National SCIENCE Challenges

OUR LAND AND WATER

Toitū te Whenua, Toiora te Wai

Measuring the benefits of management actions

Mitigation effectiveness monitoring design (proof of concept development phase)

31 March 2021

Olivier Ausseil, Joanne Clapcott, Zeb Etheridge, David Hamilton, Simon Linke, Fleur Matheson, Mananui Ramsden, Ian Ruru, Diana Selbie, Chris Tanner, Amy Whitehead, Alice Bradley.

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EXECUTIVE SUMMARY

Background

The 2020 "Essential Freshwater" package refers to a suite of rules and regulations released by the New Zealand government in September 2020. The package introduces new rules and regulations to:

- stop further degradation of New Zealand's freshwater resources and improve water quality within five years
- reverse past damage and bring New Zealand's freshwater resources, waterways and ecosystems to a healthy state within a generation.

In partnership with central government, the Our Land and Water (OLW) National Science Challenge (Toitū te Whenua Toiora te Wai) and a range of stakeholders, potential end-users, and experts in freshwater, land management and Mātauranga Māori identified critical knowledge gaps in how the benefits of actions taken to improve freshwater are monitored. Consequently, OLW established three streams of work within its Future Landscapes research theme:

- Working Group 1, Mitigation Effectiveness Monitoring Design: The design of environmental monitoring programmes to enable a holistic and more certain understanding of freshwater outcomes resulting from land management actions taken within a catchment or a freshwater management unit (FMU).
- Working Group 2, Monitoring Technology: Defining what technologies are available (or soon will be) that can be successfully used to monitor the effects of freshwater improvement actions.
- Working Group 3, Enacting Te Mana o te Wai through mātauranga Māori: Ensuring the integrity of Te Mana o te Wai is upheld, supporting the mauri of our wai to thrive and flourish through creating the infrastructure and tools needed to ensure that Te Mana o te Wai is given effect in its implementation and how it is able to lead monitoring of freshwater quantity and quality through the mana whenua of that place/ waters.

This report provides a summary of the work undertaken by Working Group 1 as of 31 March 2021.

Key research topics

The project addressed the following key research topics:

- Review existing examples of mitigation effectiveness monitoring;
- Develop a framework for the design of monitoring programmes to assess the effectiveness of on-the- ground management actions (taken on land, at the land/water interface and within the water bodies) on a range of freshwater environmental indicators of ecological, recreational and cultural values;
- Test and verify the framework.

Literature review

The review of scientific literature and information sourced directly from key stakeholders supported the view that dedicated mitigation effectiveness monitoring was not a standard practice in New Zealand. Key conclusions from our review indicated that:

- Monitoring and evaluation for restoration projects is often not required or not formally reported, and many restoration programmes do not include enough funding for monitoring in their original scope.

- There are no standardised practices for monitoring of the freshwater outcomes of mitigation or restoration programmes.
- Land and water managers have tended to rely on existing "status quo", rather than targeted, monitoring programmes; however, their spatial scale is often inadequate to specifically measure the effectiveness of a given mitigation plan.
- Mitigation plans should have measurable goals and enable targeted to evaluate success or failure of restoration actions.
- Monitoring should be targeted at restoration actions, should include pre- and post- restoration and control vs. impact sites monitoring and involve stakeholders.

Stakeholder Engagement

Communication and engagement with potential end-users and stakeholders was considered very important for the success and future uptake of the tools and resources created as part of this project. Over 25 presentations, webinars, workshops and meetings (on-line and in-person) were run to increase the project's visibility and invite stakeholder input into each phase of the project.

Mitigation Effectiveness Monitoring Plans

A five-step process was developed to answer the key question asked of Working Group 1: "Have the mitigation actions resulted in improved freshwater outcomes?":

- Step 1: Define the monitoring purpose. Clearly identifying and articulating the question(s) the monitoring plan will need to address is critical to its development.
- Step 2: Identify the catchment's values and natural characteristics: This is about assembling data and information to build a "state of knowledge" picture of the catchment or waterbody.
- Step 3: Characterise and quantify potential effects of mitigation. This step assumes that the mitigation plan contains a set of spatially explicit management actions and improvement objectives. Wherever possible, this step should be undertaken on the basis of information contained in Farm Environmental Plans (FEPs).
- Step 4: Determine the likelihood of detecting change. Use information and analysis gathered as part of the first three steps, to determine the likelihood of detecting a change, and the time required to detect it, in freshwater attributes and indicators at various locations in the waterbody and/or catchment.
- Step 5: Develop the monitoring plan: a general 3-tier structure for mitigation effectiveness monitoring plans is proposed:
  - Tier 1: Monitoring and detecting early response.
  - Tier 2: Monitoring medium- to long-term freshwater outcomes.
  - Tier 3: Mitigation longevity and sustainability.

To assist with the implementation of the five-step process described above, a range of information repositories, Decision Support Tools (DSTs) and modules were created:

- An overall DST guiding the user through the various components and modules;
- Information repositories and resources, including:
  - freshwater values, attributes and indicators and their interrelationships
  - a repository of mitigation action effectiveness
  - a statistical analysis module, focusing on change detection
  - a contaminant load estimation module
  - guidance on monitoring edge-of-field mitigation devices.

Due to timing constraints, only preliminary and exploratory work was able to be initiated with regards to how mātauranga Māori measures may be used to monitor the effectiveness of freshwater mitigation or restoration. Examples of this exploratory work included:

- Incorporate the Mauri Compass indicators into the database linking freshwater values, Attributes and Indicators as an exploratory example of how Māori knowledge systems may be incorporated into mitigation effectiveness monitoring.
- Use a theoretical /simplified scenario to explore how monitoring design and technologies may be used to monitor the outcomes of a land mitigation plan aiming at improving mahinga kai in a small catchment.
- Identify avenues for future work.

Three specific Decision Support Tools were developed:

- A riparian mitigation DST, providing supporting information, analysis and a case study following the five-step process in the context of a mitigation plan based on riparian management of a stream network.
- A Lake Mitigation DST, providing guidance on monitoring the effectiveness of combinations of 6 in-lake interventions for 6 lake types and 7 freshwater attributes selected as a representative subset of conditions commonly encountered in New Zealand.
- A groundwater Nitrate DST, which includes analysis modules on lag time, time series power, Forward-looking Counterfactual Inference (FCI) and spatial distribution and a case study, demonstrating the above analyses in the context of regulatory reductions of on-farm losses of nitrogen via Farm Environmental Plans in the Canterbury Region.

All components and resources that compose the Monitoring Design Framework are hosted in an online platform (Atlassian Confluence).

Recommendations

The Working Group made recommendations or suggestions for potential further work to develop specific elements of the framework beyond the “proof of concept” stage and develop and integrate user-ready tools to guide the design of mitigation effectiveness mitigation plans, including:

- Refine the definition and integration of mitigation actions in FEPs and linkages with existing on-farm mitigation assessment and monitoring tools and projects.
- Further develop and expand the riparian, lakes and groundwater DSTs.
- Develop an end-user interface to enable direct use by a range of users in specific projects, in particular community-led projects.
- Further development of a mātauranga Māori-based monitoring framework (including guidance on who should undertake the monitoring and managing sensitive information), integration with the framework developed during this “proof of concept” phase and application to case studies.
- Further consideration of integration of monitoring (including mātauranga Māori / mahinga kai) into the Farm Environmental Plan (FEP) process, possibly using the Te Waihora/Lake Ellesmere catchment, in Canterbury as case study.
- Further explore the potential to combine modelling and monitoring to report on progress towards freshwater outcomes, particularly in situations where changes may not be measurable in the short- to medium- term.
- Further integration with the work produced by the Technology working group, including how continuous or event-based monitoring may influence change detection power, and integration of monitoring technology, costs, and change detection analyses into a monitoring network optimisation routine.

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1 Introduction and background

1.1 Our Land and Water National Science Challenge

The Our Land and Water (OLW) National Science Challenge (Toitū te Whenua Toiora te Wai) has a vision which looks to a future where catchments contain mosaics of land uses that are more resilient, healthy and prosperous than today. This is a future in which all New Zealanders can be proud of the state of our land and water and share the economic, environmental, social and cultural value that te Taiao offers.

Te Taiao is the environment that contains and surrounds us. It has four major components, Whenua (land), Wai (water), Āhuarangi (climate) and Koiora (all living communities). It encourages us to aspire to a future where humanity and the natural world sustain each other in an interconnected relationship of respect.

Large parts of New Zealand are dominated by single land uses that have put the wellbeing of our land, water, climate, and communities at risk. To underpin the vitality of te Taiao we require landscapes and catchments to be more diverse than they are today. When we use holistic models of assessment to consider what the land is most suited for, outcomes that support and reinforce the concept of vitality are improved. However, land stewards have difficulty envisaging the range of land use opportunities (both known and unknown) and weighing up the trade-offs in a holistic manner. Part of achieving vitality in our landscapes will require an understanding of how management practices interact with land and water, and how targeted interventions can be verified in a catchment context. Future landscapes will involve a mix of old and new land uses or practices. Some of the new land uses and practices do not yet exist. Their emergence and uptake in combination with others relies on a mix of science that demonstrates the (economic, environmental, social and cultural) viability of mixed systems and those willing to take a chance on them. Without both elements working in tandem, nothing will change.

Three key areas of investigation in the Future Landscapes theme will provision land stewards with the information and tools required to achieve a diverse (and appropriate) mosaic of future land use.

- **Flagship Concept:** Providing tools for land stewards to assess diverse land use options, to identify the best land use to support the vitality of te Taiao
- **Theme Impact by 2024**: Decisions on land-use change and management practises can be made with confidence that they will lead to improvement in te Taiao
- **Theme Impact by 2030**: The vitality of te Taiao is improving in response to our decisions as land stewards

Table 1: Key elements of Our land and Water National Science Challenge's Future Landscapes theme.

Critical Element	Current gap/need	Research focus (refer Attachment 1 for detail)	How will land stewards use this research	OLW investment
Be able to see what diversity is possible, to match land use to opportunities to support the wellbeing of te Taiao.	Ability to relate values-based decision making for land use options (at multiple scales) to policy requirements and potential benefits/impacts for te Taiao.	Developing a holistic understanding of land use opportunities. Matching this understanding to changes in the health of whenua and wai. Visualising and informing options for change in on-farm decision-making.	To test land use options in farm- and catchment-scale scenarios, in ways that facilitate holistic decision-making. To meet short and long-term policy requirements, at farm (e.g. FEP) and catchment scale.	$12.7m (aligned research = $11.8m)
Understand and model the management of healthy land and water.	Cross-sector, nationally applicable data that is transferrable across scales. A nationally consistent design for monitoring water health to detect change. The ability to transfer inputs and outputs between different land and water resource management models.	National maps and classifications relating to N, P, *E coli* and sediment delivery from source to sink. Translation of mana whenua assessments of water health into regional land use decision-making. Fine scale environmental monitoring networks that quickly and accurately reflect land use and practice change. Interoperable modelling to track N, P, *E coli* and sediment movement at all scales.	To test land use scenarios, make plans for investment, and meet NPS-FM and Carbon Zero requirements. To get a holistic picture of ecosystem health and see where land use practices will benefit water health. To use the best available models to understand and model the management of land and water.	$8.5m (aligned research = $86m)
Identify high-value land use options that support the health of te Taiao. (Crossover with Theme 2)	Where to grow high-value, healthy raw ingredients that fulfil identified market opportunities. How to grow these products in ways that benefit te Taiao.	Isolating and refining the areas able to grow the raw ingredients of healthy, high value land options. Determining the potential effects of healthy, high value land options on te Taiao.	To identify high-value land use options that have a lower footprint than present land use.	$2m (aligned research = $1.8m)

1.2 2020 Essential Freshwater reform

The 2020 "Essential Freshwater" package refers to a suite of rules and regulations released by the New Zealand government in September 2020. The package introduces new rules and regulations to:

- stop further degradation of New Zealand's freshwater resources and improve water quality within five years
- reverse past damage and bring New Zealand's freshwater resources, waterways and ecosystems to a healthy state within a generation.

New National Environmental Standards for Freshwater and a new National Policy Statement for Freshwater Management aim at preventing further loss and degradation of freshwater habitats and introduce controls on some high-risk activities. These came into force on 3 September 2020, along with new stock exclusion regulations and regulations that require real-time reporting for water-takes data.

The Essential Freshwater package was gazetted in September 2020, i.e. during the early stages of this project. The project's expression of interest document requires that the work "be consistent with the freshwater legislative framework at the time of writing the outputs". Accordingly, the Essential Freshwater Package was reviewed, with a focus on restoration/improvement and monitoring requirements. Details of the review can be found in Section 3.2 of this report.

1.3 Project inception

In partnership with central government, the Our Land and Water (OLW) National Science Challenge (Toitū te Whenua Toiora te Wai) convened a series of "scoping" workshops and hui in February and March 2020, assembling a range of Stakeholders, potential end-users, and experts in freshwater, land management and Mātauranga Māori.

These workshops identified critical knowledge gaps in the design of environmental monitoring capable of verifying the impact of action on the ground as well as the most appropriate technologies for facilitating verification of actions. Consequently, OLW established three streams of work within its Future Landscapes research theme:

<u>Working Group 1</u>: Monitoring Design: The design of environmental monitoring programmes to enable a holistic and more certain understanding of freshwater outcomes resulting from land management actions taken within a catchment or a freshwater management unit (FMU).

<u>Working Group 2</u>: Monitoring Technology Defining what technologies are available (or soon will be) that can be successfully used for the measurement of holistic freshwater values, as related to freshwater use or contaminant discharge; with specific regard to how useful these technologies would be for regulating water use or contaminant discharge.

<u>Working Group 3</u>: Enacting Te Mana o te Wai through mātauranga Māori. Ensuring the integrity of Te Mana o te Wai is upheld, supporting the mauri of our wai to thrive and flourish through creating the infrastructure and tools needed to ensure that Te Mana o te Wai is given effect in its implementation and how it is able to lead monitoring of freshwater quantity and quality through the mana whenua of that place/ waters.

Following the workshops, summary documents were prepared, leading to the development and subsequent released of documents seeking Expressions of Interest (EOI) from experts interested in joining the Working Groups or the Advisory Group (AG) for Working Groups 1 and 2, as follows:

- Two EOI documents were released in early June 2020, seeking expressions of interest to form part of WG1 and WG2 and an AG covering both these working groups;

- An EOI document for WG3 was released towards the end of September 2020. The WG3 members were still being appointed at the time of writing.

Twenty-six applications were received for WG1, and 12 for the AG (18 for WG2). Applications were reviewed by a panel composed of OLW management and Working Group leads. All WG1, WG2 and AG appointments were confirmed by mid-July 2020.

1.4 Scope of this report

This report provides a high-level summary of the Mitigation Effectiveness Monitoring Design project and its outputs as of 31 March 2021. The actual components and resources that compose the Monitoring Design Framework are hosted in an online platform (Atlassian Confluence). This report includes multiple links to specific components of the monitoring design framework within the Confluence space, which can be accessed here: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/overview?homepageId=49348612

2 The Project

2.1 Aim and research topics

Overall project aim: The design of environmental monitoring programmes to enable a holistic and more certain understanding of freshwater outcomes resulting from land management actions taken within a catchment or a freshwater management unit (FMU).

Key research topics addressed by the project are:

- Review existing sources of environmental data and monitoring networks and their purpose and objectives. The review should focus on identifying catchments/examples of monitoring programmes specifically focused on management actions aiming at improving freshwater quality and/or ecological outcomes;
- Develop a nationally consistent framework for the design of monitoring programmes to assess the effectiveness of on-the- ground management actions in affecting the state and direction of travel for a range of freshwater environmental indicators of ecological, recreational and cultural values. The framework must be applicable nationally and be consistent with the principles of Te Mana o te Wai;
- Test and verify the Monitoring Design Framework in at least three catchments or sub-catchments that cover a range of characteristics and conditions (including exemplar At Risk Catchments). This means applying the Framework to develop monitoring programmes in each of these catchments or sub-catchments, but excludes the implementation of the monitoring programmes.

The expected level of readiness is that of a "proof of concept" monitoring design framework, as opposed to a fully end-user ready tool.

End-users: The Advisory Group identified Regional Councils, Iwi, and multi-agency catchment groups as the key end users for the MDF. A reasonably high level of end user technical proficiency was assumed for the initial development of the project. A "simplified" module may be developed in the future.

2.2 Scope

The project's scope includes:

- All freshwater systems, including groundwater
- A range of on-the-ground management actions, including actions taken on land (e.g. farm management), at the land/water interface (e.g. riparian management) and within the waterbodies (e.g. in-lake management)
- The monitoring of freshwater indicators relating to ecological, recreational and cultural freshwater values.

The scope does not include:

- Defining what mitigation actions should happen, where or when, or the freshwater objectives of a mitigation plan. These are treated as an input into the Monitoring Design Framework
- Defining or identifying freshwater Values, Objectives or outcomes for a waterbody or a catchment. This is a complex process mandated by the NPS-FM and falls outside the scope of this project. Again, it is assumed that the freshwater Values, and objectives will be identified separately and are treated as an input into the Monitoring Design Framework
- Designing or re-designing existing "routine" (e.g. State of the Environment) monitoring programmes

- Establishing dose-response relationships (e.g. between water quality and ecological indicators)
- The development of catchment models
- The development of field protocols (rather reference is made to existing national standards or protocols)
- Urban, estuarine or coastal environments
- The development of an interactive, end-user ready platform/interface

Initial work sessions highlighted the very broad scope and complex nature of this project. The project essentially needs to characterise relationships between a broad range of mitigation actions (e.g. on-farm, edge of field, forestry, in-river, in-lake) on a range of freshwater indicators and values (the list of 14 values and 22 freshwater attributes in the NPS-FM forming the starting point), in the context of a broad range of freshwater environments (rivers, lakes and groundwater, each with sub-types), biophysical (e.g. surface vs groundwater pathways), social and cultural environments. The tool developed also needs to be usable/accessible by a broad range of end-users. The strategy adopted to deal with this very broad scope was to exercise judgment as to what components could sensibly be dealt with within the time and budget constraints of the project and identify components that will need to be addressed through further work.

The scope of work required as defined in the EOI requires that the monitoring design must incorporate measurements of "Environmental indicators and information, including, but not limited to freshwater attributes from the National Objectives Framework (Appendix 2 of the NPSFM) and mātauranga Māori records, measures and indicators". The three working groups were structured so that Working Group 3 would provide input and guidance on mātauranga Māori into the work undertaken by working groups 1 and 2. Two members of working group 3 were delegated to working groups 1 and 2 in November 2020.

Given the timing of this appointment, only limited work was able to be undertaken, and the approach taken was to focus efforts on exploring how mātauranga Māori may be used to monitor the effectiveness of freshwater mitigation or restoration. Examples of this exploratory work included:

- Incorporate the Mauri Compass indicators into the database linking freshwater values, Attributes and Indicators (as described in Section 4.4.1) as an exploratory example of how Maori knowledge systems may be incorporated into the Monitoring Design Framework;
- Develop a theoretical /simplified scenario to explore how monitoring design and technologies may be used to monitor the outcomes of a land mitigation plan aiming at improving mahinga kai in a small catchment (Section 4.5.4)
- Identify avenues for future work, as described in Section 4.5.5.

2.3 Project Plan Deliverables

The project's final milestones and deliverables (Table 2) include:

1. A final Monitoring Design Framework.

As described above, the level of readiness is that of a "proof of concept", as opposed to a fully end-user ready tool. Given the very broad scope of the project, and the time and resources available, the approach taken was to focus on the development of an overall framework and "proof of concept" -level development of tools and examples. The various components and resources that compose the monitoring Design Framework are hosted in an online platform[1] (Confluence).

[1] https://olw-decision-tree.atlassian.net/wiki/home

2. A Manuscript or report, with emphasis placed on public dissemination and presentation of the results

Delivery of this milestone is composed of:

- A summary report (this report) providing a high-level summary and guidance about the Monitoring Design Framework hosted on-line;
- A manuscript focusing on the monitoring and evaluation of in-lake restoration. The target journal is: *Inland Waters* (special issue on Preventative Lake Management)
- Extensive end-user engagement and consultation to receive input and feedback and ensure dissemination of results as described in Section 2.4.

3. An executive summary in plain language, prepared in collaboration with OLW Communications Advisors.

The overall project timeline and overall project plan is presented in Figure 1. Contractual Milestones are in Table 2 below.

Table 2: Working Group 1 Milestones and Deliverables

Milestones and Deliverables

Period	Milestones	Deliverables
FY 2020/2021 Quarter 1 (Jul, Aug, Sept)		
July/Aug/Sep 2020	M1.1: Recruitment process for Working Group and Advisory Group M1.2: First Advisory Workshop and Group Meeting M1.3: First Working Group Workshop and Meeting M1.4: Scope of work and Sub-subcontracts for members of the Advisory Group and the Working Group completed M1.5: Project Planning finalised M1.6 Stakeholder Engagement planned	D1.1 Brief progress report, including outline of project plan
FY 2020/2021 Quarter 2 (Oct, Nov, Dec)		
Oct/Nov 2020	M2.1: Review existing sources of environmental data and monitoring networks and their purpose and objectives. M2.2: Stakeholder engagement underway M2.3: Second Working Group (WG1) workshop and meeting M2.4: Conceptual MDF M2.5: Second Advisory Group workshop and meeting M2.6: Test catchments (including "At Risk" catchments) identified for later trial of MDF.	D2.1 Concept of Monitoring Design Framework completed – presented to Advisory Group and the Challenge.
Dec 2020	M2.7 Draft Monitoring Design Framework (MDF) completed M2.8 Third Advisory Group workshop and meeting held. M2.9 Desktop validation of MDF on Test catchments completed.	D2.2 Brief progress report, including outline of draft MDF
FY 2020/2021 Quarter 3 (Jan, Feb)		
Jan – March 2021	M3.1 Final Monitoring Design Framework.	D3.1 Manuscript submitted to a high-quality journal (preference) or a high impact report co-designed with key stakeholders. Emphasis is placed on public dissemination and presentation of the results, by providing open access to the results for use by the relevant New Zealand communities. D3.2 Prepare an executive summary in plain language, submitted to the Challenge's Senior Communications Advisor to guide outreach to Challenge stakeholders and media.

Table 3: Composition Advisory Groups and Working Groups 1 and 2.

<table>
<tr><td colspan="2">Advisory Group</td></tr>
<tr><td>To advise on:
▪ Project scope, approach and deliverables
▪ Links with other research and resource management projects
▪ Stakeholder / end-user engagement
▪ Integration with mātauranga Māori
▪ Test catchments</td><td>• Alice Bradley, Ministry for the Environment
• Craig Depree, Dairy NZ
• Julie Everett-Hincks, Otago Regional Council
• Jane Higgins, Ngāi Tahu Forestry
• Michelle Hodges, Waikato River Authority
• Tanira Kingi, Scion Research Institute
• Scott Larned, NIWA
• Roger Young, Cawthron Institute</td></tr>
<tr><td colspan="2">Working Group 3 members delegated to Working Groups 1 and 2:
▪ Ian Ruru, mauricompass.com
▪ Mananui Marsden, Environment Canterbury</td></tr>
<tr><td>Working Group 1: Mitigation Effectiveness Monitoring Design
▪ Olivier Ausseil (Project Lead) Aquanet Consulting
▪ Alice Bradley, Ministry for the Environment
▪ Joanne Clapcott, Cawthron Institute
▪ Zeb Etheridge, Komanawa Solutions Ltd
▪ David Hamilton, Griffith University (Aus)
▪ Fleur Matheson, NIWA
▪ Diana Selbie, AgResearch
▪ Chris Tanner, NIWA
▪ Amy Whitehead, NIWA</td><td>Working Group 2: Monitoring Technology
▪ Rogier Westerhoff (Project Lead), GNS Sceince
▪ Abigail Lovett, E+E Science
▪ Joerg Wicker, University of Auckland
▪ Kohji Muraoka, James King – Ministry for the Environment
▪ James Brasinger – University of Canterbury
▪ Magali Moreau – GNS Science
▪ Mark Hamer – Waikato Regional Council
▪ Maryam Alavi – Plant and Food Research
▪ Moritz Lehmann – Xerra
▪ Neale Hudson – NIWA
▪ Richard Muirhead - AgResearch</td></tr>
</table>

2.4 Advisory Group

A small advisory group of stakeholders and technical experts was appointed to cover both Monitoring Design and Monitoring Technologies. The role of the Advisory Group was to attend and contribute at regular meetings and forums, by challenging thinking and sharing their expert advice.

Three Advisory Group meetings were held on 6th August and 20th October 2020 and 23rd February 2021.

At each meeting, an update from the two working groups were presented, and the following topics were explored:

- Project scope, approach and deliverables
- Links with other research and resource management projects
- Stakeholder / end-user engagement
- Integration with mātauranga Māori
- Test catchments
- Work undertaken to date

2.5 Project Team

Twenty-six applications were received for the Monitoring Design working group in response to the EOI. Applications were reviewed by a panel composed of OLW management and Working Group leads. Working Group members were appointed on the basis of their expertise and experience to cover the following areas of expertise:

- Land (on farm, edge-of-field), interface and in-lake/in-river mitigation actions
- Stream, rivers, lakes and groundwater
- Freshwater quality and ecology
- Statistical analysis.

In addition, two members of working Group 3 were delegated to working groups 1 and 2 to guide the incorporation of Te Mana o Te Wai principles and mātauranga Māori into the Monitoring Design and Technologies projects.

2.6 Stakeholder Engagement

Communication and engagement with potential end-users and stakeholders engagement was considered very important for the success and future uptake of the tools and resources created as part of this project. A large number of presentations, webinars and meetings (on-line and in-person) were run to increase the project's visibility and invite input and feedback from potential end-users and stakeholders, to:

- Initially, receive input regarding current practices, state of knowledge and gaps in the monitoring and evaluation of mitigation effectiveness;
- Receive input regarding needs and expectations;
- Test and receive feedback on the usefulness and applicability / workability of this phase (proof of concept) of the project;
- Receive input on deliverables and priorities for potential further phases of the project.

Some of this engagement is summarised in Table 4: below.

Table 4: Summary of Stakeholder engagement and consultation

Contact	Description	Date
Regional Sector Special Interest Groups/ Resource Managers	Emails to Regional Sectors Special Interest Groups (SIGs) (surface water, groundwater, land management, land monitoring), Resource Managers Group (RMG) Discussions with SWIM and Groundwater Forum convenors	August / September 2020
Groundwater Forum	Presentation for Groundwater Forum	26 August 2020
Regional councils and Ministry for the Environment	Webinar hosted by MfE, invites sent to Regional SIGs Follow up conversations	September /October 2020
Tasman DC, Annette Becher	Individual discussion on how TDC can assist	10 September 2020
Department of Conservation	Meeting about alignment with Jobs for Nature programme	14 September 2020
LMAR Project	Initial discussions re. consistency of management action records. Agreed to catch up regularly	September / October 2020
NZHS	E-current Newsletter with project descriptions	1 November 2020
NZFSS/NZHS conference	Presentations on the project for scientific community, incl. regional councils	3 December 2020
Workshop Gisborne	Workshop with GDC and WG3 on the involvement of one or two Mauri Compass test studies and inclusion of Mahinga Kai monitoring in farm plans (Wolfgang Kanz – GDC; Ian Ruru, Mananui Ramsden)	4 February 2021
Presentation to SWIM	Presentation focusing on WG1, inviting feedback & input	11 February 2021
Environment Canterbury **Bay of Plenty Regional Council** **Greater Wellington Regional Council**	Three half day workshops with Regional Councils Science/Land management/Policy teams. Testing usefulness /applicability of tools developed to existing/upcoming regional council projects and processes	ECan (24 Feb) BoPRC (25 Feb) GWRC (3 March)
Freshwater Implementation Directors Group	Presentation to Freshwater Implementation Directors Group	26 February
Ministry for the Environment	Presentation to MfE Staff	18 March

3 Literature review

The first research topic for this project was a review of existing sources of environmental data and monitoring networks and their purpose and objectives. The focus of this review was to identify catchments/examples of monitoring programmes of management actions aiming at improving freshwater quality and/or ecological outcomes.

In addition, the 2020 Essential Freshwater package came into force during the early phases of the project (September 2020). The scope of the project specified that the outputs of this project should be consistent with with the requirements of the freshwater legislation in force at the time of writing and the outputs be compatible. As a result, a high-level review of the freshwater improvement objectives and associated monitoring and reporting requirements set out in the 2020 Essential Freshwater package has been undertaken and is presented below.

Where required, specific literature reviews were undertaken for the development of "proof of concept"-level tools and resources. These literature reviews and reference lists are provided in the relevant components of the framework hosted on the Confluence space, rather than in this report. In some instances, further literature reviews on specific points would be required for development beyond the "proof of concept" level. These reviews fall outside the scope and resourcing of this project but, where applicable are identified as further work.

3.1 Mitigation effectiveness monitoring

A literature review of freshwater restoration/improvement and associated monitoring was undertaken, with a particular focus on:

- Whether monitoring was part of the mitigation/restoration plan;
- Where monitoring was present, how it was designed and;
- What conclusions were drawn from the monitoring data
- Key conclusions and recommendations from the authors.

In addition to a standard scientific literature search, information was sought directly from key stakeholders in New Zealand. Interestingly, this process yielded surprisingly little information, supporting the conclusion that dedicated mitigation effectiveness monitoring was not a standard practice in New Zealand.

Key conclusions of the review are summarised below; the details of the review can be found in the confluence space[2].

Shortcomings of monitoring for restoration:

- There are no standardised practices for monitoring of the freshwater outcomes of mitigation or restoration programmes
- Restoration programmes with no specific goal(s) can lead to uninformative evaluations
- Land and water managers have tended to rely on existing "status quo", rather than targeted, monitoring programmes

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[2] https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/434962458/Monitoring+the+effectiveness+of+freshwater+restoration+mitigation+plans

- Time frames and intervals for monitoring vary greatly (untargeted)
- The spatial scale (reach/catchment) of monitoring is often inadequate to specifically measure the effectiveness of a given mitigation or restoration plan;
- Different variables have different response times (water quality/geomorphology/biotic communities)
- Monitoring and evaluation for restoration projects is often not required or not formally reported
- Many restoration programmes do not include enough funding for monitoring in their original scope

Overall recommendations:

- Specific and measurable goals make it easier to evaluate success or failure of restoration actions
- Monitoring should be targeted at restoration actions
- Restoration monitoring should have an interdisciplinary approach
- More stakeholder involvement often leads to greater success
- Equal efforts should be made in monitoring pre and post restoration and control vs. impact sites.

3.2 Essential Freshwater Package

The 2020 "Essential Freshwater" package refers to a suite of rules and regulations released by the New Zealand government in September 2020. The package introduces new rules and regulations to:

- stop further degradation of New Zealand's freshwater resources and improve water quality within five years
- reverse past damage and bring New Zealand's freshwater resources, waterways and ecosystems to a healthy state within a generation[3].

Central to the Essential Freshwater package, the National Policy Statement for Freshwater Management (NPS-FM) sets Te Mana o Te Wai as guiding principle and establishes a hierarchy of obligations within its framework: to waterbodies first, then to the essential needs of people, and finally for other uses. The NPS-FM must be given effect to as soon as reasonably practicable.

Te Mana o te Wai is a concept that refers to the fundamental importance of water and recognises that protecting the health of freshwater protects the health and well-being of the wider environment. It protects the mauri of the wai. Te Mana o te Wai is about restoring and preserving the balance between the water, the wider environment, and the community.

Broadly, the NPS-FM sets out a range of requirements that directly relate to this project:

- The National Objectives Framework (NOF) and associated appendices, as well as specific clauses of the NPS-FM define a wide range of attributes and how they relate to the values. These Attributes, Values and relationships were included in the Monitoring Design Framework as described in Section 4.4.1;

[3] https://www.mfe.govt.nz/essential-freshwater-new-rules-and-regulations

- The NPS-FM places particular emphasis on tangata whenua involvement in freshwater management, including implementing the NOF, identifying mahinga kai and other Māori freshwater values and developing and implementing mātauranga Māori monitoring
- The NPS-FM places significant emphasis on the assessment of temporal trends, with specific requirements to ensure that sampling programmes are appropriate to assess trends. These aspects are considered in the Statistical Analysis Module described in Section 0
- Various policies require the development of monitoring and action plans, to characterise the state of the freshwater resource and respond to degraded or degrading freshwater, with a common requirement to monitor and evaluate the effectiveness of policies, rules and methods (including action plans) and progress towards environmental outcomes. These considerations are at the heart of the Mitigation Effectiveness Monitoring Framework described in Section 0 below.

Further details of the monitoring requirements set in the NPS-FM can be accessed here: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/435028005/2020+Essential+Freshwater+Package

4 Mitigation Effectiveness Monitoring Design Framework

4.1 Problem definition

At heart, the mitigation effectiveness monitoring design framework needs to answer the following question (Figure 1):

"Have the mitigation actions resulted in improved freshwater outcomes?"

Where:

- "mitigation actions" are taken in a broad sense, and may include changes in farming/ land use practices, actions taken at the "edge of field" (such as constructed wetlands, bunds and trenches), at the land/water interface (such as riparian restoration), or directly in the waterbody (such as stream habitat restoration and in-lake interventions);
- "mitigation or restoration plan" means a set of mitigation actions taken with the objective of improving one or several freshwater outcomes;
- "Freshwater outcomes" has a meaning similar to that of the Freshwater Values as defined in the NPS-FM.

The review of available literature (Section 3) indicated that freshwater mitigation/restoration plans often did not include dedicated monitoring of freshwater outcomes. The general tendency seems to rely on pre-existing monitoring networks, such as "state of the environment" monitoring programmes. Whilst these programmes often present the advantage of providing long-term datasets, they are, by nature, not designed to measure the effectiveness of a specific intervention or mitigation plan. As a result, they are often ill-suited to the early detection of change or the establishment of a cause to effect relationship (has the change been caused by the intervention?).

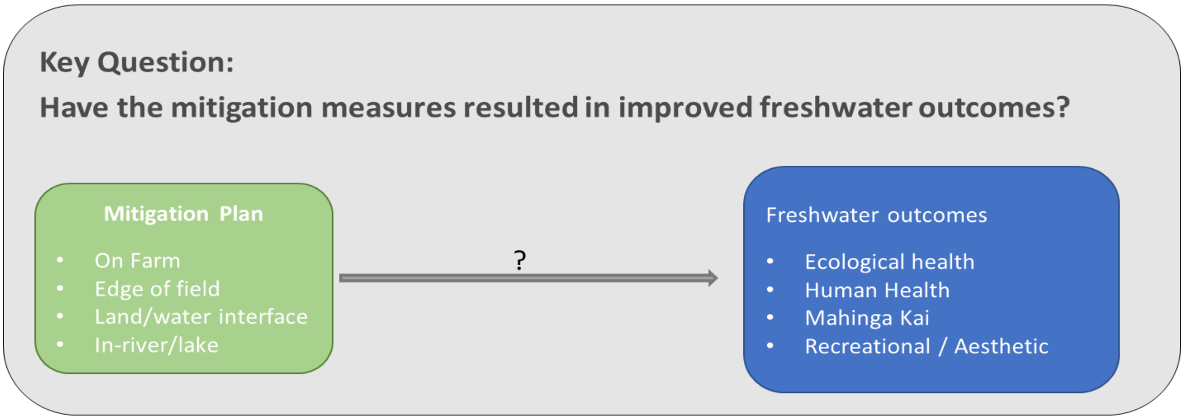

Figure 1: Mitigation effectiveness monitoring design framework: key question.

The above question is posed within a typical state/pressure /response/ evaluation cycle, illustrated in a simplified way in Figure 2. When a response (a mitigation plan) is formulated to address a pressure or an issue (degraded state of freshwater resource), monitoring the outcomes (and not just the mitigation actions) enables an evaluation of the effectiveness of the response. Understanding successes and failures, and their reasons, is a necessary part of the cycle leading to greater confidence about the effectiveness (or lack thereof) of various mitigation actions in a range of contexts and the formulation of more effective mitigation plans. This greater confidence is critical to the uptake and implementation of mitigation plans by land and water stewards.

In the specific context of the three work streams, Te Mana o Te Wai forms the overarching principle guiding freshwater management and feeds into every step of the cycle. The Mitigation Effectiveness Monitoring Design project (this project) aims at defining what should be measured, where and when, whilst the Monitoring Technologies project provides guidance on monitoring technologies available, their level of readiness and their indicative cost.

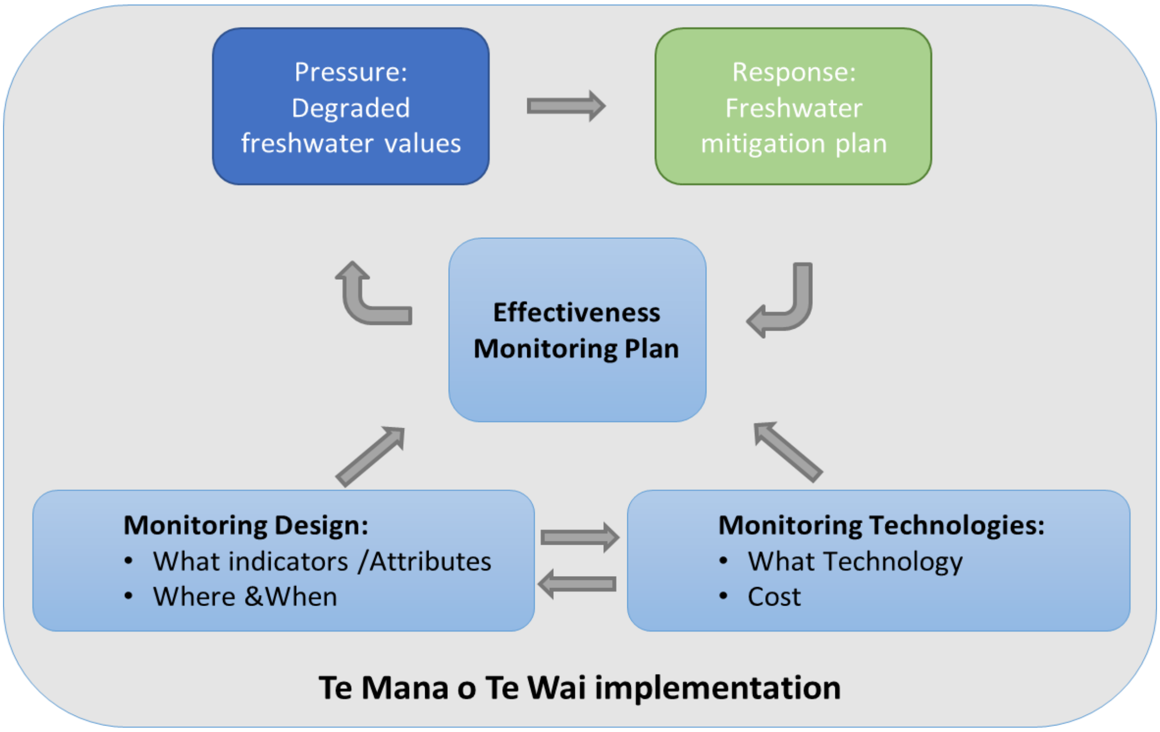

Figure 2: Diagrammatic representation of the three OLW monitoring workstreams.

4.2 Overall approach

The various elements of the Monitoring Design Framework are conceptually represented in Figure 3. The key inputs, elements and outputs of the framework are as follows:

1. Inputs
    a. Mitigation actions: What mitigation actions will be /have been undertaken, where and when, is information that is assumed to be an input into the framework.
    b. Catchment/waterbody characteristics: Available information on the subject catchment and waterbody is also considered an input into the framework. This includes for example lake/ stream /aquifer types, contaminant pathways, lag/ transport/ response times, climate, geology, as well as existing water quality and ecology data.
    c. Freshwater values/outcomes for the catchment or area of interest. Setting freshwater values or objectives falls outside the scope of this project and is assumed to be known by the user (e.g. outcomes of consultation processes, regional plans, etc.), and is thus treated as input information into the framework.
2. Decision Support Tools: The Monitoring Design Framework involves a range of tools and resources to support the design of a monitoring plan, including:
    a. Expected Benefits of mitigation action: Tools and resources to qualify and quantify the expected benefits of the proposed mitigation plan, i.e. what freshwater attributes may be directly or indirectly influenced by the mitigation, by how much and where.

b. Detecting change: a range of statistical tools and methods to assess the likelihood of detecting change in freshwater attributes, including where and when change may be detected, depending on sampling frequency.

3. Output: Monitoring Plan: The final output of the framework is a monitoring plan, including what to monitor, where and when.

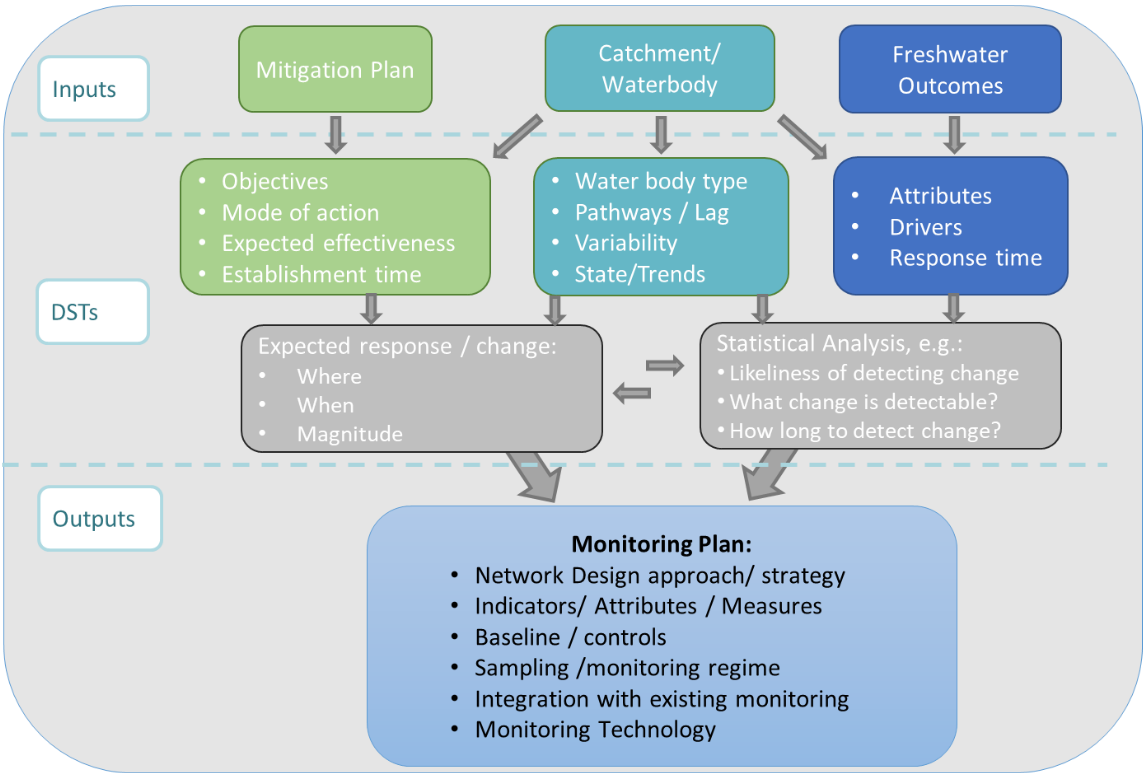

Figure 3: Key elements of the Mitigation Effectiveness Monitoring Design Framework.

The Mitigation Effectiveness Monitoring Design Framework provides information, resources and guidance on how above inputs can be considered, analysed and integrated, forming the basis for the formulation of a monitoring plan. The process follows five key steps leading to the formulation of a 3-tier monitoring plan, detailed below.

4.2.1 Step 1: Define the monitoring purpose

The first step in the process is to define the purpose of the monitoring plan – in essence what question(s) will the monitoring plan need to address. Clearly identifying and articulating these questions is a critical step in the process, as they will guide the development of the monitoring plan.

Generally, a mitigation plan will have a stated objective or objectives, which should constitute the starting point. Current mitigation plans in New Zealand include a range of objectives, formulated more or less specifically, for example:

- The stated objective may be relatively general, and not quantifiable or time bound, e.g. improve ecological health or mahinga kai values in a sub-catchment;
- The stated objective may be quantified, either explicitly (e.g. achieve a Trophic Lake Index of X) or by reference to a standard or guideline (e.g. achieve the NPS-FM national bottom line for a given Attribute);

- The stated objective may also be quantified, spatially explicit and time bound. For example:
    - Achieve swimmability national bottom line at a specified site by 2030; or
    - Reduce sediment load delivery to a harbour by 50% by 2050.

Defining the monitoring purpose(s) will inevitably provide direct guidance as to what should be monitored and where.

For example, if the mitigation plan's main objective is to reduce nitrate concentration below a certain level at a given location, then (obviously), the monitoring plan will need to include nitrate monitoring at that location (or a representative location).

The way the mitigation objectives are expressed may place additional constraints on the monitoring methods and frequency. For example, most NPS-FM Attributes are expressed in a relatively directive way, generally including sampling frequency and duration, and sometimes sampling protocol, in order to establish an Attribute State grading for the site.

Importantly, restoration of freshwater values is often a long-term (sometimes multi-generational) aspiration due to a combination of natural processes (e.g. contaminant transport processes, ecological response times), monitoring/statistical constraints (e.g. time required to detect a change once it has happened) and the social and economic factors associated with the implementation of a mitigation plan (e.g. time given to farmers to implement change). Management or mitigation plans often acknowledge the long timescales involved, and sometimes set intermediary targets. In these circumstances, early detection of improvement and the ability to report on progress/direction of travel becomes critical.

At a national scale, both the long timescales required to achieve a healthy state of the resource and the desire to detect a measurable improvement quickly are recognised in the stated objectives of the recent Essential Freshwater package:

- "stop further degradation of New Zealand's freshwater resources and improve water quality within five years
- reverse past damage and bring New Zealand's freshwater resources, waterways and ecosystems to a healthy state within a generation"

4.2.2 Step 2: Catchment values and natural characteristics

The second step in the process is to understand the catchment's characteristics and how they might affect mitigation effectiveness, or our ability to measure change. In essence, this is about assembling data and information to build a "state of knowledge" picture of the catchment or waterbody, including what is known about:

- Lake river and/or aquifer type
- Freshwater values associated with the waterbody, including where they apply
- State and trends of water quality and ecological indicators
- Catchment processes, contaminant pathways and transport/lag times.

Through this step, the following should be identified:

- Attributes, indicators and measures;
- Locations of interest (e.g. where a specific value applies, such as a mahinga kai site);
- Where possible, an indication of potential lag/transport and response times.

The following resources provide guidance through this step:

- A table identifying the linkages between freshwater Values and Attributes (refer to Section 4.4.1 for more detail);
- Guidance on lake types and relevant interventions and freshwater attributes in the Lakes Mitigation DST[4] (Section 4.7);
- Guidance regarding estimating groundwater lag time (Lag time module)[5] in the Groundwater DST (Section 4.8.3).

4.2.3 Step 3: Characterise and quantify potential effects of mitigation

The third step in the process is to characterise the mitigation actions/interventions and estimate their potential benefits, as follows:

- Establish (e.g. from the mitigation plan) what mitigation action, or group of actions, will be (or have been), and where;
- Understand the mitigation action's mode of operation, i.e. what it is meant to do and when. In some circumstances it is advisable to verify that the intervention has worked as expected.
    - For example, it is advisable to undertake monitoring of water column suspended solids/ turbidity in the hours/days following the application of a phosphorus inactivation agent.
- Establish what freshwater indicators /attributes may be influenced by the mitigation action and when (establishment time).
    - For example: Riparian vegetation may require 5-15 years to influence stream bed shading and water temperature
- Taking into account the local context (e.g. stream type/width, land slope, soil type), Quantify the potential benefits of the mitigation action(s) at the local scale;
- Aggregate the above information to establish the potential benefits of the mitigation plan as a whole at the appropriate measurement scale (e.g. catchment, zone, supply well recharge area).

The level of detail required to undertake this step depends on the mitigation plan and particularly whether mitigation actions need to be considered individually or if they are "packaged" together at the property scale as part of a Farm Environmental Plan (FEP).

Farm Environmental Plans (FEPs) are currently required in many regions in New Zealand, particularly for intensive land use, and the Essential Freshwater Package strengthens these requirements. Regional plans often require FEPs to demonstrate achievement of specified performance targets, such as a given reduction in contaminant losses from the property. As such, FEPs have become a key policy implementation tool by which contaminant emissions from a property are managed. In this context, individual mitigation actions are formulated as part of a "toolbox" of options available to achieve the contaminant loss reduction targets.

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[4] https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/119996429/Lake+monitoring+DST

[5] "Lag time module": https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/49348614/Lag+time+module

Wherever practicable, the intent for this monitoring design framework is to use the information contained in FEPs as an input into the monitoring design framework. For example, the groundwater DST case study uses the nitrogen loss reduction targets set by the Waimakariri Plan Change 7C as input (Refer to Section4.8.7).

However, there were two circumstances where mitigation actions were considered individually (and not as part of a FEP):

- In-lake interventions are not generally part of an FEP process, and were thus considered individually in the Lake Monitoring DST (Section 4.7 of this report).
- Riparian buffers are often implemented outside of farm planning processes as part of non-regulatory processes, e.g. by catchment community groups. In addition, relevant information relative to the effectiveness of riparian buffers has recently been compiled. Given the current prevalence of riparian management in many restoration projects in New Zealand, it was considered essential that this information specifically incorporated in the framework, leading to the development of the Riparian DST (section 0 of this report)

The following resources have been developed to guide the user through this step:

- A database (currently contained in a series of excel spreadsheets) compiling information on the potential effectiveness of mitigation actions on contaminant losses from land and stream habitat characteristics, as well as the expected establishment and effective lifespan of the mitigation. Whilst a range of on-farm and edge-of field mitigation actions were considered, this database was fully populated for riparian buffers only for the "proof of concept" phase of the project[6].
- A methodology to estimate a "Riparian Buffer Effectiveness Index" to estimate the potential benefits of riparian buffers on contaminant losses, shade and water temperature[7];
- A compilation of information relative to the mode of action and potential effectiveness of in-lake interventions[8].

[6] https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/257884193/Mitigation+Actions+Effectiveness

[7] https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/263716865/Estimating+the+potential+water+quality+and+habitat+response+to+Riparian+Buffers

[8] https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/119996429/Lake+monitoring+DST

4.2.4 Step 4: Detecting change

The fourth step in the process is to determine, based on the information and analysis gathered as part of the first three steps, the likelihood of detecting a change, and the time required to detect it, in freshwater attributes and indicators at various locations in the waterbody and/or catchment.

The Monitoring Design Framework uses various versions of power analyses to detect effect size and temporal trends, as described in the Statistical Analysis Module[9] (Section 0. Power analyses can be used for range of purposes, including:

- Test the ability of the existing monitoring network to detect the potential changes brought by the mitigation plan (e.g. what is the likelihood of detecting a change within, say 5 years, on the basis of existing monitoring locations and sampling frequencies?). From this, a gap analysis can be conducted to identify situations and locations where the existing monitoring network has a very small chance of detecting the potential changes and needs to be supplemented by additional/alternative monitoring;
- Determine locations where the likelihood of detecting a change within a given time period is highest in the catchment;
- Test whether increasing sampling frequency, or changing the sampling regime, is likely to increase the change detection power.

The Riparian and Groundwater Nitrate DSTs provide worked examples of these questions in the context of test catchments/ scenarios. In the future, it is anticipated that this analysis can be built into an interface as a series of user defined questions.

The following resources provide guidance through this step:

- A Statistical Analysis module, described in Section 0;
- A Forward Counterfactual Inference (CFI) module, described in Section 0;
- Worked examples, in the context of:
  - A riparian buffer mitigation plan[10] and
  - Farm interventions aiming at reducing nitrate concentrations in groundwater and spring-fed stream[11]

4.2.5 Step 5: Monitoring Plan

The last step of the process is to assemble the information and analysis undertaken as part of the first four steps to develop a monitoring plan. The monitoring design framework proposes a general 3-tier structure for mitigation effectiveness monitoring plans.

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9 https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/119865345/Statistical+analysis+module

10 https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/255459372/Case+Study-+Riparian+Management+DST

11 https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/137297935/Scenario+2+-+Groundwater+Nitrate+Pathway

Tier 1: Monitoring and Detecting Early Response.

This component of the monitoring plan focuses on:

- verifying that the mitigation action has worked as expected.
  - *For example, monitoring of water column suspended solids/ turbidity in the hours/days following the application of a phosphorus inactivation agent;*
- Monitoring early indicators of success, by focussing the monitoring on locations and freshwater attributes or indicators that are the most likely to show a fast response.
- This tier of monitoring may focus on locations and indicators most likely to show a response within 5 years, and thus be used to assess success and/or progress against the Essential Freshwater package's short term objective: "*stop further degradation of New Zealand's freshwater resources and improve water quality within five years*"
- Tier 1 monitoring may be undertaken at locations which are somewhat remote from the location where the mitigation plan's outcome(s) have been set, or measure indicators that are known drivers (as opposed to a direct measure of) the mitigation plan's outcomes. For example*:*
  - *Nitrate concentrations in shallow groundwater close to where the on-farm nutrient mitigation measures are implemented is likely to show a faster response than a spring-fed stream located further downgradient;*
  - *Measuring a response in ecological measures (e.g. periphyton abundance or macroinvertebrate communities) may require a long period of time. Known drivers of ecological health, such as habitat, deposited sediment, nutrient concentrations or shade may provide an earlier indication of a likely direction of travel.*

Tier2: Monitoring Freshwater outcomes

This component of the monitoring plan focuses on medium- to long-term monitoring of the mitigation plan's freshwater outcomes. Depending on the time scale involved, monitoring should focus on:

- Monitoring whether the mitigation plan's objectives have been met at the locations and to the extent specified in the mitigation plan.
- This tier of monitoring may be used to assess success against, or progress towards, the Essential Freshwater package's long-term objective: "*reverse past damage and bring New Zealand's freshwater resources, waterways and ecosystems to a healthy state within a generation".*
- Monitoring to estimate the direction and magnitude of change to evaluate whether the mitigation plan is "on track" to achieve long-term objectives, and if not, to adjust the mitigation plan.
  - *For example, the Waimakariri Plan Change 7 sets long-term objectives as nitrate concentrations at given sites, and several cycles of on-farm mitigation followed by monitoring and evaluation and, if required, further requirements to reduce nitrogen losses from farms.*

Tier 3: Mitigation longevity and sustainability

This component of the monitoring plan focuses on medium to long-term monitoring of the longevity and sustainability of the mitigation plan, including:

- Monitoring the longevity of those mitigation actions that are expected to have a limited lifespan (e.g. constructed wetlands, sediment retention bunds).
- Evaluating if an intervention may need to be repeated periodically, and how often.
  - *For example, in-lake interventions such as application of a phosphorus inactivation agent or weed harvesting may need to be repeated periodically as nutrient inputs from the catchment replenish the in-lake available nutrient loads. Monitoring incoming contaminant loads from surface and groundwater inputs (and atmospheric deposition) will help determine how often the intervention will need to be repeated*.
- Monitoring whether the freshwater outcomes achieved by the mitigation plan are maintained in the long-term.
- Monitoring risks or potential side-effects of the mitigation actions.
  - *For example, metal accumulation in lake sediment may need to be monitored following application of metal-based phosphorus inactivation agent*.

In all tiers of the monitoring plan, the spatial and temporal elements of the mitigation plan and monitoring purpose will also guide the monitoring network design approach. For example:

- In situations where a monitoring plan is formulated and able to be implemented before the mitigation actions are implemented, or where no mitigations are implemented, a Before-After-Control-Impact (BACI) design may be used, where data are collected at or below the mitigated site and a control site before and after the mitigation is applied.
- Where the mitigation purpose is to improve an attribute overall within a given spatial unit (e.g. catchment-wide mitigation to improve ecological health), catchment-scale monitoring networks may be designed using a range of approaches, including randomised locations, sites stratified proportionally within environmental or geographic classes or optimised to reduce redundancy within the network.

The following resources provide guidance through this step:

- Monitoring network design guidance (Section 0)
- A contaminant load estimation module (see section 4.4.4)
- Monitoring guidance for combinations of 6 lake types, 6 interventions and 7 attributes (see lakes DST, Section 4.7);
- Scenarios/ case studies, in the context of:
  - A riparian buffer mitigation plan to reduce sediment loads and improve ecological health (Section 4.6.5);
  - A waterway improvement in a coastal estuary to improve mahinga kai (Section 4.5.4)
  - Farm interventions aiming at reducing nitrate concentrations in groundwater and spring-fed stream (see Section 4.8)

4.3 Decision support tool

To assist with the implementation of the five-step process described above, a range of information repositories, decision support tools and modules have been created and are described in Sections 4.4 to 4.8 below.

Flowcharts below (Figure 4 and Figure 5) guide the user through the various components of the DST.

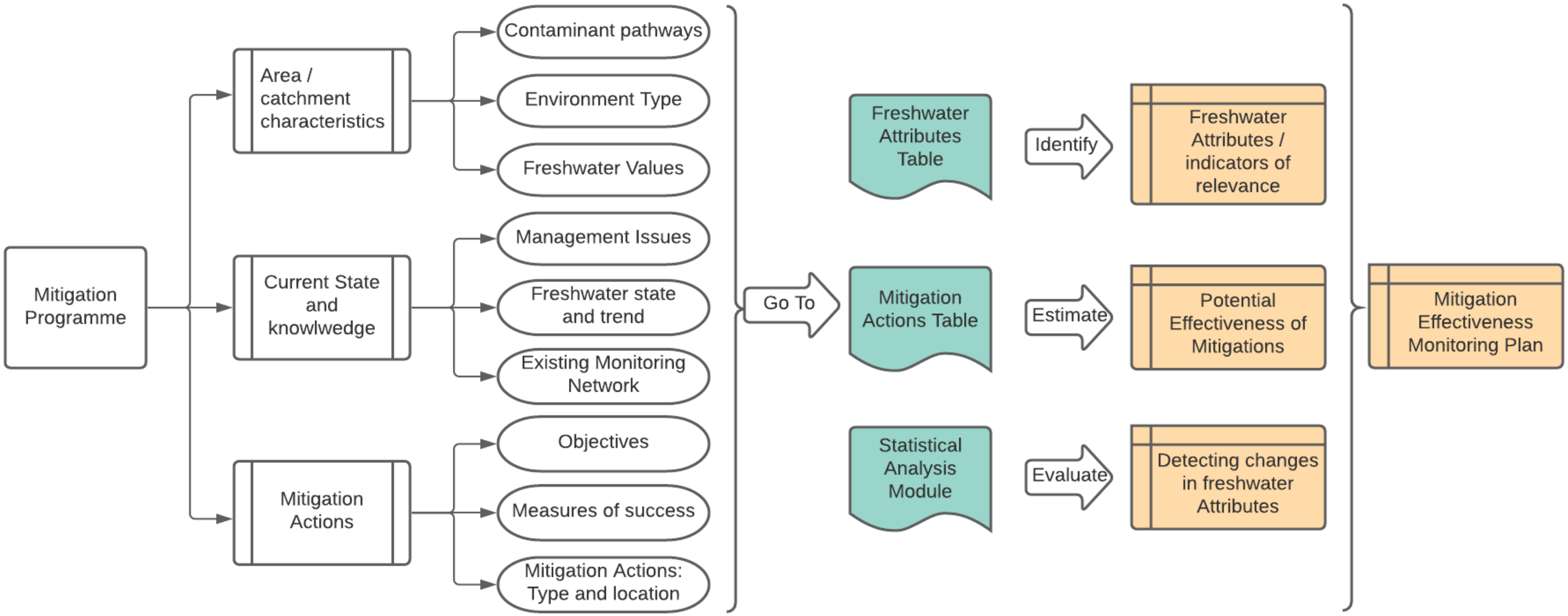

Figure 4: Mitigation Effectiveness Monitoring Design DST: Flow diagram of information required (items in white), resources available within the DST (items in blue) and outputs (items in orange).

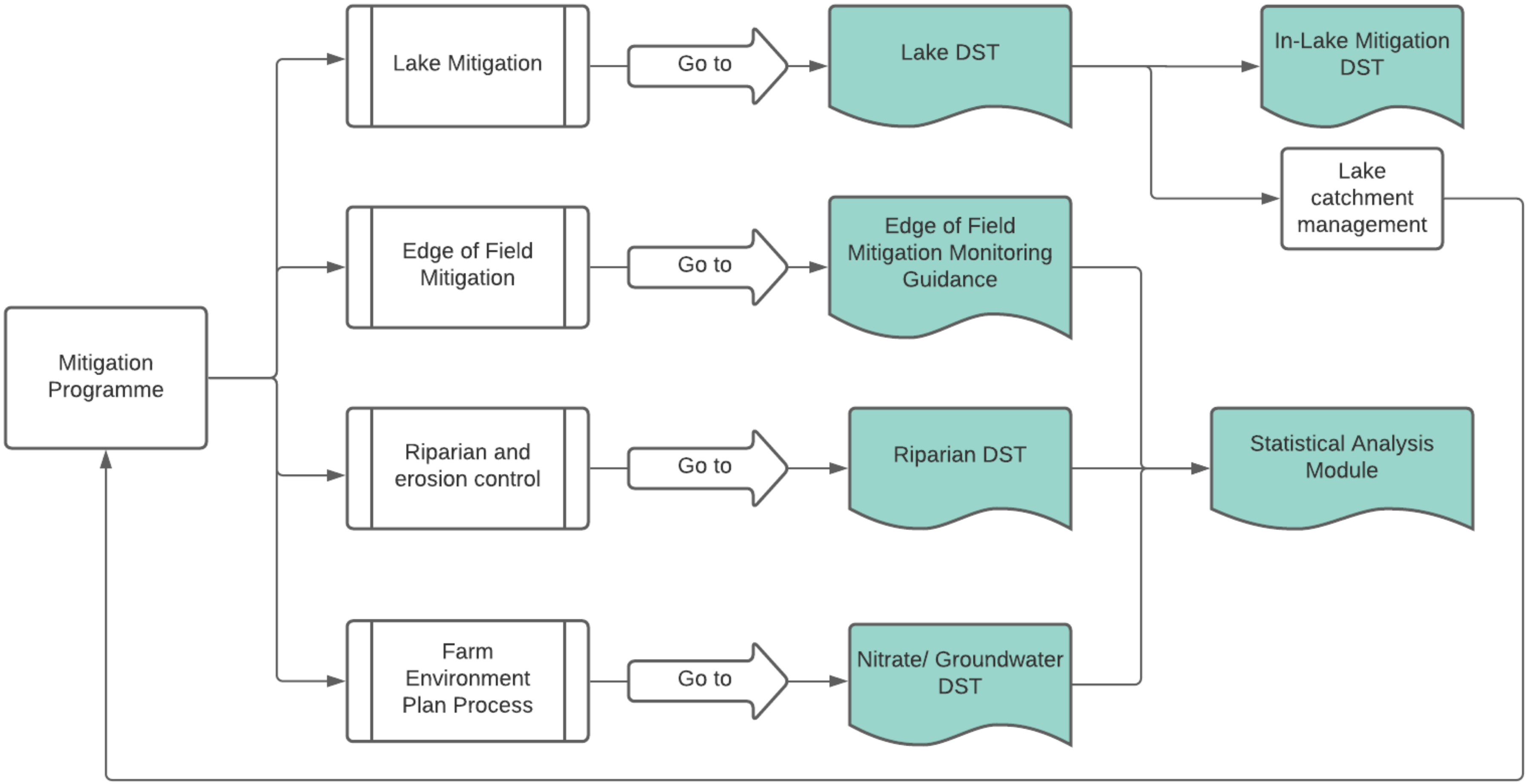

Figure 5: Mitigation Effectiveness Monitoring Design DST: Flow diagram of information required (items in white), resources available within the DST (items in blue) and outputs (items in orange).

4.4 Information repositories and resources

To assist with the implementation of the five-step process described above, a range of resources and information repositories have been created, as described below.

4.4.1 Freshwater Values, Attributes and Indicators

The EOI document, setting up the original scope of this project, required that the monitoring design incorporate measurements of environmental indicators and information, including, but not limited to freshwater attributes from the National Objectives Framework (Appendix 2 of the NPSFM) and mātauranga Māori records, measures and indicators. The EOI incorporated a conceptual representation of the linkages between freshwater Attributes and values within Te Mana o te Wai (Figure 6).

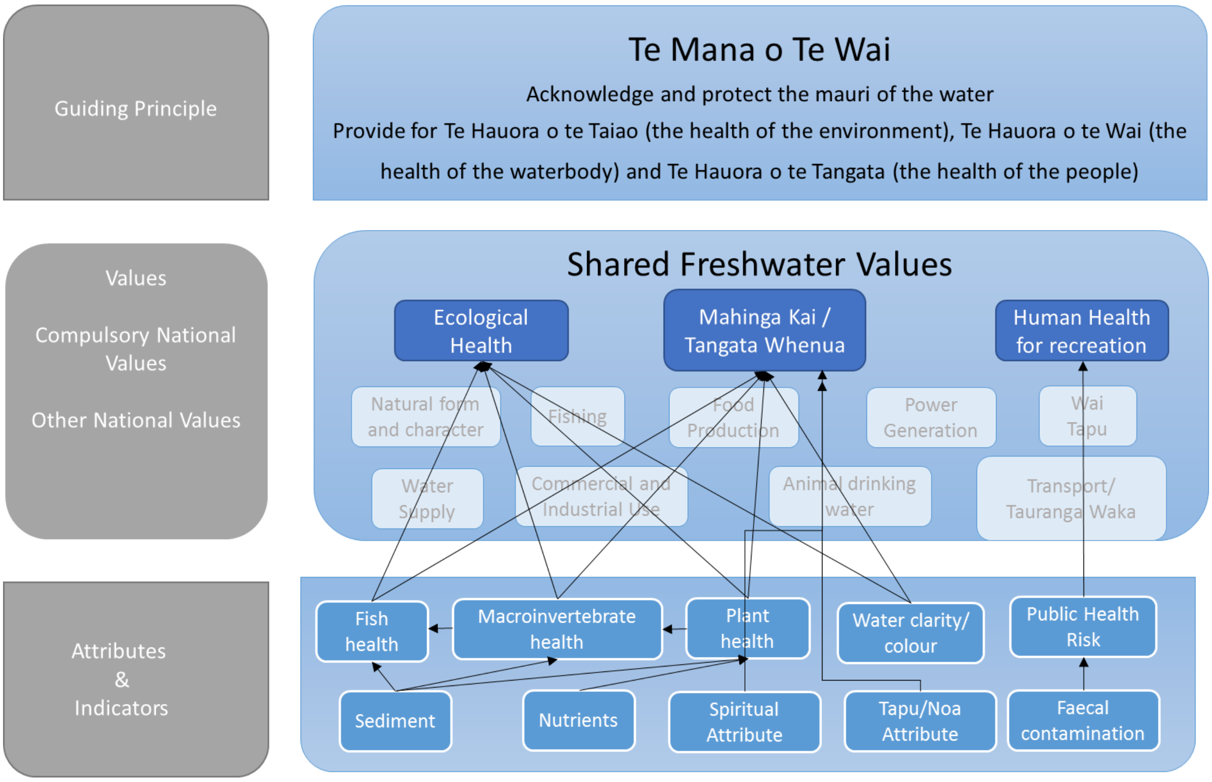

Figure 6: Conceptual representation of the linkages between Attributes and Values within Te Mana o Te Wai as per the June 2020 EOI document for Working Group 1 (Compulsory National Values were from the 2019 Draft NPS-FM).

Accordingly, one of the working group's first tasks was to compile an information repository documenting the linkages between the updated set of values set in the NPS-FM (2020) and freshwater Attributes and indicators. The set of freshwater Attributes and Indicators incorporates all Attributes included in Schedule 2 of the NPS-FM, as well as a range of additional attributes, indicators and measures that were considered relevant as either direct measures of a freshwater value or as controlling factors or ancillary measures.

Work was also undertaken to incorporate measures and indicators included in the Mauri Compass, as an example of how mātauranga Māori records, measures and indicators may be incorporated in the framework (Section 0).

The information repository, currently under an excel spreadsheet format, is available on the confluence space: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/257785880/Freshwater+Values+and+Attributes+Table

4.4.2 Mitigation Actions Effectiveness

Another of the working group's early tasks was to assemble information relative to the types of mitigation actions and their effectiveness in a broad range of context.

The following categories of mitigation actions were identified:

- On-farm/farming practices, such as nutrient management, grazing regimes, etc.
- Edge of field mitigations such as constructed wetlands, de-nitrification trenches and detention bunds;
- Mitigations at the interface between land and the waterbody, such as stock exclusion, riparian buffers, bank erosion control;
- Interventions taken within the water body, such as in-lake or in-river interventions

The information relative to mitigation action effectiveness is assembled in a database hosted on the Confluence platform: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/257884193/Mitigation+Actions+Effectiveness

Given the broad range of mitigation actions potentially available, not all mitigation categories could be explored in detail within the scope of this project.

Wherever practicable, the intent for this monitoring design framework is to use the information contained in FEPs, particularly regarding the contaminant loss limits or targets stated in the FEP, as an input into the monitoring design framework. However, specific guidance was developed for two types of mitigations that were considered outside the FEP process:

- In-lake interventions, as described in the Lake Monitoring DST (Section 4.7)
- Riparian buffers as described in the Riparian DST (section 4.6).

The working group identified the following potential further work:

- Further work to the link the methods and outputs Land Management Actions Register (LMAR) project as inputs to this Monitoring Design Framework, potentially further developed using a farm typology approach.
- Incorporate in-river mitigation actions, such as bank erosion control measures, in-stream habitat restoration, etc.
- Incorporate erosion control measures, such as spaced planting, marginal land retirement, etc.
- Incorporate mitigation actions taken within commercial forestry plantations to reduce adverse effects during and following harvest.

4.4.3 Statistical Analysis Module

A statistical analysis module was developed, providing guidance on:

- Power analysis
- Temporal trend analysis
- Network design

The Statistical Analysis Module can be accessed here: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/119865345/Statistical+analysis+module

It is acknowledged some of this guidance could be developed further, including:

- Develop further guidance to relative to events-based and continuous monitoring, with a particular focus on how these may affect change detection (including likelihood and time required);
- Develop more detailed guidance on monitoring network design.

4.4.4 Load estimation module

The Load Estimation Module provides detailed guidance on lake contaminant load estimation methods, including internal lake loads and loads associated with atmospheric deposition. It also provides limited guidance on fluvial load estimation methods.

Should this module be fully developed, further guidance should be included on groundwater and fluvial load estimation methods.

The Load Estimation Module is available here: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/194936856/Load+Estimation+Module

4.4.5 Edge-of-field mitigation monitoring

The highly variable nature of diffuse flows in time and space creates significant challenges for monitoring the effectiveness of edge-of-field mitigations. Low-frequency (e.g., monthly) monitoring of contaminant concentrations in inflows and outflows is unlikely to be sufficient to be able to usefully quantify and compare performance.

Ideally both flows and concentrations of contaminants need to be measured in both inflows and outflows (including groundwater) across the range from base-flow to storm-flow conditions. To determine long-term load reductions, inflowing and outflowing loads (flows x concentrations) need to be compared over multiple annual periods. High frequency monitoring using optical spectral probes (e.g., for nitrate-N) or potential proxy parameters can (with suitable cross-calibration) greatly improve monitoring resolution. Potential proxies include turbidity for suspended solids, particulate phosphorus and faecal microbial indicators, and electrical conductivity for dissolved nutrients.

The guidance document on monitoring the effectiveness of edge-of-field mitigation may be accessed here: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/258211913/Monitoring+the+effectiveness+of+Edge-of-Field+mitigations

4.5 Mātauranga Māori monitoring

4.5.1 NPS-FM requirements

The National Policy Statement for Freshwater Management (NPS-FM) sets Te Mana o Te Wai as guiding principle. Te Mana o te Wai is a concept that refers to the fundamental importance of water and recognises that protecting the health of freshwater protects the health and well-being of the wider environment. It protects the mauri of the wai. Te Mana o Te Wai is about restoring and preserving the balance between the water, the wider environment, and the community.

The NPS-FM places particular emphasis on tangata whenua involvement in freshwater management, including implementing the NOF, identifying Mahinga Kai and other Māori freshwater values and developing and implementing mātauranga Māori monitoring.

4.5.2 Māori knowledge systems

Rainforth and Harmsworth (2019)[12] provide a summary of iwi and hapū-based tools, frameworks and methods for assessing freshwater environments. Their review cover 9 assessment methods in detail and reference another 9. The authors compiled attributes, indicators and Tools used within the assessment methods reviewed, reproduced in

Table 5

4.5.3 Approach

An initial hui was held in Gisborne on 4th February 2021, assembling members of the three working groups (Ian Ruru, Mananui Marsden, Joanne Clapcott, Rogier Westerhoff and Olivier Ausseil). Wolfgang Kanz (Gisborne District Council) joined the hui and presented examples of the application of the Mauri Compass . The focus of the hui was to discuss general principles relating to:

- Implementation of Te Mana o Te Wai,
- Kaupapa Maori assessment tools,
- What Mahinga Kai means
- The importance of whakapapa in mātauranga Māori monitoring
- Work undertaken to date by all three working groups
- The potential for integration.

There was general comfort that the thought processes involved in developing the monitoring design and technologies frameworks were generally compatible with, or could be modified or adapted to incorporate both kaupapa Māori and biophysical attributes and measures. However, it was recognised that significant additional work would be required, to achieve this.

Given the time limitations applicable to this component of the project, only preliminary and exploratory work was able to be initiated, focusing on exploring examples of how mātauranga Māori may be used to monitor the effectiveness of freshwater mitigation or restoration.

[12] Rainforth, H. J. & Harmsworth, G. R. (2019). Kaupapa Māori Freshwater Assessments: A summary of iwi and hapū-based tools, frameworks and methods for assessing freshwater environments. Perception Planning Ltd. 115 pp.

Examples of this exploratory work included:

- Incorporate the Mauri Compass indicators into the database linking freshwater values, Attributes and Indicators (as described in Section 4.4.1) as an exploratory example of how Māori knowledge systems may be incorporated into the Monitoring Design Framework;
- Develop a theoretical /simplified scenario to explore how monitoring design and technologies may be used to monitor the outcomes of a land mitigation plan aiming at improving mahinga kai in a small catchment (see below);
  Identify avenues for future work, as described in Section 4.5.5.

Table 5: list of indicators and tools used in nine Kaupapa Maori assessment tools, methods and approaches (adapted from Rainforth and Harmsworth, 2019).

Attribute or Indicator	Tool
Meta-physical aspects	Mauri
	Wairua and spiritual practices
Unique aspects of the waterbody	Voice
	Smell
	Special character
Cultural and social aspects	Iwi health and wellbeing
	Tikanga and cultural practices
	Sites of significance
	Significance of place or catchment
	Gut feeling about a place
Species aspects	Stream insect measures
	Fish and mahinga kai species presence/absence
	Abundance (links with Mahinga Kai - Availability)
	Growth rates
	Species health
	Invasive/exotic species
Mahinga kai	Food safety
	Water safety
	Access
	Availability (links with Species aspects - Abundance)
Ecology, water quality and habitat	Landscape-level habitat/catchment land use
	Riparian habitat
	Water quality parameters e.g. clarity, pH, temperature, dissolved oxygen
	Sediment issues
	Algae and plant issues
	Overall degree of modification or health
	Habitat variability

Water Quantity	
Hydrology and geomorphology	Degree of hydrological modification
	Channel modification
	Continuity of flow from source to sea
Pollution	Sources of pollution
Potential for restoration	
Risk to site, waterbody or catchment	
Other	

4.5.4 Case Study

A simplified, theoretical scenario was developed, where a range of mitigation actions (including wetland and riparian restoration) will be implemented in a coastal estuary and contributing freshwater catchment to improve mahinga kai.

Mahinga kai is the natural connection between the atua [gods], the land, the sea, the rivers, tangata whenua and their natural resources. It is underpinned by tikanga and is rich in mātauranga Māori. Mahinga kai, as a compulsory value under the National Objectives Framework, also refers to the traditions and practices associated with harvesting and gathering of species for food, tools or other resources and including the places where those species were found.

Table 6 below provides a summary of the scenario and board-level monitoring plan. Table 7 provides a summary of the monitoring technologis available for the monitoring of two key attributes, tuna (eel) and *E.coli*.

Table 6: Summary of scenario - Improvement of waterways in a coastal Estuary to improve mahinga kai.

Scenario A: Improvement of waterways in a coastal Estuary to improve mahinga kai	
Catchment	A small coastal catchment with awa (rivers) that flow into tidal estuaries that support mahinga kai practices. The aim is to improve the health of freshwater waterways in to a state where they can support mahinga kai “the way we gather resources, where we get them from, how we process them, and what we produce”. If the practice of mahinga kai is nurtured, then tangata whenua can teach their mokopuna to harvest and process food the way their tūpuna did. Hence, traditions and connections associated with mahinga kai can be better retained and better passed on to future generations. In this rohe, an assessment with the Mauri Compass (Ruru and Kanz, 2020) has been undertaken. The Mauri Compass assessment is one of a range of tools and frameworks that iwi and hapū can use to monitor the environment that encompasses mātauranga Māori. The tool is used to assess the state of freshwater using mātauranga Māori and western scientific data. A wide range of indicators are included in the Mauri Compass, including: tangata whenua, tikanga, wairua, mahinga kai, habitat, biodiversity, water biology, water chemistry, kai species richness, kai species abundance, kai species health, catchment health, and kai growth rates.
Mitigation Programme	The mitigation plan involves 1. Riparian management (stock exclusion, planting) in the contributing freshwater catchment 2. Wetland restoration in the estuary and catchment. Objective (what does success look like?): 1. Increased range of kai species available 2. Improved abundance and health of the taonga/sentinel kai species 3. Reduced contaminants/health risk associated with the consumption of Mahinga kai 4. Reduced risk of exposure to water-borne pathogens and contaminants when gathering mahinga kai
Monitoring Plan	
Monitoring plan	1. Regular monitoring at traditional mahinga kai sites as advised by tangata whenua to track improvement over time: a. using the Mauri Compass, b. monthly E.coli monitoring c. 3-monthly tuna (eel) abundance monitoring 2. Within the freshwater catchment, use the riparian DST to determine optimum location of monitoring sites for early detection of improvements in E.coli, macroinvertenrate communities sediment, shade and habitat

Table 7: Summary of attributes and available technology for monitoring of mitigation actions, including comment on justification, frequency of monitoring and relevant comments (Adapted from: Westeroff et al., 2021).

Attribute	Available technology	Justification	Frequency of monitoring	Additional comments
E. coli	Auto-sample for laboratory analysis (HACH, YSI ProSample, GlobalWater WS700 series or FSS, ISCO)	Any frequency	Discrete or composite sampling	Varies with hydrographs; other sampling intervals are also possible, (e.g. flood event). Requires submission to laboratory for analysis (*E. coli*) within 24 hours.
E. coli	Grab sample: throughout the year for laboratory analysis	Long to medium term trends	weekly or monthly	Will monitor 'state' over time to give longer term trends, and provide estimate of risk to recreational users (Table 9 of NPS-FM 2020).
E. coli	Fully automated and online automated systems (VWM-Coliminder, ColiFast ALARM or CALM)	Satisfy bathing season criteria and provide long term data	within 15 min – 12 hours;	High initial cost; low consumable cost; maintenance required; range of applications; may need additional data; high frequency uses indirect indicators; detection time is longer for direct indicators (*E. coli*); Colifast ALARM also measures turbidity.
Tuna (eel) count	Netting/trapping (e.g., fyke nets; Gee Minnow traps, scoop nets, whitebait nets)	Generally non-lethal	3-monthly	Can either be baited or non-baited; potential to catch non-target species; not all eels forage at the same time; nets/traps may only catch a selection of the species via size; and environmental conditions can influence capture rates. These limitations can be reduced or minimized through appropriate sampling design.
Tuna (eel) count	Depletion fyke netting	Generally non-lethal	3-monthly	Nets are set to fish overnight for a period of three nights; nets are emptied each day and the catch is retained and counted; eels are released > 5 km upstream of the nets. Can provide information on the population to provide an estimate of the capture efficiency and hence population size.
Tuna (eel) count	Electric fishing (eeling)	Generally non-lethal, capture and release	3-monthly	Not as suitable in deeper waterways areas (or can be undertaken via boat/vessel), most suitable in wadeable streams and reaches. Potential to select non-target species; not all eels forage at the same time; and environmental conditions can influence capture rates. These limitations can be reduced or minimized through appropriate sampling design.
Tuna (eel) count	Visual spotting at night time	Less invasive but less accurate	3-monthly	Using spot lighting equipment if water is clear and shallow enough to see. Relatively cheap and easy especially if only count is required (e.g., less ability to measure length, weight, species). Tuna may be covered by in stream debris or living under the banks.

Tuna (eel) count	Environmental DNA analysis (e-DNA)	Non-invasive	3-monthly	Requires collection and analysis of water quality. Results would identify the species (e.g., longfin, shortfin) that are present, but not the number.
Tuna (eel) count	Community and stakeholder survey from recreational and commercial eeling	Provides likely number of eels removed from the ecosystem	3-monthly	Cost-effective but may take some time. Collection of information from community and stakeholders in the catchment to identify count of eels.

4.5.5 Further work

The following potential further work/ projects were identified

- The monitoring design and technologies frameworks currently do not define <u>who</u> should undertake the monitoring. The fundamental importance of whakapapa and the need for mana whenua to undertake monitoring within their rohe, using tools they feel comfortable with, was highlighted.
- The sensitive nature of some of the information forming part of kaupapa Māori assessment frameworks (e.g. Wahi Tapu) means that matters of confidentiality and access to the data must be considered further;
- Further expand and test the potential for the Monitoring Design Framework to incorporate both kaupapa Māori and biophysical attributes and measures
- Identify one or several catchments and mitigation plans where the expanded framework could be tested.
  - The Tahurehu River catchment, a tributary of the Waipaoa River near Gisborne has been identified as a potential test catchment. Gisborne District Council (GDC) plan to
    - undertake a baseline ecological and mātauranga Māori cultural health assessments (including mahinga kai and Mauri) of the waterway,
    - undertake a mahinga kai assessment, as envisaged in the NPSFM, through a mātauranga Māori process, utilising the Mauri Compass and
    - assess the Te Mana o Te Wai framework will be assessed through use of the Mauri Compass, addressing the six principles and the hierarchy of obligations in the NPSFM 2020.
- Explore the potential to include mahinga kai/ matauranga Maori monitoring requirements in Farm Environmental Plans.
  - The Te Waihora/Lake Ellesmere catchment, in Canterbury, has been identified as a potential case study

4.6 Riparian Decision Support Tool

4.6.1 Approach

The approach taken within the Riparian DST follows the five-step process described in Section 4.2. The Riparian Mitigation Decision Support Tool (DST) in the Confluence space[13] comprises:

- A core decision-support module identifying the main steps (Figure 7).
- A series of information pages which guide and assist with use of the DST, including the information required and the methodology to estimate the potential improvements in water quality, habitat and ecological attributes.
- A scenario-based case study to demonstrate usage of the DST.

4.6.2 Information required

A summary of the land, riparian buffer and stream information required to estimate the potential water quality and habitat response to riparian management, as well as publicly available online information sources are provided on the Confluence space:

https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/263618561/Information+required

4.6.3 Estimating the water quality and habitat response

Three types of riparian mitigation are included in the DST, these are:

- Type 1 = fencing for stock exclusion
- Type 2 = fencing as above combined with a grass filter/buffer strip;
- Type 3 = fencing as above combined with a mixed buffer consisting of a grass filter/buffer plus sedges, shrubs and trees.

The contaminant attenuation and shading efficacy of each type of riparian mitigation in the context of varying catchment characteristics is provided in the Riparian Mitigations Table (Section 0). It was assumed that Type 1 mitigation could only mitigate bank erosion, while Types 2 and 3 mitigation could mitigate both bank erosion and overland flow (runoff) as sources of sediment to stream.

Details of the methodology and information sources are provided on the Confluence space:

https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/263716865/Estimating+the+potential+water+quality+and+habitat+response+to+Riparian+Buffers

[13] https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/257917093/Riparian+Mitigation+DST

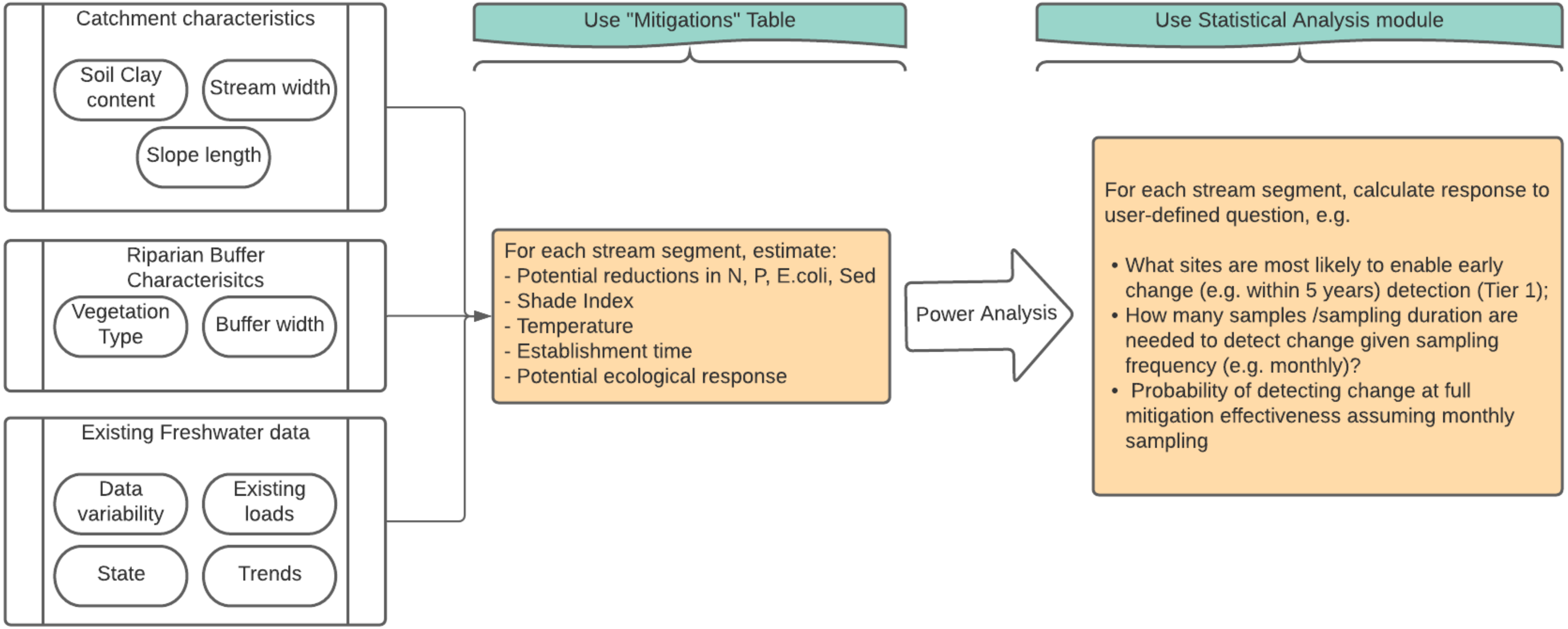

Figure 7: Diagrammatic representation of the Riparian Buffer DST.

4.6.4 Estimating the ecological response

Riparian restoration through streamside fencing and plant re-establishment is a common approach to mitigate the negative effects of land use on in-stream values. Riparian planting and fencing is assumed to mitigate the delivery of excess sediment, nutrients (direct and diffuse) and light into streams with the outcome being improved water quality, but very few studies, if any, have quantified the rate of recovery of in-stream outcomes relative to changes in riparian inputs.

The recovery pathway is unlikely to be the same as the impact pathway due to the interaction among pollutants (driving variables) and hysteresis (temporal lag). However, because recovery pathways are yet to be quantified, we rely on the impact pathway to provide a best estimate of the relationship between drivers and response variables. This estimate is then guided by hypothetical recovery curves to approximate when an improvement is likely to be detected.

Quantifying the impact pathway

The impact pathway between driver and response variables is complex (Figure 8). Each driver directy affects primary response variables which in turn interact to affect secondary and tertiary response variables. The relative influence of each variable is dependent on i) the current state of the variable, because the relationship is not always linear, and ii) the environmental setting, because other factors can mediate interactions among variables. For example, sediment input directly influences the amount of sediment deposited on the stream bed, but a 20% increase in deposited sediment will affect a stream with 5% existing deposited sediment more than it will a stream with 60% deposited sediment. Further, a 20% increase in deposited sediment will have minimal affect on a fish community limited by wetted habitat due to flow allocation or a downstream barrier to migratory species. Therefore the relative efficacy of riparian mitigation on in-stream response variables is dependent on current state and environmental setting.

The Riparian DST provides method and assumptions to estimate the relative efficacy of riparian mitigation on in-stream response variables via the pathways of sediment, shade, and nutrient effects (i.e. the primary factors influenced by riparian fencing and planting). It is based on best available information, which is referenced. A major assumption is that there are no other factors present that limit recovery, such as insufficient wetted habitat due to habitat or flow alteration, barriers limiting dispersal, or toxicants inhibiting life.

Details of the methodology and information sources are provided on the Confluence space: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/468647943/Estimating+ecological+recovery+following+riparian+restoration

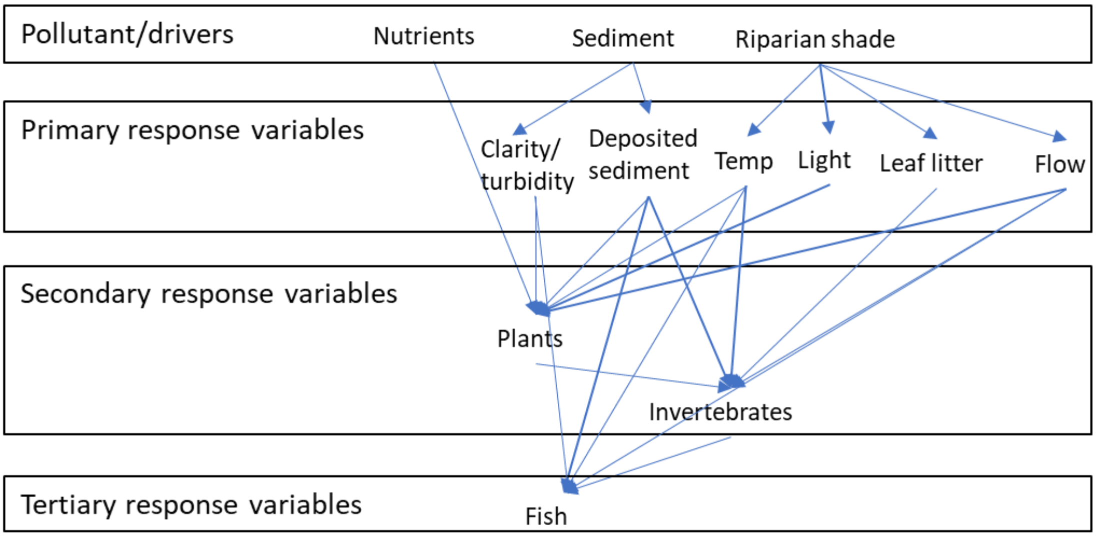

Figure 8: Conceptual network of the relationship between primary drivers and in-stream response variables.

4.6.5 *Scenarios/case studies*

To test the workability of our “proof of concept” Riparian DST, we applied it to a case study catchment. This catchment was selected because underlying physical and water quality data required to run the models were readily available. Importantly, the case study is narrowly focused on focused on a set of arbitrarily defined mitigation scenarios and a subset of water quality, habitat and ecological variables. As such it does not consider the full set of ecological, cultural or recreational values (and associated freshwater attributes) potentially associated with the catchment and should be taken in that context.

Our application of the riparian management DST focused on a catchment with three main sub-catchments. The mitigation scenarios involved the implementation of three types of riparian buffers (fencing only, grass buffers and mixed buffers) to all stream reaches in the central sub-catchment only (Figure 9). Throughout the analysis, we assumed that water quality and habitat conditions in the unmitigated sub-catchments remained constant over time.

The assessment followed the five-step process described in Section 4.2:

- Step 1 (Define monitoring purpose): the monitoring purpose is to measure the benefits of each of the three mitigation scenarios (fencing, grass buffers and mixed buffers) on water quality, habitat and ecological variables;
- Step 2 (Identify freshwater values and attributes): This analysis focused on four water quality (Suspended Sediment), habitat (shade and temperature) and ecological (periphyton) attributes;
- Step 3 (Quantify potential effects of mitigation): the potential improvements in the four attributes resulting from each of the three mitigation scenarios were assessed following the methodology detailed in Section 4.6.3;
- Step 4 (Detecting change): consisted in power analysis on each reach in the catchment to quantify the likelihood of detecting the expected changes if mitigation was effective.
- Step 5 (Monitoring plan): the above analysis an illustration of how it can be used to prioritise stream reaches where change detection is most likely within a given timeframe, thus guiding the placement of monitoring sites.

Steps 3, 4 and 5 are detailed further below, with full details of the analysis, information sources and assumptions and limitations available on the Confluence space: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/255459372/Case+Study-+Riparian+Management+DST

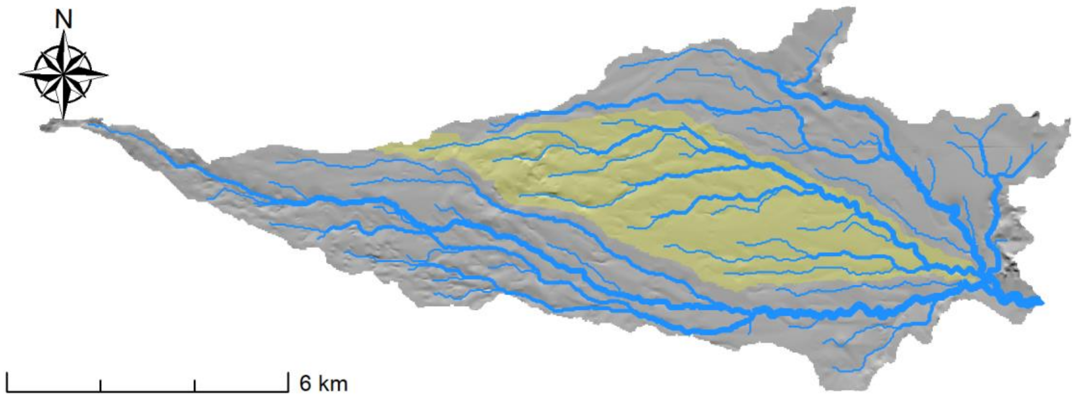

Figure 9: Map of the case study catchment, with the mitigated sub-catchment indicated in yellow.

Predicting the effectiveness of mitigation

We modelled the likely effectiveness of three riparian mitigation options: 1) fencing, 2) a grass buffer and 3) a mixed buffer on four water quality variables (total suspended solids, shade, water temperature and periphyton cover). The efficacy of each mitigation option for each water quality variable was obtained from the Mitigation Options table (Section 0).

Figure 10 shows the expected state of the catchment for each water quality variable under the three mitigation scenarios, while Figure 11 highlights the expected change in state compared to the initial starting conditions.

What is evident from these figures is that the fencing mitigation scenario is only likely to be effective at reducing TSS, with no impact on shade, water temperature or periphyton cover. In contrast, the grass and mixed buffer mitigation scenarios are expected to result in improvements in all four water quality variables tested, although greater improvements are likely with a mixed buffer for shade and periphyton in some parts of the catchment.

Predicting the power to detect a change in state

The second part of this analysis identifies the parts of the catchment where we might be most likely to detect a statistically significant change in water quality state, using a statistical power analysis at the reach-scale. For each scenario, we calculated the power to detect the expected reduction at specified time periods after the mitigation has matured, assuming a typical monthly sampling regime.

Figure 12 highlights that the power available to detect the expected reductions in water quality state varies by water quality variable and mitigation type, as well as spatially throughout the catchment. Increased power to detect a change was associated with greater expected magnitudes of reduction.

While there appears to be little difference in power between the grass and mixed buffer scenarios, it is apparent that we would be unlikely to detect an effect of these mitigation actions on water temperature and periphyton after five years of the mitigations being fully effective (i.e., six years after implementation of the grass buffer and 15 years after implementation of the mixed buffer). This analysis also highlights that the location of reaches within the stream network with the highest power also varies by water quality variable, again linked to the expected reduction in state. While the power to detect a statistically significant reduction increases with the number of samples taken (Figure 12), we may still be unlikely to detect a reduction in some variables even after 10 years of monitoring.

4.6.6 Further work

The following further work was identified by the working group, to bring the Riparian DST from its current "proof of concept" level of development to a user-ready tool:

- Further refine shade and water temperature prediction capabilities
- Extend to include nutrient prediction
- Extend to quantitatively predict ecological responses from water quality responses taking into account current state
- Acquire real data on landscape and response parameters for one or more test catchments, validate results
- Develop a user interface for the tool including links to (or creation of) national datasets/layers for landscape and response parameters

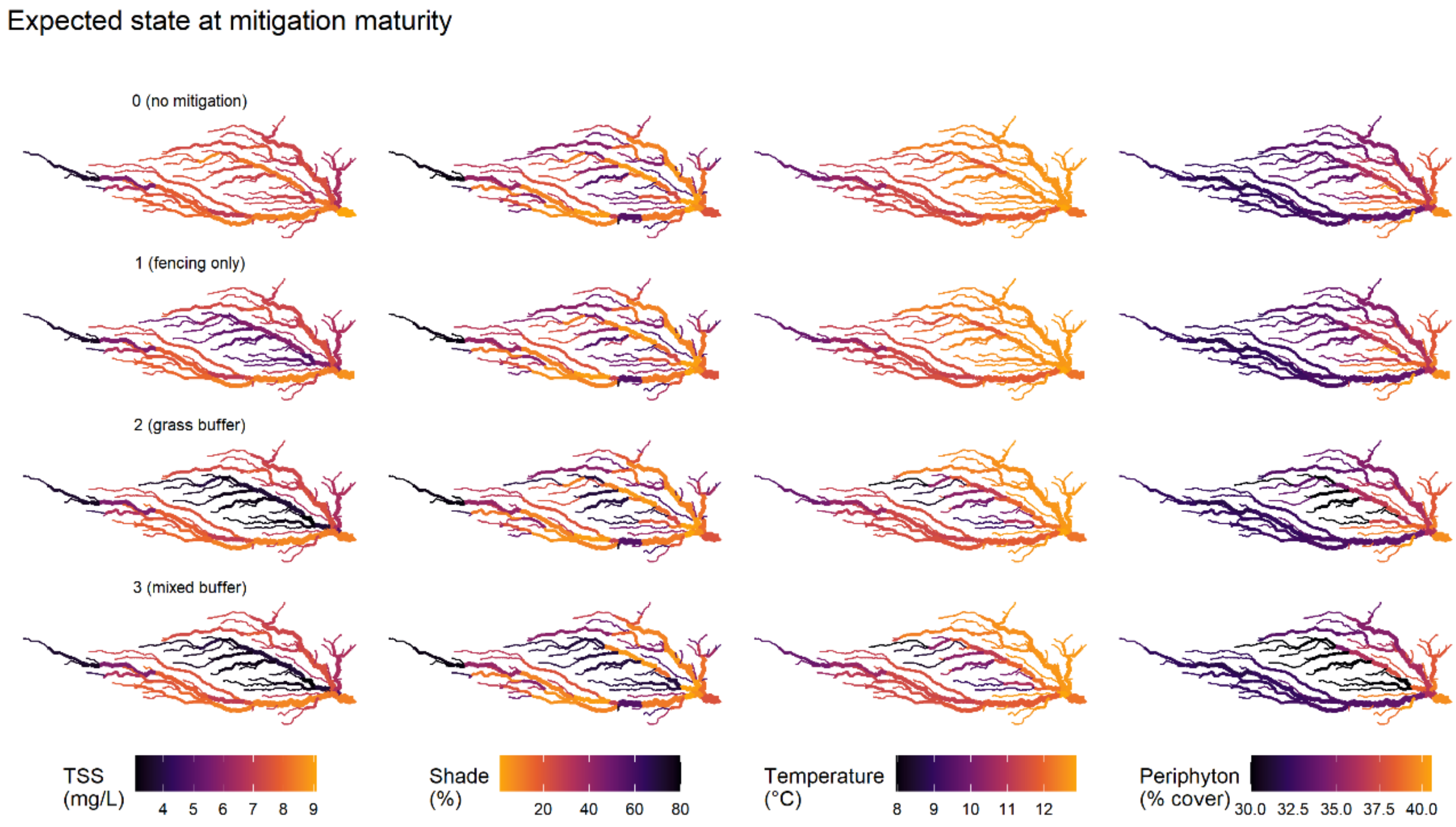

Figure 10: Expected state of four water quality variables (columns) when four mitigation scenarios (rows) reach maturity. Darker colours represent a "better" state in water quality. Only the central sub-catchment is mitigated in each scenario, while the no mitigation scenario represents the initial state of the catchment.

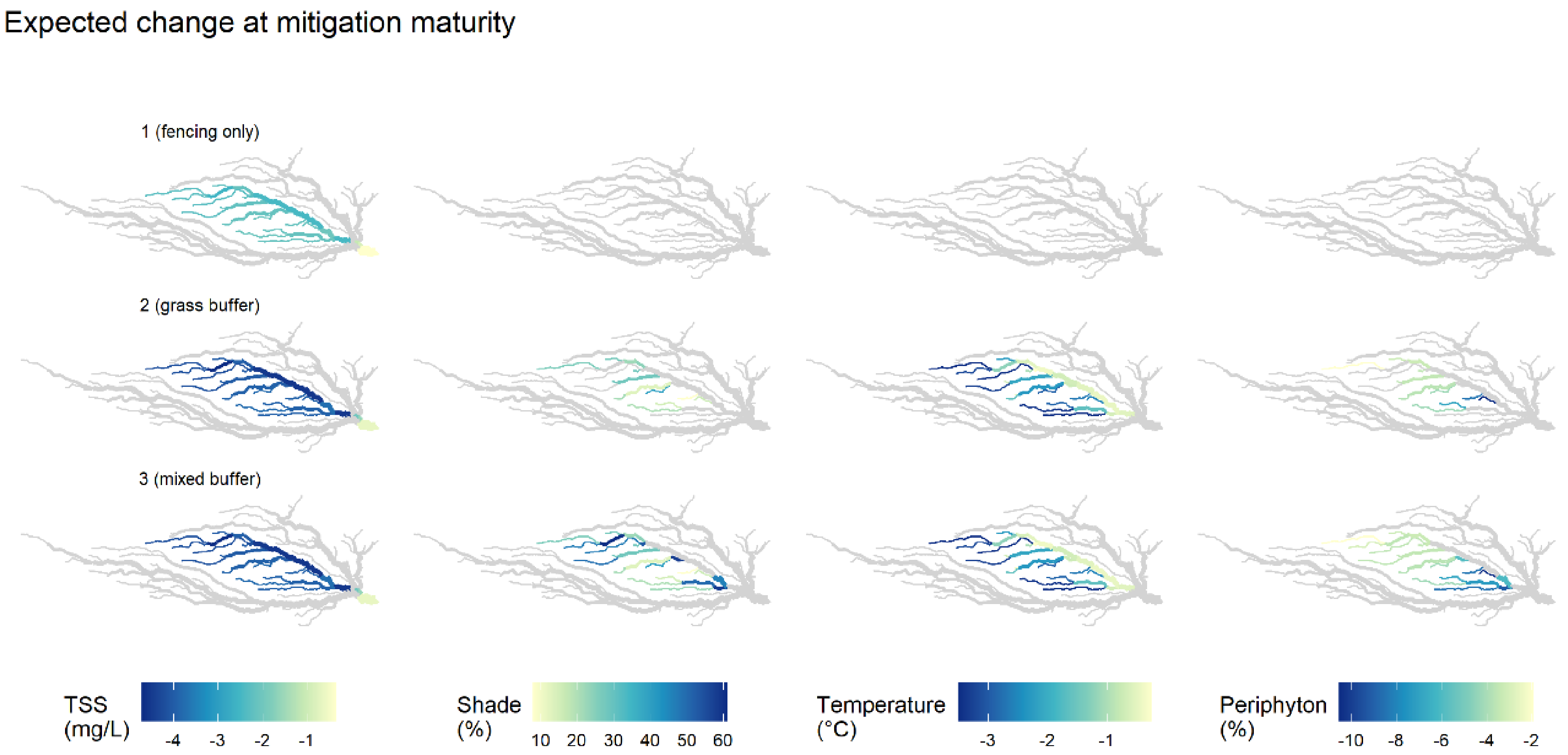

Figure 11: The expected reduction in state for four water quality variables (columns) when three mitigation scenarios (rows) reach maturity. Blue tones represent a greater change in state, while grey reaches indicate no change.

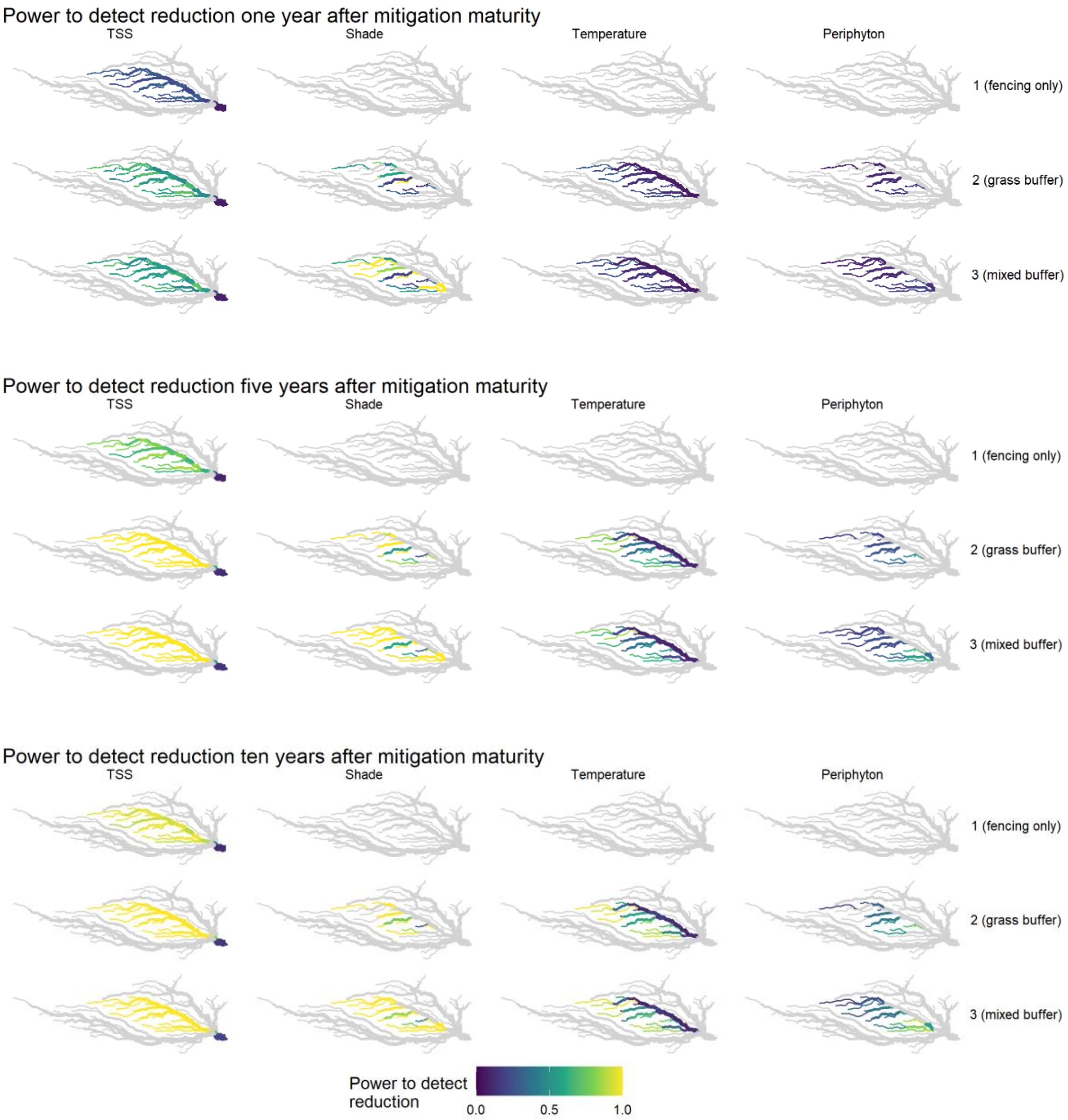

Figure 12: The power available to detect the expected reduction in state (Figure 3) for four water quality variables (columns) at three time-steps after three mitigation scenarios (rows) have reached maturity. Yellower tones indicate a higher power, while grey reaches indicate no expected change in state and, therefore, no power to detect a change. The analysis assumes a monthly sampling regime.

Designing a monitoring network

The third aspect of this case study aims at identifying parts of the catchment that may be most effective for undertaking monitoring to detect improvements in water quality state resulting from the mitigation actions. Here we have taken the results of the power analyses for each of the water quality variables and calculated summary statistics (minimum, maximum) across all water variables for each time period to identify where the power is greatest (Figure 13).

High values of maximum power identify reaches where we would be likely to detect the expected reduction in at least one of the monitored water quality variables, while the high values of minimum power can be used to identify reaches where a change is likely to be detected for all four water quality variables. The minimum and maximum values for the fencing scenario are the same as we only expect to see a reduction in TSS.

Key conclusions from the analysis presented in Figure 13 are:

- As expected, the power to detect a change increases with the length of the monitoring period and is greater where the expected changes are greater.
- The maximum power plots indicate that for grass or mixed buffers, we will likely detect a significant reduction in at least one of the measured variables anywhere within the mitigated sub-catchment five years after mitigation.
- In contrast, ten years of sampling would be required to detect changes under the fencing mitigation scenario, and changes would be more likely to be detected in lower order reaches in the upper catchment.
- In all cases, establishing a monitoring site right at the bottom of the catchment is likely to be ineffective at detecting reductions associated with the mitigations as there is very low power. In this scenario, this is likely due to the inputs from the unmitigated sub-catchments "diluting" the improvements associated with the mitigation plan.

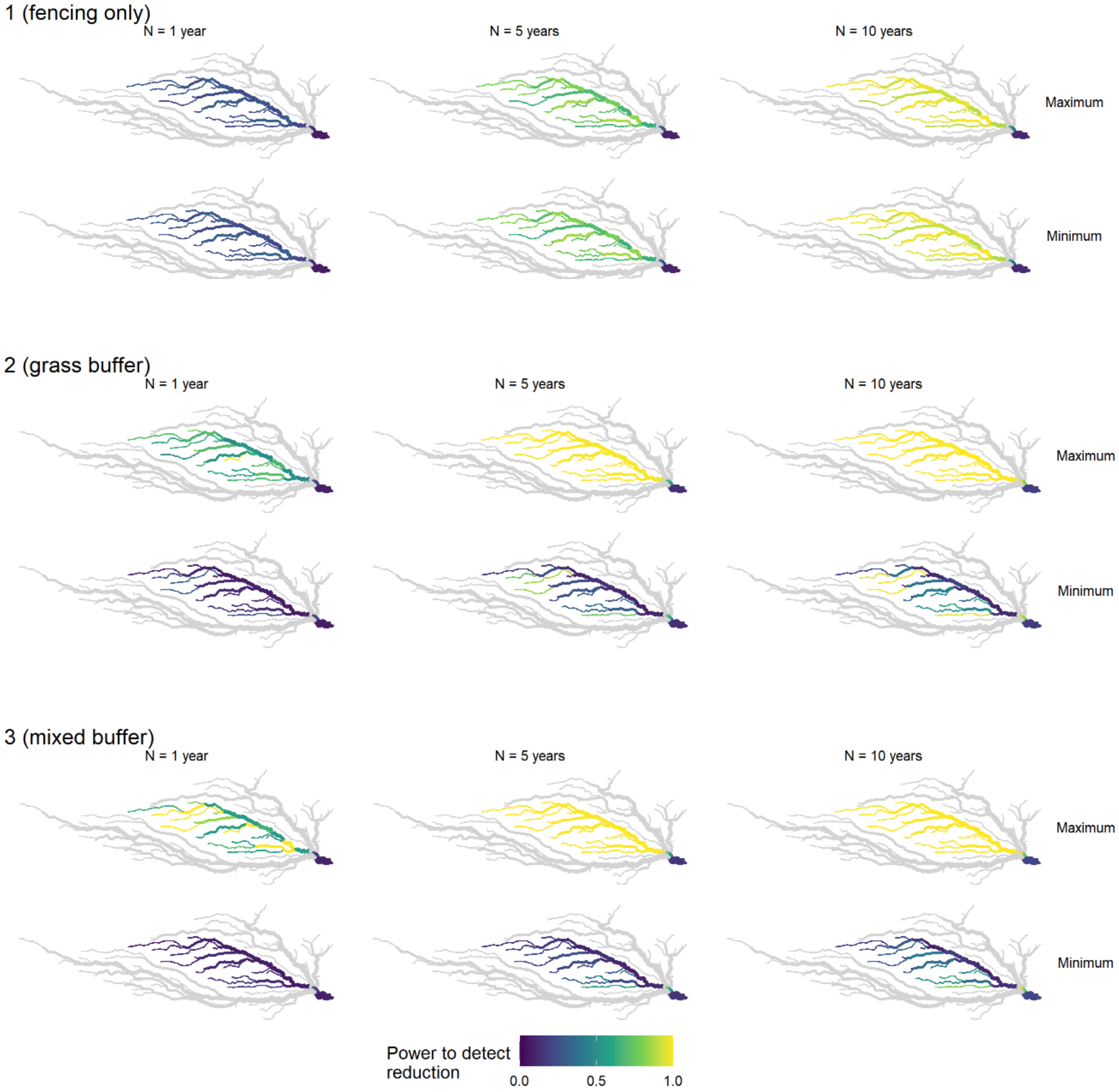

Figure 13. The minimum and maximum power available to detect the expected reductions across all water quality variables for three mitigation scenarios (rows) at three time steps (columns). Yellower tones indicate a higher power, while grey reaches indicate no expected change in state and, therefore, no power to detect a change. The analysis assumes a monthly sampling regime.

4.7 Lake Mitigation Decision Support Tool

4.7.1 Approach

Lakes are a particular focal point for restoration and require implementation of reliable, consistent monitoring programmes that are comparable between catchments, regions and across the country. The needs for restoration is evidenced by concerns about the state of lakes; between 2007 and 2016, 33 percent of monitored lakes were in excellent or high ecological condition, 31 percent were in moderate condition, and 36 percent were in poor ecological condition or were entirely without submerged plants. It should be noted, however, that of the 3800 lakes in New Zealand with area less than 1 hectare, less than 5% have any form of consistent monitoring.

In view of the current emphasis on lake restoration in New Zealand and globally, we identified the need to document general and comprehensive lake monitoring plans to support the evaluation of restoration actions. We specifically sought to

- develop an overarching decision framework based on monitoring to quantitatively evaluate lake restoration success according to selected in-lake restoration actions,
- provide advice on when, where and for how long to monitor, and
- document how to tailor monitoring according to the lake type and the in-lake restoration action.
-

For this “proof of concept” stage of the project, combinations of 6 lake types, 6 in-lake interventions and 7 freshwater attributes were selected as a representative subset of conditions commonly encountered in New Zealand.

Although our work focused on in-lake mitigation, these should form part of a lake catchment mitigation plan and needs to be aligned with a catchment mitigation plan. Inability to achieve such an alignment is one of the reasons for reversion of lake condition to the pre in-lake intervention condition. The in-lake mitigation DST should therefore be considered in a whole-of-catchment context as part of the overall Mitigation Effectiveness Monitoring Design framework (Figure 5).

4.7.2 In-lake mitigations

Unlike preventative restoration methods that mitigate nutrients and other pollutants before they reach lakes, in-lake restoration methods are often chemical or mechanical engineering methods. Such examples include mechanical dredging of lake sediments, nutrient flocculation (geoengineering) and artificial destratification, while ecological interventions include weed biocontrol or fish manipulations.

- <u>Mechanical De-stratification</u>: Stratification reduces the vertical transfer of heat, dissolved oxygen and nutrients, and can lead to deoxygenation and anoxia of the lower water layer and bottom sediments when there is an adequate supply of labile organic matter in the water column and bottom sediments. Mechanical destratification by bubble plumes can mix the stratified layers and hence increase oxygen in the hypolimnion and sediments, reducing the release of nutrients from bottom sediments.
- <u>Phosphorus inactivation</u>: Counteracting high nutrient concentrations that lead to eutrophication and algal blooms, phosphorus inactivation is a chemical (rather than mechanical) restoration method, hereby a flocculant – for example Alum (aluminium sulphate), Phoslock (lanthanum-enriched bentonite) or Aqual-P (modified zeolite) – is added to the water column. The suspended phosphorus then flocculates and is deposited in the

sediment. Although this is highly effective, more flocculant needs to be continuously added to water column, especially in summer. It also has potential side effects which need to be monitored.

- Aquatic weeds are commonly counteracted using two mechanisms:, mechanical harvesting and biocontrol measures.
  - Mechanical weed harvesting requires considerable manual effort; however it is effective. Harvesting has some side effects that need to be monitored and mitigated.
  - Weed biocontrol by large herbivore fish such as grass carp can be effective, but bears the usual caveats of introducing a large, non-native and potentially invasive species into an ecosystem.
- Sediment dredging is an effective way to remove excess nutrients (Van der Does, Verstraelen et al. 1992), however – like most of the restoration options discuss – needs ongoing maintenance. Liu, Zhong et al. (2016) recommend re-dredging every three years, yet this will depend on the lake size and magnitude of eutrophication. Dredging will remobilize sediments which can lead to increased turbidity. A more serious side effect of dredging can be mobilization of persistent organic pollutants such as PCP and PCDDs, as well as heavy metals. These pollutants will also persist in dredging disposals, which may have to be stored in special waste facilities.
- Inflow Diversion: Lake inflow diversion can be an effective way to divert nutrient- and/or algae-rich inflows directly into the outflow of the lake, thus reducing the potential for these nutrient loads to cause in-lake degradation of water quality and ecology.

4.7.3 Lake types

Six lake types, considered representative for the purpose of this work, of the range of conditions, issues and potential intervention types typically encountered in New Zealand were considered:

- Oligotrophic glacial lakes
- Eutrophic glacial lakes
- Volcanic lakes
- Riverine lakes
- Peat lakes
- Shoreline lakes.

A description of each lake type’s typical characteristics, values, issues and potential in-lake or catchment mitigation actions is provided in the Confluence space: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/204800006/Monitoring+considerations+by+lake+types

4.7.4 Monitoring recommendations

We stratified monitoring recommendations by three variables: lake types, the pressures associated with the lake types, as well as three timeframes: immediate after restoration, monthly and long-term. Depending on the lake types, we introduce different monitoring variables, including nutrients, water chemistry, macrophytes, zooplankton and benthos, as well as fish. Monitoring frequency and duration are defined following the three-tier structure of monitoring plans as recommended in Section 4.2.5.

Table 8: Monitoring matrix by lake type, where GO =Glacial oligotrophic, GE=Glacial eutrophic, V=Volcanic, R=Riverine, P=Peat, S=Shoreline

	Nutrients	DO	Turbidity	Chemicals	Macrophytes	Zooplankton	Benthos/ fish
Tier 1 (immediate)	G_O, G_E, V, R, P, S	G_O, G_E, V, R, P, S	G_E, V, R, P, S		G_O, G_E, V, R, S	G_E, V, R, P, S	
Tier 2 (monthly)	G_O, G_E, V, R, P, S	G_O, G_E, V, R, P, S	G_E, V, R, P, S		G_O, G_E, V, R, S		
Tier 3 (long term)	G_O, G_E, V, R, P, S			G_E, V, R, P, S	G_O	G_O, G_E, V, R, P, S	G_O G_E, V, R, P, S

4.7.5 Further work

The lake DST would benefit from the following additional work:

- Expand the DST to cover all New Zealand lake types,
- Expand the DST to cover additional mitigations/interventions and freshwater attributes,
- Integrate further analysis of how various monitoring technologies may impact on monitoring design and frequency and thus on statistical detection of change
- Integrate further analysis and consideration of the implications of very low concentrations (e.g. of nutrients in oligotrophic lakes) and changes in laboratory methods on long-term detection of trends/ changes

4.8 Groundwater Nitrate DST

The following sections provide a summary of the Groundwater DST, which is available here: https://olw-decision-tree.atlassian.net/wiki/spaces/OMDF/pages/78217217/Groundwater+DST+overview

4.8.1 Challenges

Groundwater systems represent a key transport pathway between nitrogen discharge sources and lakes, streams, rivers and water supply well receptors. Monitoring the effectiveness of nitrate discharge mitigations for these groups of receptors can be challenging:

- Lag times between mitigation implementation and a clearly identifiable response at a receptor can often mean that the effectiveness (or otherwise) of mitigation actions cannot be determined within practical timeframes
- Previous land use change in many parts of Aotearoa New Zealand mean that baseline conditions are not static. Evaluating the effectiveness of mitigations in areas where nitrate concentrations are trending upwards (or may start trending upwards in the future) due to past land use change presents a critical challenge for effective mitigation monitoring.
- The high signal-to-noise ratio in receptors with significant seasonal, climate or weather-related nitrate concentration variability can make detection of mitigation efficacy problematic.

- High dilution ratios and detection limit constraints present challenges for nitrate mitigation monitoring in sensitive lakes.
- Monitoring nitrate concentrations in all receptors (e.g. private water supply wells) may not be practical where large numbers of receptors are present.

4.8.2 Groundwater Nitrate Pathway DST overview

The Groundwater Nitrate Pathway DST responds to the challenges outlined above for catchment mitigations comprising nitrogen leaching rate reductions at source. The two main components of the process (illustrated in Figure 14) are a time series data evaluation process based on Effective Lag Time (ELT) and Forward-Looking Counterfactual Inference (FCI) analysis and a monitoring network spatial distribution analysis. The components are explained in more detail and illustrated via a scenario evaluation in subsequent sections of the report.

This process could also be used for lakes, with additional consideration given high-sensitivity low nutrient lakes where high dilution rates lead to very low nitrate concentrations. Mitigation efficacy monitoring in-lake may be impractical here due to detection limit constraints, and alternative out-of-lake monitoring sites would need to be considered as per the discussion in Section 4.8.7.

The process shown in Figure 1 is explained in more detailed in the following method description sections and via a scenario-based case study in Section 4.8.7 below.

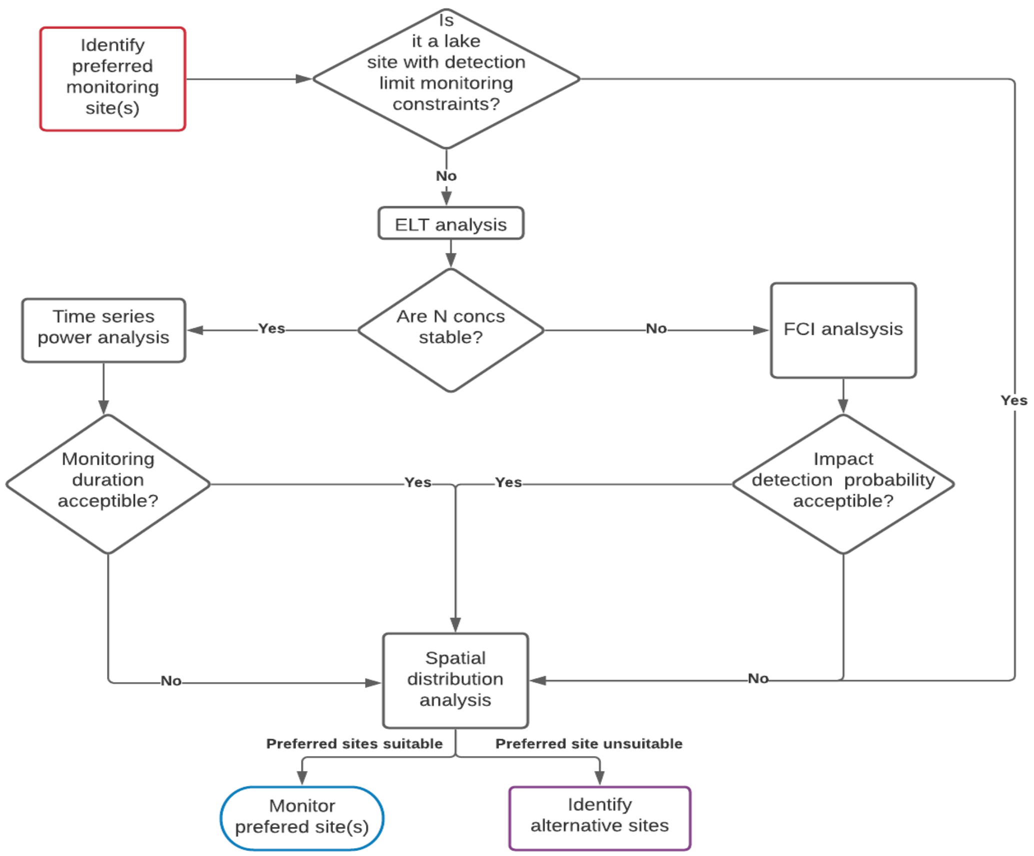

Figure 14: Monitoring duration evaluation for preferred monitoring sites.

4.8.3 Lag time analysis

Determination of the lag time between a change in nitrogen inputs (e.g. implementation of a mitigation programme) and the associated response at a given monitoring location (well, stream, river or lake) is a pre-requisite for determination of mitigation monitoring duration. Table 9 below provides some terminology and definitions for clarity.

The process for determination of the Effective Lag Time (ELT) for a given monitoring site is as follows:

1. Collect and analyse age tracer samples, taking specialist advise on sample number and timing as required.
2. Translate age tracer concentrations into water age using an appropriate age distribution model, taking specialist advice as required.
3. Use age distribution model to determine the 90th percentile age, i.e. the ELT

Table 9: Transport time terminology.

Term	Definition
Lag time	Period between a change in the nitrogen leaching rate and realisation of the effects at a monitoring location.
Equilibration period	Period between a change in the nitrogen leaching rate and realisation of the full effects at a monitoring location, i.e. to achieve steady state conditions, with no further trend over time
Breakthrough time	The time taken for a change in the nitrogen leaching rate in the catchment to become detectable at a monitoring location (assuming no background noise)
Age distribution	Water travels through aquifers and into surface waters via a mixture of faster and slower pathways. The age distribution describes the mixture of ages in a water sample.
Mean residence time (MRT)	The average age of water in a water sample.
Effective Lag Time	We used the term Effective Lag Time (ELT) to describe the time taken for 90% of the effects of a change in catchment nitrogen inputs to be realised at a given monitoring location. Use of the ELT is preferable to the equilibrium period, which could become impractical due to long tail age distributions. It is also preferable to the mean residence time, represents an unspecified proportion (e.g. 50% for a gaussian distribution) of the nitrate concentration change.

4.8.4 Monitoring duration analysis under equilibrium conditions: time series power analysis

The age distribution model selected and parameterised via the method above can be used to project future nitrate concentrations following implementation of a mitigation programme as per the example shown in Figure 6 below. The projected nitrate concentrations and ELT in Figure 15 are based on the following:

- A binary age distribution model with a 5.5 year MRT which gives an ELT of 15 years
- A stable pre-mitigation receptor nitrate-N concentration of 4.6 mg/L
- Two nitrate loss mitigation scenarios: a 15% catchment N load reduction and a 30% catchment N load reduction, both fully implemented in January 2021

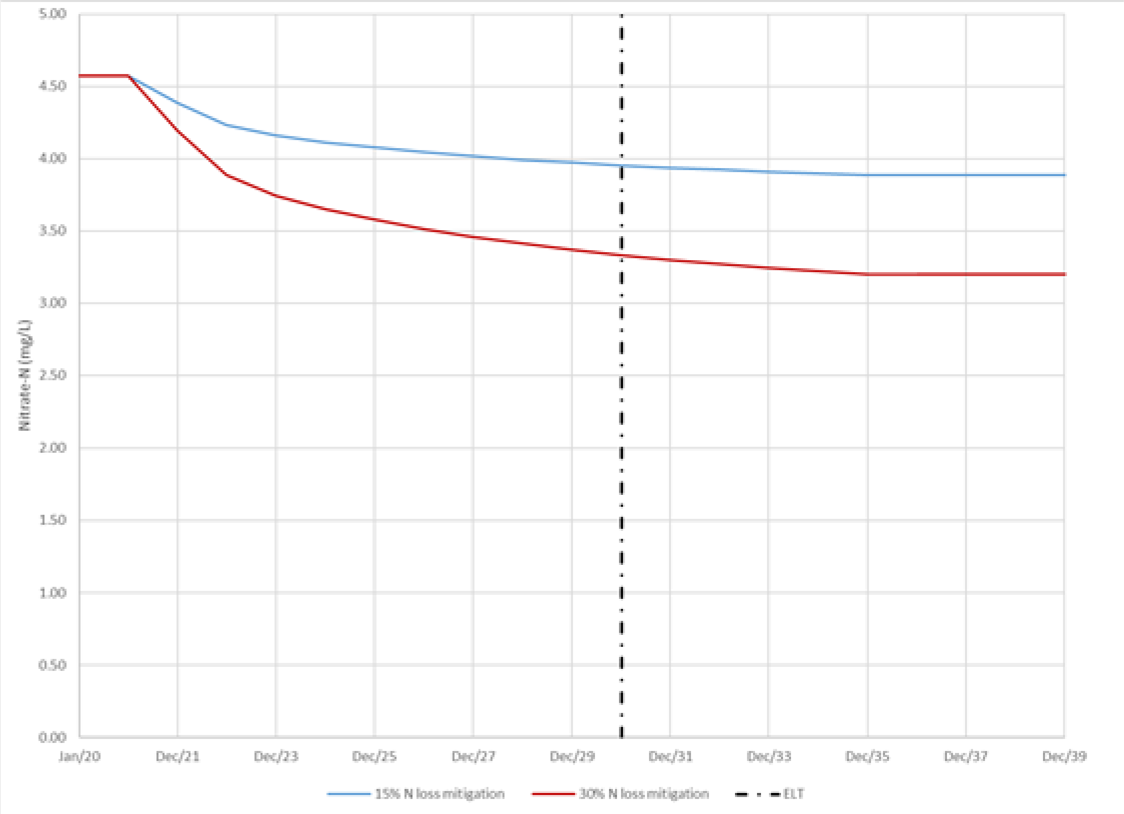

Figure 15: Projected future nitrate concentrations following nitrate loss mitigations

Statistical power analysis can then be undertaken to evaluate the monitoring duration required to detect the expected change in nitrate concentrations, assuming that the standard deviation remains unchanged post-mitigation. A worked example of the method is provided in Section 4.8.7. Alternative monitoring locations (e.g. closer to the mitigation locations) should be identified if the monitoring duration is longer than acceptable (e.g. a 10 year duration is required but information on mitigation efficacy is required within five years). Guidance on identification of suitable locations is provided in Section 4.8.7.

4.8.5 Monitoring duration analysis under non-equilibrium conditions: FCI analysis

Recent land use intensification and increasing nitrate concentrations in streams, rivers, lakes and groundwater are increasing in some parts of New Zealand mean that nitrate concentration reductions associated with land use mitigations are likely to be offset by the gradual arrival of some proportion of these higher nitrogen loads via slower flow paths. Failure to account for the effects of land use history will increase the likelihood of statistical error (e.g. a false negative) during the mitigation efficacy evaluation process.

Considering the above, key questions for mitigation monitoring design are as follows:

1. If nitrate concentrations are lower post-mitigation, can we conclude with confidence that mitigation has been effective?
2. If nitrate concentrations are <u>not</u> lower post-mitigation, can we conclude with confidence that mitigation has <u>not</u> been effective?
3. Can unambiguous information be derived from the existing monitoring network given recent land use intensification and lag times?

Causal inferences about nitrate concentration changes post-mitigation must consider:

- The expected effect of mitigation
- The effects of climate variability
- Lag times and disequilibrium with past land use change

A method referred to as a forward-looking counterfactual inference (FCI) has been developed to evaluate whether the effects of mitigation are likely to be identifiable at monitoring sites with non-stationary nitrate concentrations. The FCI method seeks to understand the plausible range of nitrate concentrations that may occur with and without mitigation.

A posterior counterfactual inference approach to water quality monitoring data evaluation would involve analysis of post-mitigation implementation monitoring data. A model would be developed to generate a synthetic set of water quality time series data set which incorporates all key water quality drivers but excludes the mitigation action. The synthetic and measured data set would then be compared and evaluated, taking account of modelled and measured data uncertainty bounds, to determine whether mitigation efficacy can be inferred from the difference between the factual (measured data) and counterfactual (synthetic data) with a suitable level of statistical confidence.

The forward-looking counterfactual inference approach generates two sets of modelled water quality time series data, with and without the expected effects of mitigation, with uncertainty bounds which account for seasonal and inter-annual variability and uncertainty over historic catchment N loads and water age distributions. The two data sets are then evaluated to determine whether it is likely to be possible to identify mitigation efficacy with a suitable level of statistical confidence at the monitoring site.

The FCI process involves the following steps for a given monitoring site:

1. Evaluate the ELT as described above.
2. Define the catchment/recharge area for the site (obtaining specialist advice as required).
3. Evaluate the catchment nitrogen load history at annual resolution for the ELT period (e.g. if the ELT is 10 years and the mitigation is implemented in 2022 the ELT period is 2012-2022 period), including a suitable error band
4. Validate the catchment nitrogen load history (and possibly also the age distribution interpretation) against measured nitrate concentrations/loads at the monitoring site if sufficient data are available. Adjust the error bands such that the estimated catchment

nitrogen load history is not inconsistent with the measured data set, giving due consideration to age distribution uncertainty

5. Use future nitrate load projections for the mitigation scenario and business-as-usual scenario (factual and counterfactual respectively) as inputs for future nitrate concentration projections.

This process is illustrated in Section 4.8.7 .

4.8.6 Spatial distribution analysis

Requirements and usage

Development of a groundwater monitoring network upstream of key receptors may be required under the following circumstances:

1. The time series power analysis for equilibrium condition sites shows that the required monitoring duration is too long at the receptor due to the ELT length and/or the magnitude of the catchment N load reduction given the temporal variance in nitrate concentrations (seasonal, weather, climate).
2. The FCI analysis shows that monitoring at the receptor is unlikely to yield conclusive results within the required time frame due to disequilibrium between catchment nitrogen inputs and outputs (e.g. the effects of recent land use intensification have not been fully realised within the monitoring data).
3. Monitoring at a receptor is not possible due to high dilution ratios and detection limitations (e.g. lakes).
4. Nitrate attenuation between source and receptor introduces uncertainty into monitoring results which can be resolved via upstream monitoring.

The mitigation monitoring spatial distribution analysis process described below could be used:

1. To identify upstream groundwater monitoring locations if monitoring at a preferred downstream site (e.g. a stream or river SOE site) is unlikely to provide conclusive information on mitigation efficacy within the required timeframe.
2. To evaluate the number of monitoring sites required to reliably detect a specified reduction in nitrogen leaching rates for a given receptor/group of receptors.
3. To determine whether existing monitoring networks are spatially representative.

Analysis process

The spatial distribution analysis process is as follows:

1. Define the mitigation monitoring area (e.g. a catchment or a flow path between the mitigation area and downgradient receptors).
2. Determine the expected the nitrogen loss reduction for the proposed mitigation within the catchment area for the receptor.
3. Evaluate the spatial variability in both nitrate loss rates and the expected rate reductions within the receptor catchment area.
4. Determine the ELT requirement for the monitoring site given the catchment N loss reduction rate and the expected mean and standard deviation nitrate concentrations at potential monitoring sites (e.g. shallow wells).
5. Develop a preliminary monitoring design and use the time series and spatial power analysis tools to determine the likelihood of successful mitigation monitoring.
6. Modify the preliminary monitoring design as required based on the outcomes of step 5.

4.8.7 Case study

Overview

The mitigation monitoring design decision support process outlined in the previous sections is applied to an example catchment (the Waimakariri management zone in Canterbury) to illustrate concepts and their implementation in more detail. Two of the main watercourses in the catchment, Kaiapoi River and Cust Main Drain, were selected for analysis. Private water supply wells are also considered towards the end of the case study.

Environment Canterbury has proposed a change to the Land and Water Regional Plan (LWRP) to reduce nitrate discharges to water bodies within the zone. The notified plan proposes:

1. A 15% N loss reduction from dairy farms and 5% for all other consented land uses by 2030.
2. Continued N loss reductions if monitoring and science work undertaken for a proposed 2032 plan change shows nitrate concentrations still exceed or are likely to exceed the target values.

A science update and progress review is sought by the community in 2025 to evaluate the effectiveness of mitigations implemented by that time, to evaluate likely future nitrate concentrations and to assess the need (or otherwise) for ongoing nitrogen loss reductions. This information is of significant importance for farm planning and investment decision-making. Determination of the monitoring period required to assess mitigation efficacy is therefore of great value for the community, local stakeholders and the regional council.

It is important to note that the results presented in this case study are indicative only and are not based on a rigorous analysis of the data and QA. They are intended to illustrate the DST as a “proof of concept” and should not be used to support decision-making on monitoring design in the Waimakariri zone.

Step 1: ELT Analysis

Age tracer testing (tritium) of samples collected from the Kaiapoi River and Cust Main Drain monitoring sites in 2016 under baseflow conditions gave a mean residence times (MRTs) of 5 - 7 years and 8 – 10 years respectively (van der Raaij, 2016[14]).

The aquifer is conceptualised as a dual porosity system with relatively fast flow through buried river channel deposits (open framework gravels), near surface deposits and the land area proximal to the stream. Flow through the fine-grained alluvial sediment matrix, which encapsulate the river channel deposits, and through the deeper aquifer system is much slower. A binary exponential piston flow model has therefore been used to hypothesise a range of age distributions for the water sample. Two possible cumulative age distributions for five and seven year MRTs (i.e. the Kaiapoi River site) are plotted in Figure 16. The data give an ELT range of 10 – 18 years for the Kaiapoi River site; an equivalent analysis for the Cust Main Drain site gives an ELT of 16 – 27 years.

[14] Van der Raaij R., 2016. Tritium results and residence tome interpretations for spring-fed streams in the Waimakariri Water Management Zone. GNS letter report 16/7/2016 to Environment Canterbury

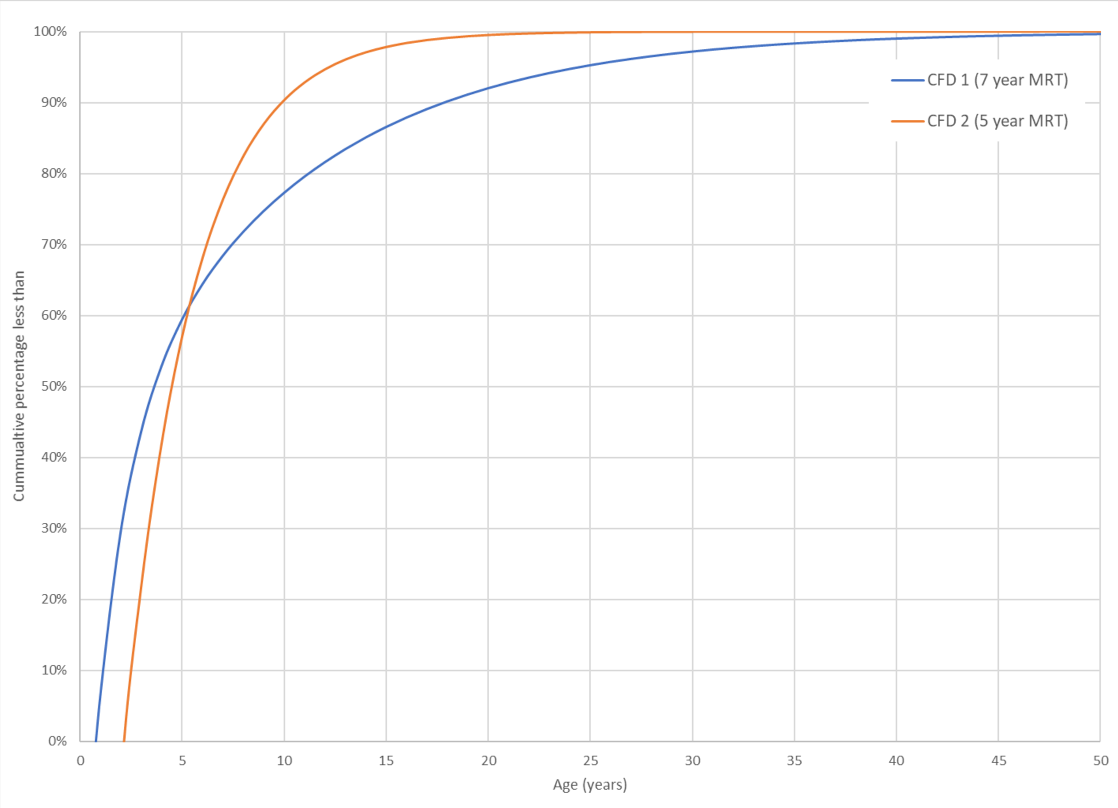

Figure 16: Cumulative distribution of water age for Kaiapoi River site

Step 2: Nitrate concentration trend analysis

Recent land use intensification in the Waimakariri zone and relatively slow travel times through the vadose zone and saturated aquifer to streams and water supply wells means that nitrate concentrations are either increasing or have the potential to increase in some locations, especially receptors that receive water from the deep aquifer pathway. Continued nitrate concentration increases are expected in the future as the system moves towards equilibrium with the recent increases in catchment nitrogen loads. Rising nitrate concentrations in the Kaiapoi River are shown in Figure 17.

Nitrate concentrations are not increasing everywhere, however: concentrations in the Cust Main Drain (a foothill runoff and groundwater-fed stream) are more variable (Figure 18), partially due to inconsistent irrigation by-wash discharges sourced from low nitrate alpine river water and partially due to runoff from the foothills, but show no clear trend over time.

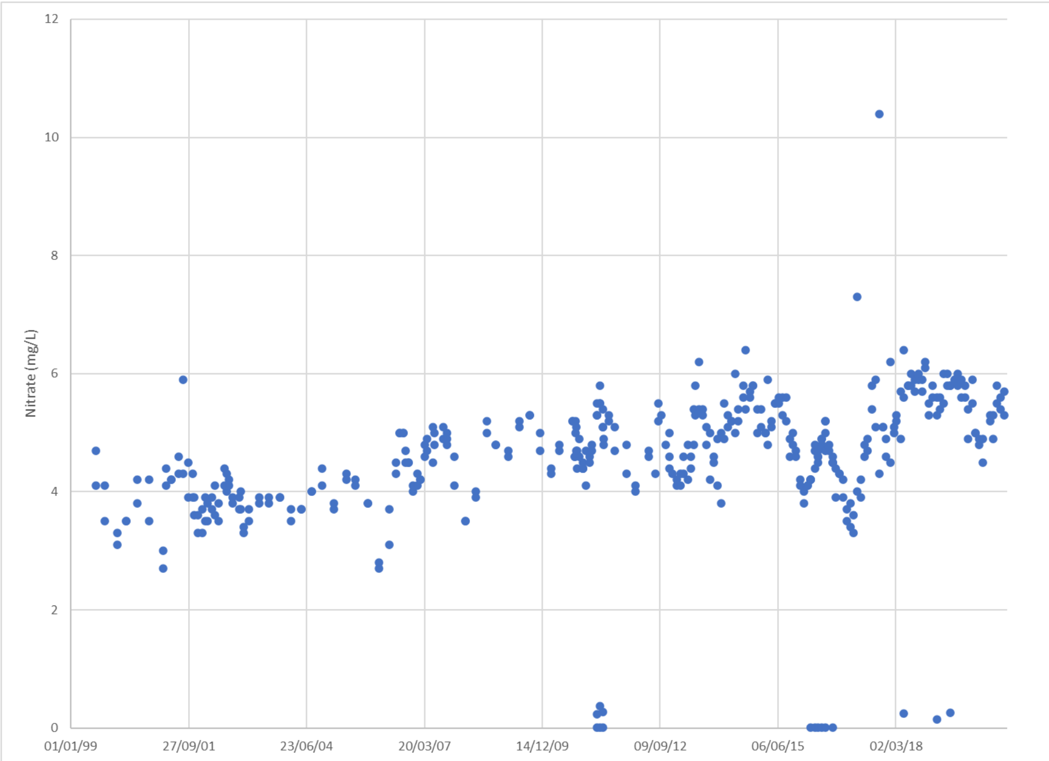

Figure 17: Kaiapoi River nitrate monitoring data

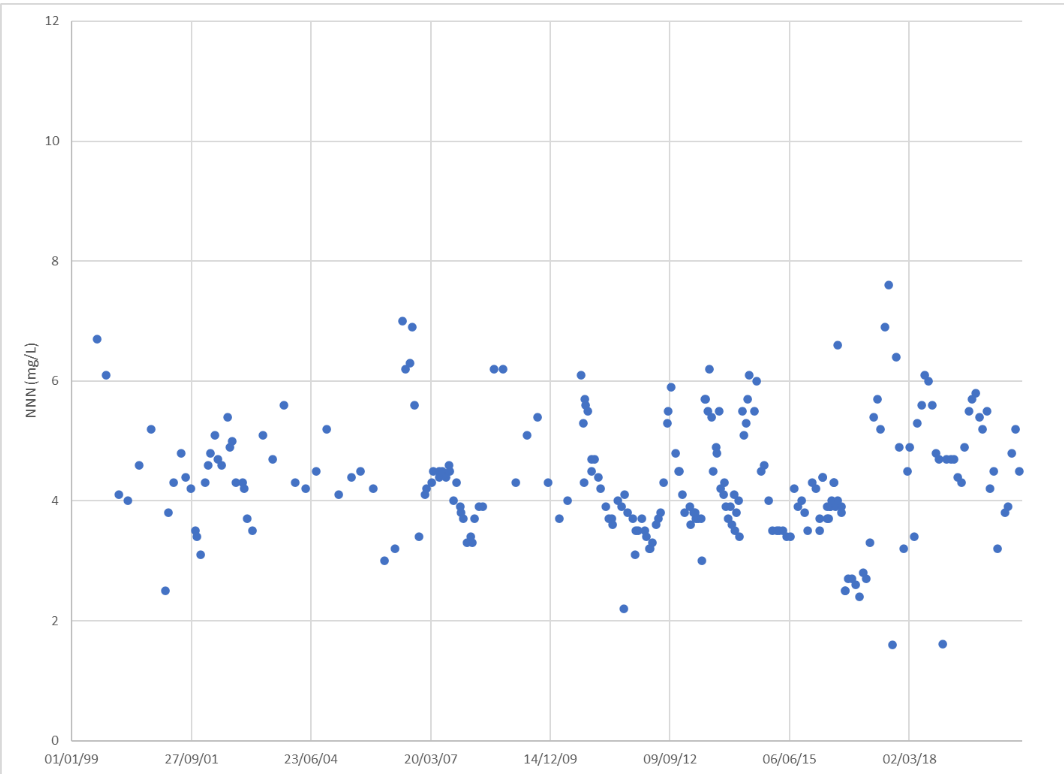

Figure 18: Cust Main Drain nitrate monitoring data.

Step 3: Time series power analysis

Assuming that nitrate concentrations in the Cust Main Drain are stable (which may not be the case in reality given the long ELT and possibility that the effects of land use intensification have been masked by irrigation water discharges), time series power analysis can be applied to determine the monitoring duration required to detect concentration reductions associated with mitigation actions. The process is as follows:

1. Calculate the nitrate concentration standard deviation from past monitoring data
2. Project future nitrate concentration reductions via the age distribution model (see Figure 19 below)
3. Calculate the projected future mean nitrate concentrations for a series of intervals (e.g. 3 year, 5 year, 10 year)
4. Apply statistical power analysis to these data to determine monitoring duration requirements for a given statistical power and sampling frequency.

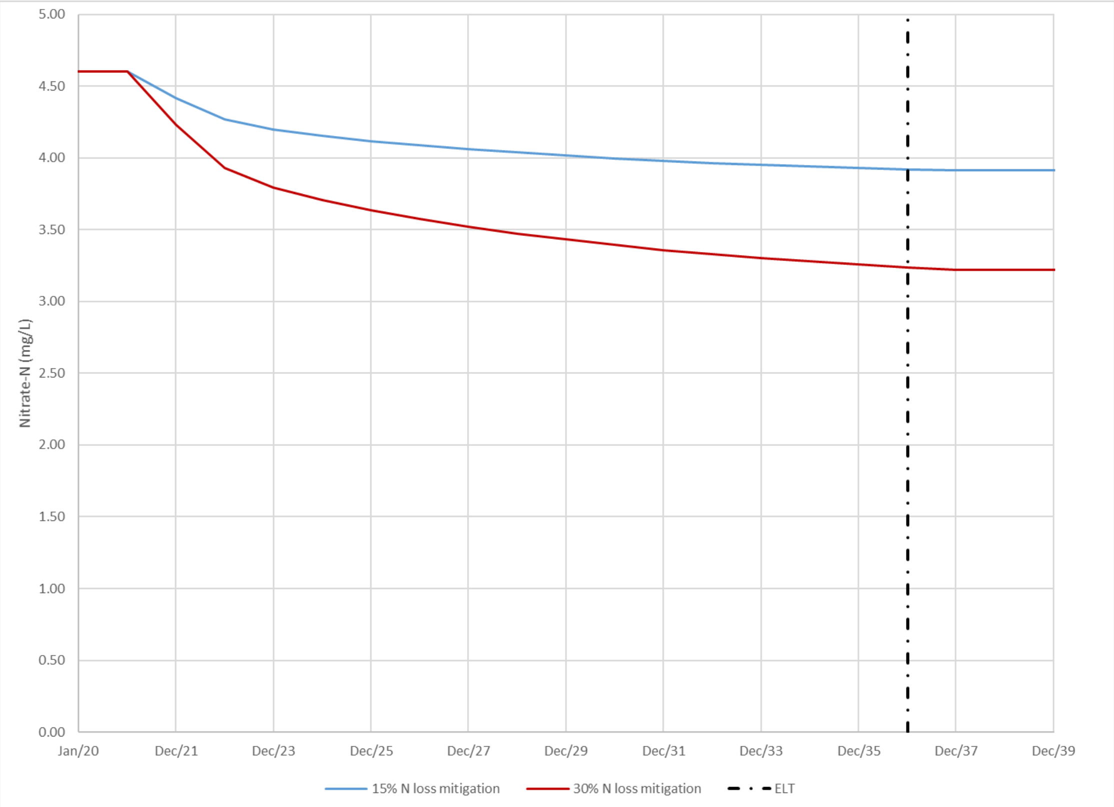

Figure 19: Nitrate concentration reduction projections for 145 and 30% catchment N loss reductions

The results of step 4 above (Figure 20 below) indicate that it should be possible to detect the effects of a 15% catchment N loss reduction within five years for quarterly sampling and within approximately two years for monthly sampling. Lower monitoring durations would be required for a 30% catchment N load reduction. It should be noted that these results are indicative only and are not based on a rigorous analysis of the data and QA process (e.g. the ELT used for the statistical power analysis related to another site with a lower ELT). They are intended to illustrate the concept and not to provide information for decision-making on monitoring design in the Waimakariri zone.

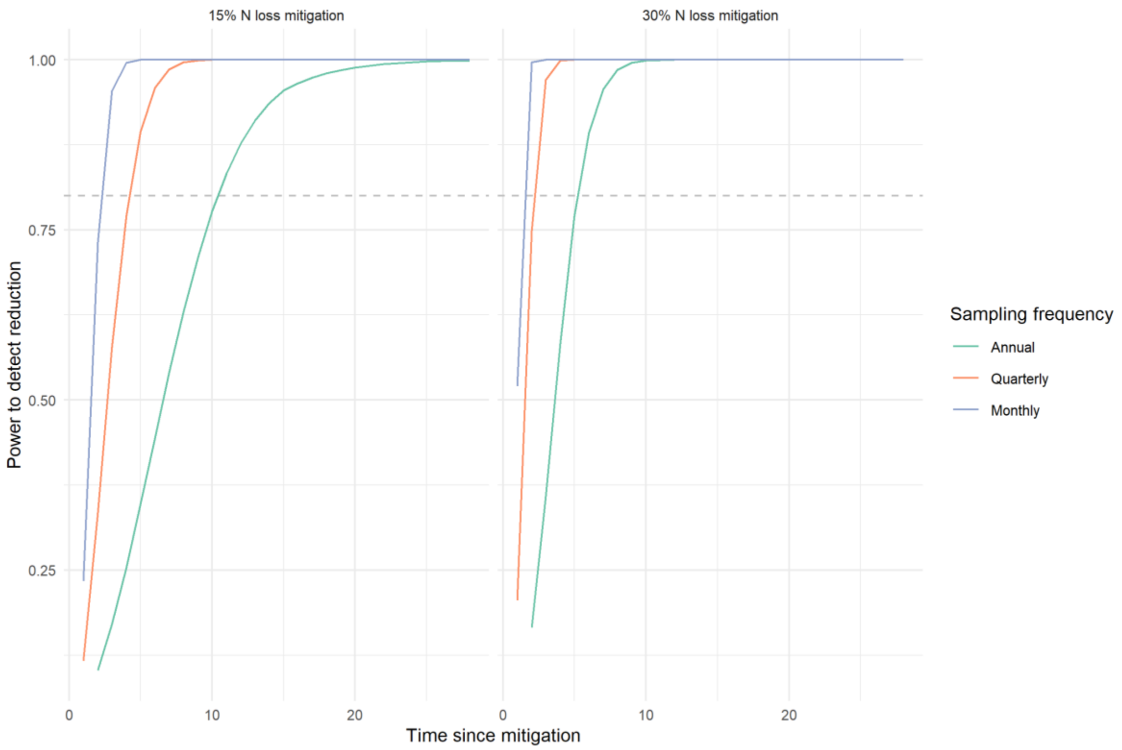

Figure 20: Times series power analysis results.

Step 4: FCI analysis

Nitrate concentrations in the Kaiapoi River are increasing and hence monitoring duration requirements should be evaluated with the FCI tool.

Figure 21 presents an example of the FCI method implementation. Scenario 1 and Scenario 2 are the upper and lower bound counterfactual nitrate concentration time series (i.e. assuming no mitigation); Scenario 3 and 4 are the upper and lower bound factuals for a 15% and a 30% catchment N load reduction respectively.

Results show that under Scenario 3 (15% catchment N load reduction) the projected future nitrate concentrations fall within the possible range that could occur in the absence of mitigation (i.e. within the counterfactual envelope). It would therefore not be possible to determine the effectiveness of the mitigation with a sufficient degree of certainty. Under Scenario 4 the projected future nitrate concentrations fall outside of the possible range that could occur without mitigation. Whilst it would not be clear in this example whether the mitigation had reduced nitrate concentrations in 2025 by 1.3 mg/L (from 6.2 to 4.9 mg/L for Scenario 1 minus Scenario 4) or by 0.6 mg/L (from 5.4 to 4.9 mg/L for Scenario 2 minus Scenario 4), the nitrate reduction associated with the mitigation actions would be identifiable in the measured data. It could therefore be concluded that an alternative monitoring location, most likely closer to the nitrate load mitigation area, would be required to evaluate mitigation effectiveness under a 15% catchment N load reduction. Monitoring at this site would be a viable option under the 30% N load mitigation scenario, but the degree to which the mitigation had been effective would be somewhat uncertain. Alternative monitoring sites would be required to resolve this uncertainty.

Note that the upper and lower bounds were derived from approximate visual matching to the measurement-based stream N loads, for illustrative purposes. A methodology improvement recommendation is provided in Section 0.

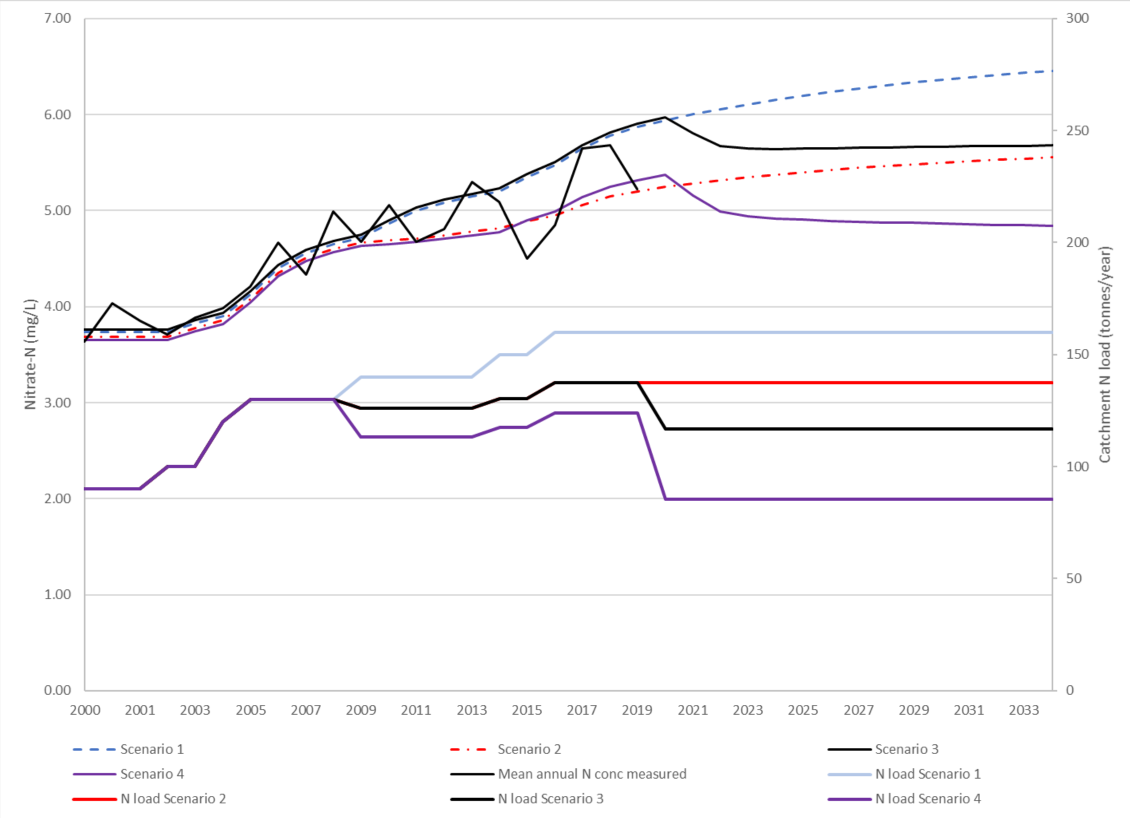

Figure 21: FCI nitrate time series data.

Step 5: Spatial distribution analysis

Because the FCI analysis for Kaiapoi River indicate that it will not be possible to determine the effectiveness of the mitigation with a sufficient degree of certainty by monitoring at that site, upstream monitoring sites are likely to be required. The spatial distribution analysis process is used to identify the number of monitoring sites required and to evaluate the requirements for collecting samples which are representative of the target population (see discussion below).

Determination of the mitigation monitoring area (e.g. a catchment or a flow path between the mitigation area and downgradient receptors) is the first step in the process. This case study uses the area shown in Figure 22 below for illustrative purposes, noting that is not the true catchment area of the Kaiapoi River monitoring site.

The second and third steps in the spatial distribution analysis process are to determine the expected nitrogen loss reduction for the proposed mitigation within the catchment area, and to evaluate the spatial variability in both nitrate loss rates and the expected rate reductions within the area.

The notified version of proposed Plan Change 7 of the Canterbury Land and Water Regional Plan sets out a 15% nitrate loss reduction for dairy farms and 5% for other land uses which require a land use consent under the LWRP (e.g. sheep, beef, deer, horticulture, pig farming). These nitrate loss reductions are applied to the mapped land use for the mitigation monitoring area to generate a layer from which the loss reduction mean and standard deviation can be calculated.

The fourth and fifth steps in the process are to 4) determine the ELT requirement for the monitoring site(s) and 5) develop a preliminary monitoring design and use the time series and spatial power analysis tools to determine the likelihood of successful mitigation monitoring via the preliminary design.

Although we have not included step four in this case study due to time constraints, the method is demonstrated in the ***Step 3: Time series power analysis*** section above. The ELT could be determined by age tracer sampling in a selection of monitoring wells covering a range of depths and locations. The time series nitrate concentration standard deviation could be determined from existing monitoring wells. Implementation of the Step 3 process would then help to identify the ELT requirements for determination of the effectiveness of mitigation within a specified time frame, and wells selected accordingly. By way of example, the process might show that an ELT of 6 years is required, with the age tracer sampling and analysis showing that wells screened within 2 m of the water table would generally achieve this. The monitoring network design would therefore need to include wells which meet this criteria.

Step 5 of spatial distribution analysis process comprises use of time series and spatial power analysis tools to determine the likelihood of successful mitigation monitoring via a preliminary monitoring network design. We have used Environment Canterbury's 16 groundwater quality wells in this area as the preliminary network (see Figure 22) for this case study.

We have assumed for current purposes that nitrate sampled from a well is representative of the land use within which it is located. In reality this is unlikely to be either entirely the case, or the case at all, especially where the monitoring wells is relatively deep and located downgradient of a different land use to that within which it is located. Monitoring well recharge area analysis would be required to provide a foundation for more robust spatial distribution evaluation.

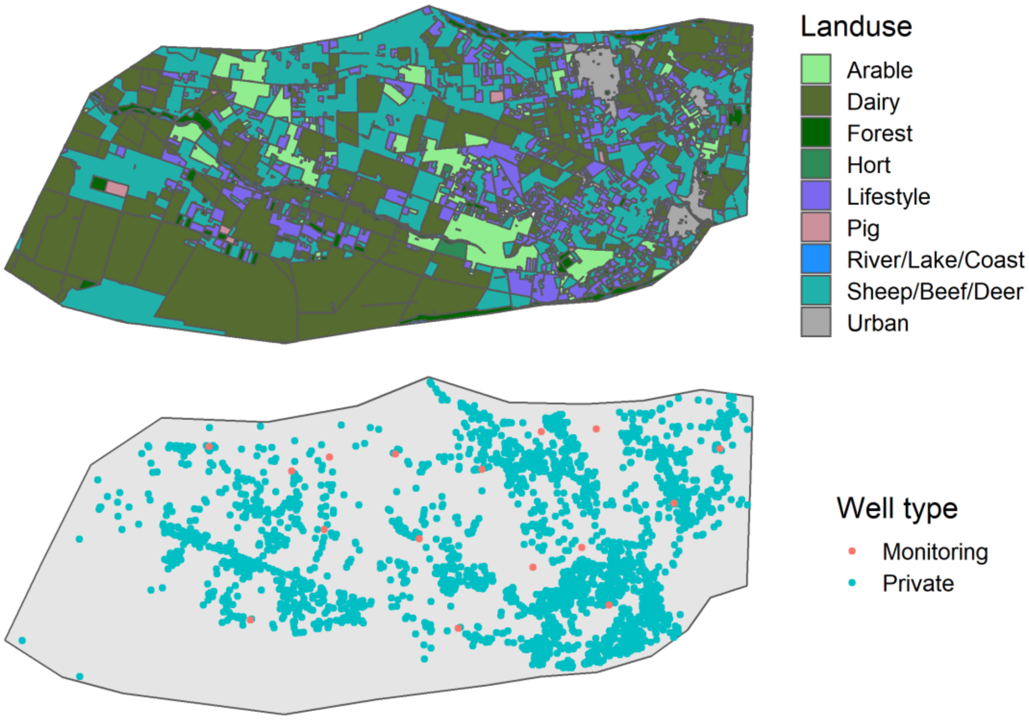

Figure 22: The current landuse in the Waimakariri Zone with respect to sixteen existing State of the Environment (SOE) monitoring wells and 2381 private wells.

A significant number of private water supply wells are present within this catchment area, as shown in Figure 22. We have included an illustration of how the spatial distribution analysis can be used to assess the whether the existing monitoring is likely to provide representative data for determination of the effectiveness of nitrate loss mitigations on nitrate concentrations in private wells, as an extension to the case study described above.

The spatial data power analysis uses mean and standard deviation nitrate concentrations as inputs for determination of the number of sites required to obtain a statistically robust sample of the population. Whilst these metrics could be determined from a soil leaching nitrate concentration layer (e.g. derived from Overseer™ modelling), it is possible that this would overestimate the variance of groundwater nitrate concentrations (and hence the number of monitoring sites required) due to the possible smoothing effect of mixing and dilution processes in groundwater. Further work could be undertaken to explore this. For the Waimakariri case study we have used water table nitrate concentration data generated via a groundwater model. Model data were readily available for a status quo model run (referred to as Current management Practise, CMP) and a Good Management Practice + 20% Dairy, which simulates groundwater nitrate concentrations following implementation of GMP and with dairy farms having reduced nitrate losses by 20%. Although this differs slightly from the proposed Plan Change 7 mitigation requirements, it is still useful for demonstration of the mitigation monitoring design process. Figure 23 below shows modelled groundwater nitrate concentrations for these two scenarios. The lower figure shows the difference between the CMP and GMP + 20% Dairy concentration layers.

We assessed the ability of the current monitoring network to detect the expected reduction in nitrate across the region using an analytical power analysis, where the mean and standard deviation were based on the CMP modelled nitrate layer and assuming a Type I error of 0.05. Figure 24 shows that the power available to detect a reduction in nitrate increases as the magnitude of the reduction and/or the number of monitoring wells increases.

The existing monitoring network is unlikely to detect the median expected change in nitrate (power = 0.264). Based on this analysis, a minimum of 100 sites would be required to detect a 20% reduction in dairy farm nitrate leaching. A median reduction in nitrate leaching of at least 47% would be required to provide 80% confidence of detecting the reduction via the existing 16 monitoring sites.

Installation and maintenance of 100 monitoring sites would be expensive, possibly prohibitively so (although the cost of implementing mitigation measures which later prove to be ineffective or significantly less effective than expected would also need to be considered in these circumstances). Targeted mitigation monitoring sites could potentially be installed to reduce monitoring costs. The process for identifying targeted sites would be similar to the spatial distribution analysis process described previously, but focused on the areas immediately downstream of the mitigation areas:

1. Map land areas where mitigations are proposed
2. Evaluate the spatial variability in nitrate loss reductions for these areas
3. Use the power analysis approach described above to determine the number of sites required
4. Use knowledge of ELT requirements and flow paths between nitrate sources and groundwater monitoring locations to identify potential monitoring sites

For step 2 a more detailed analysis of local-scale variability in nitrate loss mitigation and integration of local on-farm knowledge of land use practices would be required for the monitoring network design.

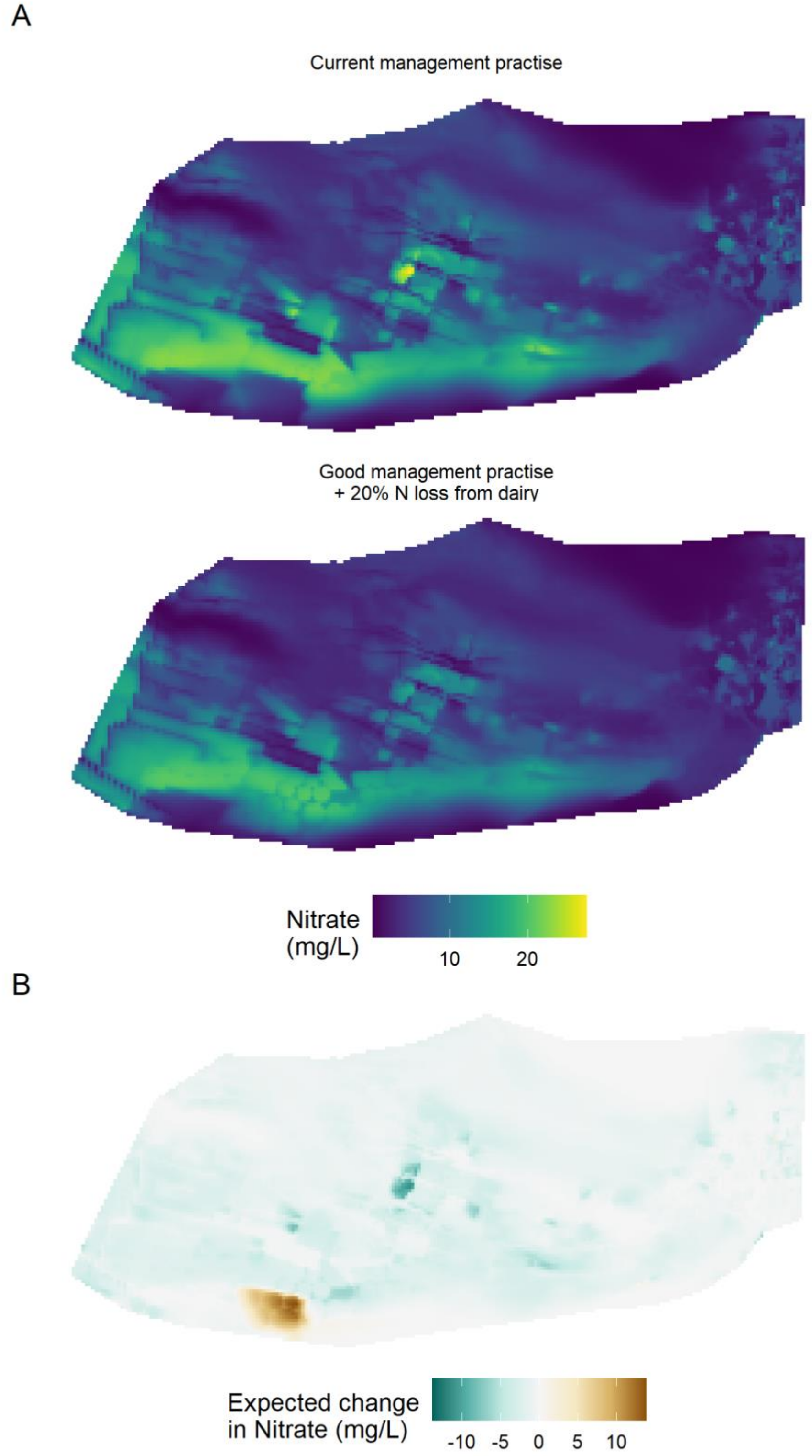

Figure 23: Modelled groundwater nitrate (mg/L) under two management scenarios (A) based on current management practises and a change to good management practises (GMP) plus a 20% N loss reduction on dairy land. The expected change in nitrate (mg/L) (B) represents the difference between the two scenarios, with nitrate predicted to decrease across most of the region. Modelled concentration increases are due to an increase in irrigation efficiency under GMP that reduces dilution and increases nitrate concentrations.

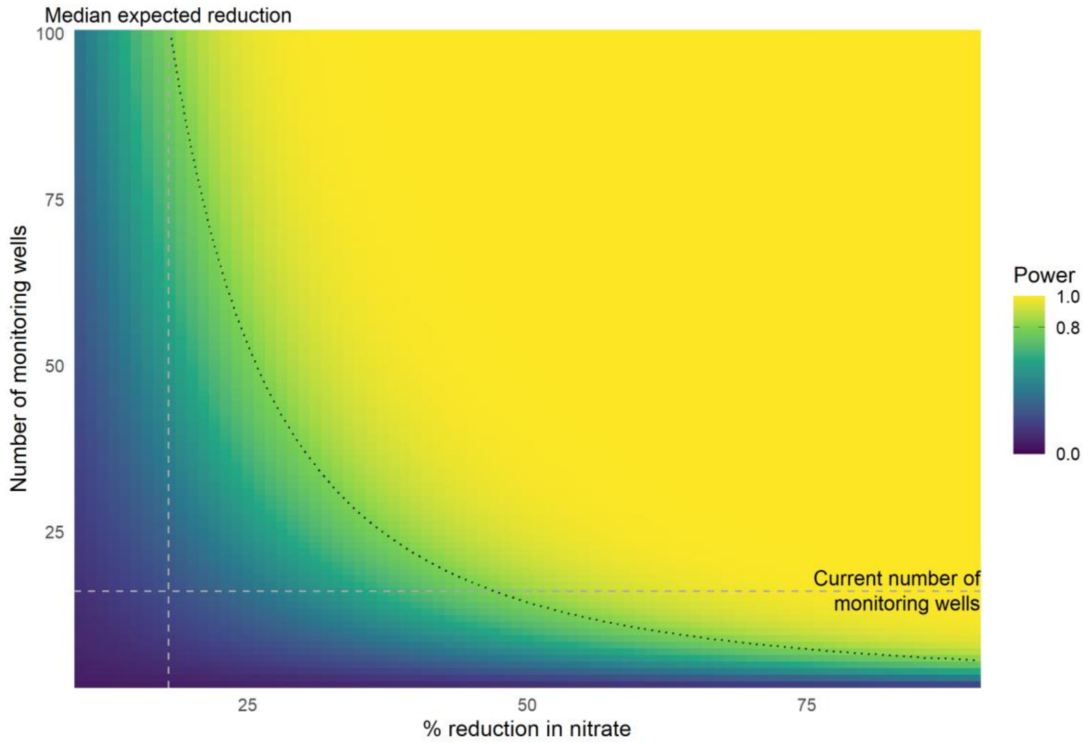

Figure 24: The power available (colour) to detect a % reduction in nitrate (x-axis) across the region as the number of monitoring wells increases (y-axis). The dashed grey lines represent the current number of monitoring wells (16) and the expected median reduction under the GMP + 20 dairy scenario across the region (17.9%). The dotted black line indicates the contour at which we would be 80% confident of detecting a reduction (power = 0.8).

Additional utility – evaluation of steady state nitrate concentrations

Determination of steady state nitrate concentration (when receptor nitrate concentrations equilibrate with catchment inputs), is critically important for freshwater improvement planning, regulation and mitigation design in catchments with increasing nitrate concentrations if these either currently exceed nitrate limits or could do so in the future. The FCI tool presented in Section 0 provides a simple, efficient and low-cost method for equilibrium nitrate concentration analysis via the following process:

- Application of an age distribution model to historic catchment nitrogen load time series data to derive synthetic nitrate concentration time series data.
- Optimisation of the load time series and age distribution model parameters to match synthetic and measured concentration or load time series data in streams or groundwater.
- Forward projection of equilibrium nitrate concentrations, as per the example in Figure 25 below.

We note that the equilibrium nitrate concentration projections derived from this method are significantly lower than the median and 95th percentile values projected via a steady state numerical groundwater model developed to support Environment Canterbury's Plan Change 7 limit-setting process (see Kreleger and Etheridge, 2018). These results, if correct, would have significant beneficial implications for stakeholders and farming land values in this catchment. Because the age tracer-based steady state projections extract information from the measured concentration time series and age tracer data which cannot be readily incorporated into a numerical groundwater model they are potentially a more robust source of information.

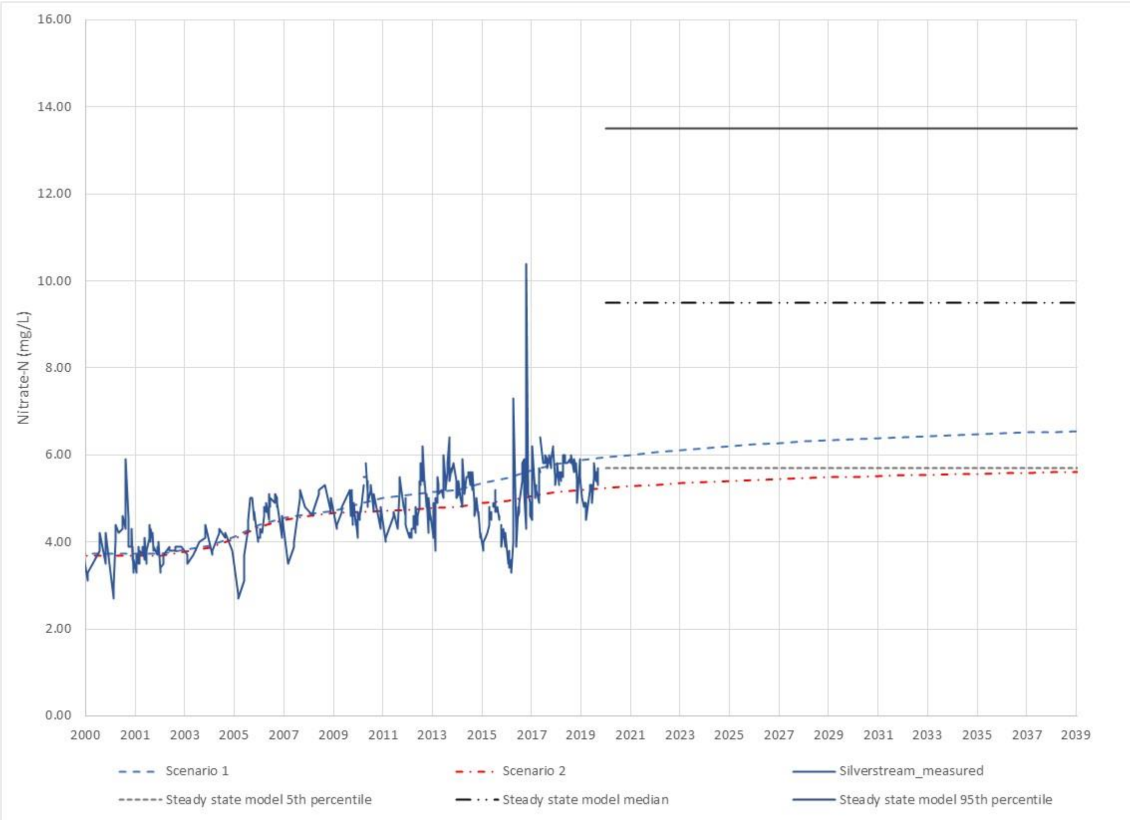

Figure 25: Projected future nitrate concentration range

Additional utility – existing monitoring network evaluation

A monitoring network designed to detect change across a region should ideally be representative of the environments within the region of interest, with all environmental classes likely to be affected by the mitigation included proportionally to their occurrence across the region. An analysis of representativeness can used to identify the environmental classes that are under- or over-represented within an existing monitoring network and make recommendations about where new sites might be best situated to reduce network bias.

We assessed the representativeness of the current Environment Canterbury SOE monitoring wells within the Waimakariri Zone with respect to landuse. We calculated the proportion of the region, the SOE monitoring wells and the private wells in each landuse class. The "representative number of wells" was calculated as the product of the total number of existing SOE monitoring wells and the proportion of the region in each landuse class.

Six SOE monitoring network wells are present on land classified as lifestyle, with three wells each on urban and sheep/beef/deer land and two wells each on dairy and horticultural land (Table 10). The private wells predominantly occur on land classified as lifestyle sheep/beef/deer. The representativeness analysis showed that two landuse classes are over-represented in the current SOE monitoring network (lifestyle, urban), while three are under-represented (arable, forest and pig).

Table 10: The number and proportion of SOE monitoring and private wells in each landuse class compared to the proportional area of each class across the region (ordered from most to least prevalent). The final two columns show the representative number of wells required to provide an unbiased network based on the existing number of monitoring wells (n = 16) and the number of additional wells needed in each landuse class to ensure an unbiased network that has sufficient power to detect the median regional reduction in nitrate (n = 100; Figure 24). Both columns are rounded to the nearest whole number. Blue shading represents classes that are over-represented and yellow shading represents classes that are under-represented.

Landuse class	% whole region	% SOE monitoring wells (n)	% private wells (n)	Representative number of wells	Additional number of wells
Sheep/Beef/Deer	16.1	18.8 (3)	32.7 (778)	3	13
Dairy	15.5	12.5 (2)	8.6 (204)	2	14
Lifestyle	13.9	37.5 (6)	41.5 (987)	2	8
Arable	13.7	0 (0)	7.5 (178)	2	14
Forest	13.3	0 (0)	1.6 (39)	2	13
Horticulture	9.9	12.5 (2)	2.8 (66)	2	8
Urban	9.1	18.8 (3)	3.1 (73)	1	6
Pig	6.4	0 (0)	0.6 (15)	1	6
River/Lake/Coast	2.0	0 (0)	0.1 (3)	0	2

A second aspect of representativeness relates to whether reductions of nitrate measured at each of the monitoring wells is likely to reflect those expected both across the region and at the private wells (Figure 26). Across the whole region, nitrate is expected to reduce, on average, by 0 – 20 %. However, there is considerable variation within and between landuse classes. In addition, some irrigated land may see increases in nitrate concentrations (despite load reductions) due to increased efficiency in irrigation practices that reduce the effects of dilution relative to nitrogen load reductions. The median expected reduction in nitrate at monitoring wells in each landuse class generally differs from the median within each landuse class across the whole region and at the private wells. The two monitoring wells on dairy land are likely to underestimate both the median regional reduction in nitrate and the median reduction occurring at private wells. In contrast, monitoring wells on land classified as lifestyle are likely to overestimate the median reductions at private wells and across the region. In general, nitrate concentrations in the private wells are likely to be representative of reductions across the region. We note that no wells (monitoring or private) are currently present in the areas of dairy where the large increases in nitrate concentration are modelled (Figure 23), so it would not be possible to detect whether these increases happen by monitoring any existing well.

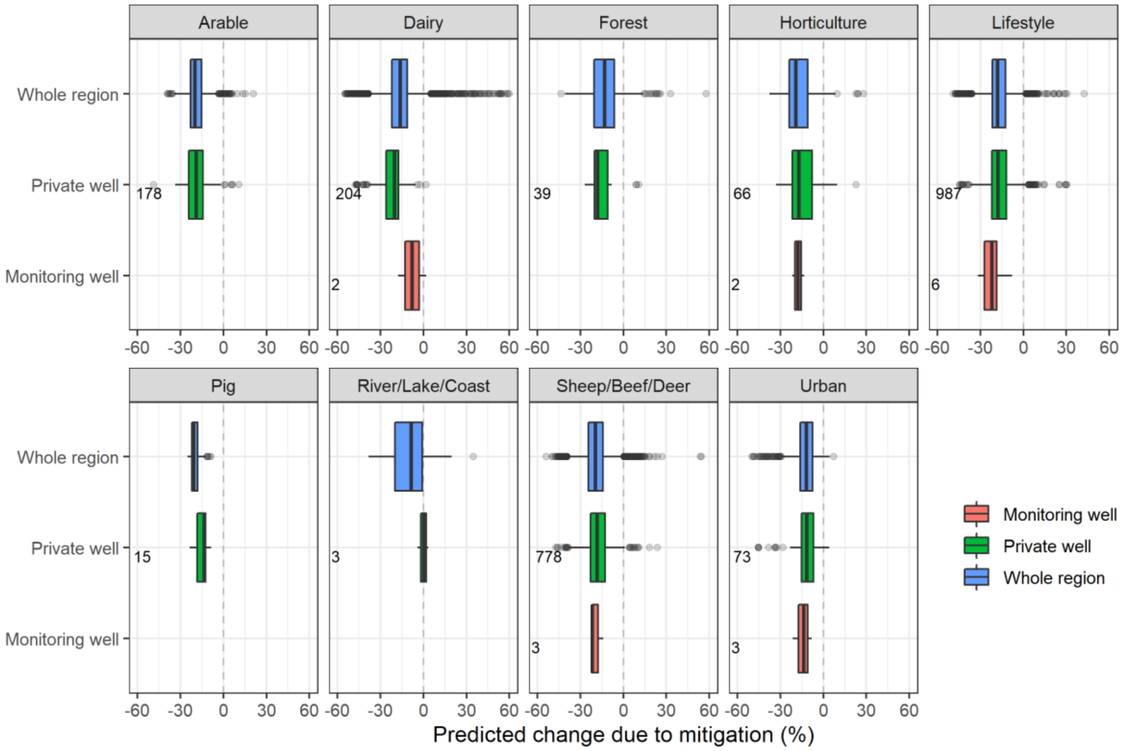

Figure 26: The predicted percent change in groundwater nitrate expected at SOE monitoring wells, private wells and across the whole Waimakariri Zone under the proposed policy changes. Data are based on modelled predictions (Figure 23), where negative values represent a predicted reduction in nitrate. Note that the x-axis has been clipped to a maximum of 60% but nitrate is projected to increase by up to 300% in a small number of locations on dairy land across the region. The number of monitoring and private wells in each landuse class is shown on each plot.

In summary, the power analysis indicates that the current monitoring network will not be sufficient to detect the expected median reduction in nitrate across the Waimakariri region, with ~ 100 wells needed to detect the modelled reduction with 80% confidence. In addition, the representativeness analysis showed that the existing network is biased with respect to landuse classes, with over-representation in land associated with lifestyle blocks, urban and pig farming and under-representation in arable land and forestry. An additional 84 monitoring wells would need required, with the majority of wells located in land associated with dairy, arable, sheep/beef/deer and forestry, if the goal of the monitoring network was to detect the overall change in groundwater nitrate concentrations associated with this mitigation.

4.8.8 Further work

The nitrate mitigation monitoring design decision support tools presented above would benefit from further development and extension to improve their ease of use, application range, scientific rigour and ultimate uptake by end users. The following actions are recommended:

- Further development of the Confluence site as a mitigation monitoring design information and toolkit hub
- A literature review of scientific methods for groundwater monitoring design (this could not be undertaken within the resourcing limitations of this project)
- Improvement of the FCI methodology through development of an automated inversion process to determine the range of historic catchment N loads and age distributions that are consistent with the measured data. These data could then be used to derive upper and lower bound future nitrate concentrations for the factual and counterfactuals within a specified confidence interval and to provide robust estimates of equilibrium nitrate concentrations for freshwater improvement planning, regulation and mitigation design in catchments with increasing nitrate concentrations.
- Method testing on a range of catchments and receptors (lakes, wells, streams and rivers) and at a variety of scales
- Deployment of easy to use tools and guidance for statistical power analysis, with worked examples for some New Zealand catchments
- Research into the spatial and temporal variability in groundwater nitrate concentrations and spatial variability in loss reductions due to land use mitigations to
- Guidance on delineation of recharge/catchment areas for wells and groundwater-fed water bodies, drawing on recent and currently ongoing research in this field
- Evaluation of the potential for inclusion of soil/vadose zone nitrate monitoring within the DST suite.

A methodology for mitigation monitoring cost-benefit analysis would also be useful. It is possible that monitoring networks which may be considered to be cost-prohibitive prove, via such analysis, to be significantly less costly than investment in mitigations which ultimately prove to be less ineffective than expected, or in more mitigation than might ultimately be necessary to achieve water quality goals

We believe that this extra work could help to:

- Accelerate mitigation implementation by improving stakeholder confidence in mitigation investment decision-making;
- Identify which mitigations are more and less successful; and
- help regional councils and stakeholders verify that nitrate loss reductions indicated through modelling and accounting methods only, have happened in reality.

5 Further work

5.1 Improvements to the existing framework components

Throughout this report, recommendations and suggestions for further work were identified for the possible future development of specific elements of the framework beyond the "proof of concept" stage. For convenience, these are summarised below.

1. Definition and integration of mitigation actions:
    a. further consideration is required on how mitigation plans and mitigation actions may be integrated within the Farm Environmental Plan process, as well as situations where this integration may not be possible or desirable.
    b. Further work to the link the methods and outputs Land Management Actions Register (LMAR) project as inputs to this Monitoring Design Framework, potentially further developed using a farm typology approach.
2. Range of mitigation actions: The following mitigation actions were not covered in this phase of the project, and would require further work:
    a. In-river mitigation actions, such as bank erosion control measures, in-stream habitat restoration, etc.
    b. erosion control measures, such as spaced planting, marginal land retirement, etc.
    c. Mitigation actions taken within commercial forestry plantations to reduce adverse effects during and following harvest.
3. Statistical analysis module: Further work is recommended to:
    a. Develop further guidance to relative to events-based and continuous monitoring, with a particular focus on how these may affect change detection (including likelihood and time required);
    b. Develop more detailed guidance on monitoring network design approaches and how they may be used in the context of this monitoring design framework.
4. Load Estimation module: Should this module be fully developed, further guidance should be included on groundwater and fluvial load estimation methods.
5. Mātauranga Māori: The following potential further work/ projects were identified:
    a. The monitoring design and technologies frameworks currently do not define who should undertake the monitoring. The fundamental importance of whakapapa and the need for mana whenua to undertake monitoring within their rohe, using tools they feel comfortable with, was highlighted.
    b. The sensitive nature of some of the information forming part of kaupapa Māori assessment frameworks (e.g. Wāhi Tapu) means that matters of confidentiality and access to the data must be considered further;
    c. Further expand and test the potential for the Monitoring Design Framework to incorporate a both kaupapa Māori and biophysical attributes and measures;
    d. Identify one or several catchments and mitigation plans where the expanded framework could be tested. The Tahurehu River catchment, a tributary of the Waipaoa River near Gisborne has been identified as a potential test catchment.
    e. Explore the potential to include mahinga kai/ mātauranga Māori monitoring requirements in Farm Environmental Plans. The Te Waihora/Lake Ellesmere catchment, in Canterbury, has been identified as a potential case study

6. Riparian DST: The following further work was identified by the working group, to bring the Riparian DST from its current "proof of concept" level of development to a user-ready tool:
    a. Further refine shade and water temperature prediction capabilities
    b. Extend to include nutrient prediction
    c. Extend to quantitatively predict ecological responses from water quality responses taking into account current state
    d. Acquire real data on landscape and response parameters for one or more test catchments, validate results
    e. Develop a user interface for the tool including links to (or creation of) national datasets/layers for landscape and response parameters
7. Lakes DST: The lake DST would benefit from the following additional work:
    a. Expand the DST to cover all New Zealand lake types,
    b. Expand the DST to cover additional mitigations/interventions and freshwater attributes,
    c. Integrate further analysis of how various monitoring technologies may impact on monitoring design and frequency and thus on statistical detection of change
    d. Integrate further analysis and consideration of the implications of very low concentrations (e.g. of nutrients in oligotrophic lakes) and changes in laboratory methods on long-term detection of trends/ changes.
8. Groundwater nitrate DST: The following actions are recommended:
    a. Further development of the Confluence site as a mitigation monitoring design information and toolkit hub
    b. A full literature review of scientific methods for groundwater monitoring design;
    c. Improvement of the FCI methodology through development of an automated inversion process to determine the range of historic catchment N loads and age distributions that are consistent with the measured data.
    d. Method testing on a range of catchments and receptors (lakes, wells, streams and rivers) and at a variety of scales
    e. Deployment of easy to use tools and guidance for statistical power analysis, with worked examples for some New Zealand catchments
    f. Research into the spatial and temporal variability in groundwater nitrate concentrations and spatial variability in loss reductions due to land use mitigations
    g. Guidance on delineation of recharge/catchment areas for wells and groundwater-fed water bodies, drawing on recent and currently ongoing research in this field
    h. Evaluation of the potential for inclusion of soil/vadose zone nitrate monitoring within the DST suite.

5.2 Tool development and integration

In addition, the working group makes the following suggestions to facilitate further tool development and integration with other programmes of work:

9. Catering for a range of end-users: The Advisory Group identified Regional Councils, Iwi, and multi-agency catchment groups as the key potential end-users for this "proof of concept" phase. A reasonably high level of end user technical proficiency was assumed for the initial development of the project. Consultation with potential end-users has indicated that a "simplified" module may be useful to enable access by a wider range of users, including in particular community groups;

10. End-user interface. Feedback from regional councils has indicated interest in an interface-based tool to enable direct use in specific projects. This is particularly the case in the context of non-regulatory mitigation projects initiated by catchment or community groups, where users could directly input the anticipated mitigation actions (in particular riparian management) and produce colour-coded maps to guide the development of a monitoring plan;

11. Extending the framework to urban and/or estuarine environments. This phase of the project specifically excluded urban and estuarine/coastal environment. Stakeholder engagement has highlighted significant interest in extending the framework to cover these environments;

12. Mātauranga Māori monitoring: Further development of a mātauranga Māori-based monitoring framework, integration with the framework developed during this "proof of concept" phase and application to case studies;

13. Integration with FEPs: Further consideration of integration of monitoring, including mātauranga Māori / mahinga kai monitoring into the Farm Environmental Plan (FEP) process;

14. Integration with catchment/lake Modelling: Given the long-term, sometimes multi-generational, nature of freshwater ecosystem restoration, and the limitations and uncertainties associated with environmental monitoring it is sometimes desirable to rely on a combination of modelling and actual monitoring data to evaluate the achievement or progress towards, a given environmental outcome. On this basis, further consideration should be given to how this monitoring design framework may be used to develop monitoring plans to support the development, calibration and validation of catchment and/or lake models.

15. Integration with Monitoring Technologies: Further integration with the work produced by the Technology working group, including:

    a. guidance on how the introduction of different monitoring technologies, protocols and frequency/timing (e.g. continuous or event-based monitoring) may influence change detection power;

    b. Integration of monitoring costs to facilitate cost/benefit analysis of monitoring network options (including a comparison with modelling costs where monitoring costs may prove prohibitive);

    c. Integration of monitoring technology, change detection, and costs into an optimisation routine to minimize costs whilst optimising the likelihood of detection change within the timeframe sought.