anticipated timeframe of the present plan development process. If during the objective and limit setting process circumstances arise where more complex component models are indicated, then process design decisions would be required that weigh the merits against the time delays and costs involved with gathering more data and building such models.

However, we do consider that better information can be obtained concerning current resource use, and the costs of interventions. This includes:

- Detailed current resource use data, if possible, at the scale of individual enterprises;
- The collation of representative assessments of contaminant source loads (e.g., farm nitrogen and phosphorus loss rates); and
- Costs of any interventions that the planning process may need to consider.

Gathering more information of this type will improve HRC's ability to simulate possible future land use and intervention scenarios and evaluate the economic impacts using the analytical framework we have proposed.

In this report, we outline the role of science in the NPS-FM process and recommend how the science contribution to the process can at least be initiated. We do not consider that the concepts and recommendations presented in this report are a comprehensive, final or tidy blueprint for the HRC to follow. Because the NPS-FM process involves stakeholder input and is expected to be recursive, it is not possible to foresee what will be expected of the HRC science team throughout the process. It has been our observation that science input to NPS-FM implementation, and the policy planning process itself, necessarily progresses incrementally with adaptation at each step. This science plan report offers as much structure as is possible at the outset and also some principles that should at least be considered, if not adhered to, at each step in the process.

# 1 Introduction

Horizons Regional Council (HRC) require a science plan to position council with appropriate scientific information to support objective and limit setting as part of its process to develop a new regional water plan that implements the National Policy Statement – Freshwater Management (NPS-FM). The aim of the science plan is to set out the role of science and the tasks to be undertaken by HRC's science team in the objective and limit setting process. The science plan will also identify work that should be undertaken in the immediate future to ensure that the science team and information systems are well prepared for the regional planning process.

The science plan needs to establish a clear understanding of the role of science, define the scientific tasks, and develop the philosophy for how science interacts with the objective and limit setting process. The plan also needs to establish a philosophy for how issues concerned with the degree of detail and uncertainty should be dealt with. The science plan has both a science and planning audience because the objective and limit setting process requires a close connection between these two disciplines and because to a degree, the science requirements are dependent on the how the planning process is designed and unfolds.

The aim of this report is to provide advice to HRC regarding the role and implementation of science in the NPS-FM policy and planning process. We note at the outset that HRC has not yet decided exactly how the policy and planning process to implement to the NPS-FM will be undertaken. However, HRC's proposed 'Draft Roadmap'[1] makes clear the intention to have early and continued engagement with mana whenua, and multiple opportunities for community consultation. Informed by this roadmap, we have structured the report into four key areas:

1. Defining the role of science in the NPS-FM policy and planning process;
2. Clarifying the key science tasks associated with implementing the NPS-FM;
3. Recommending a fit for purpose approach to providing science input to implementing the NPS-FM;
4. Assessing the HRC science team's level of preparedness in terms of data, models and tools, and skills and expertise needed.

The focus of this report is on the biophysical and economic science needed to support the water quality objective and limit setting components of the NPS-FM policy and planning process. However, we acknowledge that managing water quantity is a necessary component of managing most if not all freshwater values and therefore will need to be included in HRC's NPS-FM implementation. The approaches we advocate to NPS-FM implementation around water quality are equally applicable to managing water quantity but the role and implementation of science in the NPS_FM process specific to water quantity are beyond the scope of this report. For the purpose of this report, we refer to the biophysical and economic technical work as the 'science'.

We recognise that there are other pertinent science disciplines (such as the social sciences) that we do not cover, and that science is not the only knowledge system that should be used to help inform the policy. The NPS-FM promulgates the active involvement of tangata whenua

[1] Draft Roadmap – NPS-FM Implementation and Associated Plan Change Process 2020 – 2026. Presented to HRC Tuesday 8 September. URL: https://www.horizons.govt.nz/HRC/media/Media/Agenda-Reports/Strategy-Policy-Committee-2020-8-09/20120%20Annex%20A%20NPSFM%20Implementation%20Roadmap.pdf

in freshwater management, the identification of Māori freshwater values and the application of a diversity of knowledge systems including mātauranga Māori. Mātauranga Māori provides ways of thinking, and perspectives and principles of land and water management and sources of knowledge that must also be incorporated into the higher-level policy and planning processes. In this report, we identify where biophysical and economic science needs to link to these other areas, but recommendations about how this should occur is beyond the scope of this report.

# 2 Regional plan development under the NPS-FM

## 2.1 NPS-FM process

The operative NPS-FM (NZ Government, 2020) recognises the fundamental concept of Te Mana o te Wai and establishes a hierarchy of obligations in Te Mana o te Wai that prioritises:

a) first, the health and well-being of water bodies and freshwater ecosystems,

b) second, the health needs of people (such as drinking water), and

c) third, the ability of people and communities to provide for their social, economic and cultural well-being[2].

The NPS-FM requires that freshwater is managed in a way that gives effect to Te Mana o te Wai and places numerous requirements on regional councils when developing regional policy statements and plans for the integrated management of freshwater and the use and development of land[3]. Within this broader requirement, the NPS-FM prescribes the objective and limit setting process set out in the National Objective Framework (NOF). The NOF requires regional councils to:

1. identify values;
2. set environmental outcomes for each value and include them as objectives in regional plans;
3. identify attributes for each value and set target attributes states for those attributes;
4. set limits[4] and prepare action plans to achieve the environmental objectives.

The NOF also includes requirements for regional councils to monitor freshwater bodies[5] and operate and maintain accounting systems for freshwater takes and contaminants[6].

Robust plan and policy development makes use of science to understand the impact of choices of freshwater objectives and limits on community values and aspirations. Therefore, we see the NOF process as part of a larger process of the development of regional plans under the Resource Management Act (RMA), and science as a component of the NOF process. The science therefore must serve and be integrated into these larger processes; these ideas are represented schematically in Figure 1.

[2] Part 1: Clause 1.3.
[3] Part 3, including Subparts 1 to 3.
[4] Part 3: Subpart 2: Clause 3.14.
[5] Part 3: Subpart 2: Clauses 3.7, 3.18 and 3.19
[6] Part 3: Subpart 3: Clause 3.29.

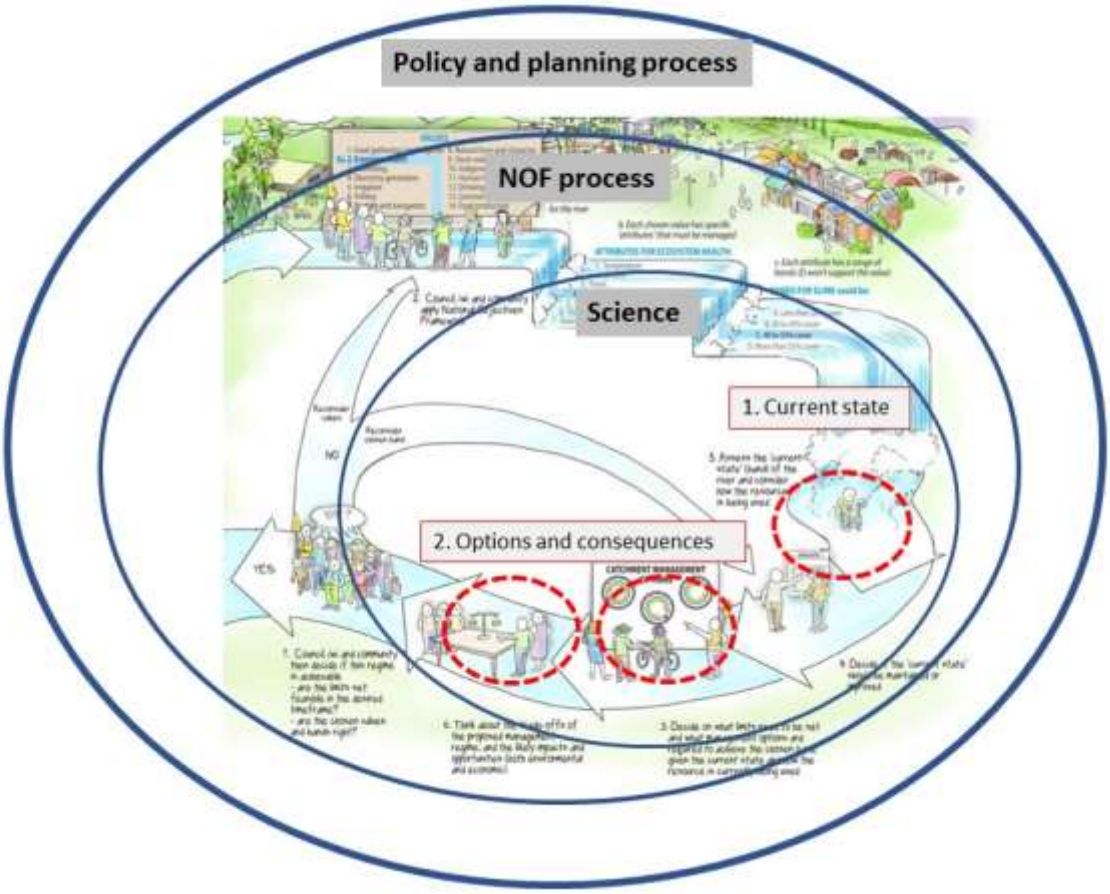


*Figure 1. Schematic diagram of the position of science within the NOF objective and limit setting process. The NOF process is shown within the broader NPS-FM planning and policy development process (adapted from https://www.mfe.govt.nz/fresh-water/). The scope of this report concerns the use of biophysical and economic science in water quality aspects of the NOF objective and limit setting process (i.e., the inner blue oval).*

## 2.2 Role of science in design of the policy and planning process

HRC will need a group of people who are responsible for designing and then running the whole policy and planning process depicted in Figure 1, which we refer to as a "process design team". The multi-faceted and complex nature of the process will usually require that this team:

- Includes lead representatives from groups across the organisation (e.g., at least the Policy, Science and Te ao Māori groups indicated in HRC's "Draft Roadmap" for NPS-FM implementation[7]);
- Designs and leads the process in response to being informed by all the contributing council groups as well as the community and numerous stakeholder organisations;
- Is probably directed by some form of steering group with council executive, governance and Te Tiriti o Waitangi partner representation;

[7] Draft Roadmap – NPS-FM Implementation and Associated Plan Change Process 2020 – 2026. Presented to HRC Tuesday 8 September. URL: https://www.horizons.govt.nz/HRC/media/Media/Agenda-Reports/Strategy-Policy-Committee-2020-8-09/20120%20Annex%20A%20NPSFM%20Implementation%20Roadmap.pdf

- Initially begins as a process design team but transitions into a “process implementation team” once process implementation is fully underway;
- Is agile in revising the design to respond to shifting circumstances and learnings as the process proceeds.

HRC’s science team will need to both inform and be informed by the process design team, usually via a lead science representative on the design team. There are at least two key reasons for this. First, in our experience there is no single “right” way to design the process. It will involve making decisions based on many aspects of HRC’s situation (e.g., current plan processes and resourcing priorities), including what science is or could be available and the implications of doing more or less science work. Second, there is no single “right” way to provide the science; it will depend on the design of the process and the nature of the intended plan. While the NPS-FM provides clear compulsory elements of the NOF process and published best practice guidance contains core principles to adhere to, regional councils have considerable discretion to design processes that suit local circumstances.

We have found in previous processes in other regions that there is often a “chicken and egg” dilemma where the science team is trying to design a science plan and identify knowledge gaps without knowing exactly what the design of the process or the future plan is going to look like. The planning team on the other hand may be trying to design a process without being sure what science will be available or possible, and what some of the implications of its design choices are. We have found there is often potential for expectations of what the process and ultimate plan will look like to be mismatched between groups such as science, planning and Te ao Māori. We have found an effective solution is to ensure explicit and on-going multi-way lines of communication via lead representatives for all the necessary groups represented on the process design team.

There are several key aspects of the process design that can have substantial implications for the science plan and vice versa. These include choices about:

- Where the process will sit on the spectrum of participation from consultation to collaboration;
- Scale of spatial units for running community consultation and/or collaboration, and to be ultimately used as management units in the plan (e.g., sub-catchments, groups of catchments, waterbody types and or region-wide scale);
- Types of limits to be used (e.g., individual resource user output limits such as nutrient discharge allowances versus input limits and other more general controls);
- Matching the regional council’s available resources and statutorily required timeframe with the detail of both the process and the plan content.

The above choices are important decisions that the process design team needs to make as early as possible. This will help efficient management of Science, Policy, and Te ao Māori groups and other resources. However, our observation from previous processes is that it is inevitable that some circumstances will change during the life of a typical NPS-FM planning process, including potentially changes to decisions related to the topic areas above. The process design team will need to be agile and to develop with the process. Therefore, lines of on-going communication between all parts of the process design team will be critical. To help inform the process design team we elaborate further on the above aspects and their implications for science in section 2.4.

## 2.3 Role of science in the NOF objective and limit setting process

In our opinion, it is useful to think about the role of science in the NOF objective and limit setting process as one of describing, as quantitatively as possible[8], the relationship between values associated with freshwater resources. The objective of the NPS-FM is clear that there is the following order of priority for those values:

1. the health and well-being of water bodies and freshwater ecosystems,
2. the health needs of people, and
3. the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.

Within this prioritisation, there is a tension between the level of support for environmental values and their related social, cultural and economic benefits and the economic and social benefits of resource use. The role of science is to provide the community and decision makers with options for regimes within which competing values could be managed.

In our opinion, *attributes* provide the first key point of focus for science's contribution to the NPS-FM process. Attributes are technical measures of support for values. *Target attribute states* define, in measurable terms, the desired level of health and well-being of water bodies and freshwater ecosystems. Because attributes provide a way of quantifying support for values, they enable a robust approach to the process prescribed by the NOF. The approach is represented in Figure 2 as a logic chain. The chain is a linked set of steps and concepts for deriving the management regime in which each link is justified by the preceding link (i.e., reading Figure 2 from left to right). The chain can also be seen as linked justification of the management regime, in which each link is justified by the preceding link (i.e., reading Figure 2 from right to left).

The chain describes the role of biophysical science in the NOF process. Starting with *values*, *attributes* are scientific measures that must be used to define *freshwater objectives.* The fourth step in the logic chain represents the use of science to describe and quantify the relationship between the state of the attribute and the level of resource use and to provide options for limits to resource use that will allow the freshwater objective to be achieved. The fifth step represents the use of science to describe the range of actions that could potentially be used to constrain resource use to the specified limits.

The second key point of focus for science's contribution to the NOF objective and limit setting process concerns quantification of the economic impacts. Limiting resource use involves economic implications for resource users with flow on economic and social implications for the wider community. The scientific discipline of economics involves quantifying the costs of the range of potential actions for constraining resource use. Therefore, the process shown in Figure 2, cannot occur in isolation from economic considerations. In our opinion, the process shown in Figure 2 should be undertaken in the context of the best available knowledge of the causal linkages and interconnections between biophysical, social, cultural and economic components of what we refer to as the '*land-water-social system',* noting that this will include both quantitative and qualitative information.

[8] Noting that the word science is constrained here to mean biophysical and economic considerations (where quantification is an ideal).

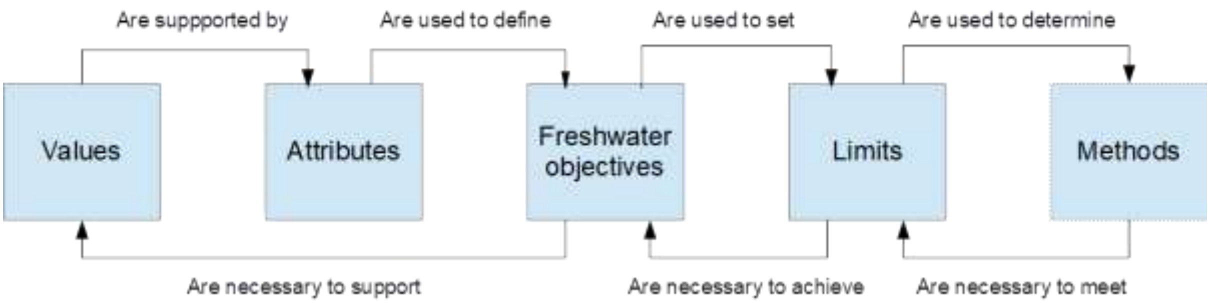


*Figure 2. Schematic diagram showing the NOF's linked set of steps and concepts for deriving the management regime. The diagram shows the process (reading from left to right) that results in plan provisions and how the provisions are justified (reading from right to left) (adapted from MFE, 2018).*

Once the management regime has been defined and formalised in a regional plan, science has roles in monitoring both the implementation of the actions and the impact on the environment. The primary purpose of monitoring both the implementation and the impact is to measure the degree of implementation and success of the plan. Science is used to determine the frequency and spatial intensity of monitoring effort, for both actions and impact, to ensure that the level of implementation and success can be known in the future at an appropriate level of confidence. Monitoring also acknowledges that science is always uncertain, and a plan may not achieve all its objectives even if it is perfectly implemented. A secondary purpose of monitoring then is to improve the state of knowledge for the future and to test the assumptions made underpinning the management regime.

Setting limits is underpinned by the accounting provisions in the NOF[9]. To set a limit, councils must first identify the current level of resource use. Limits define how much more (or less) of that resource use can occur. When a contaminant limit is set, accounting is used to quantitatively track how much the allocated quantum increases or decreases over time. Contaminant accounting enables councils to know when the limit threshold is reached and further allocation should cease (e.g., when a stocking rate is reached) or that current resource use exceeds the threshold and should be reduced.

In summary, the role of science in the implementation of the NOF objective and limit setting process is to:

1. Describe how the biophysical and economic system works in general and particularly how attributes support values and how resource use affects attributes;
2. Describe current state and trends, particularly with respect to attributes or variables that are closely linked to values;
3. Provide plausible options for objectives specified in terms of attribute states;
4. Define resource use limits that will achieve the various options for objectives and assist with the assessment of methods (i.e., actions prescribed in a regional plan), thus informing decisions on the objectives;
5. Provide technical support for justification of the management provisions (e.g., objectives, limits and methods and quantification of costs and benefits[10]);

[9] NPS-FM Part 3 Clause 3.29
[10] Section 32 of the Resource Management Act 1991 is integral to these requirements.

6. Establish appropriate monitoring strategies to assess the effectiveness of the plan;
7. Establish water quality and quantity accounting systems to facilitate plan implementation.

The above science roles cover a range of science disciplines. Biophysical disciplines are required to describe current state of freshwater bodies (often in terms of measurements of attributes), current levels of resource use (for example, current levels of water use and contaminant discharge). Economists describe the economic consequences of this resource use and social scientists describe the social impacts. All these disciplines have a role in the development of options for objectives and limits to achieve these. Impacts that need to be considered under the NOF process include the biophysical environment (e.g., including hydrology, water quality and ecology of groundwater, river, lake and estuaries), the economics of individual enterprises, the flow on economic impacts to the community and region and impacts on social, cultural and Māori values. All science disciplines have a role in the RMA regional plan writing and the associated Section 32 analysis.

## 2.4 NOF process and Horizons Regional Council approach

While science is important, making decisions about objectives and limits must reference the fundamental role of values as the basis for the NOF process. In our opinion therefore, science must not be conducted in isolation from the central purpose of managing for values. In that respect, we consider that the integration of science into the planning and decision-making process is fundamentally important.

In this report we recognise there are various ways that science could be effectively integrated into the decision-making process. We are not in a position of sufficient understanding to recommend a single best approach for HRC. Rather we have identified (in section 2.2) the need for a multidisciplinary "process design team" and we provide advice throughout this report to inform the design decisions to be made by that team. We note that the details of HRC's science team activities will depend on how the planning and decision-making processes are conducted.

HRC's intended process is already mapped out at a high level in a draft roadmap and implementation plan of activities for the next seven years to guide implementation of the NPS-FM and the associated plan change. The roadmap and implementation plan will guide development of further details for an engagement strategy with iwi, stakeholders and other community members, as well as outlining the steps for the development of the policy, science and how and when mātauranga Māori will be used.

In the following sections we elaborate on several aspects of the process design that we understand are yet to be decided and which have important implications for the science team's activities. We anticipate that this report will inform further consideration of HRC's planning and development of further process detail by the process design team.

### 2.4.1 Consultation to collaboration spectrum

The NPS-FM allows councils to choose an approach to the planning process on a spectrum of stakeholder involvement from consultative to collaborative, although a specific requirement is that regional councils must work collaboratively with tangata whenua. In our opinion, the fundamentals of the science are not influenced by the approach, but what is considered relevant, credible and legitimate[11] by the relevant parties, and the way science is involved and integrated into the decisions may be.

At one end of the spectrum a fully collaborative approach requires that stakeholders (i.e., collaborators) are involved in choices around scope, the level of scientific detail, tolerance of uncertainties and how the science is conducted and integrated into decision-making, potentially even being involved in decision-making. At the other end of the spectrum, in a strictly consultative approach, scientific choices tend to be made by the planning and science teams, and stakeholders are given the opportunity to submit on the adequacy of the supporting science only after it has informed proposed plan decision-making.

There are of course numerous other options along the spectrum, such as including opportunities for stakeholders to review, comment and/or contribute on draft material prepared at various stages by the council science and planning teams. Different approaches can be taken in different areas of the process and for different values – for example, a fully collaborative approach may be adopted for assessing the economic cost of mitigations, but a consultative process for estimating the relationship between loads and ecosystem values. Choices about the level of stakeholder involvement will affect the way that some of the science work is done. In general, we have found that collaborative approaches take significantly more time and resources up front, particularly for science teams, but may reduce contention and save time and resources in the latter stages of a process (e.g., during submission and hearings) compared to strictly consultative approaches. Choices around this may be influenced by a council's experience with its previous plan processes and its resourcing priorities, among other things.

### 2.4.2 Spatial detail

The NPS-FM allows discretion for councils to choose the geographic size of freshwater management units, for objective and limit setting, accounting systems and for various other spatial units, as necessary. Decisions about the geographic size of freshwater management units effectively define the "spatial detail" or "scale" of the plan provisions. There is also discretion around the spatial scale at which consultation and/or collaboration is conducted.

Previous approaches in other regions have used spatial units ranging from region-wide to sub-regional FMU areas (groups of catchments), whole catchments and sub-catchments, waterbody types and even particular reaches or sites on individual waterbodies. It is likely that some combination of all these scales will ultimately be needed for different purposes. In general, finer spatial scales require more detailed and time-consuming locally specific science work. Broader spatial scales can be handled using science tools that are based on broad scale environmental patterns but have lower accuracy at fine scales and constrain the specificity of the final plan provisions.

Choices about spatial scale for different parts of the plan framework (e.g., objectives, limits, methods and accounting) will affect the way that some of the science work is done, as discussed further in sections 3.5.2, 5.1 and 6.5.1. To some extent these choices are determined by the scientific data and tools that are available, even though there may be a desire or expectation by planners, stakeholders and/or the community for greater accuracy and finer spatial resolution. It may be possible to increase the spatial resolution and accuracy of some of the science information if the additional time and cost is judged to be justified by the process design team.

[11] After Cash *et al.* (2003).

It will be useful if the process design team can give at least interim direction to the science team around expectations for the spatial scale at which objectives, limits and accounting will occur in the future regional plan. However, it is also possible that choices about spatial scale will evolve as the process progresses and more is understood about values at different locations, and therefore spatial scale will be a key topic for on-going communication between the science team and the process design team. It is for this reason that the science plan should maintain the greatest practicable agility in providing information at a collapsible or expandable range of spatial scales.

### 2.4.3 Types of limits

The NPS-FM prescribes some detailed compulsory aspects of limits and the accounting for limits[12], but also allows considerable discretion for councils to choose the type and spatial scale at which different limits should be set[13]. It is likely that a range of different types of limits, applied at differing levels of spatial detail, will be used in the regional plan. Choices about what type of limit to use for different resource uses and contaminants (e.g., land use, input or output controls[14]), and at what spatial scale, will need to be a key area of on-going communication between the science, planning and other groups represented on the process design team.

Choices around types of limits could fundamentally affect the way that some of the science work is done. For example, the scientific analysis would vary depending on whether limits are going to be expressed as land use controls (e.g., constraint on extent of an activity), input controls (e.g., an amount of fertiliser that may be applied), or output controls (e.g., a rate of discharge of a contaminant). In general, the degree of technical detail in the analytical framework would need to be considerably higher for the latter type of control compared to the former types, as discussed in sections 3.5 and 3.5.2. The latter types of controls also generally require much more sophisticated allocation systems and accounting frameworks to implement, which in turn will have implications for science and plan implementation resourcing down the track. These choices are considerations for the process design team and the planning team, particularly around which type of limit to use for which resource uses and contaminants.

It is likely that different types of limits will be more suitable, or even possible, for different resource uses and contaminants. As for the choices of spatial scale in the previous section, choices about the type of limits will be to some extent constrained by the scientific data and tools that are currently available, even though there may be a desire or expectation by planners, stakeholders and/or the community for more sophisticated types of limits and/or accounting. It will be useful if the process design team can give at least interim direction to the science team around expectations for the type of limits to be used in the future regional plan. This could be informed by the science that is currently available as described in later sections of this report. It is likely that choices about types of limits will evolve as the process progresses and therefore be a key topic for on-going communication between the science team and the process design team.

### 2.4.4 Resource availability and timeframes

The availability of scientific resources and timeframes will directly affect choices around all the above aspects of process design and many more. Prioritising use of resources and timeframes will be influenced by many considerations associated with the wider process and will likely

[12] For example NPS-FM Clauses 3.17, 3.13 and 3.29
[13] NPS-FM Clause 3.14.
[14] See NPS-FM Clause 3.14

evolve. The process design team will need to understand the implications for science and other teams when making these decisions. This is another reason for strong on-going communication between the science team and the process design team.

# 3 Science tasks

Implementation of the NPS-FM including the development of objectives, limits and methods and the drafting and justification of the regional plan is a complex task involving technical work, deliberations, and decisions. Elements of the process are recursive (Figure 3). Generally, an initial set of options for objectives, limits and methods is developed and the impacts of these, environmentally, economically, socially and culturally, are assessed. If elements of the assessment are considered unviable or unfavourable, it is likely the process will need to be repeated with refinements until an acceptable set of options and outcomes is found. The technical mechanism used to inform this recursive exploration of options is generally scenario analysis, which is discussed in more detail below. The process and participants who receive the scenario analyses for deliberation and decision-making vary depending on the design of the planning process as described in the previous section. The integral role of science in providing and understanding options and justification for the quantitative aspects of the management regime means that there are many science tasks involved in the implementation process.

At the outset of an NPS-FM process it is not possible to predict all the questions that will arise or the technical difficulties that will be encountered in answering them. It is therefore not possible to predict all the science tasks that will be involved in the implementation process. In our experience, several cycles of the process of generating options for objectives, assessing the impacts and considering the viability of these to take forward to the plan writing stage will be required (Figure 3). To some extent, the degree to which stakeholders are involved will determine the science tasks because this is likely to affect the number of options that require consideration. The science tasks are also likely to be influenced by the response to uncertainty when it is encountered. In our experience, a common response to encountering uncertainty is to undertake more technical work but this can considerably increase the tasks at hand and there is a risk that uncertainty will not be greatly reduced. It would be advisable to seek agreement with the design team about any limitations so that expectations are clear from the outset and key decision points are clearly identified.

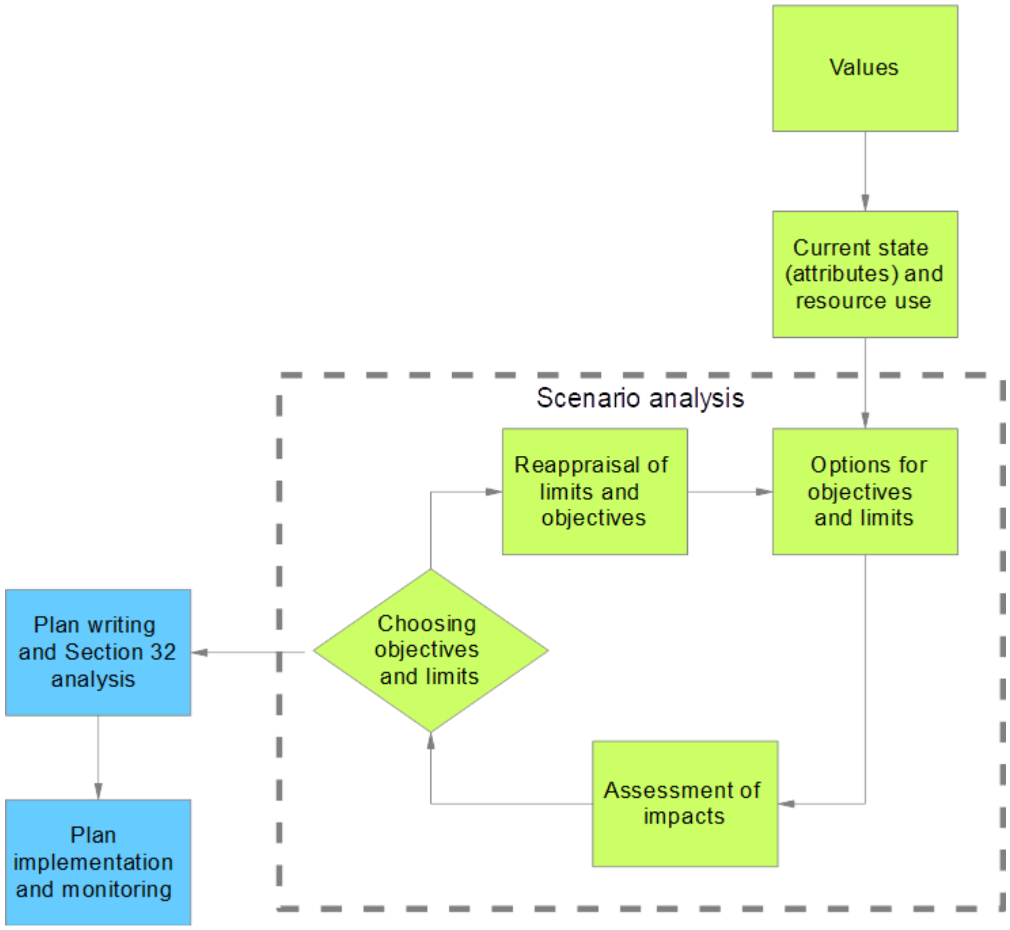


*Figure 3. Stylised representation of stages in the NPS-FM planning process (green) and subsequent plan making under the requirements of the RMA (blue). Adapted from Harris (2016).*

Although the detail and size of the tasks cannot be reliably estimated at the outset, in our experience the following list describes at a high level the science tasks that are always involved:

1. Informing and supporting the process design team;
2. Developing an agreed conceptual understanding of the land-water-social system;
3. Describing current state and trends based on available information;
4. Providing support for exploration of options based on scenario analysis;
5. Building an analytical framework;
6. Establishing monitoring strategies to assess the effectiveness of the plan;
7. Establishing water quality and quantity accounting systems to facilitate plan implementation.

The following sub-sections describe these tasks in more detail.

## 3.1 Informing and supporting the process design team

Informing and supporting the process design team is already underway via HRC's afore-mentioned draft roadmap and implementation plan and will be an on-going task for the science team. This report is another step in this task. The on-going nature of this task recognises that circumstances are likely to change during the life of a typical NPS-FM planning process and the process design is likely to evolve accordingly. It is useful if the science team can be aware of potential changes and maintain some agility to respond where possible. Strong lines of communication with the process design team are important.

## 3.2 Developing an agreed conceptual understanding

At the broadest level, the state of knowledge can be represented by a *conceptual model*, which describes our understanding of the causal linkages and interconnections between biophysical, social, cultural and economic components of the land-water-social system. The conceptual model describes current knowledge, from a range of knowledge sources and observations from the past such as:

- How water moves through the landscape;
- How contaminants are generated and transported to receiving environments;
- The land and water resource use pressures and how these affect attributes and values;
- The interventions that can reduce the land and water resource use pressures;
- The costs of these interventions to individual resource using enterprises and the flow-on economic impact to the broader community;
- The types of limits to resource use that may enable the objectives to be achieved.

The conceptual model is like the skeleton of the science. The conceptual model underpins the scientific analysis, through which the possible alternative futures (i.e., scenarios) are explored. The conceptual model is often represented as a systems diagram; as such it is not a model that measures or quantifies anything but is a representation of our understanding of the system.

Developing an agreed conceptual model is primarily a science role because a subsequent task is to use this to develop a detailed and quantitative analytical framework to represent the land-water-social system (see Section 3.5). However, in our experience, it is useful if the development of the conceptual understanding of the system is carried out in association with mana whenua, communities, and stakeholders. These groups may bring sources of knowledge and perspectives not available to technical experts, such as local and historical knowledge and mātauranga Māori. Consulting widely at the point where the conceptual model is developed may help build a more robust and accepted foundation for the later science tasks. It may also help highlight alternative views and uncertainties that need attention early, saving difficulties later in the process if the conceptual understanding proves to be incorrect or contested. In our experience also, it is useful if policy staff who will be involved in the scenario analysis and plan writing phase of the process are also involved in the development of the conceptual model.

## 3.3 Describing current state and trends

The baseline for any discussion concerning freshwater objectives is the definition of the current baseline, which includes the description of current state and changes over time of freshwater bodies, and current and expected future resource use pressure. At the outset of a NPS-FM process, current state of water bodies needs to be described at least in terms of the relevant attributes and this technical assessment needs to explain the level of support provided by current state for the values (Figure 2).

The starting point for describing the current state of water bodies is generally state of environment (SoE) monitoring data. For water bodies, SoE data comprises measurements of NOF attributes (e.g., visual clarity, *E. coli* concentrations, periphyton biomass, biological measures such as macroinvertebrate community index (MCI)) and other related indicators (e.g., nitrate and phosphorus concentrations). These data are summarised to describe 'state', which is the characteristic condition in the recent past that is quantified using a statistic such as the annual median and 95$^{th}$ percentile values[15]. Current state of freshwater bodies needs to be described at least in terms of NOF attribute states. Site NOF attribute state 'grading' is based on the distributional statistic associated with the attribute (e.g., median), which is calculated from the observed SoE data and generally expressed in terms of the attribute bands (A through D or E) defined by the NOF. Changes in the observed values over time (i.e., trends) are also derived from the observations and monitoring data describing concentrations of contaminants such as nitrogen, phosphorus and sediment and biological attributes such as invertebrate indices (MCI) and periphyton biomass.

Water quality and ecosystem health measurements are made regularly, generally on a monthly, quarterly or annual basis, at several river, lake, estuary and coastal sites across the region. These data are therefore a sample of a population that are used to infer the state, trends and loads of the measured quantities at the monitoring sites and more generally the state of an FMU or the region. Using the sample data to represent current state and trends means that the evaluations are uncertain because the data only measures a small part of both time and space. An important science task associated with describing current state and trends therefore is to quantify and communicate this uncertainty and to carry the limitations to precision and resolution implied by the uncertainties through into subsequent analyses. This is discussed in more detail in subsequent sections of this report.

The key resource use descriptions that are needed to support the science components of the process include the current state of resource use and how this has changed in the recent past (i.e., resource use trends). This includes detailed description of regional land use, and compilation of datasets describing point sources and abstractive water use. Land use descriptions need to comprise mapping of land use categories and descriptions of land management activities. The level of detail of the land use map and the description of management needs to be commensurate with the details of subsequent considerations of how these activities may be managed. In broad terms it is necessary to understand land use and point sources in sufficient detail to estimate the loss of contaminants from these resource uses. Similarly, it is necessary to understand the quantities of water abstracted from water bodies and where this occurs.

Recent changes in resource use provide information about likely future resource use pressure. An understanding of this pressure is an important component of formulating a management regime that will be effective. Qualitative or quantitative descriptions of recent changes in resource use provide context and are used specifically in scenario analysis. A key science

[15] The median and 95$^{th}$ percentile values indicate thresholds that are not exceeded by 50% and 95% of the observations, and by implication 50% and 95% of the time.

task is compiling these descriptions and ensuring the information is accurate, fit for purpose (e.g., provided at sufficient resolution) and available for the process and interested parties.

### 3.4 Exploration of options based on scenario analysis

Freshwater objectives and associated limits and methods concern making decisions about the "right" balance between resource use and other values and the best ways to achieve these. These are normative (i.e., subjective judgements), not technical decisions. Because there are potentially many ways that the tension between resource use and other values can be resolved, finding the most acceptable solution involves exploration of options. *Scenario assessment* has become the most common method for exploring options in planning processes conducted under the NPS-FM.

Scenario assessments describe possible futures by simulating options for resource use and management and describing the associated environmental, social, cultural and economic impacts. Scenario assessments produce a series of simulations that predict the outcomes for values for multiple scenarios. These simulations are used to explore possible ways that the intensity and distribution of resource use within a catchment can be limited such that objectives are achieved (Figure 2). Scenario assessments provide decision-makers with two important types of information. First, a range of scenarios can define the trade-off between the level of support for environmental values and the economic benefits of resource use. Second, scenario assessments help to find an acceptable intensity and spatial distribution of resource use (i.e., limits to resource use) and to formulate an appropriate management regime to achieve this (i.e., methods).

Scenario assessment is based on simulating the land-water-social system. Simulations are a largely science-based task that mobilises what is known and knowable about the land-water-social system including the links between values at the regional and catchment scales, the state of receiving environments, resource use, and the functioning of the economy. Undertaking scenario analysis requires simulating or predicting the outcome of options for objectives, limits and other management mechanisms (i.e., what will happen to Y if we change X?). This requires some form of modelling or other analytical inference based on the conceptual model.

Scenario analysis represents a significant science task that is useful to think about as two steps. Step one is building an *analytical framework* that represents the conceptual model by combining several *component models*. Step two is scenario testing, which comprises using the analytical framework to simulate the land-water-social system to explore options. In the subsequent section we discuss step one (building the analytical framework) in more detail. In practice, steps one and two are unlikely to be as cleanly separated due to the recursive nature of the process (Figure 3). It is possible that scenarios throw up questions that require changing the analytical framework and therefore revisiting step one.

The scenario exploration process can also be broken into smaller and more staged tasks. An example we are aware of is a 'load reduction requirement analysis' such as those developed by Elliott *et al.* (2020) and Snelder *et al.*, (2020). In this type of analysis, options for freshwater objectives are proposed and compared to the current state of attributes across the region. Where the current state is not compliant with the proposed freshwater objective, the analytical framework (or at least parts thereof) is used to calculate the reductions in contaminant loads that would be required to achieve objectives at non-compliant locations. The output is a load reduction estimate (e.g., as a proportion of the current load) but without considering how these reductions would be achieved. The benefit of this staged approach is that it is a less complex analysis than one that includes considering the options for achieving the reductions at the same time. This approach can provide information about the trade-off between environmental objectives and the scale of load reductions early in the process thereby speeding up the selection of objectives and possibly constraining the scope of subsequent work to explore how the reductions can be achieved.

## 3.5 Building an analytical framework

### 3.5.1 Definition

We define an *analytical framework* to be a detailed and quantitative representation of key parts of the land-water-social system that is used to simulate the options for resource use and management and that predicts the impacts. The analytical framework comprises linked analyses and/or models that represent the conceptual model of the land-water-social system in enough detail that the scenarios can be simulated and outcomes (i.e., environmental, social, cultural and economic impacts) described in numeric, categorical or narrative terms. Ideally, the analytical framework also describes the uncertainty associated with simulations.

In line with the scope of this report we restrict our discussion of scenario analyses and analytical frameworks to *biophysical aspects* and *economic aspects* associated with managing water quality outcomes. However, social and cultural impacts will also need to be included in the process and these are likely to use outputs from the biophysical and economic assessments as inputs.

Figure 4 is a stylised representation of an analytical framework for assessing the consequences of a range of scenarios. In this representation scenarios are specified in terms of *resource use aspects* including different choices of resource use and limits (these are shown as yellow diamonds in Figure 4). The analytical framework is used to simulate the response of the land-water-social system to each scenario. The outputs of these simulations provide evidence used by decision-makers in the objective and limit setting process. The decision-makers need to know for each scenario:

1. What is the level of resource use and what limits and other interventions are assumed to be operating?
2. What is the resulting environmental state and how does this compare to that required to achieve potential objectives?
3. What is the economic, social and cultural impact associated with the resource use, management interventions and resulting environmental state?

An analytical framework comprises several component models each representing a link in the causal chain indicated by the conceptual model (Figure 4). In general, a mix of linked analyses/models will be needed to cover the various types of freshwater objectives, attributes and limits, physical environments, resource uses, and values involved. Our experience indicates that even highly sophisticated and complex models can only ever cover a subset of these relevant aspects. There is no one “do-everything” model and not all analyses are computer models; simple empirical relationships are a form of model as are observations of responses of other systems and expert knowledge. It is also important to acknowledge that not all knowledge and information will fit neatly into a modelling framework. For example, it may be inappropriate to try to incorporate aspects of mātauranga Maori into an analytical framework. In addition, while the role of the analytical framework is to represent the land-water-social system and predict impacts of management choices, it will only be possible to make quantitative predictions about the effects of limits on some of the target attribute states (see Section 3.5.3).

To cover the analyses required, a range of specialist science knowledge, skills and models need to be deployed and integrated. For example, limit setting processes will need to develop objectives and limits associated with at least four key contaminants: nitrogen (N), phosphorus (P), sediment (S) and microbes (M). Within biophysical sciences involved in water management, these four contaminants are often seen as sub-disciplines and different approaches are often taken to their analysis, modelling and subsequent management.

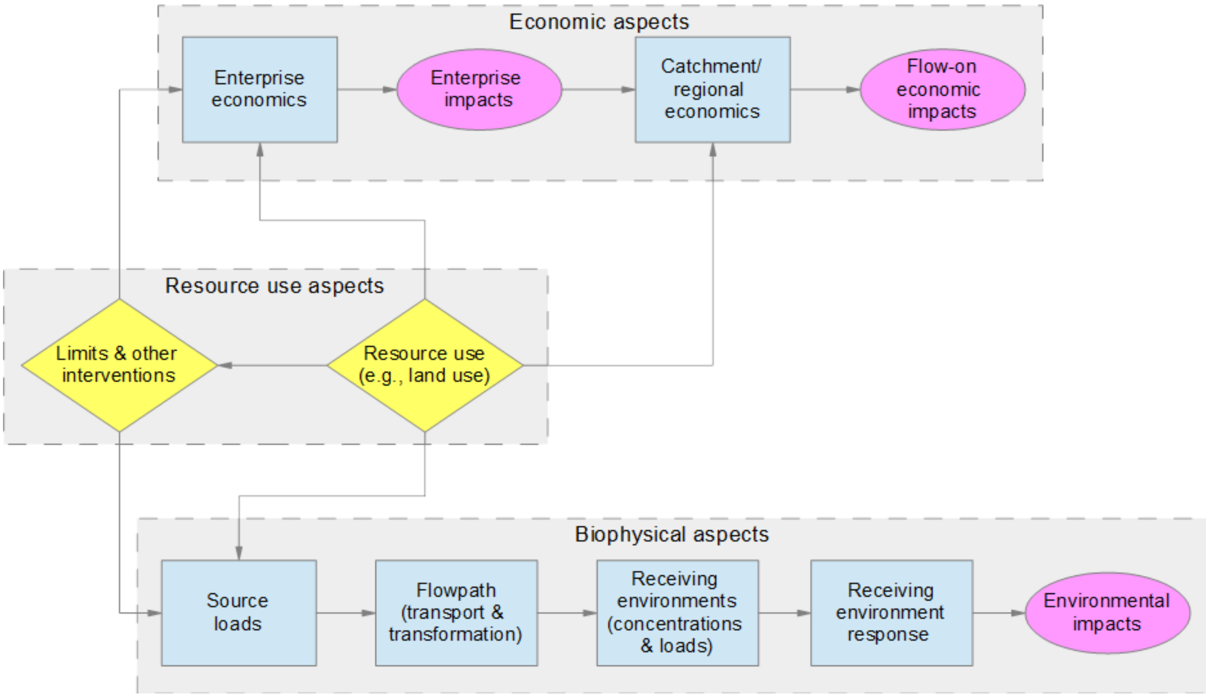


*Figure 4. Stylised representation of the analytical framework covering biophysical and economic evidence in objective and limit setting processes.*

Building the analytical framework is a significant task that is fundamentally the role of the science team. However, in our experience it is important that the analytical framework is built in close consultation with the wider NPS-FM process and particularly the development of the agreed conceptual understanding. The science team needs to be aware of the understanding of the causal linkages and interconnections that are deemed important in the conceptual model so that they are included, if possible, in the analytical framework. In addition, the science team needs to inform the development of the conceptual model about the level of detail (including spatial resolution) and accuracy with which the analytical framework will be able to represent the land-water-social system.

In our experience, the construction of the analytical framework is best approached by focussing on the spatial representation of the land-water-social system and the important environmental and economic impacts that need to be represented. We define the *spatial framework* as the collection of spatial entities including catchment areas, resource using enterprises, drainage paths and receiving environments that represent the land-water-social system. We define the outputs of the analytical frameworks to be numeric or categorical descriptions of attribute states or states of other relevant environmental indicators and numeric or categorical descriptions of economic indicators (Figure 4). Considerations for spatial frameworks and outputs and are discussed in more detail in the following sections.

### 3.5.2 Spatial framework

The spatial framework underlying the biophysical aspects of the analytical framework will always represent (Figure 4) the following linked components:

1. Freshwater Management Units (catchments which are further subdivided into sub-catchments);
2. source loads (contaminant generation from point and non-point sources);
3. drainage network including transport and transformations (e.g., attenuation) of potential contaminants;
4. accumulation of concentrations and loads in the downstream direction through a cascade of receiving environments; and
5. the response within the receiving environments to concentrations or loads (e.g., periphyton biomass in a river, algal biomass in a lake or estuary, visual clarity in rivers etc).

The level of spatial detail required for each aspect of the analytical framework must be defined in advance. The spatial detail will depend on the level of spatial variability in important system components across the region, and the degree to which it is necessary and justifiable for objectives, limits and management actions to differ spatially. The spatial detail will also depend on the need for specificity of management provisions written into a regional plan (e.g., numbers of freshwater management units) and therefore also involves consideration by planners and the process design team. These choices will in turn affect resource and time requirements, both during the plan development process and later during implementation of the plan and related accounting frameworks. While the levels of spatial detail need not match exactly across all parts of the analytical framework, any part that contributes to other components and models should seek to meet that component's requirement for spatial detail either quantitatively or with qualitative interpretation. For example, if a lake receiving environment is to be represented in the analytical framework, it is necessary to also represent its upstream catchment area.

### 3.5.3 Attributes and indicators

The environmental impacts need to be represented, at a minimum, in terms of the attributes defined in the NPS-FM (Table 1) and any other attributes that are deemed necessary by the planning process. In the context of HRC's process, additional attributes are likely to extend to the water quality targets that are already included in the operative regional plan (Table 2).

The NPS-FM attributes are defined in Table 1 along with the four key contaminants: nitrogen (N), phosphorus (P), sediment (S) and microbes (M) that need to be managed, along with other interventions in order to achieve *target attribute states*. There are two types of NPS-FM attributes: Appendix 2a and Appendix 2b attributes (Table 1). Appendix 2a attributes are those that require limits on resource use. Appendix 2b attributes are those that require action plans. Our interpretation is that both Appendix 2a and Appendix 2b attributes should be used to define numeric objectives (i.e., *target attribute states*). However, we consider that the two groups of attributes differ in the extent to which current science can link their respective *target attribute states* to resource use.

It is our opinion that Appendix 2a attributes can be quantitatively linked to catchment loads of one or more of the four key contaminants[16]. Furthermore, catchment loads of the four contaminants can be linked to resource use. This means Appendix 2a attributes provide a justifiable basis for setting resource use limits. Therefore, the analytical framework needs to provide some level of quantitative analysis that links resource use to catchment loads of N, P, S and M and to *target attribute states.*

It is our opinion that many Appendix 2b attributes cannot currently be quantitatively linked to catchment loads of contaminants. This is because the Appendix 2b attributes are the outcomes of complicated, multi-factor and poorly understood processes to a greater degree than Appendix 2a attributes. Furthermore, managing catchment loads of one or more of the contaminants is necessary, but generally not sufficient, to achieve the Appendix 2b target attribute states. For example, the state of river invertebrate and fish indices and lake submerged plant indices (which are all Appendix 2b attributes; Table 1) will depend on the catchment loads of nutrients and sediment, but also on other factors such as local habitat and riparian conditions. Managing water flows (rivers) and levels (lakes) within limits will also be necessary to achieve the Appendix 2b target attribute states. Therefore, the complicated, multi-factor and poorly understood dependencies mean Appendix 2b attributes do not currently provide a justifiable basis for setting resource use limits. This, combined with the lack of quantitative tools, leads us to consider that the outcomes for Appendix 2b attributes (e.g., invertebrate and fish indices, deposited fine sediment) need to be assessed based on qualitative analyses and expert opinion. In scenario assessments, these qualitative analyses will generally take the form of statements such as "if contaminants X and Y are restricted to levels A and B and if actions U and V are implemented, the attribute is likely to achieve the *target attribute state".* Although we highlight the deployment of quantitative methods (i.e., models) in the analytical framework to make predictions (of Appendix 2a attribute states), the framework's representation of the land-water-social system should also be a basis for organising and articulating any qualitative analyses and expert opinions (e.g., concerning Appendix 2b attribute states).

It is our opinion that HRC's water quality targets (Table 2) can also be classified into those that can be quantitatively linked to catchment contaminant loads and resource use and those that are less easily quantitatively linked to catchment contaminant loads and/or require management of other factors such as local habitat and riparian conditions.

More details concerning our proposals for representing each of the attributes and targets shown in Table 1 and Table 2 in the analytical framework are provided in Section 6.5.2.2.

[16] We note that a complication arises for periphyton because it may be possible in some circumstances to achieve target attribute states by stream shading rather than limiting nutrient loads. However, nutrient load limitation is likely to always be necessary to achieve target attribute states at the catchment level because streams join larger rivers that at some point are likely to become too wide for shading to be effective.

*Table 1. NOF attributes, the contaminants that must be managed to achieve target attribute state and other potential interventions for achieving target states. Note that managing water flows (rivers) and levels (lakes) within limits will also be necessary to achieve many of the target attribute states.*

| **Attribute** | **Contaminants that must be managed to achieve target attribute state.** | **Other interventions that may be necessary.** |
|---|---|---|
| **Appendix 2a - Attributes requiring limits** | | |
| **Rivers** | | |
| Periphyton | Diffuse and point source discharges of N and P | Stream shading to control light and temperature. Management water abstractions (minimum flows). |
| Nitrate (Toxicity) | Diffuse and point source discharges of nitrate. | |
| Ammoniacal nitrogen(Toxicity) | Point source discharges of ammoniacal nitrogen | |
| Dissolved oxygen (Point sources) | Point sources discharges of N and P and organic contaminants. | |
| Suspended fine sediment (Visual clarity) | Diffuse and point source discharges of sediment. | |
| *Escherichia coli* | Diffuse and point source discharges of *E. coli.* | |
| **Lakes** | | |
| Phytoplankton<br>Total Nitrogen<br>Total Phosphorus<br>Cyanobacteria | Diffuse and point source discharges of N and P. | Land use management.<br>Weed harvesting to nutrient cycling interventions.<br>Riparian shading and wetland enhancement. |
| **Appendix 2B: Attributes requiring action plans** | | |
| **Rivers** | | |
| QMCI, MCI & ASPM (Invertebrates)<br>IBI (Fish) | Diffuse and point source loads of nutrients and sediment. | Physical habitat including riparian conditions. Stream shading to control light and temperature. Fish passage including access from the sea for some species. |
| Deposited fine sediment | Diffuse loads of sediment. | |
| Dissolved oxygen<br>GPP, ER (Ecosystem metabolism) | Diffuse and point source discharges of N and P | Stream shading to control light and temperature |
| *Escherichia coli* (primary contact) | Diffuse and point source discharges of *E. coli.* | |
| Dissolved reactive phosphorus | Diffuse and point source discharges of phosphorus | |
| **Lakes** | | |
| Submerged plants (natives)<br>Lake-bottom dissolved oxygen<br>Mid-hypolimnetic dissolved oxygen | Diffuse and point source loads of N and P. | |
| Submerged plants (invasive species) | | Control of invasive species. |

*Table 2. Horizons One Plan targets, contaminants that must be limited to achieve target states and other potential interventions for achieving target states. Note that managing water flows (rivers) and levels (lakes) within limits will also be necessary to achieve many of the target states.*

| **Attribute** | **Contaminants that must be managed to achieve target attribute state.** | **Other interventions that may be necessary.** |
|---|---|---|
| **Rivers** | | |
| Periphyton (cover and chlorophyll) | Diffuse and point source discharges of N and P | Stream shading to control light and temperature. Management water abstractions (minimum flows). |
| Cyanobacteria | | |
| DO | Diffuse and point source discharges of N and P | Stream shading to control light and temperature |
| DRP | | |
| SIN | | |
| POM | Point sources discharges of organic matter | |
| NH4N | Point sources discharges of NH4N | |
| Clarity | Diffuse and point source discharge of sediment. | |
| *Escherichia coli* | Diffuse and point source discharge of *E. coli.* | |
| MCI | Diffuse and point source discharge of nutrients and sediment. | Physical habitat including riparian conditions. Stream shading to control light and temperature |
| **Lakes** | | |
| Chlorophyll | Diffuse and point source discharges of N and P. | |
| TP | | |
| TN | | |
| Euphotic depth | | |
| Clarity | Diffuse and point source discharges of N and P and sediment | |
| Ammoniacal Nitrogen | Diffuse and point source discharges of NH4N. | |

### 3.5.4 Economic indicators

Economic impacts are not described by attributes as defined by the NOF, however the economic impacts need to be considered during the planning process and therefore need to be represented by the analytical framework. There are a range of potential indicators for describing the economic outcomes of any scenario. The most common of these are shown in Table 3.

*Table 3: Indicators for use in describing economic outcomes.*

| Scale | Indicator |
|---|---|
| Enterprise scale | Revenue, expenses, operating profit, profit, farm value, employment, risk of insolvency. |
| Catchment scale | Revenue, expenses, operating profit, profit, employment, risk of insolvency. |
| Flow on | Revenue, GDP, household income, employment. |

In our experience, the assessment of economic impacts needs to consider a range of scales from the individual or classes of resource users (enterprise scale) to the catchment scale and the flow-on impacts to the regional and even national economy. In our conceptualisation of an analytical framework, potential resource use and associated limits and other interventions (yellow diamonds; Figure 4) are assumed to impact directly on enterprise economics. The aggregation of these impacts over catchments and broader areas is assumed to drive flow on economic impacts. Therefore, specifying land use and resource use limits for a scenario allows the analytical framework to represent the economic impacts at various scales.

As for the biophysical aspects, the economic aspects must represent the current state of enterprise and catchment/regional economics, and the impacts to these under any scenario. The effects of any scenario will require an understanding of how the enterprise changes with changes in the resource use patterns represented in each scenario – for example further irrigation will increase profits, whereas a requirement to reduce N losses will have costs for the enterprise.

The catchment economic component aggregates the outcomes for all the enterprises in the catchment under any scenario. Depending on the approach taken, this may require some prediction of the likely distribution of responses of the enterprises to policies and changes in the wider socioeconomic environment. Even if no change in the policy environment is to occur, there will be changes in the enterprise mix because of market and social changes. If a requirement for reduced losses of contaminants is included in a scenario, the lower profitability of some enterprises may result in a reduction of their occurrence in the catchment. Choices are needed therefore about whether and how to represent such changes.

The flow-on impacts describe the resulting impacts on the wider community from the aggregate changes to the individual enterprises. These flow-on impacts can be described narratively or may require models to quantify effects on measures such as GDP, household income and employment.

Economics as a discipline can also contribute to representing the values affected by environmental impacts (such as recreation and amenity values). These values can be represented by non-market valuation, which assigns an estimate of a monetary equivalent to values that are not traded directly in the market economy (and therefore are not priced directly).

We reemphasise that scenario analysis also requires predicting the impact of management options on social and cultural indicators. Although these matters are outside the scope of this report, we consider that the analytical framework's representation of the land-water-social system should be a basis for evaluating social and cultural indicators. The first steps in adding social and cultural considerations to the scenario analysis would involve identifying relevant indicators such as those shown for environmental considerations in Table 1 and Table 2.

### 3.6 Assessing plan effectiveness

The NPS-FM process results in a management regime that is set out in a regional plan and which connects values to the management of resource use by a system of limits and methods (Figure 2). Once the plan is operative, there are two requirements of the NPS-FM that are relevant to the role of science: developing a monitoring plan and developing water quality (contaminant) and water quantity accounting systems. These components are represented in Figure 5 showing their relationship to the Regional plan (top box) and the biophysical system that is being managed (bottom box). Note that the representation of the regional plan is consistent with our interpretation of the NPS-FM as a chain that connects values to the management of resource use by a regime of limits and methods (Figure 2). Note also that the biophysical system is consistent with our representation on the biophysical system in the analytical framework in Figure 4.

The requirements to develop a monitoring plan and a contaminant accounting system are integral to implementing the regional plan and therefore giving effect to the NPS-FM. Both requirements utilise science to "close the loop" between the resource management and the achievement of objectives for biophysical systems.

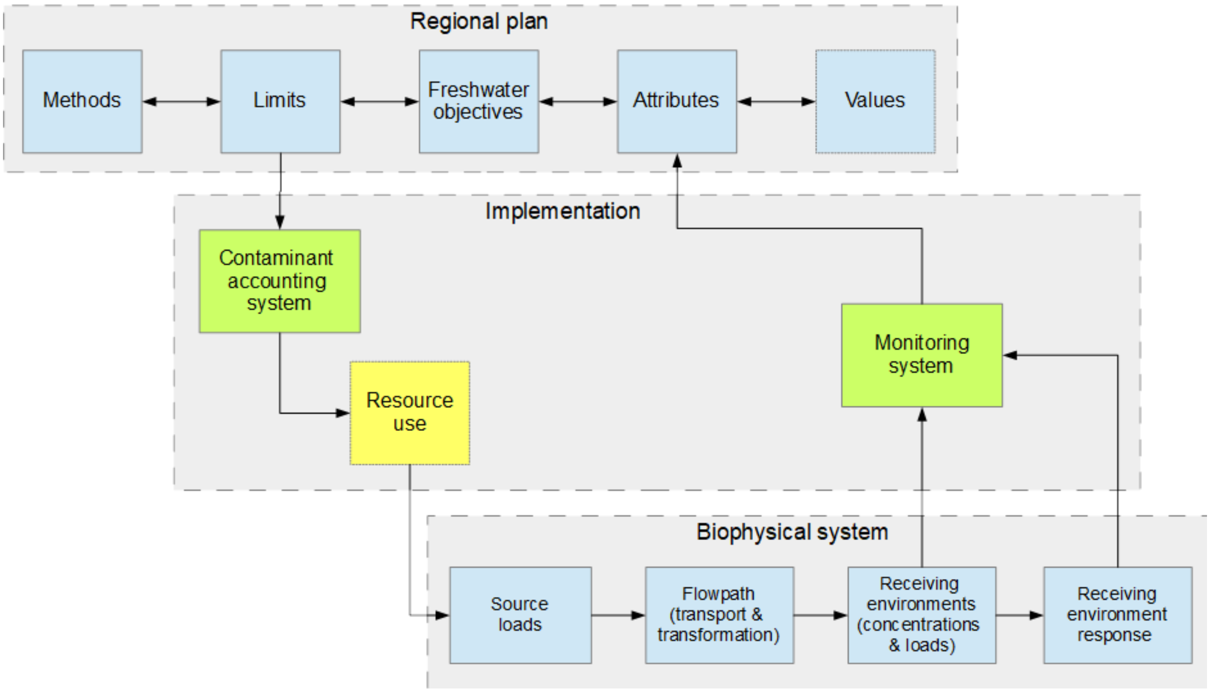


*Figure 5. Schematic diagram of the implementation of NPS-FM showing the connection between the regional plan and its implementation (i.e., management of resource use) and the biophysical system in relation to contaminant accounting.*

The role of the monitoring plan is to track progress toward or away from the plan objectives. The need for such a system is implicit in the acknowledged uncertainty of the science informing the plan's development. In effect the regional plan is a hypothesis that states that the management regime will achieve the outcomes defined by the objectives, based on the understanding captured in the conceptual model and analytical framework. The representation of the biophysical and economic system used to undertake scenario analysis (analytical framework; Figure 4) provides the context for the monitoring plan. The role of monitoring is to provide feedback from the real world to understand the impact of the regional plan, and to test the assumptions in the underlying model of the biophysical and economic system providing the reference points.

In the previous sections we have promoted the idea that the analytical framework is used to assess scenarios and determine plan provisions. In this section we promote the idea that the analytical framework also has an important role in plan implementation. In particular, the analytical framework provides a representation of the link between the management system (i.e., the plan and its implementation) and the biophysical and economic, social and cultural system. In theory, the analytical framework provides a means to explain or test whether changes in the biophysical system from the baseline are consistent with changes in resource use or management.

In practice uncertainties and unaccounted for dynamics may make it difficult to detect a management signal in monitoring data describing the biophysical system. A good example of this is the relatively poor relationship between river water quality trend and changes in catchment conditions found in recent work by Fraser and Snelder (2019b). However, the value of trying to utilise science to “close the loop” between the resource management and the biophysical systems is not just to track progress toward or away from the plan objectives, it is also to increase understanding of how the system functions. The benefit of the analytical framework when attempting to “close the loop” is that it provides a testable hypothesis and a basis for describing the efforts to protect the values and the success, so far, in doing so.

## 3.7 Developing contaminant and water quantity accounting systems

The role of an accounting system is to create a ledger, or system of reconciliation, between freshwater inputs and outputs. For water quantity this is the reconciliation of freshwater recharge with water use; for water quality this is reconciliation between the discharge of contaminants allowed by the plan and the actual loads that are discharged into the environment. Such a ledger is particularly important when the methods in the Regional Plan allocate a discharge allowance for diffuse source contaminants (e.g., nutrient discharge allowance; NDA) and where there are also point source discharges associated with individual enterprises. The ledger needs to track what has already been allocated in a manner that allows decisions for new resource use consents to be made appropriate to the limits set by the plan.

It is our understanding that Horizons has a well-established water quantity accounting framework and is currently developing monitoring and reporting frameworks to align with national policy requirements. As such, water quantity accounting is not explored further in this report. With regard to contaminant accounting, the representation of the biophysical system used in scenario analysis (analytical framework; Figure 4) is also the fundamental context for the contaminant accounting system. In particular, the contaminant accounting system needs to exist within a spatial context defined by catchments and the representation of the contaminant transport and transformation that occurs (e.g., incorporating understanding of attenuation and lags). The accounting system needs to define the allocable load of contaminants within each catchment and then to keep a running reconciliation of the allocations made to individual enterprises against the limit.

It is our opinion that, when the methods in the Regional Plan do not seek to explicitly allocate contaminant discharge allowances to individual enterprises, the contaminant accounting system is still important for tracking source loads. In this situation, contaminant accounts need to be a record of the implementation/uptake of other contaminant management methods and land use changes and a reconciliation of this against the expected environmental loads and/or concentrations. For example, if methods for achieving objectives for human health are associated with stock exclusion and riparian management, the accounting system would track progress in achieving these measures and reconcile these against the observed outcomes.

It is our opinion that the intention to close the loop between the plan and reality provides for another strong argument for using simple analytical frameworks. Complex models are difficult to run and generally require expertise that is in short supply and is likely to be a consultant outside of the council. On the other hand, if analytical frameworks are based on simple analytical models, there is a strong likelihood that these can be used and updated frequently as part of internal council processes associated with monitoring and contaminant accounting.

# 4 Limitations of science

The aim of this section is to demonstrate that the biophysical and economic input to NPS-FM processes is subject to technical limitations that restrict the detail and accuracy of assessments. The limitations have implications for how the science tasks should be approached as well as for decision-makers who are using science to inform judgments. The following sections discuss limitations associated with the detail and accuracy of scientific assessments that arise due to:

- Use of models;
- Limited precision associated with characterising current conditions;
- Limitations associated with predicting future conditions.

## 4.1 Use of models

Much scientific information is based on models. Even the simplest forms of scientific information used in NPS-FM processes, such as characterising the current biophysical state or recent changes in water quality, involve forms of statistical modelling. Any assessment that attempts to predict the impact of actions on biophysical or economic conditions is based on a model. Because models are simplifications of reality, their accuracy and detail are always limited.

The use of models to make scientific assessments is complicated by the fact that there is often more than one model that could be used. Models representing a gradient in complexity from narrative to mechanistic may be available (see Section 5). More complex and mechanistic models may be viewed as having greater credibility and may therefore be promoted as the most appropriate choice for an assessment. However, there are various reasons why the more complex models may not be the best choice including:

- insufficient input data for calibration and difficulties with calibration;
- the need to make many assumptions that are not easily appreciated by people working in other disciplines and non-modellers;
- mismatching of time and space scales with requirements of the scenario analysis;
- creating inconsistent levels of detail and precision between component parts of assessments (for example, between components of an analytical framework); and

- difficulties quantifying the uncertainty associated with model predictions.

More complex models will probably incur higher demand on science resources but may also allow for a wider range of interventions to be simulated. Careful consideration of whether it is useful to invest in more complex models is therefore important.

## 4.2 Limitations associated with biophysical assessments

### 4.2.1 Current state

The starting point for any analysis is to represent the current condition or 'baseline'. With respect to biophysical aspects, the baseline is generally defined by statistics representing the current attribute states (see Section 3.3). These statistics are derived from a sample that reflects a balance between recent data (so the statistic represents current state) and reasonable number of observations (so that the statistic is reasonably precisely estimated). Water quality scientists often make the pragmatic choice to use five years of monthly observations, which yields a sample of 60 observations, provided there are no missing observations. For some attributes, the NOF defines the number of observations that need to be used to estimate attribute states and this is often specified in terms of monthly sampling (NZ Government, 2017). The number of observations in the sample determines the precision of the estimated statistic (i.e., the accuracy with which statistic represents the true (population) value). Therefore, there is a limit to confidence in even the baseline condition. Some examples of these uncertainties are provided in Appendix A1.

### 4.2.2 Predicting future state - catchment models

Catchment models are used to describe how contaminants are generated and delivered to receiving environments. The catchment model is represented in Figure 4 by the components labelled source loads, flow path and receiving environments. In any catchment, these processes are complex, spatially variable, incompletely observed (i.e., samples are sparse in time and space) and not entirely understood. Therefore, catchment models are uncertain representations of the real world. Appendix A2 illustrates and discusses some aspects of this uncertainty as it applies to modelling catchment contaminant loads.

### 4.2.3 Predicting future state - Ecological models

Ecological models are used to describe how an aspect of the receiving environment ecosystem responds to the delivered contaminant load (or concentration). The ecological model is represented in Figure 4 by the component ecological response. Examples where this step are needed are assessments of periphyton and chlorophyll attributes in rivers and lakes, respectively. Some assessments of ecological response will need to incorporate effects of actions other than changes in loads. For example, in some streams, shading may be an effective approach to achieving periphyton objectives. There is therefore the likelihood that inputs to assessments of scenarios are not as simple as the linear cascade of models depicted in Figure 4. In addition, some assessments of ecological response will be based on narrative models (section 5.2.1), and these may incorporate the effects of more than one action, for example changes to MCI resulting from contaminant load reductions and actions to improve physical habitat. High uncertainties are a feature of ecological models (whether these are quantitative or narrative) because ecological responses are generally mediated by many processes in complicated ways and models can only crudely represent these. An example of the uncertainties associated with modelling periphyton biomass to estimate nutrient criteria is provided in Appendix A3.

## 4.3 Limitations associated with economic assessments

### 4.3.1 Current state

The models described in Section 5.3 all rely on extrapolation from limited datasets. For example, the Beef and Lamb NZ survey has a national sample size of 500 farms, and the DairyNZ farm survey has a sample of 265 for owner operators. These samples are weighted to ensure reasonable coverage of the farm types and to match average farm sizes, and so can be considered representative data. However, there is substantial diversity present in farms, particularly sheep and beef farms, and this is difficult to represent statistically because the economic indicators used do not necessarily correlate with physical variables but tend to be highly influenced by the way the farms are managed. Representative data for dairy support, arable and horticultural modelling is sparse, and available statistics generally use less than representative sampling methods. Data for novel land uses, different approaches to managing land such as organic, the influence of management/practice, and a range of existing and new 'mitigations' is absent. Therefore, our ability to model land uses outside current experience is poor. Using expert approaches and quantitative modelling reduces the sample size still further and introduces biases in relation to the expert decisions that are required to generate the data. Catchment-scale economic modelling depends largely on characterisation of land uses present and matching these to the available data. In all cases there are classification issues. There is a need to determine to which subclass of sheep and beef farms a land parcel belongs, dairy and dairy support are not always easily separable, and properties with mixed land uses can be impossible to classify. There are also usually several smaller lifestyle or quasi-lifestyle blocks for which assignment of appropriate representative models is problematic.

Data tables generated for regional flow-on modelling tend to be estimated using employment data to estimate the size of a sector, and national scale StatsNZ data is used to estimate the structure of, and flows between, enterprises. Because there are errors in the employment data and in the relationship between the national and regional sectors, this is not an accurate process, and generally involves iterative steps of estimating the table of flows between sectors, then scaling the rows and columns such that the table balances. The problem of equifinality is clear with this approach, and so we can see that with the given initial data errors, regionalisation errors and table estimation errors, the uncertainties are high. Moving beyond regional Input/Output (IO) model tables into multi region IO tables and regional Computable General Equilibrium (CGE) models (which incorporate multi region tables), the uncertainties multiply (see Section 5.3 for further explanation of these models).

### 4.3.2 Predictive modelling

The uncertainties associated with predictive modelling are additional to the uncertainties in defining current state and arise primarily from predictions of the impact of changes on enterprise economics. At the enterprise level, the costs of mitigating a given contaminant are the key source of uncertainty, particularly in relation to N mitigation, which requires a whole system understanding of change. Because each system tends to start from a unique situation, and respond uniquely, the impacts will be similarly unique. The more data that can be collected, and the better the responses are characterised, the more uncertainty can be reduced. However, uncertainty cannot be eliminated because the modelling tools are generally incomplete, the range of possible outcomes is large and there is uncertainty over future (even near future) markets and policy signals.

For the catchment scale responses, it is important to understand where and how mitigation will be undertaken, and how land use may change in response to a given stimulus. These predictions are very difficult to make and given the dynamic nature of the economic environment with multiple changes in prices, input costs, labour availability and capital costs. Any prediction of likely outcome can only be considered as indicative and used in a comparative manner with scenarios developed using the same predictive methods.

The approaches to predictions derived from flow-on modelling also have structural sources of error. IO models overestimate the impacts of a change because they do not allow for reallocation of resources to other economic activities. CGE models reduce this issue, but introduce new problems relating to the larger number of assumptions made and the treatment of key macroeconomic variables. For example, a CGE model can only allow price or supply of labour to vary, when at the regional level it is likely that both price and supply of labour will change. These and other assumptions built into the models have poor data underpinnings that result in high uncertainty in any predictions.

### 4.4 Using the best information available

The limitations of economic and biophysical science information described above highlight the importance of managing the inevitable uncertainties when informing the policy development process. The recently gazetted NPS-FM (2020) includes a new clause 1.7 that specifically addresses this issue by requiring the use of the "*best information available at the time*" and by guiding what the "best information" may include. Clause 1.7(3) also requires that decision makers "…*must not delay making decisions solely because of uncertainty about the quality or quantity of the information available*":

To give effect to NPS-FM (2020) clause 1.7 we suggest the best practice approach is, in general, to identify uncertainties and reduce them where practicable within the process timeframe, but then accept the inevitably remaining uncertainties and ensure they are effectively communicated so they can be incorporated into risk-based decision making. The Ministry for the Environment has published guidance around how this can be done (MFE, 2016).

## 5 Components of the analytical frameworks

Analytical frameworks must represent the conceptual model with sufficient detail and produce output that appropriately represents the environmental and economic impacts (Figure 4). The choice of which components to use to build the analytical framework is an important step that may need to be iteratively revisited as the process progresses. However, it is also important to recognise that there are limits to what can be realistically represented (e.g., which processes and at what level of spatial or temporal detail) and the certainty of the predictions.

This section considers the components of the analytical framework including the spatial framework and models. As noted above there is iteration between the process design, building the analytical framework and undertaking scenario analyses. This means that science activities will likely be iterative and that the science needs may evolve. Therefore, being somewhat agile in the use and choice of models is useful.

### 5.1 Spatial framework

The analytical framework is based on a geo-spatial representation of the region that comprises a number of inter-linked spatial entities including:

- the region's drainage network including flow paths, catchments and sub-catchments;

- the region's freshwater and coastal receiving environments including river segments, groundwaters, lakes and estuaries;
- all land discretised appropriately into parcels (each of which is a homogeneous unit with respect to land use and a range of factors that are relevant to production potential and contaminant losses such as soil type, climate and topography);
- the location and details of all resource using activities such as point source discharges and water takes.
- the location of sites of particular interest such as sites with special values, monitoring sites or sites where assessments may be regarded as representative of some larger area.

A key decision for the spatial framework concerns the spatial detail (or spatial resolution). An example of this is the water management zones and subzones (WMZ and WMSZ) framework used in the One Plan. The WMZ framework represents the region at a coarser level of spatial detail than the WMSZs. The first consideration relates to the spatial detail needed for the scenario analysis. If the underlying models are set up to have resolution defined by the WMZs or the WMSZs, this determines the resolution that is achievable by the analytical framework and the scenario analysis. This means that impacts on features that are internal to a WMZ or WMSZ can only be assessed as the impact for the zone itself. For example, if a scenario is evaluating load reductions that could be achieved based on a particular action, the impact on any receiving environment that is internal to the zone can only be assessed as being the same as the impact on the zone itself. Increasing the resolution of the spatial framework can allow assessments to be more spatially specific but comes at the cost of complexity and modelling effort. The second consideration relates to matching the resolution of the spatial framework with the level of resolution of the component models. It is not appropriate to have a highly resolved spatial framework if coarse models are being used or if models are calibrated based on few locations relative to the resolution of the framework. The third consideration relates to the level of spatial detail that will ultimately be practical for the plan provisions. The level of spatial detail of the plan provisions should be considered by the process design team and this deliberation should be used to guide the choice of detail for the spatial framework. For example, if objectives and limits were going to be defined at the WMZ level, there may not be benefit value in the extra effort that is required to represent a finer level of spatial detail in the scenario analysis. In this case, any scenario analysis would need to note that simulations represent the outcome for the WMZs and that there will be internal variability within these (i.e., at the WMSZ level). In our opinion, however, the WMSZ level is an appropriate level of detail (see Section 6.5.1) at least partly because this is the level of detail of some of the provisions of the existing one plan.

## 5.2 Biophysical models

There is often more than one model that could be used to represent the biophysical components of the analytical framework (i.e., land, flow-paths and receiving environments; Figure 4). Choice of model and model-based analyses are related to the representation of the details associated with each component, including the processes and spatial and temporal discretisation. The choice of component models also determines how they can be linked and therefore the representation of processes that involve transfers, interactions, and coupling between land, flow-paths and receiving environments. We define four types of biophysical models: narrative, statistical, mechanistic and hybrid.

### 5.2.1 Narrative models

We define “narrative models” to mean descriptions of relationships between variables in qualitative terms. For example, observations such as stream fencing reduces stream bank erosion and faecal contamination are narrative descriptions of relationships. Another example of a narrative model is ecological assessments that recognise that biotic communities and ecosystem health (e.g., macro-invertebrate community indices; MCI scores) are outcomes of several factors. Sometimes these assessments must be based on expert opinion, which may be based partly on quantitative assessments (i.e., model predictions) but also on qualitative information and opinion. Our experience is that at least some relationships that are important in scenario modelling, and therefore decision-making, can only be defined in these narrative terms.

### 5.2.2 Statistical models

Statistical models provide mathematical representations of relationships that are apparent in observed data. Statistical models are frequently used in environmental management in general and as component models in analytical frameworks. For example, regression and machine learning techniques are commonly combined with monitoring data to predict river water contaminant concentrations and loads (e.g., Snelder *et al.*, 2017; Unwin *et al.*, 2010). Statistical models are useful for describing relationships of land use and other catchment characteristics with water quality observed at monitoring sites and can be used to make predictions of water quality at unmonitored locations. However, for various reasons, this type of model is generally not able to be used to simulate the effect of changes of land use/management on water quality at a location.

Statistical models are often used to describe relationships between stressors (e.g., contaminant concentrations) and ecological responses. These types of models are frequently used in analytical frameworks to convert a concentration or load in a receiving environment to an ecological measure. For example, Biggs (2000) and Snelder *et al.* (2019) define regression models that relate nutrient concentrations to periphyton biomass. Zeldis *et al.*, (2017) define regression models that relate nitrogen loads discharged to estuaries to measures of their trophic state. Abell *et al.* (2019) define several regression models that predict concentrations of nutrients in lakes from mean annual nutrient loads and other lake characteristics that are a simple and potentially useful approach to simulating trophic responses in lakes.

### 5.2.3 Mechanistic models

The most detailed approach to modelling is physically based models (hereafter mechanistic models). In hydrology, this class of model is represented by spatially distributed, daily (or sub-daily) time stepping models. Examples of this class of model include INCA (Wade *et al.*, 2001), SWAT (Gassman *et al.*, 2007) and MIKE SHE (Graham and Butts, 2005) and various groundwater models. There are also examples of mechanistic receiving environment models, the most commonly applied in New Zealand being the DYRESM–CAEDYM lake model. The theoretical advantage of these models is that all relevant processes are represented at a high frequency (e.g., daily, or sub-daily) and high spatial discretisation. However, there are significant challenges with the calibration, validation and uncertainty assessment of these type of models (Beven, 1993).

Physically-based models are generally used in case study specific locations, where large amounts of data are available for parameterisation and validation, and when considerable financial resources and technical expertise can be invested for the modelling process. This class of models are generally not suitable for regional analysis, or for studies in data-poor catchments. Further, because their application even within one catchment is expensive (in terms of time, money and data), the ability to extrapolate outcomes from a small number of specific case studies that can afford this level of modelling, is limited. Applications of MIKE-SHE and SWAT in the New Zealand context have encountered difficulties with calibration and validation of the water quality predictions (Durney *et al.*, 2016; Fenemor, 2013).

In New Zealand, agricultural nutrient sources are commonly represented using the physically based model OVERSEER. OVERSEER provides farm-scale nutrient budgeting and source load estimation for N and P on an annual steady state basis (Shepherd and Wheeler, 2013; Shepherd *et al.*, 2013). OVERSEER has been used to support plan development (Baker-Galloway, 2013; Upton, 2018) and can be used to estimate source loads of N and P from individual enterprises under a range of land use and management options. OVERSEER therefore has use in many water quality management applications and can be potentially used in an analytical framework to represent sources loads of N and P (see Figure 4).

### 5.2.4 Hybrid models

Another class of catchment models combines aspects of statistical and mechanistic models. The CLUES model is a widely used spatially distributed catchment model for estimating annual steady state loads (Elliott *et al.*, 2016), and has been used across New Zealand to evaluate catchment loads of TN and TP (e.g., Palliser *et al.*, 2015; Semadeni-Davies *et al.*, 2015; Semadeni-Davies and Sunil Kachhara, 2017). The CLUES model comprises a series of component models, OVERSEER and SPASMO for modelling nutrient *sources* and SPARROW for transmission and instream processes (*pathway*). The linked models generate load estimates. The loads are then converted into instream median concentrations (indicators for *receptors*) using explicit functions derived from regressions on catchment characteristics (described in Oehler and Elliott, 2011).

Another hybrid model that is relevant to the construction of analytical frameworks is SedNETNZ (Dymond *et al.*, 2016). SedNetNZ is an erosion model that predicts the generation and transport of sediment through river networks, based on a simple physical representation of hillslope and channel processes at small sub-catchment scale (average c. 40 ha). HRC has used SedNETNZ previously to assess sediment generation under a range of scenarios (Manderson *et al.*, 2015).

## 5.3 Types of economic models

As for the biophysical modelling, there are a range of economic models available to address the economic components of the analytical framework (enterprise, catchment and flow-on impacts; Figure 4). Choice of model and model-based analyses are related to the representation of the details associated with each component including spatial and temporal discretisation. We briefly define different types of economic models for each of the economic components of the analytical framework.

### 5.3.1 Enterprise models

- Survey data models use existing or new survey data sources to estimate relationships between production, revenue, expenses and profit and how they will change under different circumstances.
- Expert approaches use either stakeholders themselves, or consultants with expertise in an area, to develop models of the enterprise.

- Quantitative systems models represent the enterprise financial and biophysical system.

Because of weaknesses in each approach, best practice tends to adopt a combination of modelling approaches. Simpler models and relationships can then be extracted from the representative systems to allow extrapolation to other situations.

### 5.3.2 Catchment models

Catchment models estimate the catchment scale responses to scenario conditions. The aggregation approach is common to all models currently being used for catchment scale modelling. The detail and scope vary according to the outputs required, number of land uses, and spatial discretisation. Estimation of catchment land use change and changes in other enterprise activity (such as mitigation of emissions) is possible through either expert or quantitative modelling approaches:

- Expert rules-based approaches involve experts or stakeholders generating a set of rules that describe the way in which land use and other enterprises are expected to change. These rules will generally try and optimise the response by minimising the profit impact or transitional costs (or some combination) for enterprises.
- Quantitative approaches use various modelling frameworks to estimate the optimum response to the policy option. These too can vary in complexity, and in the case of optimisation models have the advantage that they estimate a theoretical least cost solution. In practice, because quantitative models require some expert input to set up and calibrate with constraints, they can end up converging on a similar outcome to an expert rules-based approach.

### 5.3.3 Flow on impacts

There are three potential methods to estimate flow on impacts to the wider economy:

- Survey methods – enterprises and households in an area are questioned on the spatial distribution of their revenue and expenditure (i.e., local, catchment, region, national, international). The survey data is used to support a qualitative description of the flow of goods and services, and the potential nature of any impacts from changes that occur in a scenario. These descriptions of changes must be narrative unless the survey information is incorporated into an Input/Output model (see below).
- Input/Output (IO) models describe the relationships between different sectors of the economy. Generic models are available for the national, regional and district scale. These generic models can also be customised using survey information to better account for the sectors of interest in the analysis.
- Computable General Equilibrium (CGE) models build on IO models by including changes in prices, supply and demand in different sectors.

## 5.4 Choosing between competing models

Our observation is that complex models are time and resource hungry and that careful judgement whether they are “fit-for-purpose” is needed. There may be circumstances where more complex models are justified or needed but they should not be used in the first instance. We consider that the use of more complex models is justified where conceptual understanding is high, but this detail is not represented by the simpler model, and there is a desire by stakeholders to mobilise this knowledge to answer a specific and clearly defined question. An example of a situation where a more complex model may be needed is in over-allocated situations involving lakes or estuaries. In these situations, the presence of significant nutrients in bottom sediments may lead to internal nutrient loading of the lake or estuary. This means that there may be a considerable time delay between interventions and outcomes in the receiving environment. Information describing the likely duration of the delay may be relevant to choosing limits or other interventions and it is unlikely that a simple model can provide this sort of information.

We consider that more complex models should be avoided when data availability is poor, or where there is not a specific and clearly defined question but an expectation the model can answer “all” questions. In addition, increased detail and accuracy at one point in the modelling chain may represent wasted effort if this is not commensurate with other components of the modelling. An example of this is investing in a complex catchment nutrient model when the environmental impact that is ultimately being estimated is the trophic outcome in a downstream river or estuary. In these circumstances, the uncertainty of the relationship between nutrient loads and the trophic response is likely to be larger than the uncertainty associated with the estimate of catchment nutrient load. Therefore, decreasing the uncertainty of the input loads to the estuary does not reduce the uncertainty around the trophic response.

In our experience, the choice of model should not be made on a purely scientific basis. There are risks that more complex models may not substantially improve the information provided to decision makers compared to that provided using simpler models. There is also the risk that the higher demand on scientific resources will cause delays in the process, and delays associated with one model will have impacts on all subsequent modelling work creating bottlenecks in the assessment process. Judgements about these risks are not scientific decisions, they are associated with the aspects of the process design and therefore should be communicated to the process design team for consideration alongside issues, as described in sections 2.2 and 2.4. To help inform considerations by the process design team we offer, in the next section, our recommendations on an approach to the science tasks.

# 6 Recommended approach to science tasks and current gaps

The relatively technical and quantitative nature of the NOF process (Figure 2) can lead to the interpretation that it can be undertaken with a high degree of technical detail and accuracy. We have indicated that this is not the case in the previous sections. We have shown that there are large uncertainties associated with all science tasks. It is our opinion that these uncertainties are largely irreducible in the context of objective and limit setting processes, which are always subject to regulatory time frames and resource limitations.

The role of science in the NOF process is to help find an intensity and spatial distribution of resource use that allows freshwater objectives to be achieved, to help to formulate an appropriate management regime to achieve this, and to develop monitoring plans and contaminant account systems to assist with implementation. In our opinion, these are very difficult tasks that are best approached from the perspective of problem solving using existing knowledge, data and models. The involvement of science should not be an opportunity to generate new fundamental knowledge or to develop greater understanding of how systems work – this will create delays and potentially add to the contentiousness of decisions. As discussed in Section 5.4, we generally consider that uncertainties cannot be overcome by using more complicated models. Instead, we advocate for using the available information to best effect, using simple approaches, at least to begin with, and treating uncertainties and unknowns as information that the decision makers use when making decisions.

In the following sections we return to the seven science tasks identified in Section 3 and provide high level recommendations for how HRC science should approach these. We also comment on current gaps in data and models and identify important resources and science staff roles associated with these tasks.

## 6.1 Informing and supporting the process design team

In section 2.2 we recognised the need for a process design team who design and then run the policy and planning process. Here we recognise several distinct scientist roles for informing and supporting the process design team. First, there needs to be a 'science lead' (or leads) who has overview and coordination responsibility for the entire science contribution to the planning process. This includes biophysical, economic and social science aspects. The science lead would normally work in close alignment with an identified separate lead for incorporating mātauranga Māori. The science lead helps frame the questions that the science team will tackle and ensures that the multiple science disciplines are tackling questions in an integrable way. The science lead(s) is also the science team's representative on the process design team and is therefore responsible for ensuring that the science team's activities are directed to tasks that will effectively inform and support the process design team.

The second important roles are technical ones that are associated with the development of the analytical framework, possibly helping to specify the scenarios and certainly involved in translating scenarios into technical requirements and activities for the modelling team to action. We consider that both the biophysical and economic work require a person to be in this role, which we refer to as the 'lead biophysical modeller' and the 'lead economic modeller'. The lead biophysical modeller and the lead economic modeller need to work closely with the science lead to ensure that the policy options being considered are translated into analysable scenarios and then the scenario analysis results translated back into digestible information to be integrated with assessments from social and economic science and mātauranga Māori.

We suggest it would normally be too much for the person who is undertaking the science leadership to also have a lead modeller role. A key requirement of all these lead roles will be the ability to synthesise what the scenario analyses and other multidisciplinary science assessments mean for community values. It will also be necessary for these lead roles to have an appreciation of the evolving requirements of national policy and be able to clearly communicate relevant aspects of the science findings for this purpose.

For all members of the HRC science team that are informing policy development it is important to distinguish the different roles that can be played generally by scientists (e.g., Pielke 2007) and to clearly establish the impartial 'honest broker' role for the HRC science team and any of its contractors (e.g., Gluckman 2013, MfE 2016, Rouse & Norton 2017). This is usually worth being explicitly recognised by developing some form of agreed team 'terms of reference' for involvement in the policy development process and/or team training on the subject.

Another potentially important role is a science technical advisory panel. This can take several forms but in general provides a resource for science advice that is independent of HRC and is usually made up of people with considerable experience in using science for policy development. It may also include stakeholder expertise. Such a panel can be useful for peer reviewing the science team's ideas and proposed methods before work commences, resolving or at least informing on areas of conflict or differences of scientific opinion. This can help reassure the process design team when making decisions about process and may also share some of the burden of difficult methodological and process decisions by the science and process design teams.

Other important capabilities to provide for in the science team include:

- Transdisciplinary capability and integration of work across technical disciplines;
- Collaborative working styles with stakeholders of different interests;
- Synthesis and science communication skills;
- Techniques for communicating and handling uncertainty;
- Integrating science knowledge for evolving policy requirements.

An important consideration for HRC science is how to ensure there is capability and capacity for all these important science roles. We think it will only be possible to assess the scale of the requirement when there is more clarity on how the plan development process will be undertaken.

## 6.2 Conceptual model

An important consideration for HRC science is how to develop the conceptual model. As discussed in Section 2.2, several aspects of the process design will influence the conceptual model. Therefore, we consider that it will only be possible to fully address how to develop the conceptual model once there is more clarity on how the policy and planning process will be undertaken.

However, we also consider that HRC has considerable conceptual understanding of the land-water-social system through the development of the One Plan. In addition, HRC has already deployed models and science that have effectively mobilised components of an existing conceptual model. Examples of this include the regional spatial framework of water management zones and sub-zones and catchment sediment (Schierlitz and Dymond, 2006) and nutrient (Snelder, Cox, Kerr, *et al.*, 2020) models. These models have been used in significant regional policy making processes and therefore have established a level of credibility and legitimacy concerning HRC's conceptual understanding of the land-water-social system. We think this existing understanding should be used as a starting point and then, ideally, be refined and developed in an iterative manner with stakeholders.

We recommend that further development of the conceptual understanding of the land-water-social system should be driven by decisions of the process design team. Interaction with stakeholders should be in a manner that is consistent with where the general approach to stakeholder involvement sits on the spectrum between consultative and collaborative. We have already described some of the merits of collaborative approaches in sections 2.4.1 and 3.2. In particular, the credibility, relevance and legitimacy of the conceptual model, analytical framework and scenario analyses are highest if they have been generated in a more collaborative manner.

## 6.3 Current state and trends

### 6.3.1 Biophysical

HRC is reasonably well positioned with information describing current state and trends for lakes (to July 2017; Fraser and Snelder, 2018) and rivers (to December 2019; Fraser and

Snelder, 2021). In addition, HRC has good information on loads of the four key contaminants (N, P, S and M; Fraser and Snelder, 2020). This data is limited to monitoring locations, but its value has been maximised by using empirical modelling to produce a comprehensive picture of current state and loads for all rivers of the Region and for the range of relevant variables (Figure 6).

We consider that the information describing state and trends of the Region's rivers, lakes and estuaries is sufficient for the NPS-FM implementation task. It is likely that during the process there will be demands for more data because monitoring is always limited to specific sites. However, additional monitoring will not improve the information base in the short term because of the long-term nature of monitoring needed to improve determination of state and trends. Increasing the available data should be seen as a longer-term objective that is associated with improving information for future regional plans and monitoring outcomes at sites of special interest.

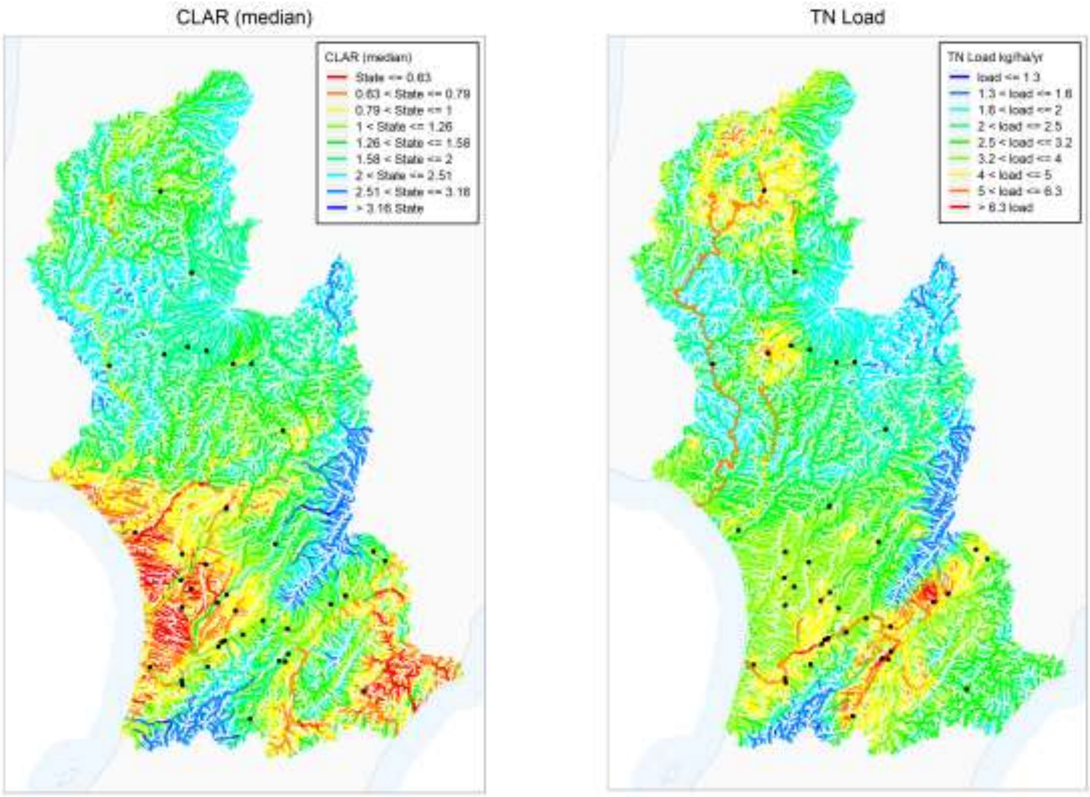


*Figure 6. Examples of predictions of current state and loads based on empirical modelling. The maps show predicted values of visual clarity (left) and total nitrogen load expressed as a yield (right) in all segments of the digital network representing the region's rivers. These and various models of other variables are described by Fraser and Snelder (2020).*

### 6.3.2 Economic

The Manawatū-Whanganui Region is substantial and covers a diverse range of environmental conditions. There is likely to be a high degree of diversity in farming systems even within enterprise types (e.g., dairy, sheep and beef farming) across catchments and different parts of the region.

As part of the One Plan Plan Change 2 process, HRC undertook work to characterise current practice and N losses from dairy farms and horticultural operations and the economic costs associated with mitigating N loss (e.g., Bloomer *et al.*, 2020). There have also been studies that have estimated N losses from other land uses in the Region (e.g., Manderson, 2015; Manderson *et al.*, 2016). However, in our experience, significant attention is drawn to the representation of current practice, nutrient loss rates and the cost of mitigation in scenario analyses, particularly by stakeholders. Getting this information as accurate and representative as possible is important to the credibility of the process. We therefore recommend that consideration be given to updating and enhancing regionally representative data describing current practice, nutrient loss rates and the cost of mitigation. Furthermore, we recommend that data describing enterprise level mitigation of nutrient losses in the Region be gathered using the approaches shown in the last column of Table 5. This should involve direct surveying and stakeholder engagement where possible, use of data from major industry sectors, and expert modelling of enterprises for major land uses. A reasonable number of enterprises per major land use should be surveyed in order to cover the range of possible climates and systems in the region. An example of the outputs from this modelling approach, where a mitigation curve for N was generated in the Waimakariri district are shown in Figure 7.

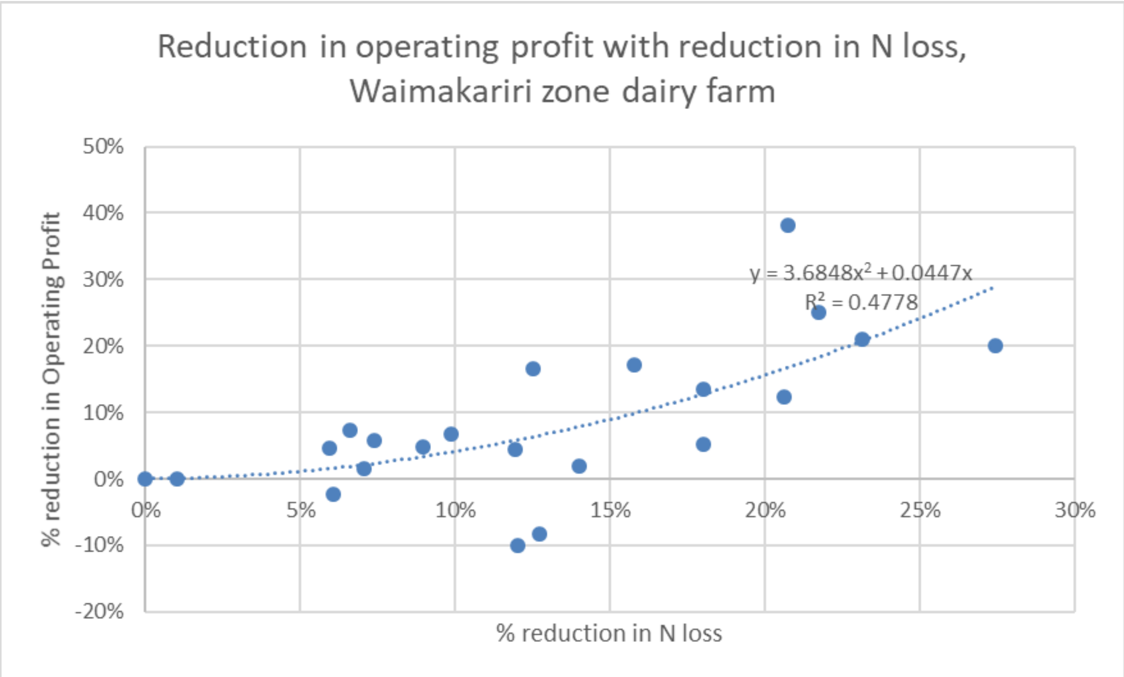


*Figure 7: Enterprise costs of N mitigation, Waimakariri dairy farm.*

## 6.4 Scenario analysis

Because HRC already has some numeric target attribute states defined in its regional One Plan, we suggest that a logical starting point would be to consider a 'load reduction requirement analysis' as an initial task. This analysis could provide HRC and stakeholders with an early indication of the magnitude and spatial distribution of contaminant load reductions that would be necessary given existing plan objectives (i.e., target attribute states). An indicative example of a load reduction requirement analysis for nitrogen is shown in Table 4 that has been extracted from the national study of Snelder, Whitehead, *et al.* (2020). The load reductions are based on the assumption that the objectives for rivers and lakes and NOF bottom lines and estuaries are an equivalent condition (see Snelder, Whitehead, *et al.* (2020)

for details). We note that some existing One Plan targets are more stringent than the NOF bottom lines and so the initial results shown in Table 4 should be regarded as indicative lower end of possible load reductions required to achieve likely objectives.

Table 4 indicates that the range of likely reductions required at the catchment level varies between the region's catchments from zero to approximately 30% of current nitrogen loads. It is noted that reductions greater than 30% are likely to be required for some WMSZs that are internal to the region's catchments shown in Table 4. This type of information can also be reasonably readily accessed for economics from an existing LWP catchment economic model (Harris *et al.*, 2021) that includes current state water quality models of Snelder and Fraser (2020), utilises the spatial framework defined by the WMSZ, and land use and nitrogen loss information. This analysis would not consider how reductions could be made but might involve a range of potential objectives so that the "cost" of more aspirational objectives could be better appreciated at an early stage in the process. This type of analysis would also allow the science team to triage its focus and target approaches depending on the extent of the interventions required. Small changes can be accommodated with less rigorous modelling and more generalised management responses, while very large reductions will require more detailed consideration of spatial and temporal allocation changes with associated modelling requirements. Ideally the load reduction requirement analysis follows the development of the conceptual model and references this model to establish legitimacy.

Following this logical starting point for scenario analysis we anticipate that further scenarios will be developed in a manner that depends on decisions of the process design team, in particular the types of limits to be explored and the extent of stakeholder involvement, as discussed in section 2.2. We suggest that the role of science lead will need to work closely with both the process design team and the lead modeller(s) to translate the policy options being considered into analysable scenarios. The analytical framework described in the next section is suggested based on our anticipation that numerous possible types of resource use scenarios will need to be assessed, of the type described generally in section 3.4.

*Table 4. The current TN load and excess TN load estimated for the main catchments in the Manawatū-Whanganui Region, and the region based on the assumption that the objectives for rivers and lakes and NOF bottom lines and estuaries are an equivalent condition. Current TN load and excess TN load are shown in absolute terms (tonnes yr$^{-1}$) and excess TN load is show relative to current loads (%). Current refers to 2017 and the excess loads include all river segments, lakes and estuaries. The values in parentheses indicate the lower and upper 95% confidence intervals for all estimates. These results were derived from the national study of (Snelder, Whitehead, et al., 2020) and are based on periphyton nutrient criteria that allow for a 20% spatial exceedance.*

| Catchment | Current TN load (t yr$^{-1}$) | Excess TN load (t yr$^{-1}$) | ExcessTN load (%) |
|---|---|---|---|
| Akitio River | 450 (159 - 811) | 130 (0 - 463) | 29 (0 - 57) |
| Hokio Stream | 97 (36 - 217) | 0 (0 - 0) | 0 (0 - 0) |
| Kai Iwi Stream | 146 (62 - 303) | 0 (0 - 0) | 0 (0 - 0) |
| Kaikokopu Stream | 96 (37 - 198) | 0 (0 - 0) | 0 (0 - 0) |
| Kaitoke Stream | 39 (14 - 79) | 0 (0 - 0) | 0 (0 - 0) |
| Koitiata Stream | 44 (17 - 81) | 0 (0 - 0) | 0 (0 - 0) |
| Manawatu River | 6659 (2615 - 12806) | 1952 (55 - 6908) | 29 (2 - 54) |
| Mowhanau Stream | 19 (7 - 47) | 0 (0 - 0) | 0 (0 - 0) |
| Ohau River | 137 (47 - 271) | 20 (1 - 46) | 15 (2 - 17) |
| Okehu Stream | 57 (20 - 132) | 0 (0 - 0) | 0 (0 - 0) |
| Omapu Stream | 5 (2 - 12) | 0 (0 - 0) | 0 (0 - 0) |
| Ototoka Stream | 34 (10 - 73) | 0 (0 - 0) | 0 (0 - 0) |
| Owahanga River | 286 (124 - 663) | 64 (0 - 319) | 22 (0 - 48) |
| Papuka Stream | 4 (1 - 9) | 0 (0 - 0) | 0 (0 - 0) |
| Rangitikei River | 2300 (853 - 4568) | 197 (42 - 1089) | 9 (5 - 24) |
| Tautane Stream | 10 (4 - 22) | 0 (0 - 0) | 0 (0 - 0) |
| Turakina River | 754 (256 - 1746) | 194 (13 - 770) | 26 (5 - 44) |
| Waikawa Stream | 57 (19 - 126) | 8 (0 - 52) | 14 (0 - 41) |
| Waimata River | 11 (4 - 23) | 0 (0 - 0) | 0 (0 - 0) |
| Wainui River | 60 (24 - 132) | 0 (0 - 0) | 0 (0 - 0) |
| Waiwiri Stream | 18 (7 - 48) | 0 (0 - 0) | 0 (0 - 0) |
| Whangaehu River | 1667 (619 - 4294) | 271 (0 - 1406) | 16 (0 - 33) |
| Whanganui River | 5859 (2025 - 12172) | 1272 (0 - 6379) | 22 (0 - 52) |
| Miscellaneous | 235 (173 - 298) | 0 (0 - 0) | 0 (0 - 0) |
| Whole region | 19045 (12353 - 28290) | 4107 (469 - 11881) | 22 (4 - 42) |

## 6.5 Analytical framework

### 6.5.1 Spatial framework

It is our opinion that the WMSZ framework represents the region at a level of spatial detail that is generally appropriate and consistent with the information, data and models that can be used to construct the analytical framework. The drainage network for the WMSZs can be represented by the GIS-based digital drainage network, which underlies the River Environment Classification (REC; Snelder and Biggs, 2002).

The catchments of the region's coastal lakes do not correspond to the WMSZ framework. The coastal lakes have high values and are likely to be currently failing to achieve objectives. Because it is likely that there will be significant attention associated with these lakes, we recommend that they and their catchments are explicitly included in the spatial framework. From a practical perspective, this addition would look like the addition of new WMSZ, sometimes being smaller than the existing zones. This will enable the modelling and scenario analysis to explicitly represent each lake and its catchment. Lakes can be added to the spatial framework based on the lakes layer of the Freshwater Environments of New Zealand GIS database (FENZ; Leathwick et al., 2010). The FENZ lake catchment polygons are defined in this database and can be added to the existing WMSZ spatial framework.

Estuaries can be represented in the spatial framework by joining the terminal segments of the river network to the national classification of 421 coastal hydro-systems (Hume et al., 2016). The river segments that terminate at estuaries can be identified by intersecting a GIS layer of estuary polygons with the river network. The contaminant loads associated with these terminal network segments can be summed to define the estuary loads.

### 6.5.2 Biophysical aspects

As stated in section 3.5.3, all NPS-FM attributes and existing One Plan targets are influenced by at least one of the four key contaminants: N, P, S and M (Table 1, Table 2). Assessment of attribute states under scenarios will therefore be either directly or indirectly reliant on analysis of these four contaminants, and therefore the analytical framework will need to include catchment models that describe the generation, transport and transformation of each of these contaminants.

The analytical framework will also need to include models that represent the receiving environment responses to the contaminants. For example, models representing trophic responses of lakes, rivers and estuaries under different nutrient loads. The minimum set of receiving environment responses that the analytical framework needs to represent are the NOF attributes or One Plan targets shown in Table 1 and Table 2.

Decisions concerning which models to include in the analytical framework should consider:

- how much detail the contaminant generation, transport and transformation, and receiving environment response processes associated with each contaminant are represented in the conceptual model;
- the extent to which these processes can be realistically represented by available models;
- the types of interventions/limits that are likely to be considered (i.e., the chosen model needs to be able to represent the impact of these interventions).

Conceptually, the chosen models will need to represent a variety of processes that the conceptual model includes as factors that influence attribute states. For example, it is likely that the conceptual model will identify substrate stability and invertebrate grazing as factors that influence periphyton response to nutrients in rivers. However, models that adequately represent all identified processes will not always be available and therefore judgements are required concerning what level of analytical detail is possible and reasonable. Ideally, these judgements should be shared with the process design team via the communication link described in sections 2.2 and 6.1, so that wider considerations can inform these decisions and responsibility for them can be shared between the process design and science teams.

In the sections below we recommend simple but fit for purpose components for the analytical framework. The components that simulate the contaminant generation, transport and transformation processes (see Figure 4) are broadly referred to as catchment models. Models that take predicted contaminant loads or concentrations and simulate the response in the receiving environment are referred to as receiving environment models.

#### *6.5.2.1 Catchment models*

We recommend that catchment models for the four key contaminants: N, P, S and M are based on annual steady state mass balance of the contaminants at assessment nodes[17]. We acknowledge that ultimately the decision on model type should be made by the process design team so this recommendation should be appropriately deliberated. This type of model provides a simple representation of the processes of contaminant production, transport and transformation. The main reason that annual steady state loads are an appropriate unit of analysis is because this is the typical temporal scale that we can quantify the impact of land management on contaminant losses. For example, nitrogen and phosphorus losses are estimated on an annual basis using farm nutrient budgeting models such as OVERSEER: PCE, 2018). Similarly, the efficacy of actions to reduce sediment and microbe losses from land are also characterised at this time scale. There is therefore little benefit in modelling contaminant fluxes in catchments at times scales less than a year.

The key output required from the catchment models is a prediction of the contaminant load delivered to any assessment node ($L_e$) under any scenario. Current values of $L_e$ can be calculated from monitoring data pertaining to all regional monitoring sites based on observed concentrations and flows (e.g., Fraser and Snelder, 2020). These load estimates are used to calibrate the catchment models (e.g., Snelder, Cox, *et al.*, 2020).

For the two key nutrients (N and P), we recommend the use of export coefficient models such as the Contaminant Allocation and Simulation Model (CASM) used in Plan Change 2 of the Regional Policy Statement and Regional Plan (the One Plan) (Snelder, Cox, *et al.*, 2020). Export coefficient models use estimates of contaminant loss rates from all land surfaces. Loss rates from agricultural land are estimated using nutrient budgeting models such as OVERSEER. Loss rates from all other land surfaces are estimated based on literature values. Point sources can also be represented in these models. The models are calibrated so that the aggregate load from all upstream areas and point sources, less the attenuation of those loads, agrees with the observed loads at monitoring sites. The calibration parameter is essentially the attenuation rate although changes to export coefficients are sometimes also necessary. Predictions of $L_e$ under scenarios are made by making appropriate adjustments to the land surface losses or point sources and using the model to simulate the outcome.

For microbes and sediment, slightly different approaches to loss rates from land surfaces are used to N and P however, an annual steady state mass balance approach is appropriate. A relatively simple sediment model called NZeem (Dymond *et al.*, 2010) is analogous to the CASM model used in Plan Change 2. NZeem allows the testing of scenarios involving at least three types of interventions: whole farm plans, afforestation and riparian exclusion (Neverman *et al.*, 2019). In addition, the more complex SedNet catchment sediment model has been used in the Manawatū-Wanganui Region and may be an appropriate framework for analysing sediment.

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[17] Although the conceptual approach is based on loads, for some contaminants, units of concentration are more pragmatic. These are discussed below.

Practical approaches to modelling *E. coli* concentrations are strongly limited by current understanding of the processes of catchment generation and transport of these microbes. In general terms, current data and modelling is unable to discriminate differences in microbial outcomes between different types of pastoral land uses (e.g., dairy versus sheep and beef). In addition, conceptually riparian buffer strips are assumed to improve bacterial water quality both by eliminating livestock defaecation in and near streams, and by trapping of bacteria by the riparian vegetation (Collins and Rutherford, 2004). However, the efficacy of these mitigations is poorly understood and estimates have very large uncertainties (Semadeni-Davies *et al.*, 2016).

Two national scale studies have estimated potential reductions in *E. coli* loads that might be achieved using a range of mitigations (Semadeni-Davies *et al.*, 2016, 2018). In our opinion, these studies represent the best available information about the outcomes of known mitigations for *E. coli* loads in the Manawatū-Wanganui Region based on current knowledge, tools and data. We consider that there is little to be gained by HRC undertaking additional modelling because the underlying base information and data would not be different to these national studies. In addition, although the above studies were national in scope, they were undertaken at a level of spatial resolution that is equivalent to the suggested spatial detail we have recommended for the HRC spatial framework. We therefore recommend that the information from the two previous studies should be utilised in the HRC process to model the *E. coli* attribute state under the known practical mitigation measures. We acknowledge that there may be an issue associated with using the results of the existing studies if the mitigations that were represented do not reduce *E. coli* loads sufficiently to achieve a defined attribute state. If this were the case, it may be necessary to undertake specific *E. coli* catchment modelling that incorporates additional mitigations and/or land use change such that a configuration of catchment resource use that allows the objectives to be achieved can be simulated.

#### 6.5.2.2 Receiving environment response models

In scenario analyses, the state of a NOF attribute or One Plan target (hereafter; $State$) must be predicted given the relevant contaminant load in the receiving environment ($L_e$). The analytical framework needs therefore to predict the relevant state in the receiving environment given the contaminant load:

$$State \sim f(L_e) \qquad \textit{Equation 1}$$

The models and tools that are represented by $f(L_E)$ in Equation 1 differ for each attribute and receiving environment (i.e., rivers, lakes and estuaries). We distinguish two levels at which $State$ can be predicted: quantitative and qualitative. Quantitative predictions of $State$ can be produced when there is a numerically defined model that links the state to a contaminant load. Notable examples of quantitative models are trophic state models for river periphyton (e.g., Kilroy, 2019), lake phytoplankton (e.g., Abell *et al.*, 2019b, 2020) and estuary trophic indicator (e.g., Plew *et al.*, 2020). These models numerically link nutrient load (via concentrations) to plant biomass or some other associated trophic state indicator.

Qualitative predictions of $State$ are those for which there is no quantitative model but for which there are empirical, anecdotal or “expert opinion” based justifications for declaring the direction of change in the attribute state with a change in load. Qualitative predictions are likely to be necessary for a number of attributes and One Plan targets, for example those that are based on invertebrate or fish indicators.

Note that statistical spatial regression models are often used to predict current state of physical, chemical and biological variables based on monitoring data (e.g., Clapcott *et al.*, 2017; Fraser and Snelder, 2020). These models are useful for informing current state (see Section 6.3). However, this type of model cannot reliably predict how state changes if contaminant loads change. This is generally because the regression models do not directly include contaminant loads or concentrations as explanatory variables.

The following sections describe our recommended approaches to predicting the state of attributes and One Plan targets listed in Table 1 and Table 2, primarily as a function of load (i.e., Equation 1). The sections below group together interrelated attributes and targets shown in Table 1 and Table 2 to avoid repetition.

In many cases, restricting one or more contaminants is a necessary but not sufficient action to achieve a required attribute or target state. In the following, therefore, we include our recommendations for considering the other limits and interventions that are indicated as relevant to achieving the required states in Table 1 and Table 2.

The recommended approaches are practical starting points for modelling that may need to be revisited if questions that become relevant during the scenario modelling process cannot be satisfactorily answered. Modelling approaches that differ from the recommendations below are generally going to be more complex and difficult to implement and we direct the reader to our advice concerning the adoption of more complex models in Section 5.4.

**River periphyton and nutrient concentrations**

River periphyton biomass is a NOF Appendix 2a attribute requiring limits and a One Plan target (Table 1 and Table 2). Practical approaches to modelling river periphyton are generally formulated using existing nutrient concentration criteria (i.e., nutrient concentration thresholds) that are expected to achieve a graduated range of biomass targets (e.g., 50, 120, 200 mg chlorophyll *a* $m^{-2}$), as opposed to predicting the periphyton biomass given a nutrient load or concentration. For example, Kilroy (2019) provides nutrient criteria to achieve different levels of periphyton biomass. We recommend that the approach taken by the analytical framework is to predict concentrations of nutrients for each scenario based on the receiving environment load ($L_e$) and then compare those concentrations with nutrient criteria associated with periphyton biomass ranges (i.e., do not attempt to predict periphyton biomass *per se*, but compare the predicted nutrient concentrations with appropriate nutrient criteria).

Because the recommended catchment models predict annual nutrient loads, this output must be converted to an equivalent nutrient concentration to allow for comparison with the criteria. The approach to this conversion assumes that the nutrient concentration difference in a receiving environment between the current state and some predicted scenario state is in proportion to the change in that nutrient's load change between the two states, i.e., the following relationship applies:

$$\frac{C_{e\ Scenario}}{L_{e\ Scenario}} = \frac{C_{e\ Current}}{L_{e\ Current}} \qquad \textit{Equation 2}$$

Therefore, the scenario concentration ($C_{e\ Scenario}$) is derived as:

$$C_{e\ Scenario} = L_{e\ Scenario} \times \frac{C_{e\ Current}}{L_{e\ Current}} \qquad \textit{Equation 3}$$

where $L_{e\ Current}$ is the relevant current nutrient load for the receiving environment, $C_{e\ Current}$ is the current nutrient concentration in the receiving environment, which will generally be a median value or some other relevant statistical quantity. $L_{e\ Scenario}$ is the load predicted by the catchment model for the scenario.

HRC has invested in developing nutrient criteria to achieve different levels of periphyton biomass (Kilroy, 2019). There are also other recently developed periphyton biomass -nutrient criteria that were developed from national data that included the HRC sites (Matheson *et al.*, 2016; Snelder *et al.*, 2019).

The One Plan targets include soluble inorganic nitrogen (SIN) and dissolved reactive phosphorus (DRP) and these two nutrients must also be included in respect of the NOF periphyton attribute (NZ Government, 2020). The same logic as above can be applied to predicting the SIN and DRP concentrations under a scenario. In modelling carried out for the One Plan Plan Change 2, Snelder, Cox, and Kerr (2020) assumed that the ratio of SIN concentration to TN load under current conditions would be preserved under each modelled scenario. This is a pragmatic assumption that allows the different constituents of the contaminant load to be predicted but should be recognised as a source of modelling uncertainty. In our opinion, with the data that is available in most limit setting studies this uncertainty is probably irreducible in the short to medium term. Note that this assumption is consistent with current modelling practice. The approach outlined above was used successfully to simulate a range of scenarios in the One Plan Plan Change 2 (PC2) process (Snelder, Cox, and Kerr, 2020). We note that conversion of loads to concentration can also be based on models such as Oehler and Elliott (2011b)[18].

The modelling process would proceed by using the catchment model to estimate the catchment nutrient load under some future scenario. Conversions from the predicted scenario nutrient load to the relevant nutrient concentration would be based on Equations 2 and 3 and these concentrations would be related to periphyton biomass based on the appropriate criteria.

HRC is well positioned to use the above approach to modelling river periphyton and nutrient concentrations. The catchment nitrogen modelling carried out for the One Plan Plan Change 2 using the CASM model framework (Snelder, Cox, and Kerr, 2020) has provided a good test case for the use of simple catchment models that was broadly accepted by stakeholders in that process. Council has good data describing current nutrient concentrations and loads at approximately 60 SoE monitoring sites and has used these to develop predictions at unmonitored locations (Fraser and Snelder, 2020). However, the definition of nutrient criteria is complex and uncertain and the “right” criterion is likely to be subject to scientific disagreement. We recommend that multiple sources of nutrient criteria are considered and treated as lines of evidence that link nutrient concentrations to likely periphyton biomass outcomes.

**River cyanobacteria**

River cyanobacteria is included as a One Plan Target. Scientific knowledge and understanding of the drivers of cyanobacteria in rivers is limited. It is understood that controlling river cyanobacteria by nutrient limitation would require very low concentrations (appreciably lower than those considered to restrict periphyton biomass to acceptable levels). A complication of reducing nitrogen concentrations in many rivers may actually increase the risk of

[18] LWP Ltd has recently extended the original models of Oehler and Elliott (2011) using large datasets with higher spatial coverage.

cyanobacteria because low nutrient conditions may allow it to out-compete other periphyton species. Cyanobacteria proliferation may also be associated with factors such as high temperatures and light, extended low flows and phosphorus enriched sediment. In our opinion, the complicated and poorly understood relationship between cyanobacteria and drivers means that it cannot be used to directly justify catchment nutrient load criteria and associated resource use limits. Nutrient limits should be based on other attributes (i.e., periphyton and nitrate toxicity). However, the analytical framework needs to be able to assess outcomes for river cyanobacteria for different scenarios. We suggest that scenario outcomes for cyanobacteria need to be assessed qualitatively, with reliance on expert scientific opinion. These assessments can be informed by the quantitative assessment of nutrients (i.e., periphyton) and sediment loads and should also consider the impact of any other factors that may be changed under the scenario such as flows, temperature and shading.

**River nitrate toxicity**

River nitrate toxicity is a NOF Appendix 2a attribute requiring limits (Table 1). The pragmatic and simple approach to estimating scenario concentrations of nitrate nitrogen (NNN) is to assume that NNN will remain the same fraction of TN under the scenario as it is currently. Based on this assumption, NNN concentration is calculated for a scenario using Equation 3, where the TN scenario load is predicted by the catchment model. This follows the same approach described above for periphyton and nutrient concentrations. It is our opinion that any more complicated approach to estimating NNN is difficult to justify given current knowledge of processes and the available data.

HRC is well positioned to use the above approach to modelling NNN. Council has invested in developing current measured and modelled NNN and measured and modelled current TN loads. The CASM-based catchment total nitrogen (TN) load model has already been used to predict TN under various scenarios in support of One Plan PC2 process.

**River ammonia toxicity**

River ammonia toxicity is a NOF Appendix 2a attribute requiring limits (Table 1). Ammonia tends to be a contaminant associated with point discharges (e.g., wastewater and landfill leachate) rather than being a significant diffuse contaminant concern for toxicity. It is our opinion that ammonia toxicity downstream of point sources is a matter that should be dealt with by limits applied through resource consenting for individual point sources and is not an issue that needs to be explicitly modelled by the analytical framework. Discharged ammonia is also usually quickly oxidised to nitrate in aerobic receiving environments, so its contribution to nutrient loads is usually picked up in assessments of nitrate nitrogen and total nitrogen which are already dealt with in other parts of the analytical framework dealing with trophic responses (e.g., river periphyton, lake and estuary phytoplankton and estuary macroalgae).

**River dissolved oxygen**

The NOF Appendix 2a includes dissolved oxygen (DO) as an attribute requiring limits for point sources, rather than a generally applicable attribute (Table 1). It is our opinion that DO downstream of point sources is a matter that should be dealt with through resource consenting for individual point sources. Because DO is not an Appendix 2a attribute that applies generally, it is not relevant to scenario analyses carried out in support of broadly applicable resource use limits. We therefore recommend that DO in association with point sources is not an issue that needs to be explicitly modelled by the analytical framework.

River DO is however included in NOF Appendix 2b as an attribute requiring action plans and is also a One Plan target (Table 1 and Table 2). There is currently limited scientific knowledge and insufficient tools for making quantitative general predictions about DO as a function of contaminant loads. DO fluctuations outside of acceptable levels can be expected if plant biomass or organic contaminant concentrations are high. However, the details of when and where this may occur are complicated by temporal variation, instream temperature and re-oxygenation rates. In our opinion, current knowledge, data and tools are not such that river DO can be used to directly justify resource use limits. Rather, limits that are justified by other attributes (e.g., nutrient limits to achieve periphyton and phytoplankton, and environmental flow limits to achieve instream habitat) will also indirectly assist with achieving DO target attribute states.

We therefore consider that the One Plan DO target should be incorporated qualitatively in scenario modelling with consideration given to the associated periphyton attribute. Any assessment of the effects of scenarios on the DO attribute will need to be undertaken in a very qualitative way with full reliance on scientific opinion about possible directions of change, informed by the outputs from assessments of other attributes, particularly plant biomass (i.e., periphyton in rivers). In addition, we consider that the appropriate response to the DO attribute in the NOF Appendix 2b is to simply consider the extent to which monitoring of this attribute is instigated so that knowledge about it may be improved for future planning processes in years to come beyond the current process.

**River visual clarity (suspended fine sediment)**

River visual clarity is a NOF Appendix 2a attribute requiring limits and a One Plan target (Table 1 and Table 2). River visual clarity is the receiving environment expression of the amount of suspended fine sediment in the water column which is in turn an expression of sediment load. Therefore, modelling visual clarity relies on a catchment model that predicts annual sediment loads for receiving environments and coupling those outputs to models of the relationship between loads and visual clarity in the receiving environment. Simple models that express clarity (in terms of the statistical measure that is required by the NOF attribute) as a function of sediment loads are presented in Hicks et al. (2016). These models are calibrated to national datasets and have associated uncertainty estimates. It is our opinion that the use of these models is the best practical approach to sediment modelling and is fit for purpose provided that any derived policy is appropriately cognisant of the uncertainties. We also note that the approach of Hicks et al. (2016) might be able to be applied to a regional dataset to improve confidence in the model and this should be investigated.

HRC is well positioned to use the above approach to modelling river visual clarity. Council has invested in developing current measured and modelled visual clarity and measured and modelled current sediment loads. The SedNet catchment sediment load model has already been used to predict loads under various scenarios in support of the sustainable land use initiative (SLUI; Schierlitz and Dymond, 2006). The modelling process would proceed by using the catchment model to estimate the catchment sediment load under some future scenario. Conversions from the predicted scenario sediment load to visual clarity outcome would be based on the models presented by Hicks et al. (2016) or similar.

**River deposited fine sediment**

River deposited fine sediment is a NOF Appendix 2b attribute requiring action plans (Table 1) There is currently little monitoring data describing the state of deposited fine sediment in rivers in the Region and across New Zealand in general. Scientific knowledge and understanding of the relationship between fine deposited sediment and catchment sediment load is poor (Hicks et al., 2016). In addition, there are no tools for quantitatively predicting fine deposited sediment as a function of sediment load (Hicks et al., 2016). Formulating action plans for locations where the state of deposited fine sediment attribute will therefore need to be undertaken in a more qualitative way, with greater reliance on expert scientific opinion, informed by the outputs from quantitative assessment of sediment loads, water clarity and/or turbidity.

## River microbes (*Escherichia coli)*

We recommend that scenario *E. coli* loads are converted to the four *E. coli* attribute statistics based on the measured or estimated current loads and statistics using the approach outlined above (Equation 3). This recommended approach is the same as that used by the recent national studies of Semadeni-Davies *et al.* (2016, 2018) as already discussed in section 6.5.2.1. It is our opinion that more complicated approaches to estimating *E. coli* attribute statistics given *E. coli* loads is difficult to justify given current knowledge of processes and the available data.

### Macroinvertebrate and fish indices

As discussed in Section 3.5.3, macroinvertebrate and fish indices (MCI, QMCI, ASPM and IBI) are listed in the NPS-FM Appendix 2b as attributes that require action plans. Managing catchment loads of both nutrients and sediment is necessary but generally not sufficient to achieve target states for these attributes. Furthermore, current scientific knowledge and tools cannot provide quantitative predictions about macroinvertebrate and fish indices as a function of catchment resource use and interventions. This is at least partly because these attributes are controlled by many environmental factors and therefore outcomes are inherently difficult to predict. Assessment of the effects of scenarios on macroinvertebrate and fish indices will therefore need to be undertaken in a qualitative but still systematic way, with greater reliance on scientific opinion. Such assessment will ideally use local expertise and locally available knowledge about a range of factors that influence invertebrate and fish communities (e.g., flow, in-stream habitat, riparian, passage and recruitment conditions) in combination with outputs from quantitative assessment of the four key contaminants.

### Ecosystem metabolism (GPP, ER)

Ecosystem metabolism, expressed as both gross primary production (GPP) and ecosystem respiration (ER), is a new attribute introduced in the NPS-FM (2020). Few sites around the country have been monitored for this attribute and only for short duration. There is also currently limited scientific knowledge and insufficient tools for making quantitative predictions about how these attributes respond to resource use and interventions. In our opinion, objectives can be set for GPP and ER, but any scenario assessment of the ecosystem metabolism attributes will need to be very qualitative and will likely be restricted to scientific opinion about likely direction of change. In broad terms, we think it will be necessary to assume that the limits that are established for the Appendix 2a attributes will achieve the ecosystem metabolism objectives. Given the uncertainty associated with these assumptions, it will be appropriate to consider future monitoring of this attribute so that knowledge about it may be improved in future planning processes.

### Lake TN, TP, and Phytoplankton (chlorophyll-*a*)

Lake TN, TP, and Phytoplankton are NOF Appendix 2a attributes requiring limits (Table 1). Input loads of TN and TP for lakes for a scenario can be evaluated from the catchment models by summing all drainage network inflows to each lake. The simplest approach to converting the input TN and TP loads to in-lake concentrations of TN and TP is by using the "Vollenweider-type" models. In our opinion, the models provided by Abell *et al*. (2019a) are an appropriate starting point for the analytical framework. Abell *et al*. (2019a) define simple empirical models that relate calculated input loads of TN and TP to observed concentrations in 166 monitored lakes throughout New Zealand. The models can be used to predict the TN and TP concentrations for any lake given the input TN and TP loads (see Snelder, Whitehead, *et al.*, 2020 for details). In-lake chlorophyll-*a* concentrations can be also estimated from estimated in-lake concentration of TN and TP using the models provided by Abell *et al.* (2019a).

We note that Vollenweider models represent steady state long-run average conditions. This means that the models will predict an in-lake outcome (e.g., a reduction in chlorophyll-*a* concentrations in response to a reduction input TN and TP loads) that in reality may take a long time to be realised due to recycling of in-lake nutrients. If the time to achieve an attribute state becomes a relevant question for detailed attention in the scenario analysis, it is likely that more detailed lake modelling will be required.

**Lake Cyanobacteria (planktonic)**

Lake cyanobacteria (planktonic) is a NOF Appendix 2a attribute requiring limits (Table 1). The attribute is designed to support the value of "human contact" and concerns the health risk of exposure to nuisance blooms. There are published New Zealand interim guidelines for managing the risk of cyanobacteria in recreational fresh waters (Wood *et al.*, 2009) and these were the source of the numeric band thresholds used in the NOF Appendix 2a. The guidelines identify several key factors which can influence the risk of nuisance bloom formation in lakes including the concentration of nutrients (phosphorus and nitrogen), temperature, lake size and degree of wind-driven mixing, although the interaction between these and other factors is complex and poorly understood. The relationship between all these factors and the level of health risk from blooms (expressed as biovolume of cyanobacteria in $mm^3/L$) is complex and we suggest that it cannot be expressed quantitatively at a region-wide scale at this time. We recommend that the analytical approach laid out above for lake attributes TN, TP and phytoplankton is a good starting point to inform development of limits for nitrogen and phosphorus to achieve those attributes but also contribute in broad terms to achieving the nutrient related aspects of the lake cyanobacteria (planktonic) attribute. This approach could be used in combination with a narrative assessment, using locally available knowledge and expert opinion about the extent to which the lake cyanobacteria (planktonic) attribute would be achieved under given scenarios.

If the need arises it would subsequently be possible to add another more detailed layer to the analytical framework by using estimates for the area and average wind speeds of all individual lakes of concern to apply the simple relationships of the MFE (2009) guidelines to estimate the relative probability of nuisance bloom formation in each lake under each scenario. Such an analysis would indicate the relative risk of nuisance blooms in relation to the green (surveillance), amber (alert) and red (action) levels defined in the guidelines and this could be a useful coarse indication of the likelihood that any given scenario would achieve the lake cyanobacteria (planktonic) target attribute states. However, we note this approach would not directly predict target attribute state in the units of biovolume of cyanobacteria in $mm^3/L$ that define the thresholds between A, B, C and D states. More complex lake-specific models, such as the mechanistic DYRESM–CAEDYM lake model would need to be employed if predictions of cyanobacteria biovolume were needed. We have reservations about the use of this sort of modelling approach in the context of implementing the NPS-FM unless very specific issues are raised during the process (see Section 5.4). We recommend starting with the above simple approach and revisiting this question later if necessary.

We note that limits on water takes, lake levels and any other activities that could affect physical conditions in lakes relevant to bloom risk (e.g., lake temperature and mixing patterns) will also obviously be relevant considerations alongside nutrient limits for achieving the lake cyanobacteria (planktonic) target attribute state.

**Lake submerged plants (Native Condition Index, Invasive Impact Index)**

The lake submerged plants attribute is a new attribute introduced in the NPS-FM (2020). It is based on the LakeSPI method for monitoring ecological condition in New Zealand lakes. Scenario assessment for this attribute will need to be qualitative, relying on local knowledge about the range of factors that influence native condition and invasive impact (e.g., current condition, physical habitat and vulnerability to invasive pest species), in combination with outputs from quantitative assessment of N, P and S. In broad terms, we think it will be necessary to assume that the limits that are established for the Appendix 2a attributes will contribute to achieving the submerged plant objectives, provided that other appropriate controls are also employed to manage physical habitat (e.g., water take and lake level limits) and invasive pests (e.g., surveillance and control where necessary). It will be appropriate to consider future monitoring of this attribute so that knowledge about it may be improved in future planning processes.

**Dissolved oxygen (lake bottom and mid-hypolimnetic)**

The lake bottom and mid-hypolimnetic dissolved oxygen attributes are new attributes introduced in the NPS-FM (2020). Available data on these attributes is limited. Scenario assessment of these attributes will need to be qualitative and rely on local knowledge about physical lake conditions and vulnerability to stratification and algae blooms, as well as using the outputs from quantitative predictions of TN, TP and phytoplankton biomass to indicate the likelihood of eutrophication induced deoxygenation. In broad terms, we think it will be necessary to assume that the limits that are established for the Appendix 2a attributes will contribute to achieving the lake dissolved oxygen objectives, provided that other appropriate controls are also employed to manage physical habitat (e.g., water take and lake level limits). It will be appropriate to consider future monitoring of this attribute so that knowledge about it may be improved in future planning processes.

**Estuary trophic conditions**

The NPS-FM does not contain any compulsory attributes for estuaries. However, the NPS-FM is clear that estuaries are receiving environments that should be considered in the limit setting process[19]. Some other regions are working to include NOF-style attributes for estuaries into their NPS-FM planning processes (e.g., Environment Southland and Greater Wellington Regional Council). A recent report by the Parliamentary Commissioner for the Environment has called for an approach that treats estuaries and the waterways that feed into them as a single entity, with every estuary being included in one or more freshwater management units under the NPS-FM process (PCE 2020).

In our view it makes sense to establish attributes for estuaries and incorporate them within the same framework as attributes for fresh waterbodies under the NPS-FM and to use these attributes to set objectives and limits. The estuary trophic index (or similar measure of trophic

[19] NPS-FM Clauses 1.4, 1.5 and 3.5(1)

state) can be evaluated using the model of Plew *et al.* (2018, 2020). Input loads of TN and TP for estuaries can be evaluated by summing all drainage network inflows to each estuary. The load can be converted to estimated potential TN and TP concentration and this can be converted to an index representing macroalgae or phytoplankton depending on whether the estuary is likely to be dominated by benthic or water column primary production. The specificity of the models of Plew *et al.* (2018, 2020) can be updated with estuary specific bathymetry.

Outputs from the above estuary trophic analyses can be used with outputs from assessments of river attributes (e.g., sediment loads) and in combination with expert local knowledge, to make qualitative assessments of effects on a range of other potential attributes for estuaries (e.g., sedimentation, muddiness, sediment oxygen level and area of gross eutrophic zone amongst others).

## 6.6 Economic aspects

### 6.6.1 Indicators

The options and choices in selecting the approaches to use in assessing economic indicators are shown generically in Table 5.

*Table 5: Sample programmes of data gathering prioritised by resources and time available.*

| | **Few resources, little time** | ⟵ | ⟶ | **Major resource, multi-year** |
|---|---|---|---|---|
| **Enterprise scale analysis** | Industry information on enterprises | Industry data and stakeholders, regional economic development agencies | Industry data, stakeholders, expert and/or quantitative modelling | Survey, Industry data, stakeholders, expert or quantitative modelling |
| **Catchment analysis** | Numbers, types and locations of enterprises affected | Aggregation modelling | Aggregation and simple estimation modelling | Aggregation and complex estimation modelling |
| **Flow-on impacts** | | Basic tables with or without some alteration | Tables adjusted with enterprise information | Tables adjusted with survey-based information |
| **Non-market valuation** | | Benefit transfer, potentially cost based approaches. | Benefit transfer, cost-based approaches, simple survey non-market valuations. | Benefit transfer, cost-based approaches and more complex survey or data-based valuations |
| **Implementation and funding** | Broad indicative costing | | | Itemised costing with funding analysis |
| **Who?** | In house, non-expert | In house economist or consultant | In house economist and/or consultant | Significant in-house resources and consultant |

### 6.6.2 Enterprise modelling

Ideally modelling of the impacts of N mitigation will have been undertaken as part of the assessment of current state, since it is most efficient to do this work at the same time as collecting information on current land use and N losses. The recommended approach is described in Section 6.3.2.

For assessing the impacts of P, S and M contamination, relatively simple methods can be adopted, since most of the measures are reasonably independent of farm systems and involve interventions such as fencing, wetlands, tree planting, and management of critical source areas. We suggest that there may need to be some systems level assessment to determine whether removal of land from production, or disruption to farm infrastructure such as water access or tracks is important. We also suggest that it may be appropriate to assess current levels of uptake of the typical mitigations that are applied to limit P, S and M contamination including stream fencing and management of critical source areas. This improves the ability to simulate the baseline conditions and therefore the outcomes under different scenarios.

### 6.6.3 Catchment modelling

Simple aggregation approaches are likely to suffice for current state and any changes which do not require major changes in land use, such as are likely for P, S and M assessment. Depending on the nature of the scenarios, this may also suffice for N, although if outcome driven scenarios (such as achieve 1 mg N /L) are used rather than input driven scenarios (all farms reduce N losses by 20%), or if changes are very substantial, other approaches to catchment modelling may be required. If sufficient enterprise data is available, the use of simple approaches initially will not preclude changes to more complex approaches later if needed.

### 6.6.4 Flow on impacts

It is likely that regional Input/Output (IO) modelling will be sufficient for the Horizons region, with update of the IO model to reflect local enterprise data being our recommended logical first step. More complex multi region or Computable General Equilibrium (CGE) modelling could be adopted later if specific questions arise during the process that need to be addressed, and the updated IO model can be utilised within the CGE model.

### 6.6.5 HRC readiness for economic aspects

HRC has recently updated the region-wide land use map (Manaaki Whenua, 2020). We consider this is appropriate information for establishing the spatial distribution of current land use. We consider that there are currently gaps in terms of accurate and representative data describing current practice, contaminant loss rates and the cost of mitigation across the major resource using enterprises in the Region. To make provision of this type of information tractable, assessments of contaminant load and economic changes would ideally be conducted for agricultural land use categories defined by the combination of land types (e.g., soils and climate) and potential uses (e.g., dairy, sheep and beef, horticulture). This type of information would enable simulation of possible future land use and intervention scenarios using the analytical frameworks we have proposed. In work undertaken for MFE by Harris *et al.* (2021) the Horizons data on land use, soils, N loss and irrigation used by Snelder, Cox, Kerr, *et al.* (2020) were combined with survey data and modelling of economic returns and mitigation costs for N and were incorporated in a hydrological framework that includes the WMSZ, lakes (where they are near outlets for WMSZ) and estuaries. This model and its framework would be suitable for the initial enterprise and catchment aggregation modelling regarding N, but would need to have P, S and M added. It can also be used to manage some of the more complex questions regarding distribution of reductions (allocation) in catchments where large contaminant reductions are required. Additional work would be required to estimate flow on economic impacts.

We are aware that HRC has data describing the magnitudes of 37 major point sources throughout the region (Snelder, Cox, Kerr, *et al.*, 2020). However, there may be gaps in terms of data describing costs associated with upgrading these and data associated with the location and magnitude of smaller point sources and their costs.

### 6.7 Plan effectiveness and contaminant accounting.

We suggest that the approach laid out in sections 6.1 to 6.6 above will provide tools that will play a role in future assessments of plan effectiveness and development of a contaminant accounting system as described in sections 3.6 and 3.7, respectively. For assessing plan effectiveness, monitoring and assessment of the attainment of numeric target attribute states (i.e., a part of the plan objectives) will be a critical step. The conceptual model and analytical framework codify the understanding of cause-and-effect relationships and plan provisions represent hypotheses about how conditions will change (i.e., receiving environment responses) in response management actions (e.g., changes of practice, changes in land use, implementation of mitigation measures). Assessment of plan effectiveness is a science task that involves development of systems of measurement of the changes in conditions (i.e., environmental monitoring), measurement of implementation of the management actions and combining these to show cause and effect.

The analytical framework described in Section 6 will provide a basis to build a ledger that accounts for individual measurable contaminant sources (e.g., estimates of nutrient loss rates from individual farms and discharged from point sources) and of contaminants that can't be individually measured (e.g., diffuse sources of sediment and microbes). We note that the analytical and spatial detail of the analytical framework may influence the detail that can be achieved by the accounting system. For example, the analytical framework may be constructed in a way that represents farm nutrient losses for agricultural land use categories defined by the combination of land types (e.g., soils and climate) and enterprise type (e.g., dairy, sheep and beef, horticulture). However, it may be that plan provisions are such that the contaminant accounting system requires that nutrient loss rates be accounted for at the level of individual farms. This may require some modification (e.g., increase in spatial detail) of the analytical framework as part of developing the contaminant accounting system.

Assessing plan effectiveness and developing accounting systems will be influenced by the final shape of the regional plan and what limits it contains, which cannot be foreseen in detail at this time so will need further attention later in the process. There are also some new requirements for monitoring and accounting systems in the NPSFM (2020) that will need to be worked through by both planning and science teams, and for which subsequent national level guidance may become available during the life of the present process. We suggest that the recommended approach to the science tasks that we have laid out in sections 6.1 to 6.6 provide at least a starting point for developing the details of a monitoring strategy and an accounting system at this time.

## 7 Next steps and recommendations

In this report, we have outlined the role of science in the NPS-FM process and recommended how the science contribution to the process can at least be initiated. We do not consider that the concepts and recommendations presented in this report are a comprehensive, final or tidy blueprint for the HRC to follow. Because the NPS-FM process involves stakeholder input and is expected to be recursive, it is not possible to fully foresee what will be expected of the HRC science team throughout the process. It has been our observation that science input to NPS-

FM implementation, and the policy planning process itself, necessarily progresses incrementally with adaptation at each step. This science plan report offers as much structure as is possible at the outset and some principles that should at least be considered, if not adhered to, at each step in the process.

Keeping in mind that the process that HRC science is involved in requires flexibility and agility, we return here to the high-level science tasks that were outlined in Section 3 and provide recommendations for the next steps. Because the science tasks listed in Section 3 need to be carried out approximately sequentially, we can be firmer about our recommendations for the earlier tasks and we expect that the details of the later tasks will be strongly influenced by what actually occurs during the NPS-FM process. Our recommendations are distinguished below by bold italic text.

## 7.1 Establishing how the policy and planning process will be undertaken, and clarifying the role of science

HRC will undoubtably continue to evolve its roadmap for NPS-FM implementation and associated plan change process. In this report we have specifically identified the need for a multidisciplinary process design team, which we assume will evolve into a process implementation team. We recommend that ***a member of these teams is the science lead (or leads)***. This person's primary responsibility is to understand the high-level process, mobilise the "best" science and ensure that the process itself is realistic about what science can provide and the level of certainty that is achievable.

In our experience, limit setting processes are difficult and stressful for information providers due to incomplete knowledge, high uncertainty, often unrealistic expectations by stakeholders and public, and the ultimate goal of making decisions about contested resources. We recommend therefore ***that adequate management oversight is provided to firstly the process implementation team, and secondly the science team***. We recommend that a key responsibility of the science lead is to manage expectations regarding what the science team can provide. We further recommend that ***a culture is fostered whereby uncertainty is regarded as information provided by the science team, rather than a failure to be helpful***.

We recommend that ***the science team itself includes a lead biophysical modeller and lead economic modeller***. Although this report has not considered social and cultural issues in any detail, we also recommend that ***individuals are identified and designated as leads for these areas as well***. The lead biophysical and economic modeller's responsibilities are to deliver the analytical framework (Figure 4) and then to manage its use to run scenario simulations. We think it is unlikely that the lead biophysical and economic modellers would build or run every component of the analytical framework, but they may be personally responsible for some of these. Therefore, the science team will comprise additional members who are responsible for individual components of the framework. For example, the science team is likely to need more than one catchment modeller to build N, P S and M models and ecologists and water quality experts that can provide various ecological response models and/or narrative assessments. Similarly, for the economic modelling it is likely that the team will need to include farm systems modellers and economists. We recommend that the lead biophysical and economic modellers will need to identify and organise the people that are needed to represent all the component parts of the analytical framework.

We recommend that ***all members of the science team adopt an impartial 'honest broker' approach to the work***. We recommend that this approach is explicitly defined and required by some form of agreed team 'terms of reference' for involvement in the policy development process and that some form of team training on this subject be provided, as well as designing processes within the science development to highlight where biases may be occurring.

## 7.2 Developing an agreed conceptual understanding of the land-water-social system

HRC has considerable conceptual understanding of the land-water-social system through its long-term scientific monitoring and studies, the development of the One Plan, and other policy processes. We consider that scientific approaches taken to date by HRC, for example by the SLUI project and Plan Change 2, are also broadly appropriate to the NPS-FM implementation process. We consider that dramatically more complicated representations of the land-water-social system are not realistic given current knowledge, models, data and the statutory timeframe. We therefore recommend that ***the current understanding of land-water-social system and ways of working are continued and used to implement the NPS-FM***. However, we consider that much of this understanding of the land-water-social system is tacit knowledge and it would be beneficial to the NPS-FM process to spend some time developing a more formal conceptual model. We recommend that ***the development of a formal conceptual model involves mana whenua, communities, and stakeholders in a way that is consistent with their involvement with HRC's implementation of the NPS-FM process in general***. We highlight that that the NPS-FM allows considerable discretion as to the extent that the process is collaborative or consultative and that this is a higher-level decision that will influence this work.

We recommend that ***the development of the conceptual understanding of land-water-social system expands the schematic model shown in Figure 4***. This process should attempt to elicit participants views on the processes that the conceptual model represents such as:

- How contaminants are generated and transported to receiving environments;
- How receiving environments respond to these contaminants;
- What factors cause appreciable differences in contaminant generation and transport and receiving environment responses;
- How regional land and water resources are used and how this contributes to social, cultural and economic conditions;
- How land and water use affect contaminant generation and receiving environment responses and what resource use factors cause appreciable differences in rates of generation and responses;
- What actions can reduce contaminant generation;
- What actions can improve receiving environment responses;
- What are the consequences of requiring actions for enterprises, the community and the region.

We recommend that ***this process be undertaken as early as possible in the implementation process***. We recommend that ***the science lead, lead biophysical modeller and lead economic modeller are strongly involved in this process*** so that, as far as is practical, the ideas that are elicited are then represented by the analytical framework.

## 7.3 Describing current state and trends

We consider that HRC science has a generally adequate understanding of current state and trends of both aquatic environments and resource use. We consider that the recently updated region-wide land use map (Manaaki Whenua, 2020) is adequate information for establishing the spatial distribution of current land use.

In the biophysical domain, we consider that HRC has generally adequate information describing contaminant loads and concentrations and receiving environment responses (e.g., periphyton and invertebrates in rivers, chlorophyll in lakes). There is a lack of data for some NPS-FM Appendix 2b attributes. We recommend that ***thought is given to commencing monitoring of these attributes but that this is seen as a long-term project***. Gaps in information represented by the new Appendix 2b attributes should not be impediments to limit setting. We recommend ***that pragmatic decisions are made regarding setting objectives based on these new attributes and expert judgments are made regarding the actions that are needed to achieve them***. We note that it is generally assumed that more quantitative and detailed assessment for these new attributes may become possible when the plan is reviewed in the future. Indeed, we doubt that statutory timeframes for implementing the NPS-FM could be met if all the new attributes had to be addressed in quantitative detail.

In the economic domain, we consider that HRC has gaps associated with region-wide, consistent and representative data describing current practice, contaminant loss rates and the cost of mitigation across the major resource using enterprises in the Region (particularly agriculture and point sources). We recommend ***that these gaps be rectified by gathering resource use information including:***

1. ***Descriptions of all current resource using enterprises[20].***
2. ***Categorisation of the combination of land types (e.g., soil, climate and topography) and potential land uses to enable application of scenarios over existing enterprises to simulate possible future land use.***
3. ***Representative assessments of contaminant source loads for categories defined by land types and potential uses.***
4. ***Economic information pertaining to:***
    - ***A. Land and water using enterprises likely to be affected by management of NOF attributes (i.e., those discharging N, P, S and M).***
    - ***B. Quantification of current practice for all resource using enterprises.***
    - ***C. Representative assessments of the costs of different interventions for categories defined by land types and potential uses.***

We consider that filling these gaps would greatly improve the robustness of the science contribution to the NPS-FM process. Furthermore, we consider that it is feasible to undertake significant data collection in this area during the initial phase of the process so that the information is ready to be used in the scenario analysis phase of the work. We therefore recommend ***that thought is given immediately to obtaining this information***.

[20] Noting that the land use map already provides this for all agricultural resource use.

## 7.4 Providing support for exploration of options based on scenario analysis

The scenario analysis work in the NPS-FM process is currently some way off in the future. Our specific next steps concerning this task are therefore limited. We highlight that recommendations that are set out in Section 7.1 concern building a science team that is adequately resourced and led so that this work can be done when the time comes.

We have observed in past processes that when there is a well-executed analytical framework, it can be straight forward to run scenarios. However, this often results in running many scenarios in an effort to find the "perfect scenario" or to test minor details. Running multiple scenarios that differ by only small details may not be a good use of resources if differences between them are within the confidence intervals of the analysis. We recommend ***that a systematic approach to scenario analysis is taken and that decisions about what constitutes a worthwhile scenario should be considered by the science team with consideration given to the overall uncertainty of modelling***. Achieving legitimacy with these decisions requires strong communication between the science team and the process implementation team and between the process implementation team, tangata whenua and the wider community . We recommend ***that the process implementation team should consider how decisions regarding the definition of scenarios are made including the level of collaboration or consultation***.

While not gaps *per se*, we also identify two additional aspects of HRC preparedness that require attention: (i) providing interpretation and integration of scenario analysis into the broader policy and planning process, (ii) establishing relevance, legitimacy and credibility of HRC science within the process. The outputs of scenario analyses need to be interpreted and integrated with the higher-level policy and planning processes. This translation process needs to provide a synthesis of what the scenario analysis means to community values. Synthesis will involve combining the scenario analysis results with other forms of assessment to describe impacts on cultural and social values (i.e., the loop back to providing for values shown in Figure 2). An important consideration for HRC science is whether there is the capability and capacity to undertake this role. We consider that it will only be possible to assess the scale of this requirement when there is more clarity on how the policy and planning process will be undertaken.

## 7.5 Building an analytical framework.

It is our opinion that the proposed analytical framework described in some detail in Section 6 will be generally adequate for a regionally comprehensive NPS-FM implementation process. provided that any derived policy is appropriately cognisant of the uncertainties. We recommend ***the use of simple and available models***. Our rationale is that many existing uncertainties associated with both the biophysical and economic aspects of scenario assessments are practically irreducible in the context of HRC's timeframes to respond to the NPS-FM planning requirements. These uncertainties will generally mean that more complicated modelling approaches are unlikely to greatly improve the information that science can provide and are likely to be far more resource hungry than simpler approaches. We acknowledge that there may be circumstances where more detailed modelling may be needed. If during the process it becomes clear that decisions cannot be made unless additional or more complex modelling is undertaken, then this is the time to undertake that additional work.

We consider that the biophysical parts of the analytical framework, concerning catchment contaminant generation and transport processes and receiving environment responses, can be built with existing information. However, considerable effort will be required to calibrate the individual models and to implement the analytical framework's modelling chain such that it is a useable scenario modelling tool. We therefore recommend *that,* ***subsequent to developing the conceptual model, and depending on any additional details that emerge from that process, the HRC science team commences assembling the component models and building the analytical framework described in Section 6***.

We also recommend ***that consideration is given to an initial load reduction requirement analysis that estimates load reduction and potentially associated catchment scale economic impact across the region for a range of potential options for freshwater objectives***. We view this as a logical and useful first step into scenario analysis. While this is not a fully developed scenario exploration because this analysis would not evaluate how the load reductions could be achieved, it does however provide stakeholders with an early assessment of the magnitude and spatial distribution of contaminant load reductions that would be necessary given existing or proposed plan objectives (i.e., target attribute states). A load reduction requirement analysis can help conversations with stakeholders concerning the cumulative nature of the water quality problems and the trade-offs associated with resource use and environmental objectives. It can also provide a good basis to then launch into consideration and design of scenarios that explore how to achieve load reductions through limits to resource use and other interventions.

As discussed in Section 7.4 above, we consider that further data is needed to build the economic and resource use parts of the analytical framework.

## 7.6 Establishing monitoring strategies and contaminant accounting system

We consider that establishing monitoring strategies and contaminant accounting system is not something that HRC needs to, or should, start immediately. This is because the details of these tasks depend strongly on the outcome of the previous tasks. However, the science team should be aware that these tasks will need to be undertaken toward the end of the policy and planning process.

We recommend that once scenario modelling commences, the science team should consider how real-world monitoring could be used to test whether simulated management actions are effective. Scenario modelling should be treated as an opportunity to generate hypotheses about cause and effect. We recommend that ***thought is given to how monitoring can provide data describing both the cause (e.g., changes of practice, changes in land use, implementation of mitigation measures) and effects (i.e., receiving environment responses).*** We note that in the past, HRC has measured implementation of actions as part of the SLUI process and that, coupled with environmental monitoring, provides a basis for "closing the loop" shown in Figure 5.

We recommend that ***when the planning and policy process starts formulating options for limits to resource use, the science team should consider how to construct a ledger(s) that tracks the actual level of resource use***. This task cannot be started until there are clear ideas about what types of limits will be used and how they will be defined and implemented.

# 8 Summary and conclusions

In advance of starting the NPS-FM planning process, HRC has a valuable opportunity to consider its approach to the underpinning science and to evaluate critical gaps. To support

HRC in its considerations, this report examines the role of science in objective and limit-setting processes, building an analytical framework and using this to simulate outcomes to a range of scenarios. This report also highlights the importance of managing uncertainty, identifies gaps in source data and conceptual understanding, and outlines the role of science in plan implementation.

Freshwater objectives and associated limits concern making decisions about the balance between resource use and other values and the best ways to achieve these. Because there are potentially many ways that the tension between resource use and other values can be resolved, finding the most acceptable solution involves exploration of options. The role of science in limit-setting processes is to support and inform this exploration. As such science is critical to objective and limit setting, however there are limitations to the degree of certainty of effects and the precision with which impacts on outcomes and values can be estimated.

In our opinion, objective and limit setting processes should not be seen as an opportunity to generate new fundamental knowledge or to develop greater understanding of how systems work – this will create delays and potentially add to the contentiousness of decisions. Scientific input to policy and planning should be approached as problem solving using existing knowledge, data and models. Areas of uncertainty and unknowns should be treated as information that informs decision-making, and therefore need to be managed and communicated in a way that makes that possible.

Modelling will form a key part of the science input to the NPS-FM process, and both narrative and numeric models will be important. However, given the irreducible uncertainties and time and resource constraints we consider that simple modelling approaches are justified. More complicated modelling could be considered in the case of well-defined questions for which the more sophisticated model has a demonstrable advantage. However, pursuing the more complicated modelling approach initially has several potential drawbacks including hiding the uncertainty and demanding a great deal of time and resources. Models that adequately represent all the processes that are deemed to be relevant will not always be available. Judgements are therefore required concerning the level of analytical detail that is possible and reasonable. Ideally, these judgements should be shared with the process design team so that wider considerations can inform these decisions and responsibility for them can be shared between the process design and science teams.

In our opinion, the ambition of the NPS-FM exceeds current capacity to implement its intent with high precision. Therefore, the initial implementation must do the best possible job given the available information with the intention to refine provisions in subsequent planning rounds in the future. Some aspects of NPS-FM implementation (e.g., some attributes and limit types) will need to be carried out with less detail and more qualitatively than others. The level of uncertainty will also vary across different parts of the implementation process and the final policy provisions. We consider that this is inevitable and needs to be transparent in order to manage expectations from governance, planning and stakeholders. It is also consistent with where other regional councils are in their implementation process.

We consider that HRC science has adequate biophysical information on which to at least embark on the NPS-FM implementation process. We do not think there are obvious biophysical science gaps that can be filled that would significantly improve the information that can be provided to decision makers. However, we do consider that better information can be obtained concerning current resource use, and the costs of intervention (i.e., industry/farm economics, farm system information, cost of mitigations). We recommend ***the collection of detailed current resource use data, if possible, at the scale of individual enterprises***. In addition, we recommend ***the collation of representative assessments of contaminant source loads and costs of any interventions that the planning process may need to consider***. To make provision of this type of information tractable, assessments of load and economic changes would ideally be conducted for land use categories defined by the combination of land types (e.g., soils and climate) and potential uses (e.g., dairy, sheep and beef, horticulture). This type of information would enable simulation of possible future land use and intervention scenarios using the analytical frameworks we have proposed.

Finally, we consider that HRC science needs to establish the legitimacy of its input to the broader policy and planning process. This legitimacy hinges on acceptance of the conceptual model and the analytical framework, including the associated simplifications, assumptions and uncertainties. It is our opinion that this acceptance starts with the development of a conceptual model and will benefit from the inclusion of a range of knowledge sources and expertise, getting a broad consensus about what is known and what is unknown or uncertain and a wide range of plausible management actions that can be represented in future scenarios. We recommend that ***the development of the conceptual model and the analytical framework involves interaction with stakeholders, potentially collaboratively, but if not at least allowing for consultation***.

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# Appendix A Uncertainties associated with current state, catchment models and ecological models

## A1 Uncertainties associated with current state

The precision of assessments of the current state of two measured water quality variables nitrate (NO3N) and dissolved reactive phosphorus (DRP) are shown in Figure 8 and Figure 9 The median and 95$^{th}$ percentile of NO3N and DRP concentrations have been calculated from five years of monthly data at 677 regional council SoE sites distributed across New Zealand. The figures indicate that precision of the calculated median and 95$^{th}$ percentile at each site as the 95% confidence intervals. The plots indicate that the statistics generally have high uncertainty, particularly the 95$^{th}$ percentile values. In percentage terms, the mean lower confidence 95% interval for the estimated median concentrations of DRP and NO3N are -15% and -27% respectively (Figure 8), and the mean upper 95% confidence intervals for DRP and NO3N are 18% and 36% respectively. The sites with largest uncertainties for calculated median concentrations for DRP and NO3N have 95% confidence intervals of -51% to 102% and -57% to 500% respectively. In percentage terms, the mean lower confidence 95% interval for the estimated 95$^{th}$ percentile concentrations of DRP and NO3N are -20% and -15% respectively and the mean upper 95% confidence intervals are 114% and 50% respectively (Figure 9). For both DRP and NO3N, the sites with largest uncertainty for the 95$^{th}$ percentile values have upper 95% confidence intervals greater than 1000%.

One implication of this is the high likelihood of “band switching” which means that a site’s attribute band grading (i.e., A, B, C or D) can change between years due to the imprecision in the statistical estimate (McBride, 2016). The important message is that even the most fundamental element of the information supporting NPS-FM implementation; the definition of measured current state, is uncertain. Sometimes this uncertainty is large, for example where attribute states are defined in terms of the 95$^{th}$ percentile the uncertainties can be larger than 1000%. This uncertainty would only be reducible by increased monitoring. However, this would present an issue in terms of assessing the attribute state for some attributes (e.g., periphyton) because the statistic is often specified in terms of monthly sampling in the NPS-FM (NZ Government, 2017).

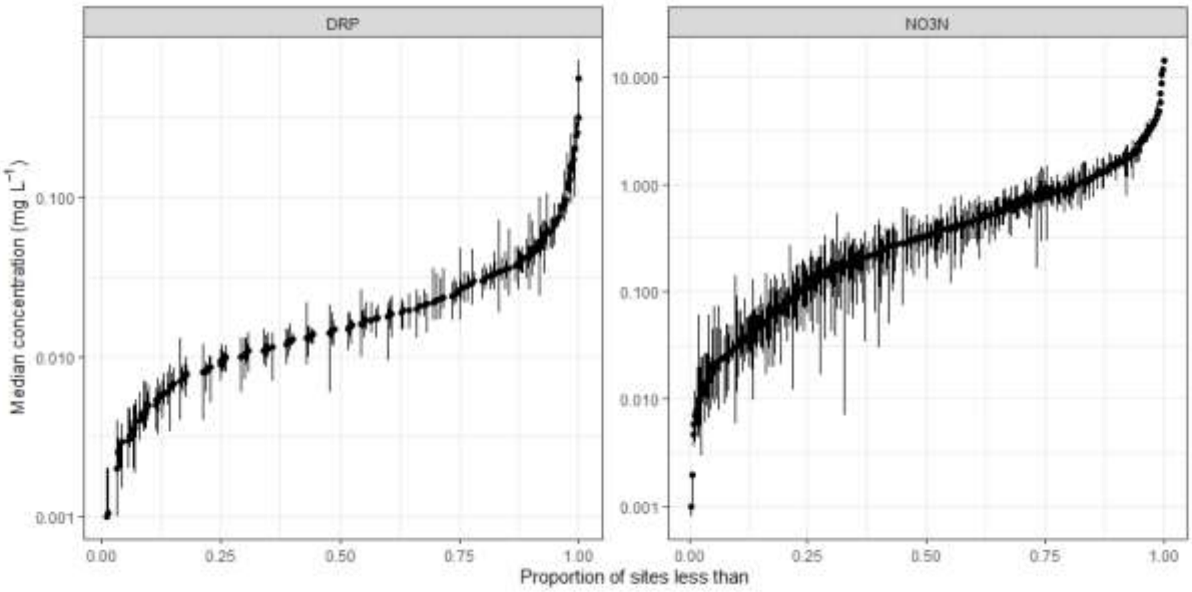


*Figure 8. Cumulative frequency distributions of site median values of NO3N and DRP calculated from five years of monthly observations ending 2017 at 677 SoE sites located throughout New Zealand. The error bars show the 95% confidence interval of the estimated (population) median at each site.*

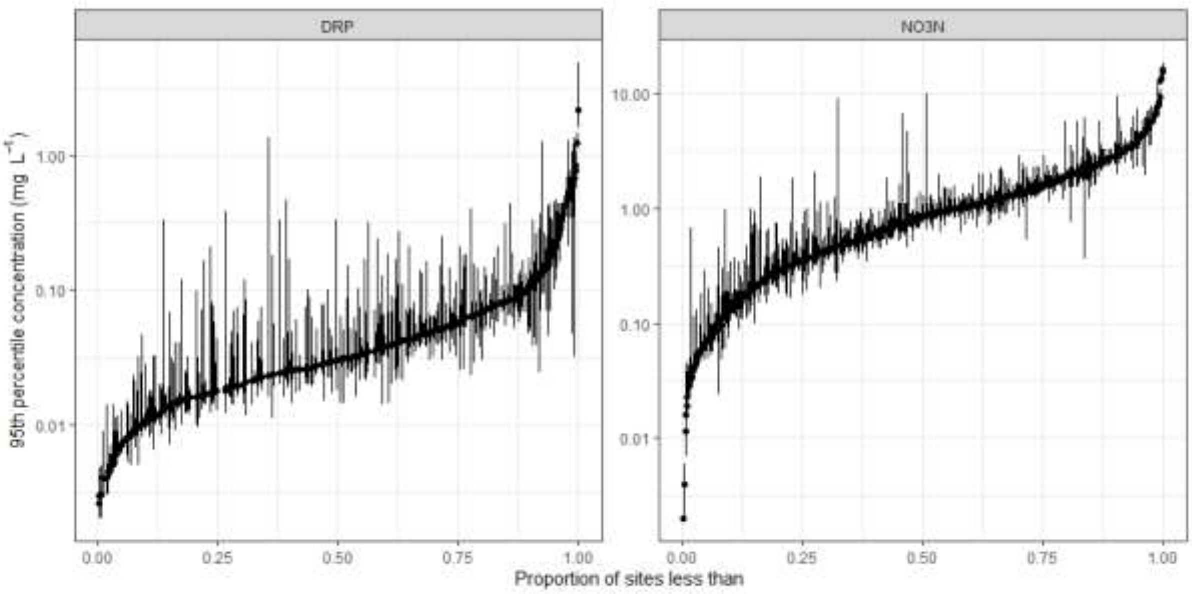


*Figure 9. Cumulative frequency distributions of site 95$^{th}$ percentile values of NO3N and DRP calculated from five years of data ending 2017 at 677 SoE sites located throughout New Zealand. The error bars show the 95% confidence interval of the estimated (population) 95$^{th}$ percentile at each site.*

Load estimates are another aspect of current state that generally have high uncertainty. The calculated loads of NO3N and DRP (as export coefficient i.e., kg ha$^{-1}$ year$^{-1}$) and their 95% confidence intervals at 677 regional council SoE sites distributed across New Zealand are shown in Figure 10. In percentage terms, the mean lower confidence 95% interval for the estimated loads of DRP and NO3N are -14% and -22% respectively and the mean upper 95% confidence intervals are 23% and 32% respectively. The export coefficients with largest uncertainty for DRP and NO3N have 95% confidence intervals of -67% to 145% and -19% to >1000% respectively. We note that Snelder *et al.* (2017) showed that the estimated precision of a load estimate based on measurements (such as those shown in Figure 10) is generally a significant under-estimate of overall uncertainty due to high variability in loads estimated at the same site but for different time period windows.

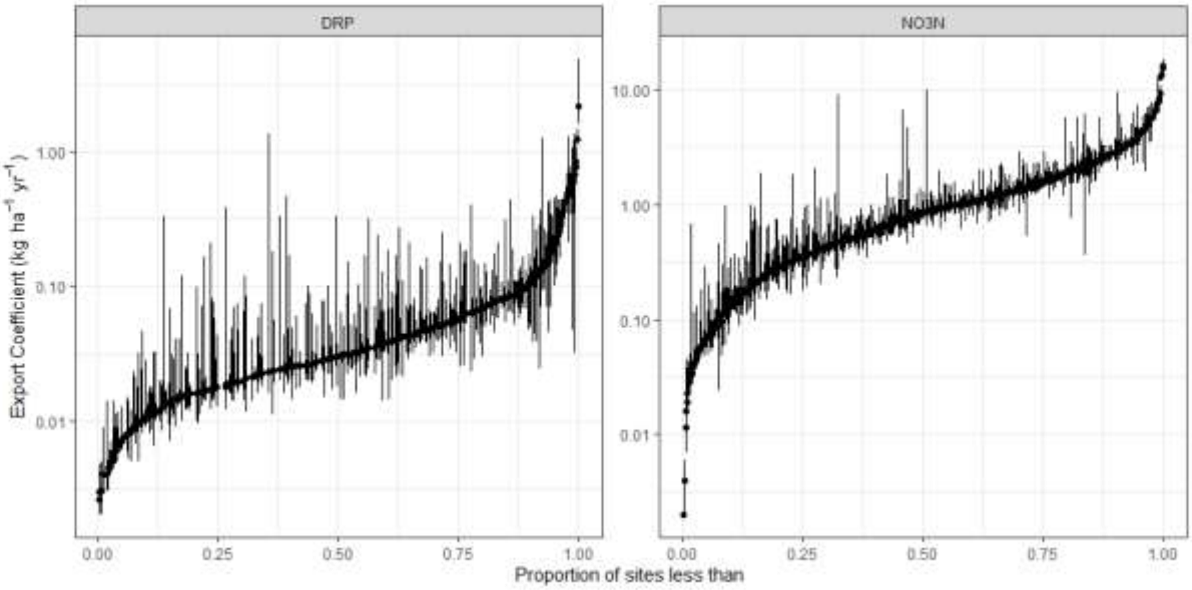


*Figure 10. Examples of uncertainties associated with load estimates for 677 SoE sites located throughout New Zealand. The plots show cumulative frequency distributions of the estimated site contaminant loads, expressed as export coefficients. The error bars show the 95% confidence interval of the estimated load at each site.*

## A2 Uncertainties associated with catchment models

The aim of the catchment model component of the analytical framework is to predict the state of the receiving environments (described by attribute state) for different scenarios (described by resource uses and management actions). When considering water quality issues, a catchment model is used to quantify a contaminant load or concentration. The load or concentration may be converted into an ecological response (e.g., a periphyton biomass in a river or phytoplankton chlorophyll concentration in a lake; see 4.2.3). Often the concentration in the receiving environment is associated with a load because this is a more convenient unit for analysis. Hereafter we refer only to contaminant loads but recognise that loads are linked to, and can be expressed as, concentrations. The catchment model therefore needs to predict the load of contaminant delivered to the receiving environment ($L_e$) for any scenario and predicts the attribute state from this load as represented as:

$$State \sim f(L_e)$$

In a simple catchment model, $L_e$ represents the accumulation of all source loads occurring in the catchment of a receiving environment, modified by any attenuation occurring between the source and the receiving environment. Source loads can be subdivided into 'manageable' ($S_m$) and 'background' ($S_b$) components. The manageable component represents any human activity that can be influenced to either increase or decrease (e.g., farms, urban development, point sources). The background component is natural load and cannot be influenced by management. If we assume that attenuation (*A*) occurs equally to both the manageable and background source loads, the load of contaminants delivered to the receiving environment can be represented by:

$$L_e = (S_b + S_m) \times A$$

As discussed above, loads representing $L_e$ are calculated for river monitoring sites where contaminant concentrations and discharge are measured. For some contaminants $S_m$ can be estimated using component models. For example, in catchments where source loads are farms and where the contaminants of interest are nitrogen or phosphorus, $S_m$ can be estimated for each farm using a model such as OVERSEER.

If we assume that $S_b$ and $A$ are constants, we can estimate their values if we have observations of $L_e$ and estimates of $S_m$. However, because both $S_b$ and $A$ are unknown, there is a range of values of both that represent solutions to the above equation. This problem is known as equifinality and means that there will be uncertainty about a model's performance even when its calibration appears to be sound (i.e., the calibrated model reproduces the observed $L_e$ with acceptable accuracy).

In practice the problems of equifinality in catchment modelling of contaminants is significantly worse than it seems because of the uncertainty in the 'known' factors. First, as discussed above, observations of $L_e$ at river sites are highly uncertain despite being treated as absolute values when the model is being calibrated. Second, if there are lags in the delivery of loads in the catchment, such that current observations of $L_e$ do not reflect the steady state load associated with $S_m$, then the parameter $A$ will incorporate lags. This means that predictions of $L_e$ will under or overestimate the steady state load (i.e., the load representing equilibrium conditions). Third, the estimates of $S_m$ are also highly uncertain. Using N and P as an example, the calibration of the OVERSEER model is itself subject to equifinality, its input data has significant error margins, and the characterisation of management practice is subject to further uncertainty. The error associated with OVERSEER is unknown, but various figures between ±25% – 30% and -40% - +60% are quoted by PCE (2018). These uncertainty estimates are based on expert judgement rather than from data. These three uncertainties result in compounding errors in the predictions, and are very difficult, if not impossible, to reduce.

A further problem with the simple catchment model outlined above is that it is generally not reasonable to assume that $S_b$ and $A$ are constants. We know that both these variables differ spatially, and this variation may be considerable. For example, the Southland Physiographic Zone project describes in detail variation in redox potential of groundwaters in Southland which is associated with variation in nitrogen attenuation rates (Rissmann *et al.*, 2019). However, letting (say) $A$ vary in space can exacerbate the problem of equifinality because it allows more freedom for the model.

Load of nitrogen to come (because of time delays in the delivery of nitrogen (lags) from a catchment) is another source of uncertainty in catchment modelling of water quality. Conceptually, the load of nitrogen can be assessed by developing an understanding of groundwater travel times and a historical time series of nitrogen loss going back in time as long as the groundwater travel time from the most remote point in the catchment. Groundwater travel times can be estimated using catchment to regional scale ground water models.

However, these types of models are complex, resource intensive, difficult to calibrate and produce uncertain outputs. Perhaps more importantly though, it is generally not possible to establish a historical time series of nitrogen loss over the entire catchment or region (Weir *et al.*, 2013). It is our opinion therefore, that from a practical perspective, loads of nitrogen to come cannot be robustly quantified by analytical means. Nevertheless, the load of nitrogen to come can be an important consideration in objective and limit setting processes but the assessment thereof represents a considerable uncertainty.

Predicting the future state of microbes (i.e., *E. coli*) and sediment indicators (e.g., turbidity, water clarity and deposited fine sediment) is more complicated than nutrients because we generally do not have models (like OVERSEER for nutrients) that estimate the manageable source loads ($S_m$). Microbes and sediment are also subject to very large temporal variation often associated with flow (e.g., high concentrations associated with storm events). This makes load estimates very uncertain and generally reduces our ability to discriminate differences in loads generated from different sources (e.g., differences in microbial loads between different types of pastoral land use are often not statistically significant). There are therefore significant unknowns associated with these contaminants – especially associated with source generation and pathways (Wilkinson *et al.*, 2011). In addition, mitigation efficiencies for microbes and sediment have very wide variation, making estimates of benefits of interventions very uncertain (Muirhead, 2016).

## A3 Uncertainties associated with ecological models

An example of large uncertainties associated with an ecological model is shown in Figure 11. In this example, the model represents the relationship between river periphyton biomass and total nitrogen (Snelder *et al.*, 2019). The plot indicates criteria for TN, derived from the model, that will restrict periphyton biomass to the NOF C/D boundary of 200 mg $m^{-2}$ in each of 21 classes of the river environment classification (REC). The restriction has the caveat that there is a 20% risk the NOF C/D boundary of 200 mg $m^{-2}$ will be exceeded. The uncertainty of the TN criteria is shown on the plot as standard errors. Note that the 95% confidence intervals would be approximately twice as wide as the error bars shown on Figure 11.

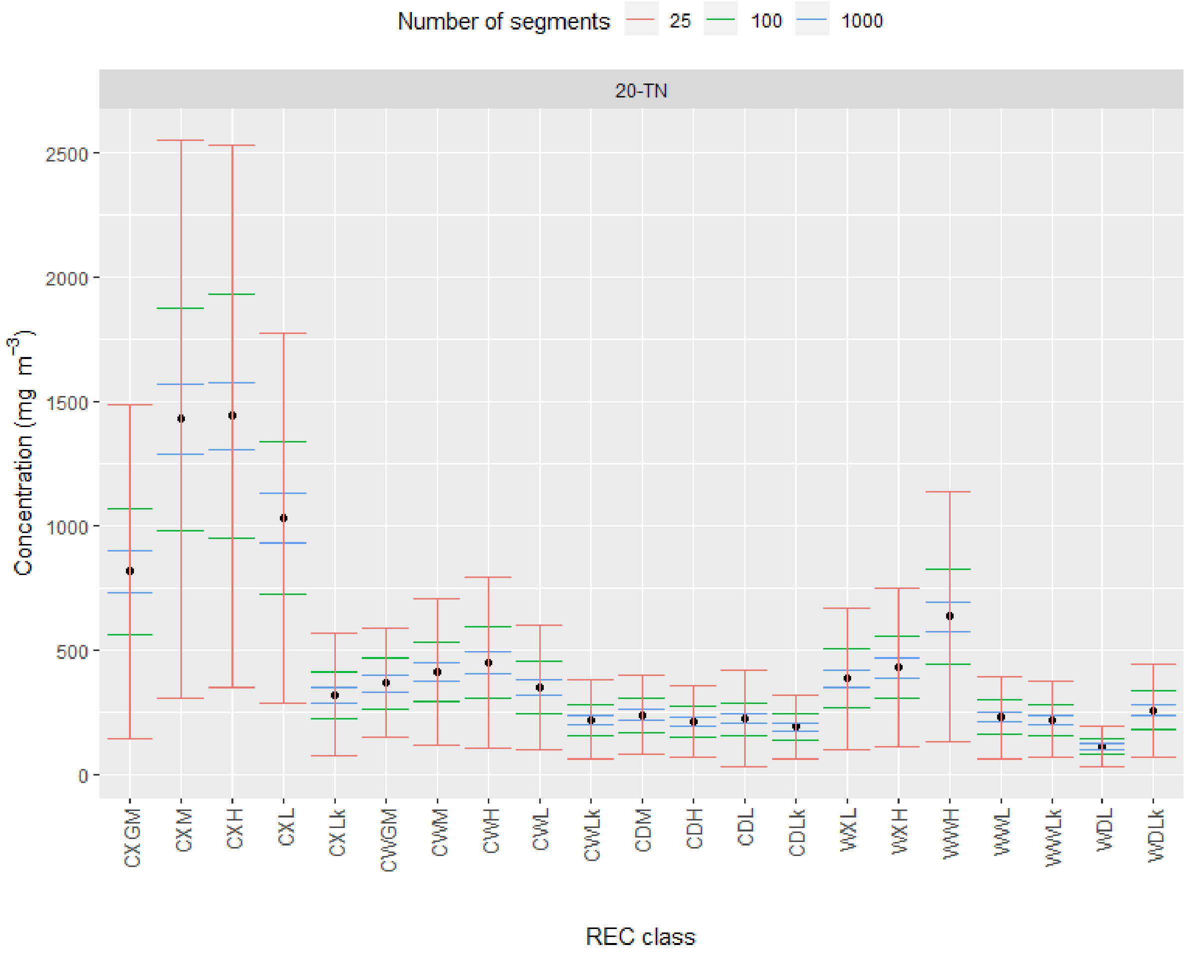


*Figure 11. Uncertainties associated with an ecological model. The plot shows nutrient targets (black dots) for each REC class to achieve the periphyton biomass threshold of 200 mg chlorophyll m$^{-2}$ with a risk of 20% that the biomass threshold will be exceeded. The error bars are the upper and lower confidence limits (as defined by the standard error). These errors depend on the number of segments over which the risk of not achieving the biomass is being evaluated (see Snelder et al., 2019 for details).*