IN THE MATTER	**of the Resource Management Act 1991**
AND	
IN THE MATTER	**of the hearing of submission on Proposed Plan Change 1 (and Variation 1 to the Waikato Regional Plan)** **TOPIC 2**
BY	**FEDERATED FARMERS OF NEW ZEALAND INC, FEDERATED FARMERS OF NEW ZEALAND (WAIKATO REGION) 1999 INCORPORATED, FEDERATED FARMERS OF NEW ZEALAND – ROTORUA TAUPO PROVINCE INCORPORATED, FEDERATED FARMERS OF NEW ZEALAND (AUCKLAND PROVINCE) INCORPORATED** **(“FEDERATED FARMERS”)** Submitter with ID: 74191
To	**WAIKATO REGIONAL COUNCIL** **(“WRC”)**

STATEMENT OF PRIMARY EVIDENCE OF IAN FRANCIS MILLNER FOR FEDERATED FARMERS ON HEARING TOPIC 2

3 May 2019

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STATEMENT OF PRIMARY EVIDENCE OF IAN FRANCIS MILLNER

1. SUMMARY

1.1 I support bespoke strategies for the farm and sub-catchment according to the contaminant that is a problem and the water quality targets that are to be achieved. I consider tailored mitigations in a Farm Environment Plan ("FEP") can do this. The benefits of tailored actions when compared to blanket rules are:

a. Tailored actions can be much more cost effective than non-targeted or blanket requirements but with the similar improvement in water quality.

b. There is no one particular action that is more important everywhere. Accordingly the identification of risks at source along with suitable management responses is a more appropriate response to the management of diffuse contaminant loss.

c. A strategy of controlling all four contaminants equally is problematic as actions to control one contaminant may contribute to increase of another contaminant. It is more suitable to find out what the issues are in the sub-catchment and property and then address those with the appropriate actions.

d. There are many mitigations or interventions that land managers can make that are not accounted for within Overseer. A FEP with tailored actions can allow and account for such mitigations or interventions.

1.2 I support tailored actions in a FEP based on Good Farming Practices ("GFP") for all farms. In paragraphs 4.20 and 4.21 I set out how I consider any catchment wide standards in Schedule C ought to be able to be tailored in a FEP.

1.4. In my opinion, there is a real risk to farmers in the 75th to 50th percentile range that the costs of demonstrating "real and enduring" N reductions are significant and take them significantly beyond GFP. I consider that the potentially available mitigations, costs and benefits should be assessed before adopting such a requirement.

1.5. Tailored mitigation in a FEP will be better than the onerous blanket requirements suggested for stock exclusion and for cultivation setbacks. I consider that what is required are the right actions in the right place.

1.6. In paragraphs 6.2 to 6.32 I set out some of the issues with the stock exclusion provisions as proposed in the S42A Report, including:

a. Stock exclusion is not always the most appropriate mitigation. In some situations, other mitigation action may be more appropriate instead of fencing. Where fencing is the appropriate mitigation strategy a different distance (rather than a one-size-fits-all) may be appropriate.

b. In areas where stock exclusion is impractical, cost prohibitive, or impossible there should be the option to employ other strategies to mitigate the loss of contaminants that are relevant in the sub-catchment where the farm is situated.

c. Fencing of drains will not prevent access for maintenance purposes. I can see no practical or logistical reasons for a 10 meter setback on council managed drains.

d. The S42A report proposes that stock ought to be excluded from intermittent waterbodies. I do not agree that this is an appropriate catchment-wide standard. This is something that ought to be considered through a tailored FEP. Intermittent waterbodies are difficult to identify, creating uncertainty for farmers and Council. Fencing might not be the appropriate response and there may be one of a range of other mitigations that are more appropriate for streams that are dry occasionally.

e. To restrict any livestock entering or passing across the bed of the waterbody except by way of a livestock crossing structure is a very blunt management option. In many cases the benefit of stock crossings will be negligible. Culverts can have a negative effects as they will require additional earthworks and tracking next to a waterway in order to construct them. They can also have adverse effect on fish passage.

1.7. A one-size-fits-all solution to the application of riparian intervention measures to reduce stream bank erosion is unlikely to be appropriate or effective everywhere.

1.8. Several attributes other than slope angle will influence the need for and if required the distance of a setback. When considering all these different factors a 5 meter setback will seldom be correct.

1.9. The primary environmental effect caused by a setback is by the fence (and associated vegetative buffer) and not by the distance of a setback. The bigger a setback distance does not automatically mean there is extra mitigation.

2. INTRODUCTION

2.1. My name is Ian Francis Millner. My qualifications are BSc, PG Dip Ecology, PG Dip Resource Studies. I am currently employed as a Senior Land Management Adviser at Rural Directions Advisory Services, a technical resource management/agricultural consultancy based in Hastings.

2.2. My role at Rural Directions is to provide technical analysis and advice for clients in the operation of existing farming businesses and due diligence on proposed investments in farm enterprises, as well as catchment-based investigations and policy advice for councils and industry.

2.3. Previously, between 2008 and 2016, I was employed as a Senior Land Management Adviser with Hawkes Bay Regional Council ("HBRC"). While at HBRC, my general responsibilities included providing advice on land management issues including erosion, drought resilience, nutrient management and farm planning. I was directly involved in development of Plan Change 6 to the Hawkes Bay Regional Resource Management Plan (the Tukituki Catchment Plan) that was considered by a Board of Inquiry between 2013 and 2015. I have been involved in various development groups at national level pertaining to the development and use of

OVERSEER® (Overseer) including the development of data input standards for Overseer.

2.4. I was a co-author of the report which documented the manner in which farm scale nutrient losses in the catchment historically, currently and in the future under the Proposed Ruataniwha Water Storage Scheme were established and predicted. Those modelled nutrient losses were a key input to the integrated catchment model constructed by Dr Kit Rutherford of NIWA.

2.5. Before the Board of Inquiry, I gave evidence on an aspect of that report (the process followed for classifying and spatially assigning land use types to the catchment), phosphorus management plan case studies I had undertaken, and on technical aspects of the rules related to stock exclusion from water bodies and the preparation and timing of farm nutrient budgets.

2.6. More recently I have been involved in on farm economic feasibility studies, consenting, due diligence and review for the Ruataniwha Water Storage Scheme.

2.7. Prior to joining HBRC, I was self-employed as a farmer on a 340ha hill country sheep and beef unit in Southern Hawkes Bay. I am a member of the New Zealand Grasslands Association, and a member of the NZIPIM. I have professional training in the use of land use capability (LUC), professional qualifications in nutrient management (Advanced)) gained from Massey University and am an independent certified Resource Management Act commissioner. I have been involved with several sustainable farming fund projects looking at aspects of resilient farm systems for the East Coast of the North Island. I have also worked with the deer industry to develop a nationally accepted and applicable landcare manual.

Code of Conduct

2.8. I have read the Environment Court's Code of Conduct and agree to comply with it. My qualifications as an expert are set out above. I confirm that the issues addressed in this statement of evidence are within my area of expertise.

Scope of Evidence

2.9. My evidence will address the following matters:

a. Brief comments on the use of Overseer .

b. Brief comments on tailored actions in FEPs.

c. Comment on the requirement for farms between the 50th and 75th percentile to demonstrate real and enduring reductions of N leaching.

d. Analyse and comment on stock exclusion and setback provisions including two case studies.

3. USE OF OVERSEER

3.1. Overseer is currently the nationally accepted and freely available agricultural nutrient budget modelling tool.

3.2. The Overseer website contains information about the key assumptions about the conditions within which Overseer need to be used. These are shown in Figure 1.

The key assumptions used in *Overseer* are:

Assumption	Notes
Quasi-equilibrium	The model assumes that inputs and farm management practices described are in quasi-equilibrium with the farm productivity.
Long-term average	For a given farm system, the nutrient budget estimates the long-term annual average outputs if the management system described remained in place.
Actual and reasonable inputs	The model assumes that inputs including animal productivity are correct. There is no checking on whether an inputted farm system is practicable, possible or viable.
Mitigations	The quasi-equilibrium and actual and reasonable assumptions means that any management changes or mitigation changes must also include changes in animal productivity
Management practices	Assumes 'good management practices' have been implemented on the farm

Figure 1: Overseer assumptions from Overseer: answers to commonly asked questions

3.3. Overseer is a model and as such is not perfect. As a model of complex farm systems in complex landscapes with temperate but variable climate it is not 100% accurate.

3.4. It is recommended that Overseer is used to measure relative change i.e. % decrease in N loss within a farm system. [1]

3.5. I have read the s42A report on the use of Overseer and I generally agree with the reporting officers. I specifically support that Overseer be used as a decision support tool to inform the development of a farm environment plan and not in a way that requires compliance with a number.

4. TAILORED FARM ENVIRONMENT PLANS

4.1. Farm Environment Plans form a key part of PC1. In general I support the use of Farm Environment Plans and tailored mitigation actions in a FEP to address contaminants.

4.2. There is an extensive literature about studies to analyse diffuse contaminate loss and methods to reduce the risk of it reaching waterways. Within the literature many methods have been identified to reduce risk at paddock and farm scale.[2]

4.3. In general these methods have sought to reduce the availability of contaminants at source or to interrupt the contaminant pathway. As an example, the construction and management of detainment bunds that slow down and trap particulates from surface runoff are gaining in acceptance and there is a broader understanding of its effectiveness.

4.4. I support bespoke strategies for the farm and sub-catchment according to the contaminant that is a problem and the water quality targets that is to be achieved. I consider tailored mitigations in a FEP can do this. I set out reasons for preferring tailored actions below.

4.5. I have to be clear however that tailored actions in a FEP for a particular farm could be more stringent than blanket catchment wide rules and I anticipate that for some farmers in areas the stock exclusion or setback requirements

[1] Parliamentary Commissioner for the Environment *Overseer and regulatory oversight: Models, uncertainty and cleaning up our waterways* December 2018.

[2] For Examples see the table pf mitigation actions at IFM1 at [4] p13

may exceed those recommended in the S42A Report in places (and the converse could also be true, in appropriate circumstances).

Costs benefit advantage of tailored actions

4.6. The report from R.W. McDowell et al[3] illustrates the difference between actions applied everywhere and tailored action as to the cost-effectiveness.

4.7. Figure 2 illustrates the impact of identifying activities that are producing significant amounts of contaminant (a critical source area (CSA) approach) and applying an appropriate management intervention to that particular CSA as opposed to a blanket requirement across a catchment. Specifically Figure 2 outlines the 'range in the cumulative percentage decrease in farm earnings before interest and tax (±standard error) and total P mitigated (kg/ha) by different strategies applied across the whole farm or within critical source areas by cost-effectiveness. Note that mitigations are sorted by suitability and cost-effectiveness before being applied across the whole farm or only to CSAs'. This work was completed in Otago.

4.8. Figure 2 presents the difference in mitigation performance, which shows little difference, between a tailored approach[4] (light blue shaded area) and catchall requirement[5] (dark blue shaded area). The dark and light blue lines then shows the increase in costs of EBIT (earnings before interest and tax) between the tailored approach and catchall requirements. The lines shows at its most pronounced that the catchall requirements have around 80% more cost of EBIT than the tailored approach.

[3] R.W. McDowell et al, *Contrasting the spatial management of nitrogen and phosphorous form improved water quality: Modelling studies in New Zealand and France* Europ. J. Agronomy 57 (2014) 52-61.
[4] Which identify the critical source area that produces the contaminant and applying a tailored managed action.
[5] A blanket requirement which applies across a whole catchment regardless.

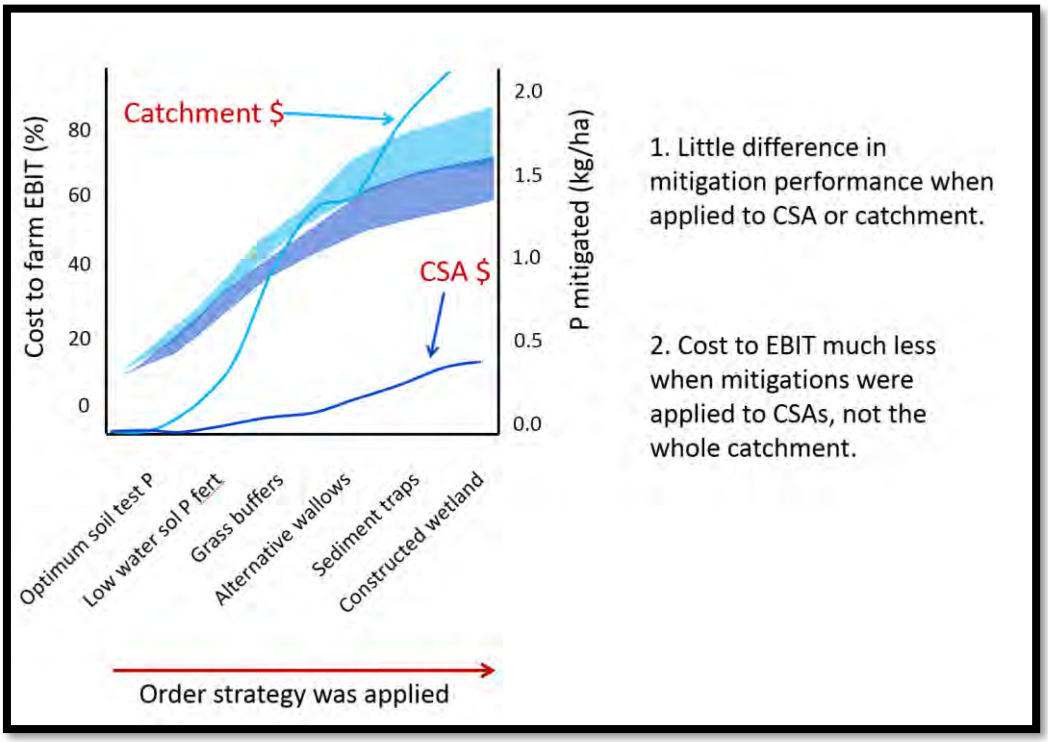

Figure 2: This diagram illustrates the relationship between the cost effectiveness of individually assessed CSAs and suitable mitigations v non targeted requirements at a catchment scale. As shown the shaded area shows the effects of both while the cost to farm EBIT is shown by the lines.

4.9. Figure 2 illustrates that the most cost effective management response action that can be done is the risk based identification of source areas and pathways along with practical methods to mitigate or manage the identified risk.

4.10. My experience on farms is similar to the report in that tailored actions can be much more cost effective than non targeted or blanket requirements but with the similar improvement in water quality.

No silver bullet

4.11. There is no one particular action that is more important everywhere.[6] As an example, stock exclusion is suggested in S42A report as a universal mitigation that can reduce different contaminants but it is also clear that the cost benefit of this mitigation is not the same everywhere and therefore, circumstances will exist where other methods may offer greater utility.

[6] See 4.20 below

4.12. C.M. Smith[7] in a Waikato based study found that ''all particulate concentrations were high in winter runoff when pasture length was short (2-5 cm), and low in spring and summer when the pasture was longer (3-14 and 15-20cm respectively). By reducing run-off velocities, long vegetation will reduce the run-off sediment-carrying potential." Accordingly a different method could be applied to stock exclusion to produce similar or better results.

4.13. This is consistent with the case study results in the AgFirst and BakerAg reports.[8] In particular, the findings that for some farmers (particularly low intensity hill country farmers) the costs of stock exclusion are extreme. This is primarily due to the need for stock crossings and water reticulation but also due to the topography and practicality e.g. the need to helicopter fencing materials in to fence steep gullies.

4.14. I note that these farms are also typically low intensity (Farm C in the BakerAg report had just 4.7 stock units per hectare) and for many of them alternative mitigations will not only be significantly more cost effective but also achieve a similar environmental outcome. One such alternative mitigation identified in the AgFirst report was the possibility of providing an alternative water source and shading away from the waterway.

4.15. The perverse (and unintended) outcome from policy of this type[9] is that it will simply encourage intensification of the farm system in order to afford the cost of compliance. I consider a FEP could more objectively analyse the risk ''in situ'' and identify practical and cost effective solutions, including where appropriate, areas of the farm that are more suitable to intensive use.

4.16. Accordingly the identification of risks at source along with suitable management responses is a more appropriate response to the management of diffuse contaminant loss.

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[7] Christine M. Smith (1987) Sediment, phosphorus, and nitrogen in channelised surface run-off from a New Zealand pastoral catchment, New Zealand Journal of Marine and Freshwater Research, 21:4, 627-639 https://doi.org/10.1080/00288330.1987.9516268

[8] The Report by AgFirst dated 4 Nov 2016 and the BakerAg report to the Hill Country Group dated 8 June 2018. The AgFirst Report is attached as PLM11 to the evidence of Paul Le Miere for Federated Farmers on Topic 1 and the BakerAg report is attatched as appendix 1 to the evidence of Richmond Beetham for Hill Country Group on Topic 1.

[9] Blanket rules for instance for stock exclusion

All contaminants

4.17. I also consider that a strategy of controlling all four contaminants equally is problematic as actions to control one contaminant may contribute to an increase of another contaminant. An example is that drainage reduces P and sediment loss but may increase N and faecal coliform (FC) loss.

4.18. Accordingly I consider it is more suitable to find out what the issues are in the sub-catchment and property and then address those with the appropriate actions. The McDowell et al report[10] (attached as "IFM1" which I refer to extensively later) states that the appropriate strategy to improve freshwater quality is to identify the contaminant of concern and the water quality objective to determine the correct strategy.

Overseer

4.19. As already described, Overseer, as the predominant farm system decision support tool, has focussed our collective understanding on the pathways modelled within its capability. However there are many mitigations or interventions that land managers can make that are not accounted for within Overseer. A FEP with tailored actions can allow and account for such mitigations or interventions.

4.20. Accordingly I support the adoption of on farm tailored actions that are based on the assessment of risk in context as opposed to the regulatory reliance stream edge mitigations.

Report for MfE

4.21. I attach and mark as "**IFM1**" a report prepared for MfE. [11] The report assesses different strategies to mitigate the impact of farm contaminants to freshwater. I endorse the report and its conclusions which I set out below with my emphasis added:

Conclusions and take home messages

[10] At [6.2]

[11] R.W. McDowell et al *Assessment of strategies to mitigate the impact or loss of contaminants from agriculture land to freshwater*. June 2013

A number of caveats apply to the selection, use and ability of mitigation strategies to achieve good water quality outcomes.

1. **Although each strategy has a range in price and effectiveness, both may be significantly improved if placed in the right place and at the right time. Each strategy will be different in this regard**. However, McDowell et al. (2012) found that in two catchments in Otago the application of strategies to mitigate P losses when applied to critical source areas (viz. areas that account for the majority of contaminant loss, but account for a minority of the area) was 6-7 times more cost-effective than applying the strategies across entire paddocks. Other examples include the consideration of soil type and the capacity of groundwater to assimilate N when putting in new irrigation schemes, or the location of winter forage crops on drier parts of the farm where there is less runoff.

2. **There is a wide range of strategies available. Strategies should be chosen according to the contaminant of concern and water quality objective.** We suggest that cost effectiveness (also called price efficiency index) is an unbiased metric to do this. However, the selection of multiple strategies that are cost-effective may not be the most optimal mix to meet a water quality objective that is required quickly, in which case decisions may be based on effectiveness alone.

3. The range of strategies presented also allows the user to mix and match the best mix for their property. However, it is also important that the co-benefits be considered as some target multiple contaminants, or could conceivably be antagonistic to one another. For example, the use of alkaline P-sorbing materials in an acid soil could end up releasing more P despite less fertiliser being applied to decrease Olsen P.

4. Using multiple strategies in one location will be less effective due to the diminishing quantity of contaminant to mitigate, than the use of multiple mitigations along the transport pathway. However, in general, it is more cost-effective to mitigate the loss of contaminants at the source than farther down the catchment (Turner et al. 1999).

5. It is unlikely that there will be one strategy that can meet a water quality objective, i.e. there is "no silver bullet".

6. Even when optimally placed and timed, the use of mitigation strategies may not meet a water quality objective for several reasons:

a. Natural factors such as catchment characteristics (soil type, climate etc) mean there will always be a water quality issue;

b. The costs or time involved at the enterprise level in using the number of strategies required to meet a community water quality objective are too great;

c. There is a lack of motivation or poor skill base by land users to enact mitigation strategies at the source of contaminants, or a lack of community understanding of the processes and timeframes involved in seeing a response in a waterbody.

7. New science (and mitigation strategies) needs to continue to inform the community and land users at the catchment scale to achieve good water quality outcomes.

Good farming practices

4.22. The S42A report proposes the use of Good Farming Practices (GFP). I will support tailored actions in a FEP based on Good Farming Practices. However, I consider that they should not be confused with minimum standards. If there was a suggestion to attempt to codify GFPs I would not support that because that would defeat the purpose of tailored actions in FEPs. Likewise, I consider any catchment wide standards in Schedule C ought to be able to be tailored in the FEP, where appropriate (such as some of the case study examples contained in the AgFirst and BakerAg reports referred to above). In farming one size does not fit all and the mitigation action should match the problem.

4.23. As a matter of principle, I consider there is merit in all farms obtaining a FEP (it could be a simplified FEP or LEP from Beef and Lamb). While I consider the cost of the exercise need to be reasonable, and the content of the FEP needs to be relevant for the farm under consideration. For low intensity farmers I consider that addressing critical source areas through a FEP is likely to achieve a better environmental outcome at lower cost than requiring them to rigidly comply with catchment-wide stock exclusion and setback standards.

5. BETWEEN 50TH AND 75TH PERCENTILE

5.1. The S42A report proposes amendments to Policy 1 to require "real and enduring nitrogen" reductions from those farmers in the 50th to 75th nitrogen percentile. No guidance is provided as to what level of reduction is required or why such reductions are needed.

5.2. In my opinion, considerable progress will be made if all farms obtain FEPs and adopt or move towards GFP. In respect of nitrogen, this assessment will appropriately identify any inefficiencies in respect of nitrogen discharges from the farm and recommend actions and changes to practices to address them.

5.3. It is not possible to assess whether farms in the 50th to 75th percentile are efficient or what their level of nitrogen discharge might be. I understand that the 75th percentile is to be assessed on the basis of the dairy curve, but that data will not be available until all nitrogen reference points are provided. I assume that the 50th percentile will be calculated on the same basis. Without this information, it is not possible to assess how many farms might be affected or what level of nitrogen reductions might be required. Without an individual farm assessment, it is not possible to assess what available mitigations might be available to farmers to make reductions and the likely costs.

5.4. In my opinion, without running a model similar to that by Dr Doole, it is not possible to estimate the likely costs or N reductions that would be achieved from reductions between the 50th and 75th percentile. The numbers of farmers affected could be significantly greater and, as explained in the evidence of Mr Matthew Newman on behalf of Dairy NZ, the costs will depend on where the farmers are at on the N cost abatement curve.[12]

5.5. In my opinion, there is a real risk to farmers that the costs of demonstrating "real and enduring" (whatever that might mean) N reductions are significant and take them significantly beyond GFP. I consider that the potentially available mitigations, costs and benefits should be assessed before adopting such a requirement.

6. STOCK EXCLUSION AND SETBACK

6.1. I have reviewed Schedule C (Stock Exclusion) and Schedule 1 (FEP) of PC1 and the non tailored or default requirements for stock exclusion and cultivation setbacks proposed by both PC1 and in the S42A report.

[12] Statement of Primary evidence of Matthew Newman for DairyNZ Ltd dated 15 Feb 2019 at [7.1] to [7.14].

Stock exclusion

6.2. In the S42A report Topic 2, the reporting officer[13] mentions that the benefits of stock exclusion and riparian margins are 'difficult to attain in practice due to the pulse of streambank erosion in the short term, and the need for battering of steep banks, meaning it can take some time for the vegetation to reach a stable equilibrium". I am aware of research in Whatawhata, Waikato which indicates that any new equilibrium may take several decades.[14]

6.3. In this context, I consider that a wider portfolio of interventions can be considered and deployed along the source-transport-sink pathways in a specific catchment context. I understand that a wider catchment-specific context is material to FFNZ's relief sought.

6.4. It is my opinion that a tailored mitigation in a FEP will be better than the onerous blanket requirements suggested for stock exclusion and for cultivation setbacks. I consider that what is required is the right actions in the right place as discussed previously under tailored actions in a FEP.

6.5. Turning to the provisions, Schedule C of PC1 sets out the main requirement for stock exclusion. It requires the exclusion of cattle, horses, pigs and deer from water bodies. Exclusion needs to be effective and could be different forms of fencing such as temporary, permanent, and virtual fencing.

6.6. I fully support the S42A report's foresight around virtual fencing and future practices to exclude stock. I anticipate that GPS collars and other future practices should, as far as possible, be enabled if it has the same environmental outcome.

Prescribed distance

6.7. The recommendations for stock exclusion in the S42A report are that stock must not be within:

a. 1m of the outer edge of the bed for land with less than 15°.

b. 3m of the outer edge of the bed for land with between 15° and 25°.

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[13] S42A report at para [909] p145.

[14] Hughes and Quinn, 2014, Before and after integrated catchment management in a headwater catchment – changes in water quality

c. 10m of the outer edge of the bed for watercourses that are the responsibility of a territorial authority or Waikato Regional Council for maintenance purposes.

6.8. Stock exclusion, whilst it can be effective is not equally effective everywhere and also has different farmer cost benefit implications. It is important to recognise that stock exclusion is not always the most appropriate mitigation (as explained generally in paragraph 4 above).

6.9. Generally steeper, less intensive land has far higher stock exclusion costs than flatter land. The additional cost associated with stock exclusion on steeper land is related to the additional earthworks required to form a workable fence line, the additional materials and time, and the need to accommodate more classes of livestock. It also may be impractical in that a suitable fence line may not be able to be built. Suitable places to put fence lines that will be durable is a major impediment to further subdivision and development in hill country. Obviously this has the associated effect of hill country being relatively less intensive than flat land with a corresponding reduction in risk associated with livestock. In hill country the primary risk is typically associated with different types of landform and landcover producing erosion susceptibility.

6.10. There is no one size fits all solution for stock exclusion. Farmers need flexibility especially where the stock exclusion requirements will be prohibitively expense and impractical. In some situations other mitigation action may be more appropriate instead of fencing. In areas where stock exclusion is impractical, cost prohibitive, or impossible there should be the option to employ other strategies to mitigate the loss of contaminants that are relevant in the sub-catchment where the farm is situated. An example is case study of Farm 2 attached and marked “IFM3”.

6.11. In my view this should be formally guided by a farm plan that allows for the recognition of other mitigations. Examples include the use of non-water soluble phosphorus fertiliser, the development of Silvopastoral/forestry systems in erodible areas, the installation of sediment bunds where appropriate, the maintenance of higher pasture covers during high risk times, and the provision an alternative water source and shading away from the waterway. The added benefit of the use of targeted mitigations is that they may be more effective at mitigating relevant contaminant loss and therefore will be more cost effective and enable innovation.

6.12. The use of catchment-specific information to support tailored effective and cost-effective interventions, be they farm-scale or catchment-scale are increasingly recognised in other regions.

6.13. These methods are increasingly employed in other regions to support smart and efficient targeting of investments, broadly based on the 80/20 rule, eg:[15]

- Spatial patterns: perhaps 80% of sediment may derive from 20% of a catchment
- Temporal patterns: perhaps 80% of sediment (or E coli, particulate nutrients) may derive from high rainfall events

6.14. An example is the work commissioned by MPI and published in November 2015.[16] The study is centred on sediment and E coli in Northland, but with a broader goal: "to help further develop national understanding of the cost-effective management of both contaminants, especially since sediment and E coli have typically received less analysis at the catchment scale, than nitrogen, and to a lesser extent phosphorus".

6.15. In brief (emphasis added):

a. The project tested alternate approaches of specifying <u>practices</u>, eg, stock exclusion; or specifying <u>targets</u>, with landowners collectively selecting options to meet targets.

b. For sediment, the project identified and quantified the various sources – landslide, earthflow, gully, surficial erosion, floodplain deposition, bank erosion – and determined that <u>85% of sediment derived from hill/landmass erosion and 15% from streambank erosion</u>

   - A scenario which tested stock exclusion fencing on all pasture land then found that this equated to "just a 5% reduction in total erosion"

[15] As an example see MPI Technical Paper No. 2017/15: "Whangarei Harbour sediment and e coli study: catchment economic modelling", November 2015 in Northland found 85/15 spatial pattern for sediment.
[16] MPI Technical Paper No. 2017/15: "Whangarei Harbour sediment and e coli study: catchment economic modelling", November 2015

- I briefly note here that the proportions may be different in this region: the key point is to estimate the region-specific proportions to inform effective and cost-effective targetting

c. For E coli[17], the project was not able to confidently estimate reductions: "Overall, there is high uncertainty in model predictions. This uncertainty should be acknowledged when determining risks, ie, which catchments should be prioritised; and prioritising investment, ie, which mitigation tools should be implemented and where should they be implemented in the catchment*".*

d. The key finding from the study was that: "The most cost-effective mitigations are those that focus on a combination of fencing, farm plans and wetlands, with landowners deciding on the optimal combination of mitigations for their farm. This enables a focus on the particular hotspots of sediment and E coli".

6.16. It is relevant to note here that MPI is aware of the difficulty in assuming relationships between stock exclusion and sediment reductions, and specifically did not consider sediment in exploring the costs and benefits of national regulation:[18]

> "The impacts of stock exclusion on sediment in water ways and ecosystem health – and assessment of the benefits and costs of riparian planting and setbacks – could not be included. Studies undertaken in Northland and Waikato show that detailed analyses, particularly sediment modelling, are very time consuming and costly".

Council responsibility for maintenance purposes

6.17. The S42A report recommends a 10m setback for waterways managed by the Council or territorial authorities. According to the S42A report this is required to align with Rule 4.2.18.1 in the current Regional Plan. This rule states that within 10m from such a watercourse the placement of fences that prevents access for maintenance are discretionary activities and similarly the planting of trees and shrubs are discretionary activities.

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[17] MPI Technical Paper No 2017/14: "Northland Sediment Study: E coli modelling", August 2015

[18] MfE, 2016: "Draft Regulatory Impact Statement: Stock Exclusion"

6.18. I have reviewed the evidence of Andrew McGiven and visited the farm in case study 1 (attached as "IFM2"). I agree with the evidence of Andrew McGiven that a 10 meter setback is both costly and unnecessary.

6.19. In my opinion, fencing of drains will not prevent access for maintenance purposes. I am aware of farmers all over the country who have fenced council drains (with a variety of setbacks) and this does not prevent a digger from reaching over the fence and cleaning the drain. I foresee that such a requirement would create bigger issues, such as how to keep a 10m strip clear and maintained, that could in fact hinder drain maintenance. This is also well explained and illustrated in Mr Andrew McGiven's evidence for Federated Farmers.

6.20. Through my inspection of the council drains on Farm 1 of the case studies (attached and marked "IFM2") I could see no practical reason why a 10m setback is required. Access to the drain is maintained perfectly well currently and indeed should a 10m setback be introduced I consider that this would introduce additional complications and costs. These are:

- A 10 meter setback is a large cumulative area and will result in significant and enduring opportunity cost for the farmer.
- The setback will require ongoing additional maintenance.
- Should the current fence become an issue for management of the council drains it would be far more cost effective for the examples discussed to simply ''drop the fence'' when and if required. This will avoid the opportunity cost of land lost in perpetuity.

6.21. In summary I can see no practical or logistical reasons for a 10 meter setback on council drains in the examples discussed.

Waterbodies

6.22. The S42A report proposes that stock ought to be excluded from intermittent waterbodies. I do not agree that this is an appropriate catchment-wide standard. This is something that ought to be considered through a tailored FEP.

6.23. My concerns include that often intermittent waterbodies are difficult to identify, creating uncertainty for farmers and Council. They will depend on variables such as seasons, extreme weather events and subjective judgment. The costs of fencing waterbodies that are wet for short periods of time might be very high and the benefits might be marginal. In addition, fencing might not be the appropriate response and there may be one of a range of other mitigations that are more appropriate such as, changes to grazing rotation, changes to types of animals grazed near them at certain times of year etc.

6.24. I consider that the appropriate way to address intermittent waterbodies is to assess them as part of the critical source area assessment in FEPs.

6.25. The new definition as recommended in the S42A report appears to be an attempt to capture streams that are dry occasionally as opposed to frequently. I can understand the desire to manage those streams that are in the margins of the definition, however by widening the definition a huge number of additional watercourses become caught in the definition.

6.26. The S42a report provides an option to add a clarification pertaining to the condition of the bed of an intermittent stream. I think if intermittent streams are to be included in the definition then this addition is necessary in order to avoid capturing the huge number of ephemeral (or 1st order) streams that may flow some water some of the time. Examples of these are provided in case study 2 attached and marked "IFM3". In many cases these areas already perform a significant mitigation service of particulate matter and N. In other cases they may be dry stream beds that only flow during significant events.

6.27. Should the additional option be added into the definition, in my opinion the management of these areas still would be better determined within the context of a FEP so that a risk based assessment of likely effects and efficacy of mitigation can take place. To be clear I am not advocating these areas are not managed, I am simply suggesting that they be managed in context.

6.28. In my opinion the management of grass based ephemeral systems is also best left to a FEP so that site and system specific management can be developed within a CSA context.

Stock crossing

6.29. Schedule C also seeks to restrict any livestock entering or passing across the bed of the waterbody except by way of a livestock crossing structure. Again this is a very blunt management option for an effect that is extremely variable. In some situations where large numbers of animals are crossing frequently (especially if on formed raceways – because they can channel effluent towards a crossing) stream crossing should be culverted or bridged. In general farmers do this as they can afford to as it facilitates management. However, in many cases where stock crossings are infrequent and with smaller mobs being moved from one part of the farm to another the benefit of stock crossings will be negligible. In many cases the culverts may have a negative effect as they will require additional earthworks and tracking next to a waterway in order to construct them.

6.30. A subsequent issue that will arise from the development of stock crossings is their inevitable effect on fish passage. This issue is illustrated in the photo marked as Figure 3. Due to the need to place culverts level and the general trend for a stream to slope results in a small drop at the downstream end of a culvert. This small drop can then further disturb the stream bed and erode it down to a new steady state. This action in effect creates small barriers to fish passage. Obviously the steeper the ground the larger the barrier. To overcome this issue will require further costs, knowledge and ongoing maintenance.

Figure 3: Photo of a drop forming at a culvert

6.31. Allowing stock to cross once a week may have better environmental outcomes than a stock crossing. Another option could be to follow the example used in PC6 to the Hawkes Bay Regional Plan where stock was allowed to cross waterways when they were actively managed with a clear definition of actively managed.

6.32. The Report by AgFirst dated 4 Nov 2016 and the BakerAg report to the Hill Country Group dated 8 June 2018 indicate that stock crossing and reticulation add significant costs for fence requirements. Reticulation is required for stock water troughs because stock cannot drink from the water body.

Cultivation setbacks

6.33. Schedule 1 (contents of FEP) of PC1 requires a 5m buffer or setback between cultivated areas and streams. According to the S42A report the purpose of the setback is that it traps sediment and microbial transport but that many variables affect the transport[19].

6.34. I do not agree with the officer's conclusion that "wider buffers trap more sediment".[20] The Officer refers to Zhang et al to support the statement. The officer omits the important caveat that the desktop analysis undertaken by Zhang et al was predicated on an assumption that pollutant removal is constant with distance travelled through the buffer. In my experience this is not always the case. Zhang et al clarify that many studies have shown confounding effects related to microtopography, preferential flows and other factors, and the authors suggest that more realistic models could be developed when more data becomes available in future.

6.35. I also consider that the reporting officer's proposition that Holmes et al (footnote 108) found that "a 5 metre wide vegetated buffer was the minimum required" should be read in context. The officer omits the important caveat that this figure was put forward as an interim recommendation with the caution that it is based on a correlative study in a single stream catchment. The authors go on to suggest that further research is needed to determine if riparian fencing widths that adequately protect instream values vary in proportion with catchment and segment-scale parameters.

6.36. The work by Holmes et al was undertaken in a springfed stream in Canterbury over one week in summer 2012.

6.37. I consider that more relevant to PC1 is the work conducted in the Whatawhata catchment in Waikato over a 13 year period. For the first six years, the entire catchment was used for hill country sheep and cattle grazing. In the subsequent years, an integrated catchment management plan was implemented whereby cattle were excluded from riparian areas, banks were planted with poplars, and the most degraded land planted in pines.

6.38. The results were summarised in 2014 including that:[21] "The exclusion of cattle from riparian areas probably resulted in a relatively rapid reduction in sediment" but in areas with riparian planting or left to regenerate naturally,

[19] S42 Topic 2 at [773] p124
[20] At [773].
[21] Hughes and Quinn, 2014, Before and after integrated catchment management in a headwater catchment – changes in water quality

water clarity did not improve (in one catchment) and declined (in another). The authors concluded that "these findings highlight the complexity of stream water quality to catchment management changes and illustrate the need for catchment managers to consider a range of factors when planning catchment rehabilitation measures".

6.39. One of the Whatawhata authors (Andrew Hughes, NIWA) went on to publish a paper in 2015[22] summarising the state of the play with riparian research in New Zealand. The paper commences with: "Improvements in riparian management, such as planting and stock exclusion are often assumed to result in reduced streambank erosion and associated sediment yield".

6.40. The paper canvasses the limited data available (only nine relevant studies) stating that: "bank erosion studies in NZ are rare and there is little information on the contributions of bank erosion to river sediment yields. This scarcity of quantitative research also includes studies that quantify the effects of catchment intervention measures".

6.41. The author references work by Williamson et al (1992) which found "no evidence that grazed stream banks were more susceptible to erosion than retired stream banks, except when intensive grazing occurred on wet riparian soils adjacent to narrow low-order streams". It was noted by the authors that this work may not be relevant to other geologies such as those found on pumice and in the central north island as the work was completed in Southland.

6.42. The author suggests that "riparian management interventions are sometimes applied in the same way throughout catchments in the expectation they will be equally effective everywhere" but that "a one-size-fits-all solution to the application of riparian intervention measures to reduce stream bank erosion is unlikely to be appropriate or effective'.

6.43. I agree with the conclusion that riparian management (including stock exclusion) is not equally effective everywhere. Through my experience in farming , soil conservation, nutrient management, and landscape evaluation I have seen many examples of ''mitigation by recipe'' that does not achieve the desired environmental outcomes. Effective riparian management should

[22] Hughes, Andrew, 2015, Riparian management and streambank erosion in NZ

be guided by an informed risk analysis in context – accepting that where known risks are high (e.g. with higher stocking rates commonly found on easier contour) it may be sensible to default to a pre-set position while enabling an adaptive response to change the default position.

6.44. The recommendations for setbacks in the S42A report is that cultivation is avoided over 15° slope and if below 15° degrees slope then a minimum setback for cultivation of 5m is required.

6.45. In theory the notion of a predefined setback for cultivation may seem appropriate but as is often the case the reality of applying such a rule is unavoidably complex. There are several paddock scale attributes that will influence the need for and the scale of setback. Briefly, it is widely accepted that where setbacks work they work by slowing down the flow of water and therefore reducing its load carrying capacity and they sometimes offer improved infiltration that allows for runoff dissipation into the soil profile.

6.46. These affects will be influenced by factors other than slope angle and will include factors such as slope length, soil type and depth, geology, rainfall, the presence of a high water table, vegetation or crop type and management, and the existence of other structures e.g. shelter belts contour drains etc. It is clear from this list that the number of questions asked about the need and size of a setback is almost infinite. It is illogical therefore to suggest that the answer to all questions is 5 meters.

6.47. An interesting example is provided in case study 1 (see appendix “IFM2”). On this farm there are 56km of drains. The existence of these drains is effectively managing the water table depth which in turn aids in the management of soil structure and infiltration rates. Soil structure of this property is so good that water only very rarely flows overland. In effect the existence of the drains reduces the need for setbacks (although unavoidably small setbacks of around 1m are maintained).

6.48. In my view the example provide by case study 1 illustrates how the requirement for setbacks should be driven by contextual need. Similarly, the context of a farm area may mean that wider setbacks are appropriate. It may be that around some sensitive wetlands with a variable water table a wider setback should be employed to avoid issues with saturation excess runoff.

6.49. The identification of need and management of setbacks for cultivation is best done through a risk based assessment of the site and practice within a FEP. This is because setbacks (or grass buffer strips) can have secondary effects. These are described in the Agresearch MfE report[23] (attached as IFM1) and need to considered and managed. These are:

a. The buffer strip can quickly become clogged with sediment.

b. Buffer strips only work in areas where upslope surface runoff is generated by infiltration-excess, they do not work in areas where surface runoff occurs due to saturation-excess conditions in, for example, near stream areas (the benefit is gained from fencing-off, not the strip itself).

c. Buffer strips only function well under sheet flow, whereas most surface runoff tends to converge into small channels that can bypass or inundate strips.

6.50. In short grass slows water down and then the water can eventually soak into the ground. In time however the areas of setback can become a critical source areas themselves due to the contaminants that get deposited there.

[23] R.W. McDowell et al *Assessment of strategies to mitigate the impact or loss of contaminants from agriculture land to freshwater*. June 2013

Figure 4: Photo where saturation excess conditions exist in a shallow swale near a wetland/stream system. In this example contaminants with surface flow will still make it into the waterbody despite a significant setback.

6.51. The primary environmental effect caused by a setback is by the fence (and associated vegetative buffer) and not by the distance of a setback. A larger setback distance does not automatically provide extra mitigation. A fixed distance for setbacks does not address a continuously changing problem ie one size does not fit all.

6.52. In my view the reliance on setbacks is an edge of field mitigation that may not provide the desired mitigation outcome. Over time they may become net sources of contaminates as opposed to sinks. (e.g. supply Dissolved Reactive Phosporous (DRP) to waterways from phosphate captured in all forms by the setback strip.) A safer and more effective use of the concept of setback would be to incorporate the short to medium term use of grass filter strips within the farm boundary – not on the edge of it.

7. CASE STUDIES

7.1. On 1 May 2019 I visited two farms for case studies. I attach and mark as appendix **IFM2** the case study for Farm 1 and as appendix **IFM3** the case study for Farm 2.

7.2. The case studies provide examples of on farm problems when applying setbacks for cultivation and to exclude stock as recommended in the S42A report.

8. CONCLUSION

8.1. In conclusion, I recommend tailored strategies for the farm and sub-catchment according to the contaminant that is a problem and the water quality targets that are to be achieved. Tailored mitigation in a FEP will be better than the onerous blanket requirements as is current suggested for stock exclusion and for cultivation setbacks. I consider that what is required is the right actions in the right place.

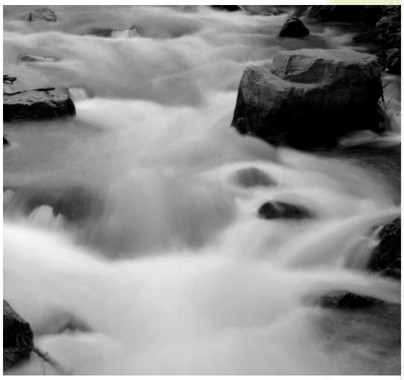
I F Millner

Assessment of Strategies to Mitigate the Impact or Loss of Contaminants from Agricultural Land to Fresh Waters

RE500/2013/066

June 2013

New Zealand's science. New Zealand's future.



Assessment of Strategies to Mitigate the Impact or Loss of Contaminants from Agricultural Land to Fresh Waters

Report prepared for MfE

June 2013

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1. Background

Freshwater management in New Zealand is going through its most comprehensive reform in a generation. Advice on reform has been sought from the Land and Water Forum, which included representatives of primary industry, electricity generators, recreational groups, environmental organisations, and iwi, with active observers from regional councils and central government. Consistent with the Forum's advice, the National Policy Statement for Freshwater Management 2011 (NPS-FM; MfE, 2011) was introduced. The NPS-FM provides central government direction to regional councils on water management. In summary, the NPS-FM requires that regional councils:

- state management objectives for waterbodies that reflect national and local needs;
- ensure objectives are achieved by setting flow, allocation and water quality limits;
- efficiently allocate resources to users within those limits;
- avoid over-allocation and address existing over-allocation;
- manage land use and water in an integrated way; and
- involve iwi and hapū in freshwater decision-making and planning.

The NPS-FM also includes a provision that gives regional councils the choice of either completing implementation of the NPS-FM by 31 December 2014, or if the council considers this impracticable, completing implementation as promptly as is reasonable in the circumstances and by no later than 31 December 2030.

The Government released its proposals for freshwater reform in March 2013. The document *Freshwater reforms 2013 and beyond* (MfE, 2013) proposed covering: 1) planning as a community; 2) the National Objectives Framework; and 3) managing within quality and quantity limits. The reforms are focussed on advancing the Government's Business Growth Agenda (MBIE, 2013) within environmental constraints.

Over the past 30 years a great deal of research has been conducted to quantify the processes, transformations and effects of contaminant loss from land to water (e.g. Di and Cameron, 2007; McDowell et al., 2004). A similar effort has been expended in designing strategies (which include technologies and better management practices) to mitigate either contaminant losses or their effects on fresh water (e.g. McDowell and Nash, 2012; Monaghan et al., 2007). This report compiles a list of current mitigation strategies available in New Zealand and provides a quantitative commentary on their relative cost-effectiveness and some context in their likely use or variability in contributing to the NPS-FM's requirement to maintain or improve fresh water quality.

2. Introduction

2.1 Variability

Agriculture emits significant amounts of nutrients, notably nitrogen (N) and phosphorus (P), faecal matter and sediment to New Zealand waterways (Howard-Williams et al., 2011). Whilst the N and P emissions may not be large by agronomic standards, the transfer of these pollutants from land to water can result in significant water quality impairment (Sorrell and Elliott, 2002; Monaghan et al., 2008; Howard-Williams et al. 2011). The proportions of N and P entering New Zealand streams and rivers, and coastal waters, from different land uses are shown in Tables 1 and 2 (Elliot et al., 2005).

Table 1. Proportions of New Zealand land area and total nitrogen (TN) load by source type. The loads have been estimated using the SPARROW model and exclude point sources discharging directly to the coast (from Elliott et al., 2005).

Source type	Load entering streams	Load to coast	Land use area
Fraction of total			
Point source	1.8%	3.2%	–
Dairy	37.8%	36.7%	6.8%
Forestry	19.7%	24.8%	39.2%
Sheep+beef	38.9%	33.3%	31.9%
Other non-pasture	1.8%	2.1%	22.1%
Total	373,900 t yr^{-1}	167,700 t yr^{-1}	263,500 km^2

Pastoral agriculture on steep, erosion-prone land and mobilisation of sediment stores deposited during deforestation are major sources of sediment to aquatic ecosystems (Elliott and Basher, 2011). Faecal matter inputs to New Zealand waterways are predominantly from pasture, with surface runoff, cattle crossings and drains being major sources (Wilcock, 2006). Mitigating these losses presents a challenge because of the diversity of geographical conditions (*viz*. climate, soils and slopes), and farming practices that vary between regions. Thus, mitigation methods for decreasing agricultural pollution of water bodies must take into account both natural and anthropogenic causes of variability and their respective proportions (McDowell et al., 2013).

Table 2: Proportions of New Zealand land area and total phosphorus (TP) load by source type. The loads have been estimated using the SPARROW model and exclude point sources discharging directly to the coast (from Elliott et al. 2005).

Source type	Load entering streams	Load to coast	Land use area
Fraction of total			
Point source	1.2%	1.8%	–
Dairy	9.9%	8.4%	6.8%
Sheep+beef	21.9%	17.0%	31.9%
Non-pasture	17.7%	19.5%	61.2%
Unknown sediment	49.3%	53.2%	–
Total	143,403 t yr^{-1}	63,057 t yr^{-1}	263,500 km^2

2.2 Natural variations

Mitigation methods are mostly based on natural processes to remove targeted contaminants and fall into three classes: (i) land-based treatment of contaminants at source, (ii) interception of contaminants along hydrological pathways, and (iii) bottom-of-catchment methods that treat contaminants within receiving waters. Each mitigation method will perform differently and vary in efficacy according to its location and the contaminant loading; at annual and seasonal time scales. The natural physical features (geography) of each location will differ spatially and temporally (Figure 1). For example, vegetated buffer strips used for intercepting and decreasing the loss of particulate contaminants have different treatment efficiencies according to the land slope, vegetative cover, seasonality and intensity and volume of rainfall, and soil drainage properties (Collins et al., 2005). Between-year and seasonal variations in rainfall affect both the amount and timing of surface runoff and mobilised particulate material and hence, the efficiency of buffer strips. The degree of slope will govern the buffer strip width required for a given trapping efficiency. Thus, a vegetated buffer strip of constant 5 m width will vary spatially in its efficiency for removing sediment, particulate P and *E. coli*, as the slope of the land varies (Collier et al., 1995).

Mitigation methods may also be classified according to their scale of operation, as being either farm-scale (e.g. stock bridges across streams and restricted grazing of winter forage crops), or catchment-scale (e.g. lower catchment wetlands, lake sediment capping). New Zealand's changeable weather patterns (e.g. droughts, tropical storms and El Niño/La Niña cycles) affect the timing and amount of runoff and hence the capacity of farm-scale mitigations to remove contaminants. Larger catchment-scale processes are affected by the volumes of water entering or flowing through them. For example, in deep lakes there is limited mixing of the epilimnetic (upper) and hypolimnetic (bottom) waters through the warm stratified period (c. 8-9 consecutive months), but active turbulent mixing occurring during the colder period (3-4 months). River uptake and transformation of contaminants varies according to the size of the river and distance of a given location from the contaminant sources (Alexander et al. 2002). For treatments involving groundwater there may be substantial lag-times. Thus, one part of a catchment may be hydrologically quite responsive, whereas another sub-catchment may have lag-times of up to 100 years (e.g. Lake Rotorua; Morgenstern and Gordon 2006).

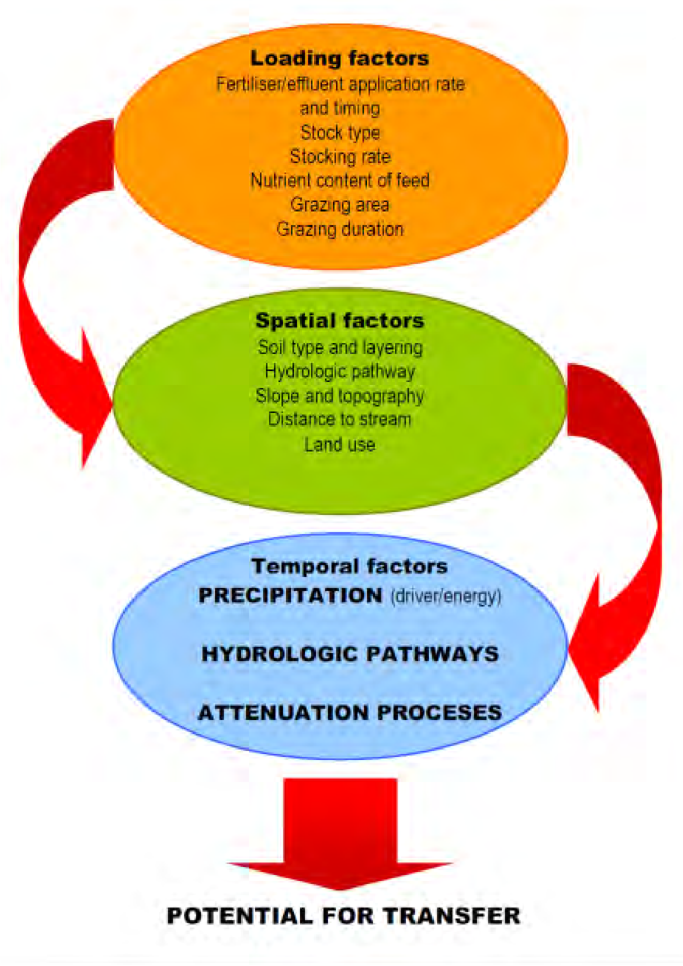

Figure 1. Controls governing pollutant transfer from pasture (from McKergow et al., 2007a).

2.3 Variability in management

Within any given region there will be a range of farming management methods used to achieve profitability. These methods are adapted to local conditions, thereby influencing the effectiveness of mitigation tools and how they interact. For example, the lower fertiliser-P losses arising from the use of low water-solubility products (e.g. reactive phosphate rock) over those in soluble forms (e.g. superphosphate) may leave more in the soil but enhance the effect of vegetated buffer strips to mitigate soil-P in surface runoff. Similarly, differences in the amounts of supplementary feed used on on-paddock in dairy farms will affect production and N leaching losses, and hence, mitigation efficacy.

Temporal variations in management include interannual changes driven by climate or financial conditions. Changes in land use (e.g. dairy conversions or changes in cropping) and irrigation (conversion from dryland to irrigated farming and changes in irrigation method) affect runoff characteristics and thus, mitigation effectiveness. Highly efficient irrigation systems that minimise water use enable more intensive forms of agriculture that may change the timing and nature of contaminant release to water bodies. Border-dyke irrigation systems with low efficiencies emit regular pulses of surface runoff of contaminated runoff, whereas highly efficient sprinkler systems may result in a build-up of nitrate that is only released spasmodically when soils are saturated.

2.4 Catchments and connectivity

Depending on the contaminant, different hydrological pathways may be taken for it to reach a water body. As a consequence, contaminant concentrations are modified and mitigated differently according to the interactions they have with soil, plants and microbes. Particulate contaminants (e.g. fine sediment and associated nutrients like P, and pathogenic microbes in animal dung) are mainly transported in surface runoff or via coarse macropores to shallow groundwater, whereas dissolved contaminants (e.g. nitrate and dissolved reactive phosphorus) are transported via surface and subsurface pathways (Figure 2). Surface and subsurface drains collect shallow surface water at depths within the top 1 m of the soil surface and transport it rapidly to nearby streams, often with very little attenuation (Monaghan et al., 2007). Drain waters pose special problems for surface waters because they often discharge directly into streams without the benefits of attenuation by riparian processes.

Surface water–groundwater interactions are important in pollutant transport and hence, mitigation methods that are based on interception methods (e.g. riparian denitrification walls, amended drainage systems having N and P adsorbents). Groundwater is inherently more difficult to treat and often emerges in surface water at a location that is remote from the source. Accordingly, it is best for mitigation methods to focus on decreasing pollutant loadings prior to drainage occurring, or on decreasing excessive drainage. The connectivity of aquatic systems means that impacts of land use affect downstream waters with varying degrees of resilience, *viz*. lakes and coastal lagoons.

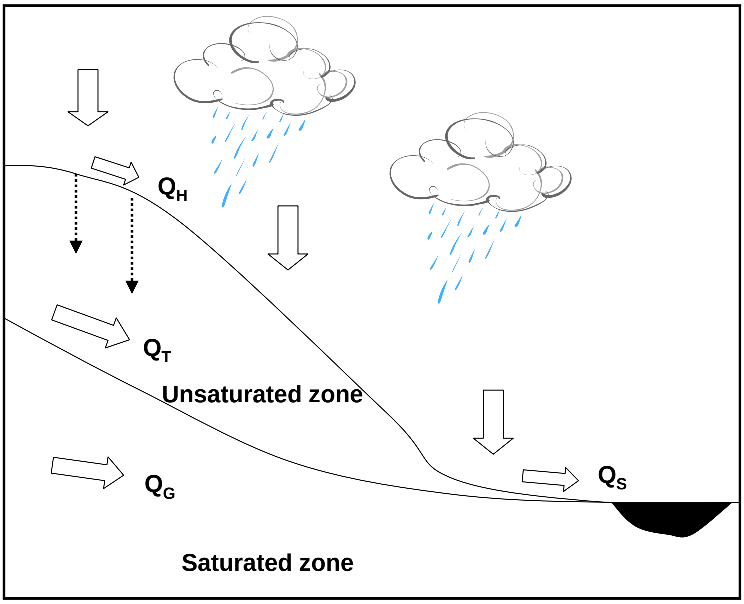

Figure 2. Hydrological processes. Q is flow and the subscripts refer to Hortonian overland flow (H), saturation overland flow (S), throughflow (T) and groundwater flow (G) (modified from Davie, 2004).

2.5 Contaminants

The major water contaminants from agriculture are different forms of N and P, sediment and faecal organisms (usually quantified by the faecal indicator bacteria – *Escherichia coli* [*E. coli*]). Other contaminants of less extensive impact include: oxidisible organic waste, or biochemical oxygen demand (BOD) and pesticides (Table 3). Ammonia in its un-ionised form (NH_3) is highly toxic to aquatic invertebrates and fish and the proportion of NH_3 in ammoniacal-N (NH_4^+) discharges from waste treatment systems increases as pH and temperature rise. Nitrate has recently been found to be toxic to a wide range of aquatic organisms. The current recommended chronic exposure guideline for 95% protection of freshwater species is 2.4 mg N/L (Hickey, 2013). Dissolved inorganic N (DIN) is the sum of ammonia-N and nitrate-N and is a target of many mitigation measures because of its influence in stimulating excessive growth of plants, such as periphyton (Wilcock et al., 2007). A further point to consider is that much of the N entering water bodies is in particulate and dissolved organic forms that are available in the long-term for uptake by plants (Timperley et al. 1985; Parfitt et al. 2006)

Table 3. Point sources and diffuse (non-point) sources of agricultural pollution, and key contaminant indicators.

Pollution source	Pollutant type	Contaminant
Point source		
Surface and subsurface drains	Farm wastes, irrigation water, dairy pond effluent, silage leachate	N, P, sediment, faecal microbes BOD
Industrial discharge	Processing wastes (e.g. abattoir, dairy factory)	BOD, toxic organics, faecal microbes, heat (warm water)
Non-point (diffuse) source		
Surface runoff from agriculture	Particulate pollutants*	P, N, sediment, faecal microbes
Subsurface runoff	Dissolved pollutants**	DIN, DRP
Riparian grazing by livestock (including livestock in channels)	Animal wastes, sediment, reduced streambank stability	Faecal microbes, sediment, N, P
Spray drift	Farm operations	Pesticides, fertiliser

*Surface drains often collect drainage from subsurface drains and hence collect dissolved and particulate pollutants.
**Subsurface drains can convey particulates if there are soil macropores (e.g. soil cracks).

Dissolved reactive phosphorus (DRP) stimulates algae growth at low concentrations. The New Zealand Periphyton Guidelines (Biggs, 2000) have been used to set maximum DRP concentrations to protect aesthetic and recreational values for rivers. Total P and N reflect the sum of the different forms of P and N, and include reactive (bioavailable) forms, and other forms that are not generally immediately bioavailable including dissolved and particulate forms of N and P, and particulate inorganic P.

For lakes the Trophic Level Index (TLI; Burns et al. 2000) has been adopted to indicate trophic state. The TLI grades lakes from “micro-oligotrophic” to “supertrophic” based on surface-water concentrations of total N and P, chlorophyll *a* (indicative of planktonic algae pigment concentrations) and Secci disk (a measure of water clarity).

2.5.1 Limiting nutrients

Excessive periphyton growth on riverbed substrate is a common issue that affects a number of river values, e.g. life-supporting capacity, contact recreation and aesthetics. The New Zealand Periphyton Guidelines (Biggs, 2000) provide some guidance on the acceptable levels of periphyton biomass in relation to protecting different river values and uses. Excessive peak periphyton biomass is dependent on extended periods of stable or low flow, and on the absence of shade from riparian vegetation and low turbidity. Once these conditions are met, the rate of development and peak biomass are most strongly controlled by concentrations of bioavailable N and P in the water. For freshwaters it is common to regard bioavailable N as being DIN, while bioavailable P is taken as being DRP. Both elements are needed for periphyton growth, in an average mass ratio of 7:1 (N:P). In practice, when the DIN:DRP ratio is less than 7, waters are commonly N-limited with respect to periphyton growth. When the ratio is >15 conditions for periphyton growth are commonly P-limited, and ratios of 7-15 may indicate co-limitation by both elements (Wilcock et al. 2007; McDowell et al. 2009). However, it should be noted that these ratios are only to be used as guidelines (i.e. subject to variation) and nutrient limitation should always be confirmed with other techniques such as a bioassay. When both DIN and DRP concentrations are very low (e.g., DIN below 5 parts per billion, DRP below 1 part per billion), then the risk of algal proliferations is low, unless there is a simultaneous discharge of both DIN and DRP into the water body. When both DIN and DRP concentrations are very high (e.g., DIN above 1000 parts per billion or DRP above 50 parts per billion), then N and P availability is probably in excess of algal requirements and increasing the concentration of either nutrient will not elicit a growth response. Under these conditions, light or a different nutrient may limit algal growth and N:P ratios are not informative.

In lakes, concentrations of bioavailable N and P in surface waters can be decreased to very low levels, sometimes below detection limits, and therefore ratios of total N to total P have been used as a more reliable method to indicate potential for nutrient limitation. On average a mass ratio of 7:1 (N:P) should indicate that lake phytoplankton growth is balanced equally by these two nutrients but in practice the ratio varies from 9 to 23 (Oliver et al. 2012). Thus for total N: total P less than 9 it is more likely that N limitation of phytoplankton is prevalent and for total N: total P greater than 23 then P limitation is more likely.

Overall, the limited number of assessments of nutrient limitation in New Zealand freshwater ecosystems has indicated that estuarine systems commonly exhibit N-limitation more than either co-limitation (i.e., N+P) or P-limitation (Larned et al. 2011). In lakes N-limitation and co-limitation occur with greater frequency than P-limitation (Abell et al. 2010; Larned et al. 2011). While in streams and rivers, P-limitation is more common than either co- or N-limitation (McDowell et al., 2009)

Nutrient management is the primary means of mitigating periphyton mats in rivers and phytoplankton growth in lakes and lagoons. Although nutrient ratios may indicate a greater algal response to one nutrient over another, it is quite common to control both N and P in water bodies because of temporal and spatial changes in N:P ratios (Wilcock et al. 2007).

2.5.2 Sediment and faecal microbes

Excessive levels of suspended solids (SS) cause siltation and smothering of river beds that may affect trout reproduction and viability, and may also result in anoxic conditions that preclude sensitive aquatic species, such as mayflies. High SS concentrations reduce visibility and alter the 'visual habitat' (and thus behaviour) of fish and birds, and decrease the amenity value for recreation (Davies-Colley et al. 2003). A black disc visibility of about 1.5 m is sought by most Regional Councils for rivers below median flow. Concentrations of turbidity correlate reasonably well with black disc clarity over a range of flows (Smith et al. 1997). A major reason for mitigating sediment inputs from land to waterways is that a large proportion of P entering natural waters is associated with sediment.

Freshwater faecal pollution is monitored using the usually harmless indicator organism *E. coli* to provide a risk assessment of pathogen infection. New Zealand has a high incidence of Campylobacteriosis by OECD standards, especially in rural areas[1] that is caused by ingestion of the *Campylobacter* bacterium. Other relevant pathogenic organisms of faecal origin are *Salmonella*, *Cryptosporidium*, VTEC/STEC[2] and *Giardia*.

[1] http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10829263
[2] www.nzpho.org.nz

3. Methods

Information was collated (see Tables 4 and 5) on strategies available in New Zealand to mitigate the loss of contaminants from land to water and within water itself. Two scales of interest were used to define those strategies relevant at a farm and catchment scale. The catchment scale relates to nutrients already within water including where nutrients either enter a lake or are within a lake. Although there are many potential water quality contaminants that may be lost from land (e.g. heavy metals, pesticides etc), our focus was on the four highlighted most often in policy or by the public, namely: nitrogen, phosphorus, sediment and faecal indicator bacteria.

In addition to the authors' knowledge of the field, researchers in Universities and Crown Research Institutes across New Zealand were given the opportunity to provide evidence and commentary on relevant mitigation strategies.

In order to provide a consistent approach across all strategies, the following criteria were strictly applied:

1. The strategy must be published in peer-reviewed literature (grey literature was not accepted), largely from New Zealand or where there are similar agricultural systems (e.g. southeastern Australia) or from countries or ecosystems where the mitigation is likely to perform similarly as in New Zealand. The exception to this was for catchment mitigation strategies where much of the technology has been applied in New Zealand only within the last five years, and the subsequent documentation has not yet been peer reviewed. If so, literature from overseas has been used to describe the wide range of nutrient mitigation strategies;
2. Published data was used wherever possible to define a range for cost-effectiveness;
3. Its relevance to different farming enterprises must be known; and
4. The mode of action and reasons for variability (e.g. soil type, climate) can be succinctly, and simply, described.

Additional commentary on the likelihood of uptake and co-benefits (within or outside the field of water quality) was invited on the understanding that this information is qualitative and may not be proven.

Although our approach is consistent, it has clear drawbacks such as: the exclusion of new, but unpublished, data from the synthesis of farm mitigation technologies; or the failure to capture the full range of costs or effectiveness for a strategy under different variables (e.g. soil type or climate, lake mixing regime). Hence, where mechanistic models are available to estimate the effectiveness and cost of particular strategy (e.g. Overseer®) they should be used to inform decisions before using our estimates. However, the majority of strategies outlined in this report are not captured within current modelling frameworks.

In the case of catchment mitigation technologies, cost and effectiveness could only be broadly approximated. For example, in contrast to farm-scale strategies, most catchment mitigation strategies leave nutrients within the water body, inactivating them through chemical adsorption and precipitation processes, and sedimentation (e.g. through flocculation, floating wetlands, discing, destratification or oxygenation). One potential strategy to mitigate poor water quality in lakes, not listed in Table 5, is to increase flushing rates (Howard-Williams, 1987). The increase in flushing rate is achieved by more discharge to the lake, which may increase nutrient load to the lake. Cost-effectiveness on the basis of $ per kg of N (for example) removed is therefore problematic. Instead, costs are given on an areal basis ($ per hectare in, for example, a lake) and percentage effectiveness is evaluated relative to the most expensive (100%) mitigation strategy.

For catchment mitigation technologies, we included only those mitigations that were specific to nutrient control and not other mitigations that addressed symptoms of excess nutrients such as algal blooms. Excluded were well-established techniques such as algaecides (e.g., copper sulphate; Steffensen 2008) and other less well-proven technologies for algae control such as dyes for shading planktonic algae (Ludwig et al. 2010), ultrasonic or UV irradiation to lyse algae cells (Rajasekhar et al. 2012), and barley straw (e.g. Everall and Lees 1997) and additions of bacteria (e.g. Peng et al. 2003) to inhibit algae growth or break down cell walls. We also excluded biomanipulation because its association with nutrient mitigation is tenuous. However, we also note that in shallow lakes, submerged macrophyte weed beds, when present at moderate to high densities, tend to suppress growth of planktonic algae and may confer some degree of resilience to increases in incoming nutrient and sediment loads (Schallenberg and Sorrell 2009). Furthermore, other biomanipulation techniques such as seeding of mussels (*Hyridella menziesi*; Ogilvie and Mitchell 1995), planktivorous fish such as silver carp (e.g. Ma et al. 2012), and filter-feeding zooplankton may be beneficial in decreasing the effect of nutrients. There is some evidence to suggest that recent unintentional introductions of large-bodied herbivorous zooplankton may now exert some control on planktonic algae populations in some New Zealand lakes (Balvert and Duggan 2009).

Information on the range of cost-effectiveness ($ per kg of nutrient or sediment retained per hectare) and percentage effectiveness were used to rank farm mitigation strategies within a contaminant and categorised into quartiles (low, medium, high and very high). The output is presented in Tables 4 and 5 and in a matrix for each contaminant showing the range of cost (e.g. per kg of N retained relative to the most costly strategy; y-axis) and effectiveness (x-axis) (Figures 3 to 5). It is recognised that categorization into quartiles could, depending on the number of strategies, lead to some strategies that the reader may interpret as mis-categorized. The two metrics are given to the reader to aid a decision on whether or not to mitigate purely on cost-effectiveness or to promote a few strategies that are highly effective, quick or require little labour/maintenance. The reader should also note that those strategies listed in Tables 4 and 5 represent only those that are currently published, there are many more in various stages of development that may come "on-line" in 2-10 years time.

This method is counter to the objective of other land-based nutrient mitigation technologies to reduce sediment and nutrient loads. This example demonstrates why it is difficult to adopt a cost-effectiveness matrix similar to that for farm-based mitigation technologies (Figures 3 to 5) in the case of catchment-scale technologies. On the other hand, given that dredging and weed harvesting remove nutrients from a lake, a similar approach to the farm-based mitigation technologies may be applicable in these cases. In general terms, however, we consider that costs for catchment-wide technologies may be best quantified on a per unit area basis.

4. Detailed tables of strategies

Table 4. Information applicable to the application of farm-scale technologies (strategies) to mitigate the loss of water quality contaminants to water.

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Multiple	All farming enterprises	Bridging stock stream crossings	Avoid direct entry of faeces, urine and entrained hoof mud, and substrate disturbance during stream crossings	NIWA	Low [N]; Low [SS]; Medium [*E. coli*]	Medium [N]; Medium [SS]; Medium [*E. coli*]	Highly dependent on stream length, width and number of crossings per farm.	Too many crossings	Avoiding stock losses in high flows.	Davies-Colley et al. (2004); Nagels et al. (2011)
Multiple	All farming enterprises	Constructed wetlands	Modification of landscape features such as depressions and gullies to form wetlands. Slow water movement encourages deposition of suspended sediment and entrained contaminants (e.g. P). Compared to many natural wetlands, constructed wetlands can be designed to remove contaminants from waterways by: 1) decreasing flow rates and increasing contact with vegetation – thereby encouraging sedimentation; 2) improving contact between inflowing water, sediment and biofilms to encourage contaminant uptake and sorption; and 3) creating anoxic and aerobic zones to encourage bacterial nitrogen processing, particularly denitrification loss to the atmosphere. Performance varies depending on wetland size and configuration, hydrological regime, and contaminant type and form. An adaptation has seen the inclusion of floating wetlands (emergent wetland plants grown hydroponically on floating mats) to remove significant quantities of dissolved P from artificial urban stormwater compared to unplanted mats. However, it is also noted that while the regular harvesting and removal of plants growing on wetland sediments may increase P removal from the wetland, unless the biomass has an economic value, harvesting is not a cost-effective strategy. Although relatively easy to construct and maintain, constructed wetlands also remove land from production, which impairs their cost-effectiveness.	NIWA	Very high [N]; Medium [P]; High [SS]	High [N]; Very high [P]; Medium [SS]	Wetland performance depends on intercepting the maximum amount of run-off from the catchment at the right flow rate.	No suitable areas on farm (i.e. catchment lies outside of farm area).	Flood attenuation, wildlife habitat and biodiversity	Headley and Tanner (2007); McKergow et al. (2007a); Tanner et al. (2005).
Multiple	All farming enterprises	Natural seepage wetlands	Natural seepage wetlands at the heads and sides of streams, commonly known as seeps, flushes, valley bottom or riparian wetlands. Wetlands slow water movement through them and encourage the deposition of suspended sediment and entrained contaminants (e.g. P). Wetlands, depending on factors such as loading rates and layout, can be sinks or sources of P. The retention of particulate bound P is usually large via sediment deposition. However, with time the ability of wetlands to retain particulate bound P decreases as the wetland becomes choked with sediment. Furthermore, as the wetland becomes reductive (anoxic) P in sediment becomes soluble, resulting in dissolved P release. The lifespan of natural seepage wetlands therefore depends on where they are located in the catchment. Locating them in places to optimize the retention of particulate bound P, together with the planting and harvesting of wetland plants may enhance their P retention.	NIWA	Very high [N]; Low [P]; High [SS]	Very high [N]; Very high [P]; Very high [SS]	Wetlands have diverse characteristics and intercept differing proportions of run-off depending on landscape, hydrogeology and human modification. Some evidence suggests that the water quality of shallow wetlands can be significantly affected by livestock access, but deeper (>0.4m) wetlands subject to less livestock incursion are not.	Price of permanent fencing >> temporary fencing.	Flood attenuation, wildlife habitat and biodiversity	Hughes et al. (2013); McKergow et al. (2007a; 2012); Nguyen et al. (1999)
Multiple	All farming enterprises	Sediment traps	Stock pond or earth reservoir constructed at natural outlet of zero-order catchment. In-stream sediment traps are useful for the retention of coarse sized sediment and sediment-associated N and P, but do little to retain N and P bound to fine sediment. As the P sorptive capacity of fine particles is much greater than coarse particles (w/w basis), sediment traps can be ineffective at decreasing P loss if the soil in finely textured and/or surface runoff is dominated by fines.	AgResearch, Landcare Research, Plant and Food, NIWA	Low [P]; Very high [SS]; Low [*E. coli*]	Very high [P]; Very high [SS]; Very high [*E. coli*]	Although design can be modified to maximise removal via settling, traps are ineffective at high flows when most sediment is transported	May require resource consent	Potential to buffer storm events and therefore potential downstream flooding.	Hicks DL (1995); Hudson (2002); McDowell et al. (2006)

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Multiple	All farming enterprises	Stream fencing	Preventing livestock access to stream, decreases stream bank damage (and sediment inputs via bank erosion) bed disturbance of sediments (and entrained *E. coli*, N and P) and stops the direct deposition of excreta into streams.	AgResearch	High [P]; Low [SS]; High [*E. coli*]	Low [P]; Medium [SS]; High [*E. coli*]	Gain is dependent on the area of the farm currently unfenced and stream density.	Price of permanent fencing >> temporary fencing.	Stream shading decreasing water temperature and light for periphyton and macrophyte growth.	Hicks DL (1995); James et al. (2007); McDowell (2007); Line et al. (2002); McDowell et al. (2006); McKergow et al. (2007b); Muirhead et al. (2011); Muirhead (2013).
Multiple	All farming enterprises	Vegetated buffer strips	Vegetated buffer strips work to decrease contaminant loss in surface runoff by a combination of filtration, deposition, and improving infiltration. The upslope edge of the strip is where most large particles and particulates (sediment and entrained N, P and *E. coli*) are filtered-out, and the speed of surface runoff slows enough that deposition occurs. If the hydrology allows, a more important mechanism that decreases contaminant loss is infiltration (i.e. there is no water for transport overland into streams). This deposits of particulate material onto the soil surface or vegetation and increases the interaction and sorption of dissolved P with the soil.	NIWA, AgResearch	High [P]; High [SS]; Low [*E. coli*]	High [P]; High [SS]; Very high [*E. coli*]	Buffer strips do have major flaws: 1) the strip can quickly become clogged with sediment; 2) they function poorly in areas that are often saturated due to limited infiltration; 3) they function best under sheet flow, whereas most surface runoff tends to converge into small channels that can bypass or inundate strips; and, 4) grassed buffer strips function best when the number of tillers is greatest, which generally occurs where biomass is harvested (i.e. under grazing).	Land adjacent to stream may not be available or suitable for a buffer strip.	Potential to stabilise stream banks.	Longhurst (2009); McKergow et al. (2007a,b;); Redding et al. (2008); Smith (1989)
Multiple	All farming enterprises with forage crops	Restricted grazing of winter forage crops	Winter grazing of a forage crop leads to large losses of N in drainage and P, sediment and E. coli in surface runoff. Restricting the time spent grazing a forage crop to 3-4 hrs so animals get maintenance feed requirements can decrease losses via erosion and excretal deposition compared to plots where animals are left in-situ.	AgResearch	High [P]; Medium [SS]	Medium [P]; Low [SS]	See above.	Must be accompanied by a stand-off area that has no connection to a waterway (e.g. runoff/effluent is captured).	Decreased soil and pasture damage caused by animal treading will help increase pasture yields and decrease N_2O emissions and denitrification rates.	McDowell and Houlbrooke (2009); McDowell et al. (2003; 2005)
Multiple	Dairy	Greater effluent pond storage and deferred irrigation	The risk of waterway contamination via land application of farm dairy effluent (FDE, otherwise known as dairy shed effluent) is high on soils with a propensity for preferential flow, rapid drainage via artificial drainage or coarse structure, or surface runoff via an infiltration or drainage impediment or application to rolling/sloping land. Deferred irrigation, which involves storing FDE in ponds when soil moisture is close to or at field capacity and applying FDE to land otherwise, has proven effective at decreasing N, P and *E. coli* losses.	AgResearch, Massey University, Landcare Research, DairyNZ; Aqualinc	Medium [N]; Medium [P]; Medium [*E. coli*]	Medium [N]; Low [P]; Medium [*E. coli*]	Depends on the number of cows, size of pond required, material and suitable location to build a pond. Inaccurate pond size can result in applications during wet periods and N and P losses. Differs with soil types and drainage status.	The requirement for storage is dictated by local climate and if too wet may make practice unrealistic.	Added water and carbon during summer and decreased (but unquantified) *E. coli* losses. Land treatment of dairy effluent culturally favoured over direct pond discharge to streams.	Houlbrooke et al. (2004); Houlbrooke et al. (2008); McDowell et al. (2005); Muirhead et al. (2011); Muirhead (2013).
Multiple	Dairy	Greater effluent pond storage and low rate effluent application to land	Coupling pond storage with low rates of effluent application can decrease P loss by minimising the potential for surface runoff and sub-surface losses via preferential flow. Some research has also shown low-rate application to be somewhat effective at decreasing P losses in sump-and-spray systems compared to a travelling irrigator.	AgResearch, Massey University, Landcare Research, DairyNZ	Medium [N]; High [P]; Medium [*E. coli*]	High [N]; Low [P]; Medium [*E. coli*]	The requirement for solid separation (using low-rate sprinklers) and degree of existing infrastructure that is already suitable (i.e. block size and mainline/hydrant layout). Difference soil types and drainage status.	Increased labour requirements compared to travelling irrigator.	Added water and carbon during summer and decreased (but unquantified) *E. coli* losses. Land treatment of dairy effluent culturally favoured over direct pond discharge to streams.	Monaghan et al. (2010); Houlbrooke et al. (2006); Muirhead et al. (2011); Muirhead (2013).

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Multiple	Dairy, piggery effluent manage-ment	Enhanced Pond Systems	Enhanced Pond Systems are an option for on-farm effluent treatment prior to land application. The system is designed for both effluent treatment and resource recovery and consists of four types of ponds: 1) Covered Anaerobic Ponds to remove and digest organic suspended solids to methane-rich biogas for energy recovery and reduced GHG emissions; 2) High Rate Algal Ponds for nitrogen and phosphorus removal and recovery as algal biomass; 3) Algae Harvest Ponds for removal of algae for beneficial use (fertiliser, feed, biogas); and 4) Maturation Ponds for further removal of faecal contaminants indicated by *E.coli*.	NIWA	Very high [N]; High [P]; Very high [*E. coli*]	Very high [N]; Very high [P]; Very high [SS]; Very high [*E. coli*]	Removal efficiency varies seasonally so designed for winter performance specifications and have higher performance in summer.	Requires substantial land area (10 to 40 m2/cow)	Energy recovery / production. Separation of effluent nutrient application from hydraulic application. Beneficial use of algae for biofuel and fertiliser or feed.	Craggs et al. (2012); Park and Craggs (2001); Craggs et al. 2008; Craggs et al. (2004); Craggs et al. (2003)
Multiple	Dairy	Restricted grazing and off pasture animal confinement systems	In fully or partially grazed systems, a strategy for minimising N, P, sediment and *E. coli* losses is to avoid deposition of urine and faeces or soil disturbance during periods of high loss risk (especially in spring and late autumn where soils are wet and growth is poor), by either removing the animals from pasture at certain times or by extending the existing housing period. Measurement and modelling of these “restricted grazing” strategies have been shown to decrease N leaching losses and surface runoff losses of P, *E. coli* and sediment. The size of these decreases depends on the duration and timing of the restricted grazing period. Disproportionately greater benefits were observed if grazing was restricted shortly preceding or during periods when losses were likely i.e. when drainage or runoff was occurring. Stand-off pads (preferably covered), herd shelters and wintering barns are some of the infrastructure options that are required for an off-pasture animal confinement system to work effectively.	AgResearch, Massey University, DairyNZ	High [N]; Medium [P]; Low [SS]	Medium [N]; Medium [P]; Very high [SS]	Costs vary widely due to variations in soil type and climate, and on the frequency of use of a restricted grazing strategy. For farms on heavy soil types and in wet locations where standing animals off-paddock is desirable, a small or nil net cost might be assumed. For dairy farms on well-drained soil types with minimal risk of soil treading damage, significant cost might be incurred.	High capital and operational costs and increased management complexity; immature design criteria and management systems that meet animal welfare and manure management requirements; and some risk of ‘pollution swapping’ by increasing NH_3 or N_2O emissions from the collected effluent and manures.	Decreased soil and pasture damage caused by animal treading will help increase pasture yields and decrease N_2O emissions and denitrification rates.	Cardenas et al. (2011); Christensen et al. (2012); de Klein et al. (2006); Ledgard et al. (2006)
Multiple	Deer	Alternative wallowing	Red deer will use or create areas for wallowing. The wallows are often directly connected to streams thereby providing a direct conduit for excreta deposited and the bed sediment disturbed during wallowing. A solution sees the fencing off or existing connected wallows and the creation of a wallow that is not connected to a stream.	AgResearch	Medium [N]; Very high [P]; High [SS]	Very high [N]; Medium [P]; Low [SS]	Poor performance could occur if runoff from alternative wallow reaches stream in large storms.	There must be an area close by that is suitable for an artificial wallow.	Allowance for natural behaviour may decrease stress (unquantified).	McDowell (2008b; 2009)
Multiple	Deer	Preventing fence-line pacing	This strategy is specifically for red deer who have a tendency to pace and erode fence-lines when stressed, for example, when feed is low or near calving. The strategy involves a combination of tree planting to provide shelter and maintaining sufficient feed.	AgResearch	Low [P]; Low [SS]	High [P]; Low [SS]	Planting, maintenance and effect of tree planting is subject to climatic influences (primarily wind direction).	Supplying sufficient feed to avoid animal stress is dependant on skill of farm manager.	Trees decrease stress and may have anthelmintic properties (if grazed).	McDowell et al. (2004; 2006)
Nitrogen	All farming enterprises	Denitrification beds	Many poorly drained soils used for farming are drained to decrease flooding and saturation of soils. Leaching water can be rapidly transported to subsurface drains and directly discharged into surface waterways. Denitrification beds are large containers filled with woodchips that intercept drain flow before discharge to surface waters. The wood chips support conversion of nitrate in water to nitrogen gas which is released to the atmosphere.	University of Waikato, Landcare Research, NIWA, GNS Science; Aqualinc	Very high	Very high	High cost when bioreactor was underloaded. True value much more likely to be at lower end when systems properly designed	Appropriate hydrology needed - tile/sub-surface drained land or small surface drains.	Might be integrated to support dissolved P removal	Barkle et al. (2008); Christianson et al. (2012); Schipper, et al (2004; 2010)

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Nitrogen	Irrigated land	Precision agriculture	Good design, including the use of novel sensors and automation of crop production, will optimise water and nutrient application according to local crop requirements. Sensors and information usage lead to individual animal based and optimised herd management. By accounting for site specific growth conditions, water demand and emission risks, precision agriculture can improve local production potentials and increase nitrogen use efficiency.	Lincoln Agritech, Landcare Research	High	Low	Varying effects in decreasing nitrate leaching: (i) differences in soil heterogeneity (leaching risks, denitrification capacity, soil fertility) and crop responses to adapted production intensity (variable rates), (ii) weather conditions, (iii) irrigation design practices and skills and (iv) management practices and skills. Varying effects in economic performance: (i) weather conditions, (ii) irrigation design practices and skills and (iii) management practices and skills of farmers.	Insufficient communication and training on benefits.	Improved farm and herd management; improved crop reliability and quality; conservation of water and better labour and management productivity.	Dalgardo and Bausch (2005); Claret et al. (2011); Reiche et al. (2002)
Nitrogen	All pastoral farming enterprises	Change animal type	Animal type influences N leaching due to inherent differences in the spread of urinary N (the major source of N loss in grazed pastures). Increased urinary spread results in a lower rate of N deposited in urine, greater utilisation by plants and less surplus N that contributes to N losses. Research has shown that N leaching from sheep and deer is approximately half that from beef cows at the same level of feed intake. Potentially differences also exist between male and female cattle (losses from male cattle being about two-thirds that of female cattle although there is high uncertainty with this). Similarly, young cattle are assumed to have greater urinary N spread than larger older cattle due to greater animal numbers per unit of feed consumed and greater number of urinations, although again there is limited data on this aspect	AgResearch	High	Medium	Highly variable over time due to changes in relative prices between cattle and sheep meat. As an example, farm profitability from finishing steers or bulls (male cattle) can be at least as great as from female cattle. Indeed, cattle breeding systems are generally less profitable than systems based on purchasing weaned animals and finishing them for meat processing	Changing relative prices between animal types over time; possibly a need for a mix of animals on a farm; and better farm management skills and farm infrastructure (e.g. extent of fencing).	This may also lead to decreased nitrous oxide and greenhouse gas emissions. However, with a change to deer it may (unquantified) lead to greater sediment and P loss.	Betteridge et al. (2005); Hoogendoorn et al. (2011); Williams and Haynes (1994)
Nitrogen	All pastoral farming enterprises	Diuretic supplementation or N modifier	Diuretics such as common salt generally result in increased water consumption by animals with an associated increase in the spread of urinary N by the animals. Potentially, other modifier materials can also either increase N utilisation by animals (e.g. monensin) thereby decreasing the amount of N excreted or decrease the amount of N excreted in urine relative to dung (e.g. tannin-containing materials). However, field proof of effectiveness of the latter materials is limited and some studies suggest animals may adapt to them leading to decreased effectiveness with time (e.g. with monensin). Research on the plot-scale effectiveness of salt as a diuretic is clear with benefits of up to 50% increase in spread of N from its use, although evidence for a decrease in N loss at a field-scale is limited.	AgResearch	Low	Low	Potential adaptation by the animal to supplementation or N-modifier leading to less efficacy of the strategy with time.	Salt is more appropriate in well-structured soils for long-term use since excess sodium in soil can potentially lead to soil structure degradation. Time requirements for supplementation and uncertainty of effects on animal health also limit its use. Not yet in models like Overseer due to limited data.	May also lead to decreased nitrous oxide and greenhouse gas emissions	Ledgard et al. (2007)

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Nitrogen	All pastoral farming enterprises	Improved N use efficiency	Greater N use efficiency can be achieved by: increasing per animal production with a commensurate decrease in animal stocking rate (replacement rates particularly) to maintain per hectare production and profitability; using less fertiliser N and some, if prices allow, low N feeds; and maximising the N value of farm dairy effluent by applying it to a greater proportion of the farm	AgResearch, Massey University, DairyNZ	Medium	Medium	The ability to decrease N losses to water depends on (i) the existing level of farm intensity and N loss, and (ii) the management expertise to implement required changes in farm practices. As a comparative example, very low input/intensity farms have little scope for decreasing inputs and N losses still further, in contrast to high input farms where less N fertilization is technically quite possible. Farms that are already very expertly managed will also have little scope to further modify farming practices to decrease N losses	Greater management expertise is required to maximise the amount of harvested feed under a low input farming system, while an increase in per cow production (to allow a decrease in stocking rate) will take time as improved genetics is introduced into herds	Decrease emissions of greenhouse gases and an improvement in energy use	Aarts et al. (2000); Beukes et al. (2011); Cardenas et al. (2011); Gourley et al. (2012a); Gourley et al. (2012b); Oenema et al. (2012)
Nitrogen	All pastoral farming enterprises	Nitrification inhibitors (Dicyandiamide, DCD)	N excreted by animals and in particular urine, is the most important determinant of N loss in stocked systems. Urinary-N deposited onto the soil is rapidly mineralised to ammonium-N and transformed by soil bacteria into nitrate. If not taken up by plants, nitrate is vulnerable to be leached. Rates of N deposition in the urine patch range from 400 up to 1000 kg N ha^{-1} (dairy cattle), which far exceeds pasture requirements, and thus leaving surplus nitrate in the soil. DCD slows the oxidation of ammonium (which is sorbed onto soil and less mobile) to nitrate, thereby decreasing the risk of leaching losses when drainage occurs and providing more time for plant uptake of ammonium.	Lincoln University, Massey University, AgResearch, Ballance Agri-Nutrients, Ravensdown	Medium	Medium	The efficacy of DCD depends on how long after the urination event the DCD is applied and once applied, the effectiveness depends on soil type, temperature and moisture.	Currently not permitted for use in dairy systems and there is a lack of proof of efficacy at a farm scale.	DCD decreases the emission of the greenhouse gas nitrous oxide by 40 to 80%	de Klein et al. (2011); Di and Cameron (2007); Gillingham et al. (2012); Houlbrooke and McDowell (2008); Kelliher et al. (2008); Monaghan et al. (2009); Smith et al. (2005)
Nitrogen	All pastoral farming enterprises	Supplementary feeding with low-N feeds	Pastures contain more N than is required by grazing animals and excess N is excreted predominantly in urine which is prone to N losses. Supplementary feeding with low-N feeds such as maize silage can increase animal productivity with little effect on the amount of N excreted in urine and lost by leaching. For example, studies with dairy cows have shown maize silage supplementation to increase milk production by one-third had little effect on the amount of N leached per hectare. Thus, it can increase N efficiency i.e. animal production per kg N leached. However, it is important to account for effects in the areas used to produce the low-N feed and when this is done there may only be small whole-system benefits unless N-efficient practices are used to grow the low-N feed crop. Potentially, this will be most beneficial where the low-N feed is a waste by-product from another sector (e.g. vegetable or fruit waste).	AgResearch, DairyNZ	Low	Low	Highly variable depending on source and price of feed and the efficiency with which it is fed to animals (with critical importance of the need to avoid substitution by the low-N feed for consumption of existing pasture). Thus, it is highly dependent on farmer management skills. On dairy farms in years of high milk payment, it can result in increased farm profitability.	Lack of facilities for feeding out supplementary feed and costs of introducing them; increased workload; requirement for increased skills in feed utilisation; and increased risk, depending on milk payout and feed prices	May also lead to reduced nitrous oxide per unit of productivity but this can be more than countered by increased carbon dioxide production in the production and feeding of the low-N feed sources.	Jensen et al. (2005); Ledgard et al. (2006); Williams et al. (2007)
Phosphorus	All farming enterprises	Low water soluble P fertiliser	Low water solubility P fertilisers decrease P loss by maintaining a smaller pool of soluble P in soil solution soon after application than highly water soluble P fertilisers (e.g. superphosphate), thereby minimising the potential for loss should runoff occur. Among P fertilisers, reactive phosphate rock (RPR) has little water soluble P; has been shown to decrease dissolved P losses by about a third from field plots grazed by dairy cattle and in a 12 ha catchment grazed by sheep in New Zealand. However, reactive phosphate rock should not be used where annual rainfall is < 800 mm and soil pH is > 6, RPR and requires a lead-in time meaning that a third of the applied P becomes available per annum such that it a field with RPR applied will have the same P fertility as a field with superphosphate applied after 3 years.	AgResearch	Medium	Low	Gain compared to highly water soluble P fertiliser is dependent on time of year that fertiliser is applied. Larger gains are evident where the coincidence of surface runoff soon after application is frequent.	Soil pH < 6.0, rainfall > 800 mm. Also cannot be used for capital applications and must gradually replace maintenance highly-water soluble P applications at a rate of one-third per annum (i.e. 100% low water soluble P in year 3)	Has a slight liming effect.	McDowell et al. (2010); McDowell and Smith (2012); Sharpley and Syers (1979)

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Phosphorus	All farming enterprises	Optimum soil test P concentration	The magnitude of P losses from soil via surface runoff or subsurface flow is generally proportional to soil P concentration, so maintaining a soil test P concentration in excess of the optimum for pasture production represents an unnecessary source of P loss. Achieving an Optimal soil test P concentration (e.g. Olsen P) can be done with nutrient budgeting software such as Overseer. The magnitude for P loss mitigation is dependent on how excessive Olsen P is, but if in-excess will always represent a profitable strategy.	AgResearch	Low	Low	Gain is dependent on soils being enriched beyond their optimum	None	None	Nash et al. (2007); McDowell et al. (2003); Gillingham and Gray (2006)
Phosphorus	All farming enterprises	Sorbents in and near streams	Management practices to decrease P in stream flow are limited. Techniques applicable to lakes, such as dosing with modified bentonite clays (e.g., Phoslock®) to sorb P, may not be applicable to streams as they rely on P attached to the adjuvant remaining on the stream bed, or for the material to cap the bed and block P dissolution from sediment. This may not occur as materials can be lost downstream during high flow events and the input and deposition of new P-rich sediment frequently negates the cap's effectiveness. An alternative strategy has been to encase P-sorbing material in a mesh. These "P socks" can decrease DRP and TP concentrations on average 35 and 21%, respectively. However, they are restricted to low flows. Near stream areas, and areas connected to the stream, are important sources of P loss to most waterways which can be decreased by the addition of P-sorbents. Areas include gateways, lanes, and around barns and troughs. One example saw P-rich runoff from a stream crossing where daily traffic by cows to-and-from the milking parlour reached a stream, accounting for 90% of the catchment P load. Installing a P-sorbent on the side of the lane decreased catchment P losses by c. 80%.	AgResearch	High	Very high	Materials may contain different quantities of sorbing materials (e.g. Al, Fe and Ca). The particle size of the material needs to maintain good stream flow but also good interaction with material	Source may be far away and the cost of transport prohibitive. Installation in stream may require resource consent	None	McDowell (2007b); McDowell et al. (2007)
Phosphorus	All farming enterprises with drained land	Tile drain amendments	By-product materials rich in P-sorptive Ca, Al and Fe have been identified as decreasing P loss from soils with varied success. These include, but are not limited to: zeolites, aluminium sulphate, water treatment residuals, and fluidized bed bottom-ash and fly ash from coal fired power plants. Selection criteria include: (1) cost of the material - does it need to be mined or is there a readily available and cheap source? (2) toxicity to the environment - does it contain heavy metals or is the material caustic?, and (3) the efficacy of sequestering P. A mixture of steel melter slag (90%) and basic slag has shown some promise at sequestering P when installed as a backfill above and around a tile drain. Similar work showed that volcanic tephra as a fill for mole channels could also decrease P loss.	AgResearch, Massey University	Very high	Medium	Materials may contain different quantities of sorbing materials (e.g. Al, Fe and Ca). The particle size of the material needs to maintain good flow but also good interaction with material	Source may be far away and the cost of transport prohibitive	Potential to decrease (via filtration) the loss of sediment and faecal bacteria (both unquantified).	Hanly et al. (2008); McDowell et al. (2008)
Phosphorus	Critical source areas in all pastoral farming enterprises	Applying alum to forage cropland	Aluminium sulphate (alum) has been used around the world to flocculate P from water columns, and in the US to decrease the water solubility of P in manures applied to land (Smith et al., 2001) and thus decrease P loss in runoff from grassland plots and catchments. Additional work in New Zealand has shown alum can decrease P losses in surface runoff when applied after animals have grazed a winter forage crop.	AgResearch	Medium	High	Alum may be ineffective in high rainfall environments where it may be washed from the soil and does not affect particulate phosphorus (the dominant form lost from cropland)	Few supplies and competing use as a water treatment additive	None	McDowell and Houlbrooke (2009)
Phosphorus	Critical source areas in all pastoral farming enterprises	Applying alum to pasture	Aluminium sulphate (alum) has been used around the world to flocculate P from water columns, and in the US to decrease the water solubility of P in manures applied to land (Smith et al., 2001) and thus decrease P loss in runoff from grassland plots and catchments. It does not impair pasture growth and ingestion at rates of 10-40 kg Al $ha^{-1} yr^{-1}$ are unlikely to impair animal performance. Alum works by binding P in the topsoil, making it insoluble in water and therefore less available for loss in surface runoff.	AgResearch	Low	Very high	Alum may be ineffective in high rainfall environments where it may be washed from the soil	Few supplies and competing use as a water treatment additive	None	McDowell (2010)

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Phosphorus	Critical source areas in all pastoral farming enterprises	Red mud (bauxite) to land	Red mud is a by-product of refining bauxite into alumina. It is alkaline (pH 10-13) and contains up to 60% Fe oxide along with lesser amounts of Al, Si and Ca – all of which bind P into water insoluble forms. In Western Australia, red mud is sold as a soil amendment under the name Alkaloam® to increase soil pH and prevent P loss via leaching from sandy soils. There are some concerns over toxicity, largely centred on the presence of heavy metals or radionuclides, but the concentrations, when applied at the recommended rate of up to 20 Mg ha^{-1}, are small and unlikely to be detrimental to livestock. However, any product with a high pH should employ a stand down period of at least 2 weeks before stock can graze pastures otherwise rumen pH could increase adversely affecting the digestion of feed.	University of Western Australia; AgResearch	Very high	Medium	Increases soil pH which may increase P solubility if outside pH range 5.5-5.9.	Few suppliers. If used for liming effect, grazing animals need to avoid treated area otherwise ingestion may impair rumen function.	Alkaline and hence can be used instead of lime.	Summers (2001); Summers et al. (1996; 2002); Vlahos et al. (1989)
Phosphorus	Flood irrigated land	Refurbishing and widening flood irrigation bays	Water exiting flood irrigation bays represents about 20-50% of that applied and carries with it significant quantities of P and other water quality contaminants. Better matching irrigation to soil infiltration rates, re-contouring irrigation bays, and/or preventing outwash/wipe-off from accessing the stream network can decrease P loss.	AgResearch; Aqualinc	Very high	High	Inaccurate level resulting in flow (and outwash) faster than anticipated. Variation in the water supply rates.	A move to spray irrigation is likely to be more cost-effective.	More efficient use of flood irrigation water.	Houlbrooke et al. (2008a); Strong (2001)
Phosphorus	Irrigated land	Dams and water recycling	The use of recycling systems to divert outwash for use in another part of the farm increases nutrient efficiency and, since no water leaves the farm, significantly decreases the load of P lost by a farm.	AgResearch	Very high	Medium	Leakage from infrastructure	Only viable if delivery of irrigation is sporadic/irregular. A move to spray irrigation is likely to be more cost-effective.	More efficient use of flood irrigation water and entrained nutrients (unquantified).	Barlow et al. (2005); Houlbrooke et al. (2008b)
Sediment	All pastoral farming enterprises	Soil conservation farm plan	Combination of retirement and pole planting on highly erodible land. Suitable for pastoral farms which contain some highly erodible hill country. Introduction of tree roots to soil regolith protects soil on steep slopes from mass movement erosion.	AgResearch, Landcare Research, Plant and Food Research	High	High	Depends on severity of erosion	No factors limiting uptake	Decreased P inputs to waterways (unquantified). Increased sustainability of pastoral farming. Increased carbon sequestration. Improved shelter for animals.	Hicks DL (1995). Dymond et al. (2010). Thompson and Luckman (1993).
Sediment	Cropping	Benched headlands	Constructed level bench that runs across the slope of a field. Suitable for use on cultivated soil where slopes are greater than 3 degrees. These encourage infiltration of water on the bench and reduce the slope length of water pathways.	HortNZ	Low	Medium	Depends on infiltration capacity of soil	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Bunds	Earthen barrier constructed along paddock edge to prevent water flowing onto or from field. Suitable for use on cropping land with slope greater than 3 degrees. Creates ponds of water at bottom of field where sediment settles out. Sediment in cropping may be collected and redistributed to the upper land slope areas. Bunds, in concert with riparian strips will further increase effectiveness.	HortNZ	Very high	High	Depends on infiltration capacity of soil	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Contour cultivation	Cultivation along contours of cropping land with slopes greater than 3 degrees. This will reduce the speed of runoff water and thereby reduce the eroding power.	HortNZ	Very high	Low	Depends on infiltration capacity of soil and slope angle	Education	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Contour drains	Temporary drains that run across the slope of a field and into a permanent drain on the side of the field. Suitable for use on cultivated soil where slopes are greater than 3 degrees. These reduce the slope length of water pathways and thereby reduce the eroding power.	HortNZ	Medium	Low	Depends on density of drains	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).

Target	Range of applications	Strategy	Description of function	Lead research agency	Effective-ness	Relative cost[1]	Reasons for variability	Factors limiting uptake	Co-benefits	References
Sediment	Cropping	Cover crop	Green manure or cover crop which is grown to be ploughed into the soil rather than harvested. Suitable for use on cropping land after harvesting of main crop and sowing of new crop. The cover stabilises bare soil from erosion and improves water penetration and drainage.	HortNZ	Very high	High	Depends on soil structure	Willingness of manager to forgo short term gain for long term gain	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Erosion management plan	General erosion management plan for minimising soil erosion on cropping land according to HortNZ code of practice. Includes design and implementation of specific mitigation measures below.	HortNZ	Very high	High	Depends on the plan design	No regulation	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010).
Sediment	Cropping	Minimum tillage	Range of techniques from direct drilling of seed into stubble or pasture, through reduced number of cultivation passes, to more judicious use of conventional ploughs and harrows. Suitable for use on cropping land. Reduces the proportion of time that land is bare during the growing cycle.	HortNZ; Plant and Food Research	Medium	Low	Depends on the amount of time land is bare	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Silt fence	Material fastened to a wire fence for filtering out sediment from overland flow. Usually a temporary measure used in cultivated growing situations.	HortNZ	Very high	Very high	Variability of material and contracting costs	High cost	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Stubble mulching	Stubble is mulched and left on field if there is direct-drilling the following season. Suitable for continuous cropping. Partial ground cover protects soil from erosion and also reduces the transport of eroded soil in overland flow.	HortNZ	Medium	High	Depends on the amount of partial ground cover	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Wheel track dyking	Series of closely-spaced indentations in wheel tracks created by tillage machinery. Suitable for use on cropping land after the use of heavy vehicles on cultivated soil. Slows surface runoff water down and settles suspended sediment.	HortNZ	Medium	Medium	Depends on the proportion of runoff coming from compacted soil	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Wheel track ripping	Ripping of wheel tracks is suitable for use on cropping land after the use of heavy vehicles on cultivated soil. Ripping allows water to percolate into the soil rather than flow down the tracks.	HortNZ	Medium	High	Depends on the proportion of runoff coming from compacted soil	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	HortNZ (2010). Dymond (2010). Basher and Ross (2002). Basher et al. (1997). Hicks DL (1995).
Sediment	Cropping	Wind break crop	Tall crop in paddock providing shelter for neighbouring cultivated paddock from prevailing wind. Suitable for use in cropping land where wind erosion is a problem. Slows wind speed down at the soil surface and thereby reduces erosive power of the wind.	HortNZ	Low	Medium	Depends on value of wind break crop	Management expertise	Increased sustainability of cropping. Decreased P input (unquantified) to waterways.	Basher and Painter (1997).

[1] Relative cost breakdowns for each quarter were (low, medium, high, and very high): N (<6.5, 6.5-40, 41-130 and 131-393 $/kg N retained/yr); P (<41, 41-108, 109-245 and 246-360 $/kg P retained/yr); Sediment (<30, 30-75, 76-150 and 151-790 $/kg sediment retained/yr).

Table 5. Information applicable to the application of lake-scale technologies (strategies) to mitigate the effects of water quality contaminants to lakes.

Target	Strategy	Description of function	Lead research agency	Effectiveness	Relative cost	Reasons for variability	Factors limiting uptake	Co-benefits	References
Multiple	Inflow diversion	Diverts nutrient–rich lake inflows downstream.	University of Waikato, NIWA	Ohau Channel inflow to Lake Rotoiti diverted towards Okere Falls outflow in Lake Rotoiti. TLI reduced from 4.45 (2003-2006) to 3.79 in (2008-2011). Sandy Creek diverted to reduce catchment area of Lake Tutira (Hawke's Bay) from 2719 to 844 ha. No evidence of improvement. Consideration given to Hamurana Stream inflow to Lake Rotorua at cost c. $12M.	Ohau Channel wall cost c. $10 million.	Dependent on the relative contribution of inflow to external loads and proximity to outflow. Success varies from apparently highly successful for a large inflow into Lake Rotoiti to moderately or marginally successful for smaller inflows or partial diversions.	Potentially very expensive and may be detract from landscape values.	–	Scholes and McIntosh (2010); Jacoby et al. (1999); Robertson et al. (2000).
Multiple	Hypolimnetic siphoning	Removes poor-quality (e.g. anoxic) water at the bottom of stratified lakes	–	Not used in NZ, but has been used in c. 50 lakes in Europe and N. America where it has proven to be an "effective low-cost restoration technique".	A proposed hypolimnetic discharge from Lake Okareka (BOP) was estimated to remove 21 kg P/ha/yr at a cost of c. $700,000 including construction of a wetland for treatment.	Preferential removal of cool bottom waters can lead to lake warming, increased O_2 consumption and reduce water column stability.	Only suitable for deep, seasonally stratified lakes where there is not a sensitive downstream water body.	–	McIntosh (2004); Nürnberg (2007)
Multiple	Dredging	Removes nutrients and sediments from a lake bed.	University of Waikato	Has not been used at large scale in NZ, but recently carried out in Oranga Lake, University of Waikato campus	Estimated costs vary from $1.6 –352 million for Lake Rotorua (8 050 ha) and $1 million for Lake Okaro (30 ha). Recent application to Lake Oranga (0.69 ha) was $0.1 million.	Multiple: depth of dredging, composition of underlying sediments that are then exposed, evenness of removal across lake; extent of disturbance and resuspension as well as disruption of benthic biota.	Disposal of spoil, disturbance of benthic fauna (invertebrates), potential release of contaminants from sediments.	In some cases spoil may be useful as a soil conditioner.	Klapper (2003) ; Faithfull et al. (2006); Miller (2006)
Multiple	Increased flushing rate	Create sufficient through-flow to physical remove phytoplankton before substantial response to prevailing nutrient concentrations	–	Flushing occurs naturally in many hydro lakes (e.g. along the Waikato River) at rates sufficient to curtail phytoplankton biomass potential, but otherwise few opportunities presented in NZ for this to be effective.	–	Flushing rate has to be reduced to c. 20 days to exert substantial control on phytoplankton biomass. Diverted inflows may otherwise act to enhance phytoplankton biomass due to additional nutrient load.	Few situations where sufficient flushing from inflow diversion is possible.	Could divert nutrient load away from system that was sensitive to this inflow.	Hickey and Gibbs (2009); Howard-Williams (1987)
Nitrogen and phosphorus	Weed harvesting	Removes nutrients assimilated in excess weed growth.	NIWA	Used for nutrient control in Lake Rotoehu, Bay of Plenty.	Hornwort harvesting in Lake Rotoehu (790 ha): $52,800/yr.; estimated at $22/kg N and $165/kg P removal cost.	–	Only suitable where invasive weeds are a problem.	Non-indigenous plant removal. Composting is possible where heavy metals not accumulated in plants (e.g. Waikato River plants not suitable for composting due to heavy metal accumulation).	Bay of Plenty Regional Council, Rotorua District Council, Te Arawa Lakes Trust (2007)
Phosphorus (and nitrogen secondarily)	Sediment capping	Provide a capping layer – either inactive (e.g. sand) or active (e.g. Aqual-P, allophane or zeolite) to decrease nutrient releases from lake bed sediments.	NIWA, University of Waikato	Aqual-P has been used both as a flocculant and to provide an active phosphorus cap on the lake bed.	Cost of Aqual-P is c. $2000 per tonne. Used in Lake Okaro (approximately 100 tonnes over lake area 31 ha).	Other naturally occurring minerals (e.g. zeolite, allophane) are potentially less expensive, but may release bound P under anoxic conditions.	Capping layer may be rapidly buried if catchment sediment load is high. Iwi are generally averse to introduction of foreign minerals into waterbodies.	Some capping materials may induce a partial flocculation of water column nutrients during application process.	Hickey and Gibbs (2009); Özkundakci et al. (2010); see special section of Hydrobiologia: Hamilton &Landman (2010).

Target	Strategy	Description of function	Lead research agency	Effectiveness	Relative cost	Reasons for variability	Factors limiting uptake	Co-benefits	References
Phosphorus and sediment	Wave barriers	Reduce resuspension of sediments and nutrients in shallow lakes through a physical barrier to reduce surface wave propagation.	NIWA	No known application in NZ. Has been used in Lake Tai (Taihu) in China to reduce sediment resuspension around water treatment plant intakes, with moderate success.	Being considered in Lake Ellesmere to re-establish macrophyte beds (in conjunction with exclosures to prevent swan grazing).	Insufficient information to assess variability. Could potentially create quiescent conditions with higher clarity that may favour blue-green algae blooms.	Applicable to shallow lakes	Water clarity improvements.	Jellyman et al. (2009).
Nitrogen	Floating wetlands	Use wetland plants to take up nutrients, wetland environment to remove N via denitrification.	NIWA	Effectiveness likely to be marginal based on areal uptake rates, especially in a non-flow-through environment such as a stream. Floating wetlands have been established in lakes Rotoehu, Rotorua and Rotoiti.	Approximately $1M in Lake Rotorua (0.4 ha) with only a very small amount of nutrient removed.	Difficult to measure effectiveness of nutrient uptake in lake environment; harvesting of plants for nutrient removal not actively carried out.	Could potentially detract from open-water vista.	Iwi enthusiastic about floating wetlands to enhance habitat for mahinga kai species.	Tanner et al. (2005).
Phosphorus	Oxygenation or destratification or mixing propellers.	Air/O_2 pumped to the bottom of lakes can decrease redox-mediated nutrient releases, particularly PO_4-P which is released under chemically reducing conditions.	University of Waikato, NIWA	Oxygenation is not used in NZ. Destratification with 'air cannons' was first trialled – largely unsuccessfully – in Lake Tutira, Hawkes Bay (1972). Mangatangi Reservoir supplying Auckland city has used destratification successfully to maintain water column mixing and avoid deoxygenation of bottom waters. Destratification recently (2012) implemented for Lake Rotoehu, Bay of Plenty.	Destratification trial in lake Rotoehu (790 ha): $524 000. Overseas, costs for oxygenation of moderate to large lakes estimated at US $ 1M set-up and operational cost of $30% of set-up cost per year (Beutel 2002).	Systems may be under-designed (with respect to air flows) or poorly designed (with respect to bubble plume dynamics).	Systems are generally expensive and may require maintenance (e.g. to prevent blockages from weeds) or blockages of air nozzles.	Can be well received by iwi due to non-use of chemicals.	Hickey and Gibbs (2009); Howard-Williams (1987); Beutel (2002); Beutel & Horne (1999); Antenucci et al. (2005).
Phosphorus	Phosphorus inactivation or flocculation	Chemicals like alum (aluminium sulphate) can 'lock up' dissolved phosphorus in lakes via adsorption and precipitation processes.	NIWA, University of Waikato, Scion	Under evaluation in selected Rotorua lakes, NZ. Has included materials such as alum, Phoslock® and Aqual-P. Alum, and Phoslock® to a lesser extent, have been highly effective in P removal and eutrophication control overseas. TLI in Lake Rotorua was 4.57 (2006-8) and 4.4 (2010-12) following continuous alum application (stream inflows). TLI in Lake Okaro was 5.6 (2002-4) and 5.1 (2010-12) following successive applications of alum and Aqual-P. TLI in Lake Rotoehu was 4.57 (2006-8) and 4.3 (2010-12) following continuous alum application (stream inflow).	Lake Okaro (30 ha) modified zeolite application c. $75,000/yrover 3 years. Alum dosing to two stream inflows in Lake Rotorua (8,050 ha) costs c. $1M/yr	Varying products, dose rates and application methods have been used; e.g. on-off lake aerial application vs. continuous inflow dosing. Buffering to reduce pH variation and optimise effectiveness has been used to varying extents and will be highly dependent on hardness of lake water.	Alum applications have occasionally resulted in catastrophic fish kills through low pH when applications are improperly buffered. Some eco-toxicological concerns about Phoslock® due to subsequent release of P-binding agent lanthanum. Aqual-P has shown little or no adverse eco-toxicological impact but efficacy for P removal is low. Maori/iwi are averse to foreign chemical introduction. May not be suitable for softwater lakes.	Primarily effective for removing PO_4-P from solution but some modified clays (e.g. Aqual-P) with similar function may also remove NH_4-N. Coagulants such as alum also remove fine sediments from the water column via flocculation.	Pilgrim & Brezonik (2005); Paul et al. (2009); Özkundakci et al. (2010); Scholes and McIntosh (2010); Hickey and Gibbs (2009); see special section of Hydrobiologia: Hamilton and Landman (2010).

5. Matrix summaries of farm-scale mitigation strategies

A visual assessment of strategies to mitigate N, P and sediment (but not *E. coli*) can be made by reference to Figures 3 to 5. However, it is important to realise that the data for each strategy are unlikely to capture the full range of cost or effectiveness due to site specific variations in climate, topography, soil type, etc. Hence, a better comparison is given with references to the relative cost and effectiveness columns listed in Tables 4 and 5. A qualitative assessment has also been published by the Waikato Regional Council (see: http://www.waikatoregion.govt.nz/menus).

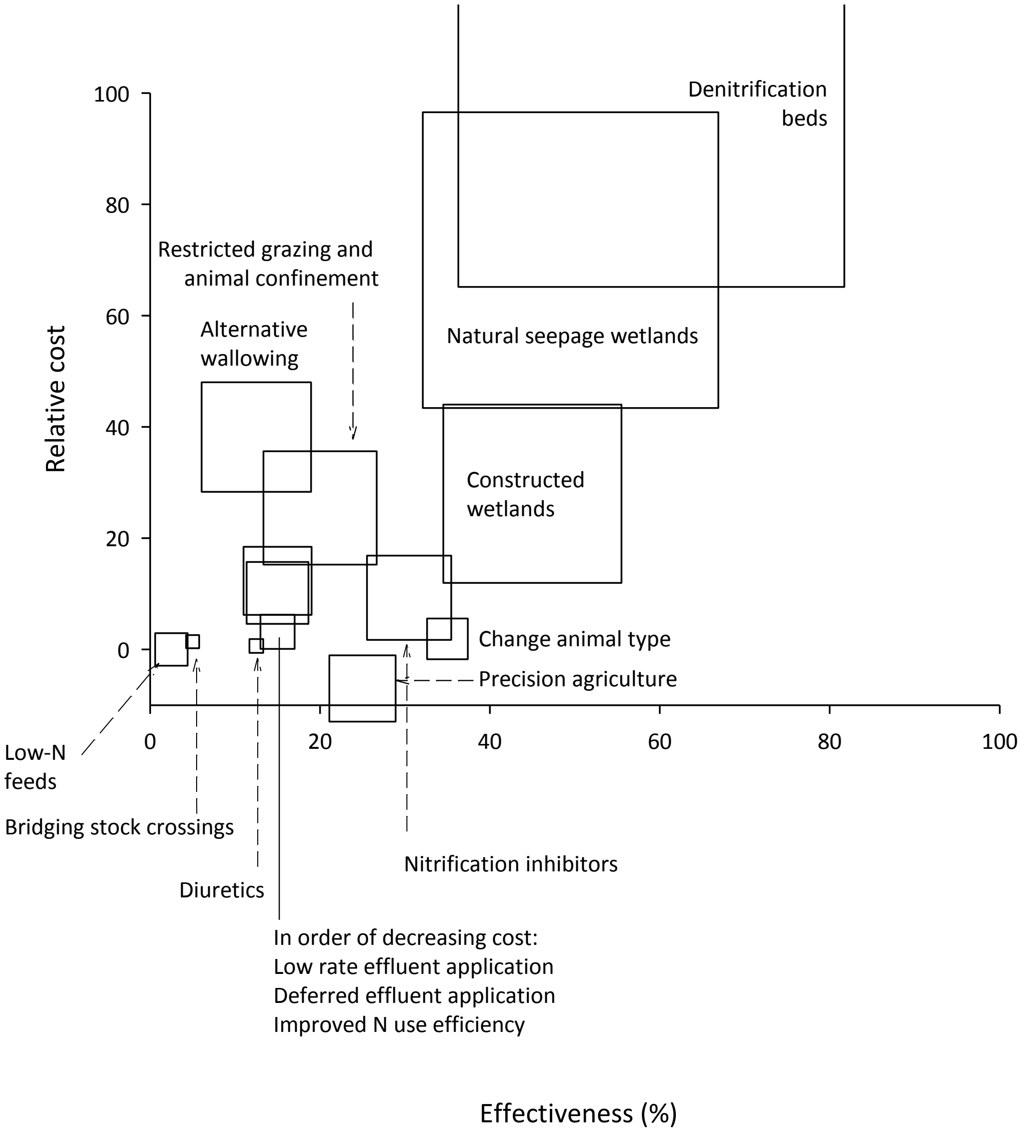

Figure 3. Diagram of the relative cost and effectiveness of strategies to mitigate **nitrogen** losses to water at the farm-scale. Cost is shown as the cost per kg of N mitigated relative to the most expensive strategy - denitrification beds at $393 per kg N retained/ha/yr. The centre of the squares represents the mid-point in the range for each strategy, while the size represents the relative variability of each strategy as the square root of the product of the range in percent cost by effectiveness.

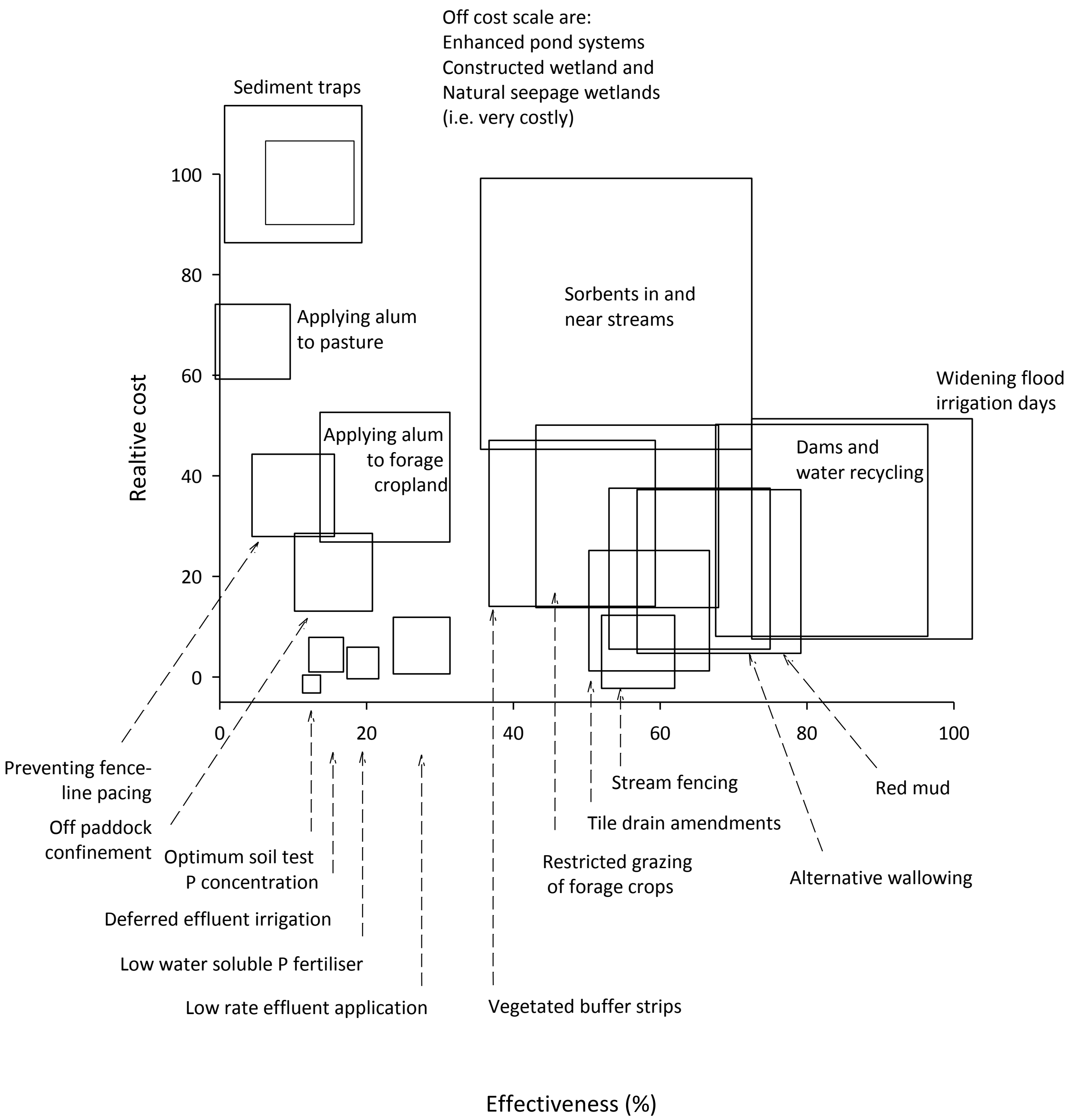

Figure 4. Diagram of the cost and effectiveness of strategies to mitigate **phosphorus** losses to water at the farm-scale. Cost is shown as the cost per kg of P mitigated relative to the most expensive strategy - sediment traps at $360 per kg P retained/ha/yr. The centre of the squares represents the mid-point in the range for each strategy, while the size represents the relative variability of cost-effectiveness for each strategy as the product of the range in percent effectiveness by the range in cost. Enhanced pond systems and the two wetland type were considerably more expensive (1400 – 4000% > sediment traps)

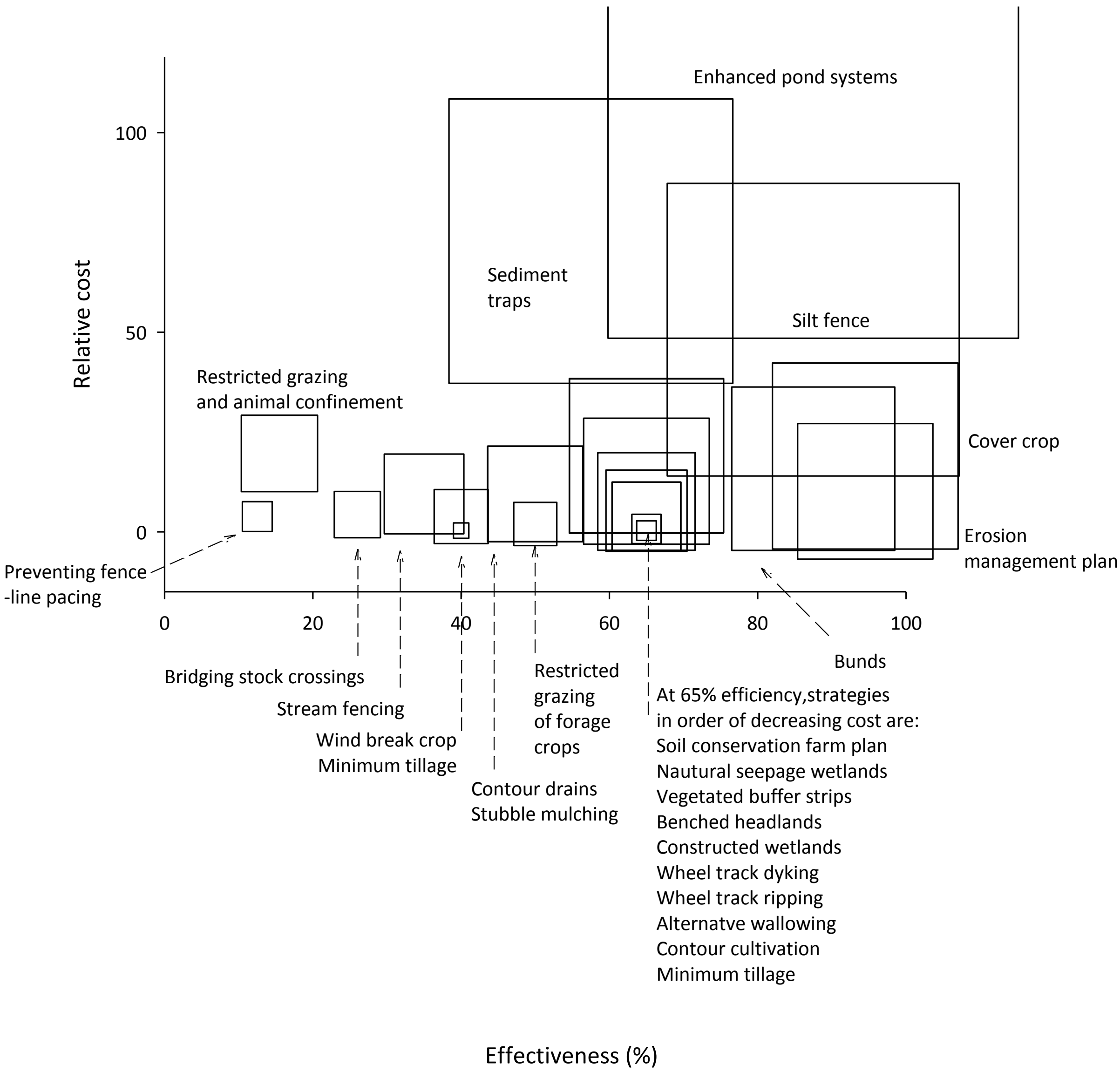

Figure 5. Diagram of the cost and effectiveness of strategies to mitigate **sediment** losses to water at the farm-scale. Cost is shown as the cost per kg of sediment mitigated relative to the most expensive strategy - enhanced pond systems at $790 per kg sediment retained/ha/yr. The centre of the squares represents the mid-point in the range for each strategy, while the size represents the relative variability of cost-effectiveness for each strategy as the product of the range in percent effectiveness by the range in cost.

6. Conclusions and take home messages

A number of caveats apply to the selection, use and ability of mitigation strategies to achieve good water quality outcomes.

1. Although each strategy has a range in price and effectiveness, both may be significantly improved if placed in the right place and at the right time. Each strategy will be different in this regard. However, McDowell et al. (2012) found that in two catchments in Otago the application of strategies to mitigate P losses when applied to critical source areas (viz. areas that account for the majority of contaminant loss, but account for a minority of the area) was 6-7 times more cost-effective than applying the strategies across entire paddocks. Other examples include the consideration of soil type and the capacity of groundwater to assimilate N when putting in new irrigation schemes, or the location of winter forage crops on drier parts of the farm where there is less runoff.
2. There is a wide range of strategies available. Strategies should be chosen according to the contaminant of concern and water quality objective. We suggest that cost effectiveness (also called price efficiency index) is an unbiased metric to do this. However, the selection of multiple strategies that are cost-effective may not be the most optimal mix to meet a water quality objective that is required quickly, in which case decisions may be based on effectiveness alone.
3. The range of strategies presented also allows the user to mix and match the best mix for their property. However, it is also important that the co-benefits be considered as some target multiple contaminants, or could conceivably be antagonistic to one another. For example, the use of alkaline P-sorbing materials in an acid soil could end up releasing more P despite less fertiliser being applied to decrease Olsen P.
4. Using multiple strategies in one location will be less effective due to the diminishing quantity of contaminant to mitigate, than the use of multiple mitigations along the transport pathway. However, in general, it is more cost-effective to mitigate the loss of contaminants at the source than farther down the catchment (Turner et al. 1999).
5. It is unlikely that there will be one strategy that can meet a water quality objective, i.e. there is “no silver bullet”.
6. Even when optimally placed and timed, the use of mitigation strategies may not meet a water quality objective for several reasons:
   a. Natural factors such as catchment characteristics (soil type, climate etc) mean their will always be a water quality issue;

   b. The costs or time involved at the enterprise level in using the number of strategies required to meet a community water quality objective are too great;
   c. There is a lack of motivation or poor skill base by land users to enact mitigation strategies at the source of contaminants, or a lack of community understanding of the processes and timeframes involved in seeing a response in a waterbody.
7. New science (and mitigation strategies) needs to continue to inform the community and land users at the catchment scale to achieve good water quality outcomes.

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Aqualinc Research:	John Bright
Dairy New Zealand:	Mike Scarsbrook

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“IFM2”

Farm 1

1. The current farmers are 5th generation, with an exceptionally high level of management and production standards, taking over from their father in 1973. The family takes pride in the crops and stock that are produced from the farm. The family is also involved in looking after community facilities, some local sports, local scouts and any other community projects that need help.

2. Farm 1 was originally two adjacent dairy farms. The dairy farms were de-converted between 1973 and 1999 and have since been used as a productive beef and lamb finishing and maize silage cropping operation with maize production.

3. The farm business employs three families, returning an EBITDA (earnings before interest, tax, depreciation and amortisation) of $2,500 per hectare. Current land value is estimated at $50,000 per ha.

4. Farm 1 has peat soils and is located near Gordonton, in the Lower Waikato catchment and straddles the Priority 1 Mangarawa and Priority 2 Komakorau sub-catchments. Farm 1 is 446 ha with 405 ha effective drystock farm carrying an average of 5,000 stock units (8 per ha), in a cell system. Maize silage is rotationally cropped over 200 ha annually, producing approximately 4,400 tonne DM of which all is sold off- farm.

5. Topography is 100% flat. The lack of undulation can be noticed even from a GIS map. Figure 1 is a GIS map with Farm 1’s boundary marked in red.

Figure 1: GIS Map with Farm 1 boundary in red.

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Relevant for PC1

6. I consider that the following is relevant for PC1:

   a. There are seven council-maintained drains, totalling approximately 6.64 km and 185 drains that divide the paddocks. Figure 2 (overleaf) is a GIS map that shows all the drains on Farm 1 marked in light blue.

   b. All the drains are currently fenced to exclude stock, including sheep, with set-backs of between 0.5 and 1 m.

   c. The physical features of the farm (topography, soil type and drains), combined with the high-level management practices (they exceed standard GFPs) seem to preclude the need for cultivation and stock exclusion setbacks. Critical Source Areas (CSA) are managed to negligible impact standards.

Figure 2: Farm 1 boundary in red with all drains in blue

GIS Analysis

7. GIS analysis was undertaken on all drains both those maintained by the Council and farm drains. The GIS analysis shows the following:

   a. Farm 1 has 6.64 km of council maintained drains. If a 10 m setback was required[1] then the land loss to the setback for council maintained drains would be 13.32ha. Figure 3 (overleaf) is a GIS map of Farm 1 with the Council maintained drains in blue. The current setbacks are between 0.5m and 1m. For calculation purposes if the mean of 0.75m setback is used at council maintained drains then the current setback land loss will be 4.98ha.

      Accordingly the difference between the current setbacks and if a 10m setback is required at a council drain will be the land loss of 9.96 ha for Farm 1.

[1] As proposed in the S42A report

Figure 3: GIS map with Council maintained drains in blue.

b. The farm drains (excluding council maintained drains) on Farm 1 are 59km in length. **Figure 4** (overleaf) is a GIS map that shows all the farm drains excluding council maintained drains.

c. As previously mentioned Farm 1 cultivates around 200ha for maize cropping. I asked the GIS analyst to map approximately 200ha (as this is rotated yearly). **Figure 5** is a GIS map prepared by the analyst. An area of 194 ha is marked in purple on Figure 5 (see overleaf). I also asked the GIS analysis to map and calculate 5m setbacks for that area (marked in yellow). The S42A report recommends that 5m setbacks be used for cultivated land

The analysis shows that in the cultivated area the setbacks from these drains total 24.8 ha. I observed that the current setbacks are between 0.5m and 1m. I then asked the GIS analyst to subtract 0.75m (median) from the S42A recommended 5m setback to roughly calculate the area that Farm 1 will lose if the 5m setbacks are applied to the cultivated area rather than the current setbacks. This equated to 18.9 ha.

Figure 4: Map of farm (non council) drains in yellow.

Figure 5: Farm 1 cultivated area in purple and 5m setbacks on drains in yellow.

Costs of 5m drains.

8. The GIS analysis shows that the additional land loss if the S42A recommended setbacks for cultivation are used is 18.9 ha. Farm 1 stated that the current value of the land is around $50,000 per ha. In my experience this seems an appropriate amount. Applying this amount to the land loss means that Farm 1 will lose $945,000 in productive land value due to the S42A recommended cultivation setback.

9. Obviously Farm 1 will also lose the income from 415.8 tonnes of maize silage (based on 22 tonne dry matter per ha over 18.9ha) . Harvested maize silage has a market value of around $320 per tonne dry matter. This equals to a $133,056 (gross) loss of income.

Observation

10. My observation is that the cultivation setback provisions and stock exclusion provisions proposed in the S42A report are onerous and impractical on Farm 1. The nature of the soils are peat and topography flat meaning that the risk of sediment contamination via overland flow caused by cultivation and stock movement is negligible. Due to the extensive drainage network on this farm the farm has an enhanced infiltration capacity that reduces the risk of overland flow significantly. Any remaining risk is appropriately dealt with by current fences therefore, increasing setback distances is unnecessary.

11. Due to the acidic and continually wet nature of the peat soils, treated wooden fence posts do not last as long as if they were in drier mineral based soils. Also, as the peat oxidises over time, it moves fences from their original position. Therefore, fences on peat soils may require replacement every 15 years as opposed to every 25 years. Accordingly the current setback will require replacing and the new fences will need to have a setback if the S42A report recommendation is adopted.

12. Instead of the onerous setbacks for stock exclusion and cultivation as recommended in the s42A report, other options for Farm 1 could include applying tailored setbacks or keeping the current setbacks.

13. I conclude that the cultivation setbacks and setbacks for council maintained and other drains as proposed by S42A report is not effective or efficient way to address water quality issues on Farm 1. A tailored approach in a FEP will have similar or better outcomes at an lesser expense.

"IFM3"

Farm 2

1. The current family has farmed on Farm 2 since 1981. The current operators are the fourth generation on the farm and are actively involved in several local community groups, including King Country Hunt Club, Otorohanga Sports Club and Otorohanga District Council. The family are fully committed to the restoration of high biodiversity areas such as the bush block which is being prepared for a QEII covenant.

2. Farm 2 was originally solely a 232.6 ha beef and sheep farm but a dairy platform was added in 1992 and a further 140.2 ha of adjacent land was purchased for maize silage cropping and additional dairy run-off.

3. The business employs three full-time staff and casual/relief staff when required. The farm business returns an EBITDA (earnings before interest tax depreciation and amortisation) of $1,580 per hectare. Current land value is $28,500 per ha.

4. This farm is located near Otorohanga in the Waipa catchment and straddles the Priority 1 Moakurarua and Priority 2 Pirongia-Ngutunui Road Bridge sub-catchments. Farm 2 is 372.8 ha with 331 ha effective (see figure 1) of mixed production farm with a dairy platform of 130 ha, carrying beef and sheep on the remaining area. Wintered stock units total 5,370 (16.2 SUs per ha). The farm crops 35 ha maize silage each year.

5. The predominant soil type is Mairoa Ash.

6. Topography is 15% flat to easy (0 to 15°), 45% rolling (16 to 20°) and 40% steep (21 to 35°).

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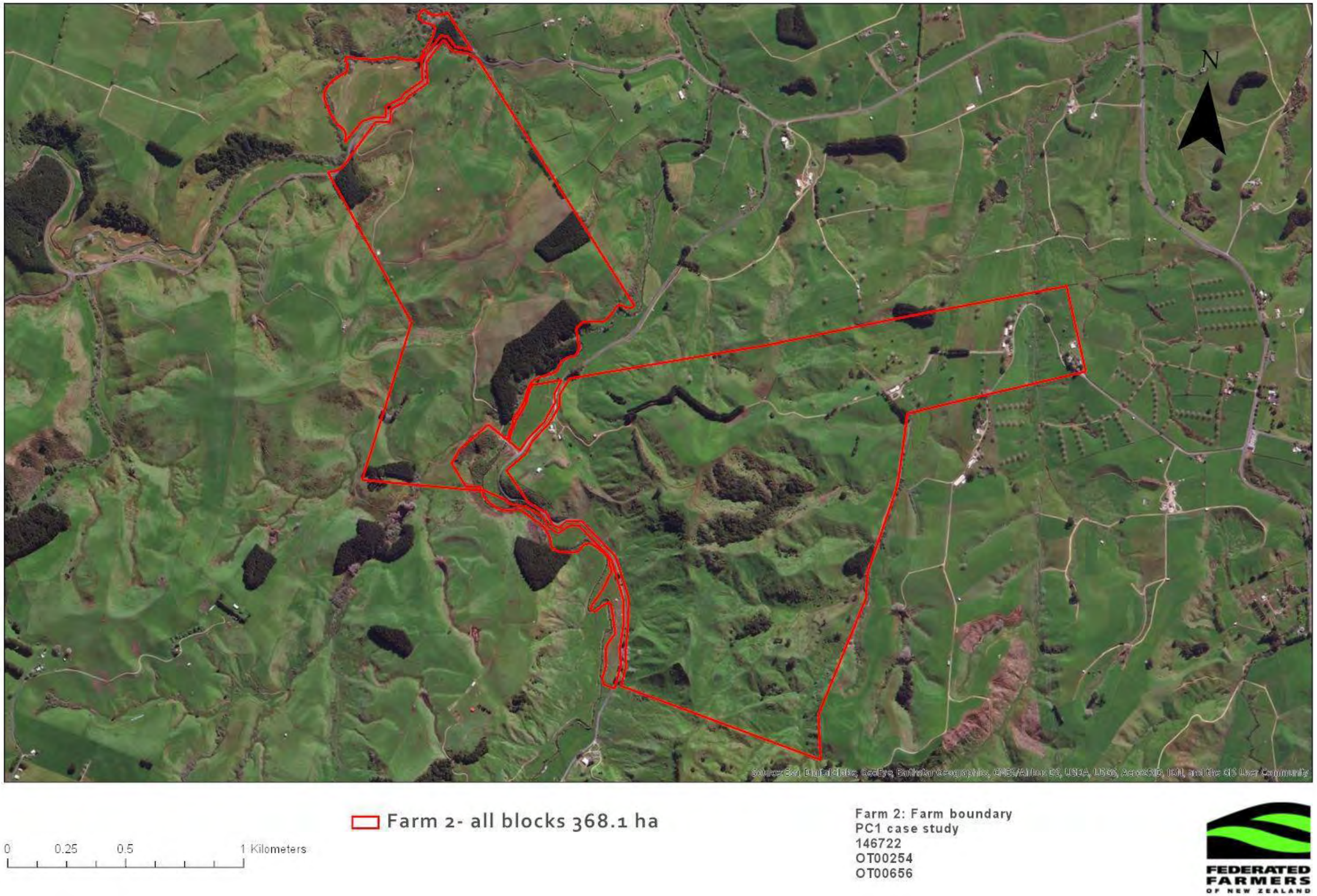

Figure 1: GIS map of Farm 2 with boundaries in red.

Relevance for PC1

7. On Farm 2, relevant to PC1, I found:

   a. That there are two distinct waterways that run through or border the property; the Turitea and Moakurarua streams, both of which are fenced for stock exclusion with help from WRC.

   b. There are over 21 permanently flowing/ephemeral tributaries over the farm that discharge into the above-mentioned streams. Some are not currently fenced exclusively due to their position and topography, and others are in the process of being fenced for stock exclusion.

   GIS analysis of the proposed fencing for stock exclusion of the waterbodies approximates to 26.2 kilometers (see figure 2). If fencing is undertaken along the GIS proposed lines, then the approximates loss of land to stock exclusion is to be 14.8 ha (see figure 3).

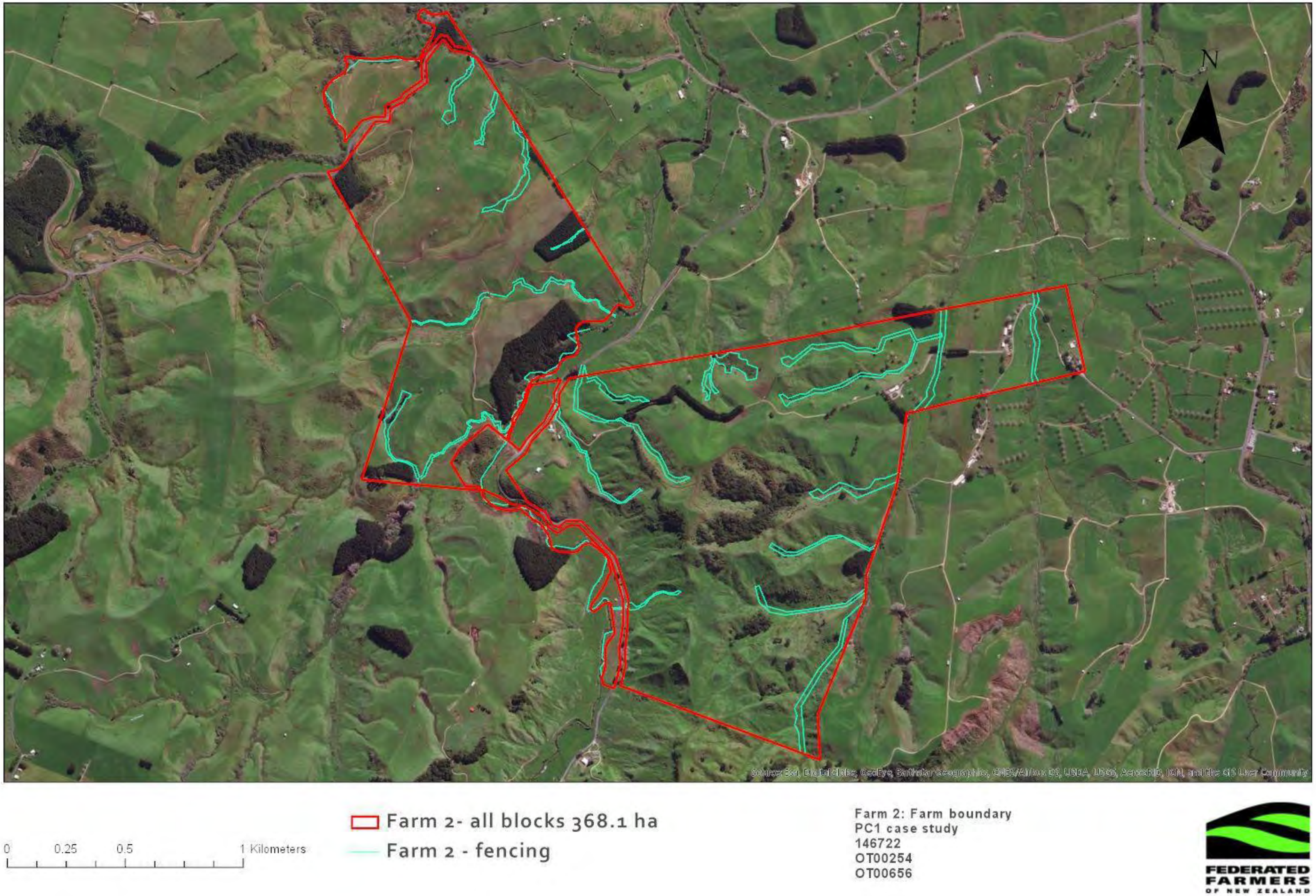

Figure 2: GIS map showing proposed fencelines

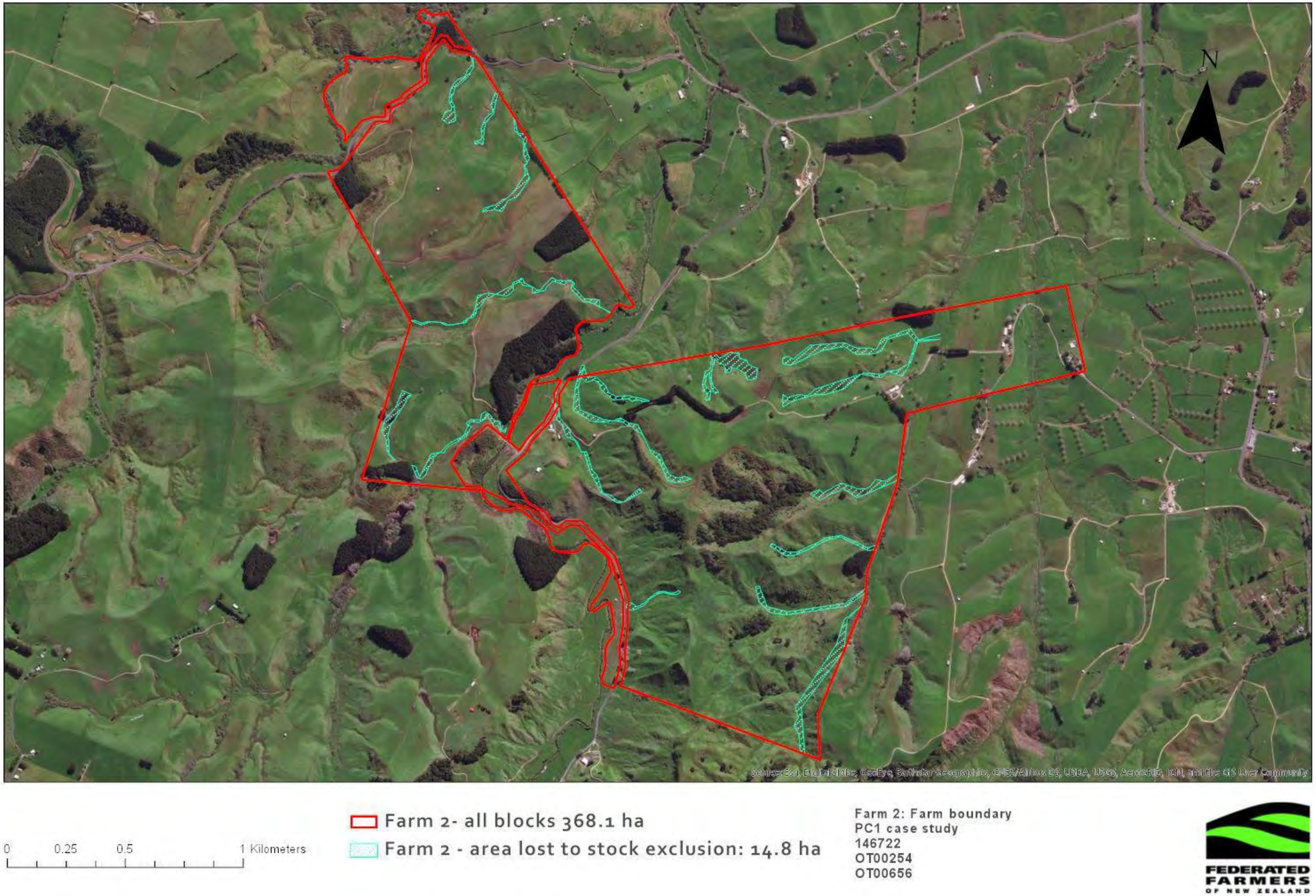

Figure 3: GIS map showing area lost to fencing.

Observations

8. While attending Farm 2, I observed preparation work for fencing of an ephemeral 1st order stream / seepage area. (See figure 4).

Figure 4: Photo of Farm 2 with earthworks preparation for fencing at a 1st order / ephemeral stream

9. Figure 4 shows earthworks in preparation of the fencing of the seepage area. It is not unusual to require earthworks in preparation for fencing although this is more frequent a necessity for steep or hill country. Earthworks can add significantly to cost and completion time of fencing. Relevantly, as the photo illustrates, they can also disturb significant amounts of soil near a water course and in effect over steepen the remaining slope which in turn elevates a soil erosion risk.

Figure 5: Photo of Farm 2 showing hill country with intermittent watercourse

10. Figure 5 is a photo of hill country on Farm 2. The small arrow indicates an intermittent flow watercourse and the large arrow shows areas of sheet erosion and mass soil movement. This photo highlights the variable nature of hill country and the ineffectiveness of a blanket rule for stock exclusion.

11. In this case the farmer might achieve a better outcome (than from simple stock exclusion) through a targeted soil conservation program and maintenance of higher pasture residuals (noting that this image was taken at the end of an exceptionally dry summer).

12. A clear feature on Farm 2 is shown in Figure 6 below. The definition of a watercourse can create significant levels of ambiguity and uncertainty when trying to practically identify a feature that changes form throughout the year.

Figure 6: Photo of an ephemeral or intermittent stream on Farm 2, the purple arrow suggesting where poplar poles could be planted.

13. The proposed new definition of waterbodies in the S42A report includes intermittently flowing stream. The question is whether the stream is an ephemeral or intermittent stream which means it may or may not require fencing.

14. The management of any stock related contaminant loss in this area can and should be managed through a risk based assessment within an FEP that is able to analyse a range of possible causes and solutions. This process might find that:

- It is more effective to control any potential gully erosion by planting poplars (see Figure 6 purple arrow)
- Any effect on the potential CSA may be better managed through consideration of stock class and intensity
- To fully fence and plant the area may provide mitigation for activities further up slope.

GIS analysis

15. Farm 2 is a large farm. I asked the GIS analyst to map fences for the waterways as recommended in the S42A report. (see Figure 2 previously).

16. The result from the analysis is that 26.2 km of fencing will be required. If a 3-4 wire electric fence cost $10 per metre then the fence alone will cost $262,000 (26.2 km x $10 per metre).

17. There would also be additional costs of earthworks for fencing on steep country.

18. There is also the additional loss of 14.8 ha productive land. If the land is valued at $28,500 p/ha then the loss of productive land is $421,800 (see Figure 3).

19. Further, the loss of income from 14.8 ha would equate to approximately $23,384 given the current (gross) EBITDA of $1580 p/ha. .

Conclusion

20. Instead of the fencing and setbacks for stock exclusion from waterbodies as proposed in the S42A report, other, less onerous and costly options for Farm 2 could include::

    a. Soil conservation practices on steeper country such as poplar poles and other suitable trees to stabilise erosion prone ground and retirement to sheep only in the winter/wet periods.

    b. Detainment bunding to reduce/prevent mass movement of soil and vegetation.

    c. Sediment ponds in key areas to reduce further sediment loss to waterbodies.

    d. Retirement of marginal land, where the income is less than the cost of fencing and additional infrastructure

21. I conclude that the stock exclusion provision as proposed by S42A report is not an effective or efficient way to address water quality issues on Farm 2. A tailored approach in a FEP will have similar or better outcomes at a lesser cost.