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MEMORANDUM

To:

From: **Ben Mackey**

Date: **29/06/2022**

Re: **Science approach to development of GMP and GMP+ land use scenarios - updated**

Name	Role	Date Completed
Ben Mackey	Author	29/06/2022
Graeme Doole (AgResearch Ltd)	External Reviewer	10/10/2022

Purpose

Development of the Land and Water Regional Plan (LWRP) requires the science team to develop a range of management scenarios to improve water quality across the Otago region.

The purpose of these scenarios is to estimate the possible improvements in water quality that are achievable for a given set of interventions. The scenario modelling will be used by the ORC Policy Team to highlight the scale of intervention required to give effect to the National Policy Statement on Freshwater Management and as a tool to guide proposed LWRP management options and rules.

These scenarios comprise a range of hypothetical land use or behavioural scenarios intended to reduce the impacts of land use on water quality. As part of the LWRP consultation, scenarios will be presented to the community so they can understand the magnitude of land use or behavioural changes that may be required to meet desired states of water quality. The scenarios illustrate a continuum of relatively minor to major changes on land, that should lead to corresponding responses in the degree of water quality improvement.

Efforts that aim to improve water quality within a given land use activity are known as mitigations – i.e., they mitigate the potential detrimental effect of a given land use activity on water quality. Examples of individual mitigations are fencing off streams to exclude stock, or applying fertilizer with more precision.

ORC science is required to predict the impact of these various land use scenarios on water quality, and enable comparison to the national standards presented in the NPS-FM and community aspirations. How these scenarios might be implemented will be developed by policy. The economic and social impact of these scenarios will be assessed by Strategy/Economics.

This memo outlines how the ORC Science team has developed land management scenarios, and how these scenarios fit into the larger LWRP process. The contaminants, Nitrogen (N) and Phosphorous (P) are the key drivers for this set of scenarios, with other contaminants (sediment, e. coli) the focus of other workstreams.

Scenario Setting Based on Land Use Typologies Approach

For any given catchment there are a range of land attributes (e.g., topography, soil, climate), and land uses (e.g., dairy, sheep and beef, cropping, vineyards etc). There is also limited information[1] about the degree of uptake of existing or proposed environmental improvement rules and initiatives, making it difficult to propose improvements without knowing what actions have already been implemented. A given mitigation technique, such as sediment trap, will only be applicable to some landscapes and land uses, so mitigations need to be targeted to suitable locations.

Therefore, we need a framework to develop management scenarios which can be systematically and consistently applied across the region, but targeted at suitable landscapes and land uses. As there are a wide range of scenarios that could be assessed, at a range of scales, a consistent regional-scale scenario approach is preferred given the constraints of time and resources.

The 'Our Land and Water' challenge is a national science initiative designed to improve New Zealand's primary production, whilst improving and maintaining land and water quality. The 'Sources and Flows' focus of Our Land and Water is aimed at improving water quality across New Zealand, largely by better understanding the source and transport of contaminants in the rural environment. A component of this project was to quantify the effect of changes in land management on water quality over the past few decades, and how further adoption of mitigation efforts could improve water quality in the future. The outcome of this work is documented in a series of published scientific papers, discussed below.

Underpinning the 'Our Land and Water' work is a 'typology' approach as described in Monaghan et al. (2021a) and Srinivasan et al. (2021), which aligns land use with key landscape characteristics. In brief, the landscape is classified into different units based on common soil, topographic, and climate characteristics. Each set of physical land and soil attributes have different inherent risk of contaminant transport to water; for example, stony, flat, free draining soils risk drainage of contaminants to groundwater, while wet poorly drained soils can be prone to surface runoff. Land use pressures or management practices are then overlain on

[1] See for example https://www.landcareresearch.co.nz/discover-our-research/environment/sustainable-society-and-policy/survey-of-rural-decision-makers/2017/

this landscape classification to enable correlation between distinct land uses with similar land characteristics, and therefore similar risks. This approach allows an irrigated dairy farm on the flat well drained lower Waitaki plains to be distinguished from an un-irrigated dairy farm on poorly drained soils in the Lower Clutha, where different risk management approaches will likely be required for these two farms.

A strength of this typology approach is mitigation practices can be targeted to certain combinations of landscape and land use where they are most applicable, rather than applying a blanket approach across a catchment, or land use. The land use and landscape characteristics can be analysed in a GIS framework, which provides flexibility in the scale of analysis that can be applied.

Combining Mitigation Methods into Management Scenarios

Developing a management scenario requires combining a suite or bundle of mitigation options. ORC identified three sources of suitable mitigations, an Abacus Bio consultant report (Abacus Bio, 2021) and two published papers that formed part of the Our Land and Water programme. These sources are briefly described below, and followed by a discussion of how these different lists were converted into two management scenarios.

2021 Abacus Bio Mitigation Assessment

In 2021 agribusiness consultancy Abacus Bio Ltd prepared a report for the Otago Regional Council assessing the likely effectiveness and cost of 20 different mitigation options (Abacus Bio, 2021). This work also utilised a typology-based framework, using information about land use and landscape characteristics from a 2021 land use assessment prepared for ORC[2]. This report focussed on the Catlins FMU and Upper Lakes Rohe, the first two areas prioritised for public consultation about the upcoming LWRP.

In Abacus Bio (2021) twenty mitigations were assessed and grouped in to 5 general management areas, consisting of crop management, critical source areas, irrigation, nutrient management, and riparian management, shown in Table 1 below.

[2] Otago Regional Council Land Use Map – Prepared for ORC by Great South Ltd, May 2021

	Management area	Description
M1	Crop management	Crop buffer strips
M2		Crop choice
M3		Minimal tillage
M4		Strategic crop grazing
M5		Catch crops
M6	CSA's	Stand-off facilities
M7		Critical source area management
M8	Irrigation	Soil moisture monitoring / scheduling
M9		Upgrade from flood to efficient irrigation
M10		Irrigation infrastructure
M11	Nutrient management	Match stock class to land use capability
M12		P form and application rate
M13		N surplus reduction
M14		Low-rate N applications
M15		Effluent management
M16	Riparian management	Riparian planting
M17		Sediment traps to filter overland water flows
M18		Suitable stock crossings
M19		Stock exclusion (fencing)
M20		Constructed wetlands

Table 1. 20 mitigation methods identified in Abacus Bio (2021) which were grouped into 5 general management areas.

Our Land and Water Mitigations and Scenarios

There are two separate lists of mitigations presented in the Our Land and Water papers. In the first, Monaghan et al. (2021b) assess how changes to farming practice between 1995 and 2015 improved water quality (or stopped it getting worse had they not been implemented). They outline 16 specific mitigation measures, and estimated the degree of implementation as at 2015, which is referred to as the 2015 current state or base line. The 16 mitigations are listed in Table 2 below.

Table 1. Mitigation measures selected for modelling assessments of effectiveness for reducing farm-scale losses of N and P to water from dairy and sheep-beef farms.

Management strategy	Mitigation measure	Alignment to typology structure	Assumed implementation 1995[1]	Assumed implementation 2015[2]	References for assumed implementation
Dairy farms					
Riparian protection	Stream fencing to exclude stock	All	48%	97%	DairyNZ 2017
Fertiliser management	Reduced surplus soil P fertility	All			Ballance AgriNutrients soil test records
	Use of low solubility forms of fertiliser P	Farms on Poorly drained soils or slopes > 7°	0%	6%	DairyNZ 2016
	Judicious scheduling of N and P fertiliser applications to avoid risk months	All	P = 100% N = 74%	P = 77% N = 43%	DairyNZ 2016
	Reducing excessive inputs of fertiliser N	All	96%	63%	Butler and Johnston 1997; DairyNZ 2016
Effluent management	Land application of FDE	All	35%	97%	Longhurst et al. 1999; Wilcock et al. 1999; DairyNZ 2016
	Enlarged areas receiving FDE	All	0%	24%	DairyNZ 2016
	Targeted fertiliser returns to effluent-treated areas	All	0%	41%	LIC 1996; DairyNZ 2016
	Deferred and/or low rate effluent irrigation	Poorly drained soils; farms on moderate slopes	0%	11%	DairyNZ 2016
Off-paddock management	Wintering in a barn or on a standoff	All	0%	7%	DairyNZ 2016
Irrigation management	Reduced flood irrigation by-wash	Irrigated farms	0%	47%	Section 5.4.4 from PCE 2004; DairyNZ 2016
	Reduced over-watering	"	<10%	39%	Section 5.4.4 from PCE 2004; DairyNZ 2016
Sheep-beef farms					
Riparian protection	Stream fencing to exclude stock	All	25%	35%	Brown 2017
Fertiliser management	Reduced surplus soil P fertility	All	41%	52%	Ballance Agri-Nutrients soil test records
	Judicious scheduling of N and P fertiliser applications to avoid risk months	All	P = 20%, N = 20%	P = 31%, N = 31%	Brown 2017
Land retirement	Stock exclusion and/or planting trees	All	By farm type	By farm type	BLNZ data; Horizons Regional Council data.

[1]based on references cited, expert assessments by Dairy and Fertiliser Industry stakeholders and Regional Council records (where available).
[2]based on Clean Streams Accord reporting (DairyNZ 2017) or Dairybase farm file information (DairyNZ 2016).

Table 2. List of on-farm mitigations taken from Monaghan et al. (2021b). These mitigations form the GMP scenario. Refer to Monaghan et al. (2021b) for full description and references.

McDowell et al. (2021a) compare the impact of best practice as at 2015 with possible best practice at 2035. The first scenario is to assess the effect of applying all conventional mitigations listed in Monaghan (2020b) to farming practice in 2015 – i.e. best practice as at 2015.

In a second list of mitigations, they further explore what would be the effect of applying all known current and potential mitigations to all farms in 2035 – i.e., what is the theoretical minimum contaminant loss that could be achieved by current land uses. There are a further 17 mitigations in the 2035 scenario, listed in Table 3 below.

Table 1. Additional 'developing' mitigation actions included in modelling farm-scale reductions of nitrogen (N) and phosphorus (P) losses to water in 2015 and 2035. Further information on the assumptions relevant to each typology is given in Supplementary Table S3.

Mitigation action	Land use	Relevant typologies	Action effectiveness (in parentheses) and priority of application 9 = high, 1 = low[a]	References
Retention dams, bunds or sediment traps	Dairy	P (8, 9, 10, 11, 20)	9 (P = 25%)	Levine et al. (2017)
Strategic grazing of pasture within critical source areas (CSAs)	Dairy	P (all)	6 (P = 26%)	McDowell et al. (2014)
Strategic grazing of crops within CSAs	Dairy	P (12, 13, 14, 15, 17, 18, 19)	6 (P = 65%)	Monaghan et al. (2017)
Tile drain amendments	Dairy	P (2, 3, 13)	6 (P = 70%)	McDowell et al. (2008)
In-stream sorbents	Dairy	P (2, 3, 4, 5, 6, 8, 9, 10, 11, 20)	4 (P = 10%)	McDowell et al. (2007)
Alum applied to pasture or crops in CSAs	Dairy	P (all)	4 (P = 28%)	McDowell and Houlbrooke (2009); McDowell and Norris (2014); McDowell (2015)
Controlled release fertiliser	Dairy	P (all)	3 (P = 5%)	
	Sheep/beef	P (all)	3 (P = 5%)	
Variable rate fertiliser	Dairy	P (all)	3 (P = 10%) 3 (N = 5%)	White et al. (2017)
	Sheep/beef	P (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13)	3 (P = 10% + Overseer)	
Variable rate irrigation and fertigation	Dairy	P (14, 17, 18)	3 (P = 65%)	McDowell (2017)
On-off grazing in autumn/winter	Dairy	P (all) N (all although 11 had effect <0.3%)[b]	2 (N/P = Overseer)	McDowell et al. (2005)
Edge of field attenuation	Dairy,	P/N (1, 2, 3, 8, 9, 10, 11, 12, 13, 14, 19, 20)	1 (P = 65%) 4 (N = 35%)	McDowell et al. (2008); Schipper et al. (2010)
	Sheep/beef	P (all, although only 3, 4, 8, 9, 11, 12, 13, 14, 15, 16 had effect above 0.3%)	1 (P = 65% + Overseer) 4 (N = 35% + Overseer)	
Controlled drainage	Dairy	P/N (1, 2, 3, 12, 13, 14)	1 (P = 14%) 4 (N = 50%)	Tan and Zhang (2011); Sunohara et al. (2015)
	Sheep/beef	P (3, 11, 12, 13, 16, 17) N (2, 11, 12, 13, 14, 15, 16)	4 (P = 14% + Overseer) 4 (N = 50% + Overseer)	
Constructed wetlands	Dairy	P/N (1, 2, 3, 8, 9, 10, 11, 12, 13, 14, 19, 20)	6 (N = Overseer) 1 (P = Overseer)	Tanner et al. (2005)
	Sheep/beef	P (all ex 4, 15)	4 (N = Overseer) 1 (P = Overseer)	
Decreasing N inputs (fertiliser and supplements) by half	Dairy	N (all ex 1, 2, 3, 4, 8 and 14)	3 (N = Overseer)	Monaghan et al. (2018)
Catch crop	Dairy	N (12, 15)	4 (N = Overseer)	Malcolm et al. (2016)
Nitrification inhibitors	Dairy	N (all ex 1, 8)	3 (N = Overseer)	Di and Cameron (2002); Smith et al. (2012); de Klein et al. (2014); Ledgard et al. (2014)
Increasing the area in plantation forestry from 12.5 to 25% of the property	Sheep/beef	P/N (all)	3 (N/P = Overseer)	Manderson et al. (2013); Baillie and Neary (2015)

[a]Data for the prioritisation of cost-effectiveness is taken from (McDowell et al. 2018). Actions are implemented in bundles for each nutrient via *Overseer* to the whole farm or the relevant proportion within a typology (+ Overseer). Where no *Overseer* analysis is available, percentage reductions were applied to the relevant area. If two or more strategies are of equal priority, calculations use the mean of relevant actions within a bundle. Percentage decreases reflect effectiveness to relevant areas within the farm, but are used in calculations at a typology scale. Additional information concerning the relevant areas within typologies is given in Supplementary Table S3.

[b]The detection limit was <1%, below which any effect was not included in the final typology calculation.

Table 3. List of on farm mitigations from McDowell et al. (2021a). These mitigations, in addition to those listed in Table 1 above, form the GMP+ scenario. See McDowell et al. (2021a) for full description and references.

Grouping Mitigations into Management Practice Scenarios

In conjunction with policy, ORC Science propose to develop three scenarios from which to assess potential improvements to water quality across a continuum from relatively minor behavioural changes and farm management practices, to potential land use changes.

Two scenarios will be based on definitions of current and future best practice, following the approach taken by Monaghan et al. (2021b) and McDowell et al. (2021a). The third proposed scenario, a Haurora state, is beyond the scope of this memo. The two scenarios discussed in this memo focus on behavioural changes (e.g. implementation of mitigation measures within existing land uses) and exclude any large scale land use purpose change.

A scenario is represented by a bundle of mitigations that can be applied to reduce the impact of land activities on water quality. As reviewed above, we had three lists of mitigations:

- 20 mitigations listed in the Abacus Bio (2021) report,
- 16 mitigations listed in Monaghan et al. (2021b) - good practices as at 2015, and
- 17 mitigations listed in McDowell et al. (2021a) – potential good practices as at 2035.

The Monaghan and McDowell lists are mutually exclusive, while there is overlap between the Abacus Bio mitigations and both other lists.

An exercise was undertaken to firstly align the 20 mitigation methods in the AbacusBio report with the 33 total proposed mitigation methods in the Monaghan (2021b) and McDowell (2021a) papers. This involved grouping mitigation methods into 8 broader management areas: Riparian management, fertiliser management, effluent management, wintering, irrigation management, land retirement, overland flow, and drainage.

The 20 abacus bio mitigations were aligned with the 33 OLW mitigations within these management areas, and rationalised where necessary (for example when mitigations were very similar). Finally each mitigation was assigned to be either current good practice, or a future method, primarily guided by the OLW papers. In 6 cases mitigations listed in the Monaghan et al. (2021) paper were considered better suited as GMP+, and vice versa. This key delineation is used to derive the two scenarios which are defined as Good Management Practice (GMP) and Good Management Practice Plus (GMP+).

Mitigations were assessed as being effective for either addressing N or P loss (or both) and whether they applied to dairy or drystock (or both). The net result is a list of 24 mitigations, 14 classed as GMP, and 10 as GMP+, that could apply to either or both dairy or drystock farming activities, and applicable to either or both N and P mitigation. Some mitigation methods were considered too unproven to be included in scenario development, and 5 mitigation methods from McDowell (2021a) were not included in this further assessment [based on advice from R. Monaghan]. A full breakdown is presented in Table 4.

Abacus Bio mitigation #	Management area	Description	Paper	N loss	P loss	Dairy	Dry stock (Sheep & Beef)	GMP bundle
M19	Riparian management	stock exclusion	Historic	Yes	Yes	Yes	Yes	GMP
M12	Fertiliser management	Optimum Olsen P	Historic		Yes	Yes	Yes	GMP
M12 ?		Low soluble P fertiliser	Historic		Yes	Yes		GMP
M13 (N)		Avoiding at risk Months	Historic	Yes	Yes	Yes	Yes	GMP
M14		Reduced N inputs stage 1	Historic	Yes		Yes		GMP
		Reduced N inputs stage 2	Future	Yes		Yes		GMP+ ?
		Controlled release P fert	Future		Yes	Yes	Yes	GMP+ ?
		Variable rate fertiliser	Future		Yes	Yes	Yes	GMP+ ?
		~~Nitrification inhibitors~~	~~Future~~	~~Yes~~		~~Yes~~		
	Effluent Management	Land application of FDE	Historic	Yes		Yes		GMP
		Enlarged FDE area	Historic	Yes		Yes		GMP
M15		Limiting fertiliser to effluent area	Historic	Yes		Yes		GMP
		Deferred and low rate FDE	Historic	Yes		Yes		GMP
M6	Wintering	Wintering in barn or standoff	Historic	Yes		Yes		GMP+ ?
		On-off grazing in autumn/winter	Future	Yes	Yes	Yes		GMP+ ?
M5		Catch crop	Future	Yes		Yes		GMP
M9	Irrigation management	Reduced flood irrigation out wash	Historic	Yes	Yes	Yes	Yes	GMP
		Variable rate irrigation and fertigation	Future		Yes	Yes		GMP+ ?
	land retirement	Stock exclusion/planting trees	Historic		Yes		Yes	GMP+ ?
		Increasing plantation forestry area	Future	Yes	Yes		Yes	GMP+ ?
M17	Overland flow	Sediment traps etc.	Future		Yes	Yes		GMP
M7?		Strategic grazing of pasture in CSA	Future		Yes	Yes		GMP+ ?
M4		Strategic grazing of crop in CSA	Future		Yes	Yes		GMP
M20		Constructed or facilitated natural wetlands	Future	Yes	Yes	Yes	Yes	GMP
		~~Alum applied to pasture or crops in CSA~~	~~Future~~		~~Yes~~	~~Yes~~		
M1?		Edge of field attenuation	Future	Yes	Yes	Yes		GMP+ ?
	Drainage	~~Tile drain amendments~~	~~Future~~		~~Yes~~	~~Yes~~		
		~~In-stream sorbents~~	~~Future~~		~~Yes~~	~~Yes~~		
		~~Controlled drainage~~	~~Future~~	~~Yes~~	~~Yes~~	~~Yes~~		

Table 4: List of mitigations linking those in Abacus Bio (2021) to Monaghan et al (2021b) (termed historic) and McDowell et al. (2021a) (termed future). Also noted is whether a mitigation is applicable to dairy and/or drystock farming, and whether it targets N and/or P. Mitigations that have been crossed out were not included in the GMP+ Scenario as deemed not viable at this stage. Underlining in the GMP/GMP+ column indicates where the mitigation catagorisation has been changed from the source lists.

GMP Scenario

The Good Management Practice (GMP) Scenario broadly corresponds to the 2015 measures described in Monaghan et al (2021b) and assumes all of these are fully implemented (as in McDowell 2021a). This will be an improvement on the current state in Otago, as although we presently lack data to quantify this, it is unlikely that there is full implementation of these mitigation measures across the region.

Management Area	Description	Paper	N loss	P loss	Dairy?	Dry stock?
Riparian management	Stock exclusion	Historic	Yes	Yes	Yes	Yes
Fertiliser management	Optimum Olsen P	Historic		Yes	Yes	Yes
	Low soluble P fertiliser	Historic		Yes	Yes	
	Avoiding at risk Months	Historic	Yes	Yes	Yes	Yes
	Reduced N inputs stage 1	Historic	Yes		Yes	
Effluent Management	Land application of FDE	Historic	Yes		Yes	
	Enlarged FDE area	Historic	Yes		Yes	
	Limiting fertiliser to effluent area	Historic	Yes		Yes	
	Deferred and low rate FDE	Historic	Yes		Yes	
Wintering	Catch crop	Future	Yes		Yes	
Irrigation management	Reduced flood irrigation out wash	Historic	Yes	Yes	Yes	Yes
Overland Flow	Strategic grazing of crop in CSA	Future		Yes	Yes	
	Constructed or facilitated natural wetlands	Future	Yes	Yes	Yes	Yes
	Sediment traps etc.	Future		Yes	Yes	

Table 5: Mitigations measures comprising the GMP scenario

GMP+ Scenario

The Good Management Practice Plus (GMP+) scenario is documented in McDowell et al. (2021a) as a suite of 'developing' or potential mitigation actions. These are mitigation methods which have been identified as holding promise, but have yet to be widely tested or implemented. These mitigations are listed in the table below taken from McDowell et al. (2021a), although with 5 mitigations not included. The GMP+ scenario is additive to GMP, and assumes previously discussed GMP mitigations are fully implemented.

Management Area	Description	Paper	N loss	P loss	Dairy?	Dry stock?
Fertilizer management	Reduced N inputs stage 2	Future	Yes		Yes	
	Controlled release P fert	Future		Yes	Yes	Yes
	Variable rate fertiliser	Future		Yes	Yes	Yes
Wintering	Wintering in barn or standoff	Historic	Yes		Yes	
	On-off grazing in autumn/winter	Future	Yes	Yes	Yes	
Irrigation management	Variable rate irrigation and fertigation	Future		Yes	Yes	

Land retirement	Stock exclusion/planting trees	Historic		Yes		Yes
	Increasing plantation forestry area	Future	Yes	Yes		Yes
Overland flow	Strategic grazing of pasture in CSA	Future		Yes	Yes	
	Edge of field attenuation	Future	Yes	Yes	Yes	

Table 6: Mitigations measures comprising the GMP+ scenario

Justification for GMP and GMP+ Scenarios

The rationale for basing scenarios the GMP and GMP+ scenarios on the mitigation bundles described in the Monaghan et al (2021b) and McDowell et al (2021a) papers above is that:

- Published, peer-reviewed scientific papers are a sound and defensible foundation to use as baseline scenarios
- Objective basis – scenarios not influenced by ORC
- Readily understood by others
- The national-scale methodology can be replicated in the Otago region with more detailed input datasets
- The REC framework used in the Our Land and Water paper enables comparison with other studies (pressure maps and sediment yield)
- Dairy and sheep/beef, the focus of the typologies work to date, are the dominant pastoral land uses in Otago (noting that other land uses will need assessment)
- Avoids having to develop bespoke or catchment specific scenarios which are not practical in the timeframes or may lead to inconsistency or inequity across the region
- GMP+ is the largest practical contaminant reduction achievable while retaining existing land use
- Gives broad scale estimate, not applicable to a specific farm

GMP and GMP+ Scenarios in Larger Workflow

The Our Land and Water analysis was undertaken at the national scale. The Otago Regional Council has Otago-specific land use maps and has developed a technical map that aligns with the landscape classification framework (slope, climate, soil) used to establish the typologies. This enables a similar assessment to be undertaken in Otago but with more detailed input data.

The GMP and GMP+ scenarios will be assessed as a bundle of mitigation measures in Overseer, and supplemented with expert judgement where mitigations are not suited to Overseer modelling. This approach will provide a percentage reduction in contaminant loss from land, compared to estimates of baseline contaminant loss (in the absence of mitigations). McDowell et al. (2021a) rationalised the number of typologies (land use and landscape type) to the top 20 by land area and a similar approach will likely be needed in Otago.

We also note the recent review into Overseer which highlighted some limitations with this software. In this exercise Overseer is being used as a fit for purpose modelling tool to assess the reduction in nutrient loss for a given set of land use scenarios, not as a regulatory tool.

The starting point from which scenarios will be assessed is base load nutrient loss for given land type and land use drawn from published base load estimates (Srinivasen et al., 2021), and expert judgement where no published estimate is available for a given typology.

The contaminant reductions calculated for the GMP and GMP+ scenarios can then be propagated into ORC's typology GIS map, with the net effect of the scenarios measured at the scale of interest (e.g., catchment, FMU).

The calculated reduction in load due to a given scenario can then be compared with pressure maps or national standards to determine whether desired or required state is achievable with the scenario.

Attenuation, Lag times, and Uncertainty

A key component of the scenario work is to predict what the effect of any land management change will be on water quality. This relationship is the key for linking scenarios to community values or national requirements for water quality.

The process for a given contaminant (such as N or P) to travel from a farm source to a water body can be complex, with multiple possible pathways, time frames and biophysical processes at play. The contaminant load can also be reduced (attenuated) by processes such as denitrification.

The attenuation or reduction of contaminant loads as they migrate from the farm to waterways is an area of active research, and there is limited data to quantify this process. Similarly, there are well established lag or travel times from when a land use activity is changed (e.g., rapid intensification) to when this signal can show up in water quality (McDowell et al 2021b).

Given the uncertainty in potential attenuation and lags, for this exercise we are assuming a one-to-one relationship between the contaminants leaving a farm to the contaminants reaching a water body. This means a change on farm will fully and immediately show as a change in water quality in stream. This simplification is conservative and likely overestimates the detrimental impact of mitigation scenarios on water quality, but there is insufficient data to justify the including of an attenuation factor or appropriate lag time in this modelling work.

Further, due to the complex processes present, uncertainty is high in base loads, the load reduction required to achieve outcomes, as well as the corresponding on land actions. Sources of uncertainty are both unquantifiable, such as understanding (e.g., inaccuracies in mapping, mitigation quantification, attenuation, etc.), and quantifiable, such as statistical approach. As such the strength of this modelling approach is to inform the magnitude, or likely scale, of change required to achieve outcomes rather than to indicate the exact changes and locations required. Given the timeframes and current available information, this approach represents the best available information on a regional scale.

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