Before an Independent Hearings Panel

The Proposed Waikato Regional Plan Change 1

IN THE MATTER OF	the Resource Management Act 1991 (**RMA**)
IN THE MATTER OF	the Proposed Waikato Regional Plan Change 1, Block 2 hearings, Topics C1 **Diffuse Discharge - Nitrogen Management**

PRIMARY EVIDENCE OF DR MARK SHEPHERD
ON BEHALF OF MIRAKA LIMITED

(Nutrient Management)

3 May 2019

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1. EXECUTIVE SUMMARY

1.1 My full name is Dr Mark A Shepherd. I am a Principal Scientist with AgResearch.

1.2 My evidence addresses:

(a) The science of how nitrogen (**N**) moves through New Zealand (**NZ**) pastoral farming systems, including the difference between source of N, internal transfers within the farm and transport of N (in relation to N leaching);

(b) How Overseer models the source, transfers and transport of N and the implications of the model for certain types of farm with high rainfall and free-draining soils;

(c) On-farm mitigation measures and good farming practices that will reduce N leaching from farms; and

(d) Methods that can be used to establish baseline positions on N status and track changes over time.

1.3 In terms of mitigating N leaching at a farm level, I explain that methods tend to target **source** of N (i.e. targeting the amount of N available for loss), **transport** of the available N (in the case of farm management, to the edge of farm) or **timing** of an agricultural practice.

1.4 Accounting methods for tracking/monitoring baseline status and a change in N leaching include: measurement; nutrient budgets (e.g. a farm gate N balance); risk assessment; and modelling.

1.5 Different accounting methods have different – but well understood – pros and cons in relation to operational scale (paddock to national), data requirements and level of uncertainty around estimates; and whether they adequately capture source, transport and internal transfer or timing aspects of mitigation of N leaching.

1.6 Furthermore, new mitigation methods are continually emerging through research, and this will continue through the lifetime of Plan Change 1 (**PC1**). It is important that accounting methods are able to capture these new mitigations in readiness for their application on-farm.

2. INTRODUCTION

2.1 My full name is Dr Mark A Shepherd. I am a Principal Scientist within the AgResearch's Farm Systems and Environment Group.

2.2 I have Bachelor of Agricultural Chemistry (Hons) and PhD (Soil science) qualifications and my specialist research area is nutrient management in agricultural systems with an emphasis on decreasing environmental impact. As a result of over 30 years of research, development and extension activity in this topic, I have a good grounding in the issues and legislation relating to agri-environmental interactions, firstly in the UK (particularly the European legislative tools known as the Nitrates Directive and the Water Framework Directive) and now in NZ (11 years).

2.3 During my research career I have been involved in and managed research programmes that seek to understand how N cycles through farm systems (cropping and pasture-based), leading to the establishment of practices to decrease N leaching losses whilst maintaining profitability.

2.4 For example:

(a) I was the National Leader of the Pastoral 21 research programme that established approaches for decreasing N leaching from dairy systems by 10-40%;

(b) I was the science leader of the EU-funded project WAgrico that developed voluntary agreements between Wessex Water and farmers to protect critical boreholes at risk of high nitrate concentrations through improved farmer understanding of diffuse pollution losses, management and mitigation effects within catchments in the South West of England; and

(c) I have published over 50 peer reviewed papers on N cycling and management within farm systems.

2.5 Additionally, I provide scientific support to Overseer Ltd for the development of the Overseer Nutrient Budgets model, particularly in relation to N cycling and N leaching estimates.

2.6 I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. My qualifications as an expert are set out above. I confirm that the issues addressed in this brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

2.7 I would be available for expert witness conferencing should that be requested by the panel.

3. SCOPE OF EVIDENCE

3.1 My evidence details the principles behind N cycling in a pastoral farm system, the key drivers of N leaching from free-draining soils typical of the Upper Waikato catchment, and implications for good and best management practices to decrease N leaching.

3.2 My evidence addresses:

(a) The science of how N moves through NZ pastoral farming systems;

(b) How Overseer models the movement of N, and the implications of that approach to certain types of farm with high rainfall and free-draining soils;

(c) On-farm actions that will reduce N leaching from farms; and

(d) Methods that can be used to establish baseline positions on N status and track changes over time, instead of using Overseer.

3.3 My evidence should be read alongside that of:

(a) Dr Gavin Sheath regarding alternative approaches to PC1 in regards to nitrogen management and limit setting; and

(b) Ms Kim Hardy regarding planning.

3.4 In relation to Miraka's requested relief on PC1:

(a) My evidence about nitrogen cycling informs Miraka's position on the use of Overseer within PC1 and the implications for certain types of farms;

(b) The alternative methods to track N leaching that could be incorporated into PC1 if Overseer leach estimate are not used; and

(c) The mitigation actions I describe are examples of Good Management Practice (**GMP**) to reduce nitrogen loss and could be incorporated in Farm Environment Plans (**FEP**).

4. NITROGEN CYCLING

4.1 In broad terms, increasing N inputs into a farm system lead to increased N leaching, as shown in Appendix I. In both examples, N losses increase disproportionately once N inputs exceed c. 250-300 kg N/ha. Fertiliser N is one input while others include imported supplementary feed and fixation of atmospheric N. Substituting one form for another will generally not change this relationship (Chapman et al 2018).

4.2 It is important to understand the underlying factors that drive leaching when considering farm practice change to reduce leaching. Nitrate loss to water is determined by the amount of mineral N[1] **on** or **in** the soil as a result of various practices, and the risk at any time of this mineral N being washed through the soil (leaching) or across the soil surface (run-off).

4.3 Therefore, we can conceptually think of N leaching risk in terms of **Source** and **Transport** factors that determine the amount of mineral N transported to surface or groundwaters. In my view:

(a) Broadly, source can be influenced by farm practice but transport is most influenced by environment and less influenced by management; and

(b) The size of the source can be broadly estimated from a farmgate N surplus (the balance of N inputs to and N outputs from the farm, as described later) but converting this into a quantity of N leached requires transport factors (e.g. environment) and subtleties in management (e.g. timing and location of applications) to be taken into account, which requires use of a model or direct measurement (Cherry et al 2008).

4.4 I also consider that N leaching can be considered to be as a result of a **Direct** or **Indirect** loss of N input. Direct leaching occurs as a result, for example, of excess fertiliser or effluent leaching through the soil. Indirect leaching occurs when fertiliser N or atmospheric fixed N (or imported feed) generates protein that is eaten by animals and then excreted as dung and urine, which is then leached. The largest source of N leaching is via Indirect loss. Different mitigations target Direct or Indirect loss.

Source factors ('nutrient availability')

4.5 Soil mineral N derives from urine and non-urine sources in pastoral farms. Urine is the predominant source of N leaching in a pastoral farm (Ledgard et al 2009) but I address non-urine sources first.

4.6 Under some circumstances non-urine sources of mineral N can contribute to N leaching when management practices and/or environmental conditions result in an accumulation in soil that exceeds plant uptake. If this coincides with a period of drainage (generally in autumn/winter or during periods of over-irrigation), mineral N will be lost from the soil profile.

[1] i.e. non-organic forms of N, generally nitrate-N and ammonium-N. Nitrate-N is more mobile than ammonium-N and ammonium-N is rapidly transformed to the nitrate form.

4.7 **N fertiliser** can be a source of excess soil mineral N in some of the following circumstances:

(a) When applied during winter when pasture growth is minimal;

(b) When applied during a drought and when the pasture is unable to utilise the N (Shepherd et al 2018);

(c) In conditions of high soil mineral N supply (e.g. from soils with a high organic matter content or with a history of organic manure), less fertiliser N is required to supplement soil N supply. Not correctly accounting for this soil N supply can result in over-fertilisation and increased soil mineral N build-up;

4.8 The risk of these scenarios occurring increases with increasing fertiliser N rate.

4.9 **Effluent** applications can increase N leaching risk in similar ways, i.e. when application rate exceeds uptake potential (Di & Cameron 2002a). Failing to reduce fertiliser N inputs on effluent blocks to account for the N applied in the effluent can lead to an accumulation of soil mineral N, with increasing N leaching risk.

4.10 **Soil organic matter** is an important source of mineral nitrogen for sustaining crop/pasture growth. It can be considered a slow release form of N that is efficiently used by crops/pasture at times of full cover. However, when pasture is ploughed, large amounts of mineral N can be released and leached from soils if the next plant cover cannot use all of the mineralised N.

4.11 The major source of leachable N on pastoral farms is **Urine** (Ledgard et al 2009). For example, over 3 seasons (2011-2014) as part of the Pastoral 21 research programme at Scott Farm, Hamilton, the annual N flows were measured for 3.2 cows/ha grazing, producing c. 1200 kg MS/milk solids/ha and applying c. 150 kg N/ha as fertiliser. In summary, it was estimated that of the 486 kg N/ha eaten by the cows as pasture and supplements c. 60% of N eaten by the cows was excreted as urine (320 kg N/ha) and c. 16% of N eaten was removed as milk (84 kg N/ha). Nitrogen in **Dung** (the remaining 24% in this case) is organically bound and poses much less of a N leaching risk.

4.12 I categorise leaching of N resulting from injudicious application rates or timing as Direct losses. However, Indirect losses are the largest source of leaching from fertiliser (and effluent), as well as from imported feed and N fixed in pastures. These losses come from N eaten by the cow in forage and supplements and then excreted as urine (and dung). These sources are described further in Table 1 in section 5.

Transport factors ('delivery from source to edge of farm')

4.13 Transport factors determine the proportion of the available mineral N that is actually leached. The two main factors are soil-type and rainfall/drainage. These are inherent properties of the site.

4.14 These two factors combine to influence leaching risk (Chicota et al 2012). In free-draining, structureless soils, 'convective dispersive flow' processes are the main transport mechanisms for leaching solutes from the soil profile (Cameron et al 2013). The result is a typical leaching curve from an individual urine patch as shown in Figure 1, expressed as cumulative N leaching with cumulative drainage.

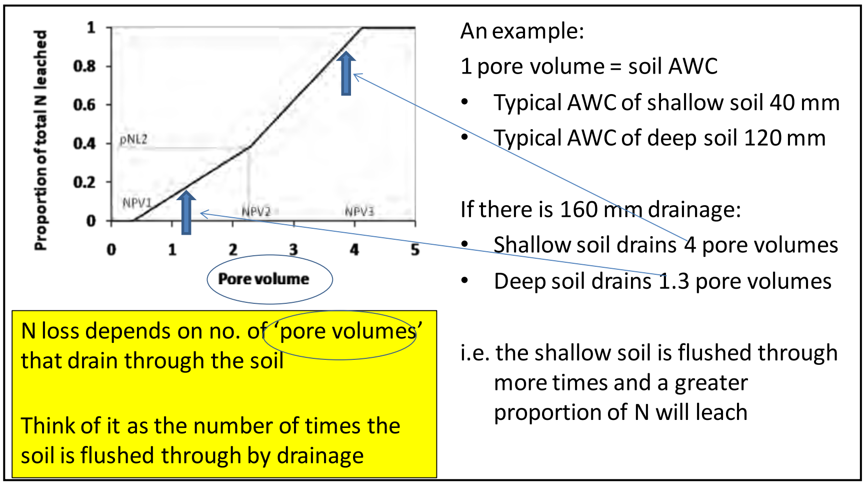

***Figure 1**. Shape of N leaching curve as derived by Cichota et al (2012). NPV ('number of pore volumes') values denote start of leaching (nPV1) an inflexion in the linear relationship between pore volumes drained and proportion of N leached (nPV2) and number of pore volumes required to complete leaching (nPV3). These values vary with soil type*

4.15 The rate at which a solute is leached from the soil by convective dispersive flow will be determined by the number of pore volumes (PVs) of drainage. Chicota et al (2012) identified a relationship between number of PVs drained and the proportion of the available N that is leached. One pore volume in their case was equivalent to the soil's Profile Available Water (**PAW**) content, also known as available water capacity (**AWC**). Therefore, if two soils drain the same amount of water, a soil with a low PAW (or AWC) content will be 'flushed through' more times than a soil with a larger PAW and leach a greater proportion of the available N (see example quoted in Figure 1).

4.16 Soil-type can further influence N leaching losses by modifying N loss pathways. For example, heavier textured soils are more likely to have periods of saturation and/or soil structural damage (e.g. when pugged during grazing). Under these circumstances, mineral N will be denitrified to dinitrogen gas and/or nitrous oxide rather than leached (Cameron et al 2013; McDowell et al 2017).

4.17 The critical implication of this is that even if two farms have generated the same amount of surplus soil mineral N but differ in soil-type and/or rainfall the amount of N leached will be different from the two farms.

4.18 For example, research work undertaken by Shepherd et al (2015) for Wairarapa Moana Incorporation showed the effect of rainfall on estimated N leaching; in this case when soil-type was the same. Using three case study farms with different baseline N leaching levels, Figure 2 shows that for every additional 100 mm annual rainfall an extra 7-8 kg N /ha was estimated by Overseer to be leached.

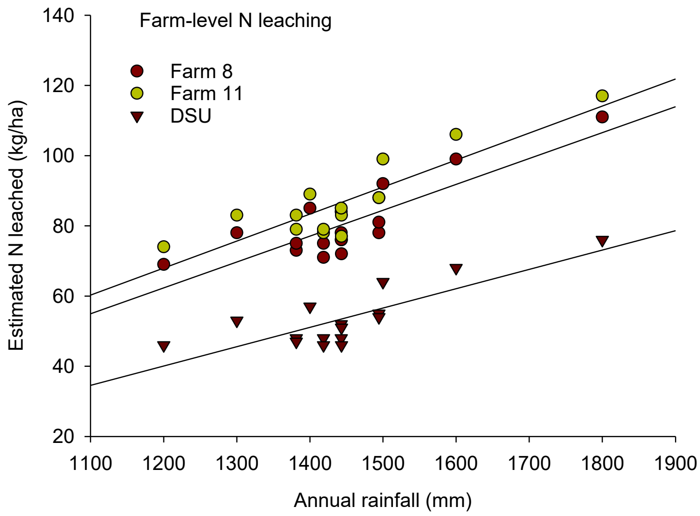

Figure 2. *Overseer estimates of N leached for three WMI farms (Farm 8, Farm 11 and Dairy Support Unit, DSU) where rainfall and drainage inputs were varied (from Shepherd et al 2015)*

4.19 Although I consider that transport factors are mainly uncontrollable, some are influenced by management:

(a) Transport can be modified, say by intercepting urine (wetlands, riparian strips); and

(b) Animal stand-off areas do not alter source but change location of deposition to a place where it can be intercepted (in a lined housing structure and effluent pond) so it could be considered a transport factor.

4.20 Overseer is a commonly used tool to assess the environment impacts of farming. It estimates both source and transport factors. Specifically:

(a) It estimates surplus soil mineral N arising from the balance of fertiliser, fixation and supplementary feed N inputs and N outputs in produce (this is in effect the 'potential surplus');

(b) It further modifies this potential surplus to a ‘net surplus’ by accounting for:

(i) internal transfers and N cycling within the farm (e.g. effluent application, soil N mineralisation from cultivation);

(ii) the timing of the surplus soil mineral N, as this is important in terms of N leaching risk;

(c) It accounts for environment factors (climate, rainfall and drainage and soil-type) that affect transport of the surplus N; and

(d) As a result of all of those three elements, it can estimate N leached from a farm and the effects of mitigation practices on N leached.

5. PRACTICAL EXAMPLES OF N CYCLING IN PASTORAL FARMS

5.1 Across the agricultural science community there is a sound understanding of the mechanisms of N loss and the implications of N farm management on N leaching losses. Given that knowledge, there is now a range of management practices that can be used to decrease leaching. I describe two examples in my evidence:

(a) Decreasing N fertiliser inputs and matching stocking rates significantly decreases N leaching; and

(b) Risks from grazed winter forage crops, including possible solutions.

Example 1: Proven reductions in N leaching of 20-45% from changed management practices

5.2 The Pastoral 21 research programme, discussed above, concluded that across a wide range of biophysical conditions, reductions of 24-44% N leached from dairy farming systems could be achieved by implementing a range of practices and mitigation measures (Shepherd et al 2017). Such practices and mitigations involve:

(a) reductions in N fertiliser inputs, particularly in the autumn;

(b) reduced forage cropping; stocking rate adjustments;

(c) restricted grazing and stand-off areas; and careful management of ‘critical source areas’.

5.3 The results from the research programme of these actions are summarised in Appendix II.

5.4 Shepherd et al (2017) provided a detailed analysis of the reasons for these reductions in N leaching:

> Firstly, strong emphasis was placed on maximising pasture utilisation, pasture quality, and the efficiency with which inputs of feed and fertiliser were converted to milk. For example, reduced total annual N fertiliser inputs meant that the timing of fertiliser application, and the amount of N applied on each occasion, was governed by the changing balance between feed supply and demand during the year, rather than applying N in regular amounts after each grazing. It also meant that less pasture and N were consumed. Decreasing the stocking rate to match the available feed grown, combined with increased per cow milk production, meant that less feed went in to animal maintenance and more went into milk production. Overall, less urinary N was produced as a result.

Thus, the **Source** was reduced. A more detailed analysis of this source reduction for the Waikato study is provided below:

> Secondly, cows were removed from the paddock at critical times to capture urinary N in autumn and winter.

5.5 Thus, a smaller proportion of the urine was deposited directly on paddock and was recycled as effluent for use at a better time of year. This could be considered a Transport effect, because the housing allowed interception of the urine before it could be leached.

5.6 Shepherd et al (2017) also make the point that:

> Importantly, the tools to help manage these systems are available now. They include: weekly farm walks and use of feed wedges to allocate pasture; spring rotation planner; autumn management tool; and feed budgets (see https://www.dairynz.co.nz/feed/feed-management-tools/); as well as off-paddock facilities (https://www.dairynz.co.nz/farm/off-paddock-facilities/) and effluent management (https://www.dairynz.co.nz/media/2832537/farmers-guide-to-managing-fde.pdf).

5.7 The strategy of growing less pasture (as a result of less fertiliser N) decreases the Source, i.e. less urinary N produced. Nitrogen balance calculations based on measurements of pasture protein eaten and removed in milk allow an estimate of urinary N production (method described in Shepherd et al 2016a). A 3-year N balance summary for the Pastoral 21 Waikato farmlet study is shown in Table 1.

5.8 In summary, decreasing annual N fertiliser rate from 150 to 50 kg N/ha/year and decreasing the stocking rate from 3.2 (Treatment A) to 2.6 cows/ha (Treatment B) to better utilise the resultant decreased forage production resulted in: 10% less pasture eaten, 14% less N eaten by the cows; and 19% less urinary N produced in Treatment B.

Table 1. *Effect on estimated annual urinary N production from reducing N fertiliser inputs and adjusting stocking rates to better utilise the grown pasture (Pastoral 21 Waikato site)*

Stocking (cows/ha) and N fert rate (kg N/ha)	Dry Matter intake (t DM/ha)			N intake (kg N/ha)			N milk (kg N/ha)	N balance (kg N/ha)	
	Past	**Supp**	**Total**	**Past.**	**Supp**	**Total**	**Milk**	**Balance**	**'Urine'**
A: 3.2/150	14.5	2.2	16.6	486	53	538	84	455	316
B: 2.6/50	13.0	2.1	15.1	413	49	462	82	380	256
Difference	*1.5*	*0.1*	*1.5*	*73*	*3*	*76*	*2*	*75*	*60*
% Change[1]	***10***	***3***	***9***	***15***	***6***	***14***	***2***	***16***	***19***

[1] Numbers rounded

5.9 This reduction in urine production contributed significantly to the reduced N leaching of 44% measured in Treatment B (Appendix II). Beukes et al (2017) estimated that 40-50% of the reduction in N leaching was attributable to the reduction in urine production, the remaining benefit was mainly due to the animals additionally being removed from paddocks for several hours per day during autumn/winter in Treatment B.

Example 2: Risks from grazed winter forage crops and possible solutions

5.10 Grazed winter forage crops have been identified as a significant source of N, P, sediment and faecal microorganisms. Grazing winter forage crops in situ during winter means that a large proportion of the consumed protein will be returned as excreta on to bare soil at a time when rainfall generally exceeds evaporation and is therefore susceptible to N leaching.

5.11 For example, a herd grazing 12 t Dry Matter/ha kale (2% N content) plus associated supplements means c 280 kg N/ha would be eaten (assuming 85% utilisation), with probably >60% of this excreted as urine on to bare soil in winter.

5.12 An analysis of 15 site years of forage crop grazing experiments covering a range of circumstances was collated as part of the Pastoral 21 research programme (Shepherd et al 2016b). The dataset comprised of experiments that measured N leaching at the paddock-scale (using porous cups or measuring drainage from pipe and mole system) after grazing brassicas (12 sites) or fodder beet (3 sites). Measured nitrogen leaching losses were variable, but the trends appeared to be that on free-draining soils, mineral N leaching losses from brassicas were >80 kg N/ha and fodder beet <45 kg N/ha. Included in this dataset were two site years in the Waikato where kale was grazed on a pumice soil. N leaching losses were > 120 kg N/ha/year (Shepherd et al 2012). In comparison, N leaching from pasture receiving 200 kg N/ha as fertiliser under similar conditions would typically be in the range 40-80 kg N/ha.

5.13 The lower N leaching from fodder beet is most likely attributable to its lower N content compared with brassicas (de Ruiter et al 2019), resulting in less N eaten, excreted and leached.

5.14 The use of a 'catch crop' post grazing shows some promise for reducing subsequent N leaching losses (Carey et al 2016) by taking up some of the surplus N, with less available for leaching. Research on catch crops and on fodder beet continues in the Forages for Reduced Nitrate Leaching (**FRNL**) research programme (DairyNZ 2016).

6. EXAMPLES OF MITIGATION MEASURES

Mitigation 'lists'

6.1 Appendix II lists a range of mitigation measures for reduction in N leaching compiled from NZ literature (Monaghan & DeKlein 2014; Vibart et al 2015; McDowell et al 2017) and further supplemented by a comprehensive study from the UK (Cuttle et al 2016). The latter has been included to demonstrate that the solutions identified by NZ scientists are similar to those from Europe. NZ is continuing its pursuit of new solutions and these did not show up in the UK list. However, in terms of currently available mitigation measures, these have been organised as:

6.2 **Good management practice** – these are considered as 'low hanging fruit' targeting the reduction in 'direct' leaching losses, for example:

(a) N fertiliser at the right rate, in the right place at the right time, and applied only to fill seasonal feed gaps;

(b) Effluent blocks large enough to avoid excessive annual loadings and N fertiliser applications omitted or at a low level that take account of the applied effluent;

(c) Reduced rates and precise timing of effluent applications; and

(d) Reduced forage cropping and careful grazing practices.

6.3 **Best management practice** – a 'next level' of management, sometimes requiring significant investment, for example:

(a) Use of pads and/or barns to remove animals at critical periods ('restricted grazing', capturing the dung/urine and recycling as effluent at appropriate times and rates;

(b) Applying less N fertiliser in total and adjusting stocking rates downwards to match the available forage as described in detail in the Pastoral 21 example, above).

6.4 **Land use change** – for example taking land out of animal production:

(a) Retiring land to trees.

6.5 Other authors group the mitigations differently, e.g. 'efficiency', 'mitigation' and 'system changes' (Monaghan & DeKlein 2014), or 'improved nutrient management', 'improved animal management' and 'restricted grazing' (Vibart et al 2015), but this is rather academic; the key point is that all authors tend to agree on the list of available mitigations, as summarised in Appendix III. The challenge is assessing the likely effectiveness of the measures and this is dealt with in a later section.

Future new mitigation measures

6.6 The Pastoral 21 research programme demonstrated reduction in N leaching of up to 44% in the systems comparisons (Appendix II). However, it is necessary to continue to develop new mitigation strategies to provide:

(a) Farms with a wider range of options to give more flexibility; and

(b) Options that are more cost-effective than those currently available.

6.7 This second point is highly pertinent because, as Shepherd et al (2017) state:

> Pastoral 21 was able to decrease N losses but was less successful at raising farm profitability; whilst we have created options for farming within environmental limits, profit is a key element of sustainability. Thus, more cost-effectiveness measures are required, especially more affordable options to replace stand-off facilities that are commonly used at the moment.

6.8 New mitigations are continually under development. Figure 3 shows examples of a range of options that have been or are being developed. This list is by no means exhaustive. Some opportunities that are close to market include:

(a) The Forages for Reduced Nitrate Leaching Research programme is developing three specific mitigations:

(i) Use of plantain rich pastures (main mode of action appears to be to reduce urinary N concentration);

(ii) Fodder beet (main mode of action is reduced dietary N intake);

(iii) Catch crops sown after grazed winter crops (main mode of action is reducing mineral N levels in the soil).

(b) Other research programmes are investigating the genetic potential of cows to partition more dietary N to milk and/or dung and away from urine; and

(c) The 'Spikey' technology is a machine that when travelling across the paddock is able to identify and treat individual urine patches with a process inhibitor, thus aiming to reduce N leaching from individual patches.

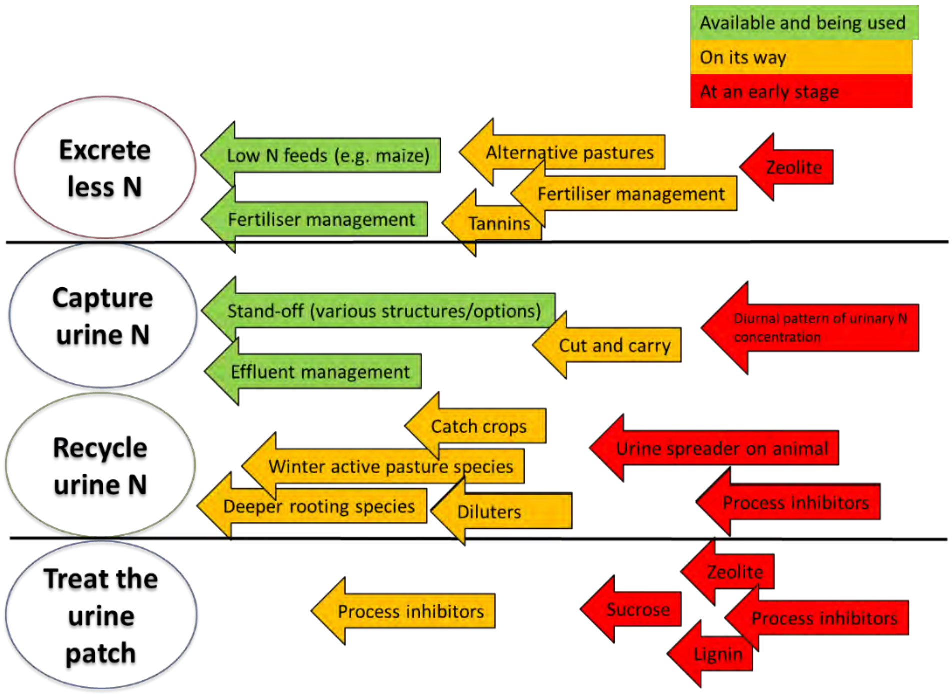

Figure 3. *An example of a development pipeline for a selected set of N mitigation approaches (from Shepherd et al (2017).*

6.9 These developing mitigation options, while showing promise, could be considered as bringing incremental improvements, very much in the business-as-usual vein. However, it is possible that we are now entering the 4th industrial revolution that is, in turn driving the 3rd green revolution (CEMA 2015) with the rapid development of disruptive digital technologies. It is probable that within the lifetime of Plan Change 1, transformational solutions for sustainable farming and food production systems will emerge from the technology revolution.

6.10 In summary, in my opinion, new mitigations will certainly emerge and, therefore, rules/regulations need to be able to accommodate any new mitigation measures.

7. ESTIMATES OF MITIGATION EFFECTIVENESS

7.1 While identifying mitigation methods is relatively straightforward, gauging both their cost and effectiveness is challenging. Firstly, both aspects will depend on the particular farm system. Secondly, measuring the effect of a practice change/mitigation measure is expensive and difficult, especially when interested in the outcomes at farm and catchment levels.

7.2 The nitrification inhibitor dicyandiamide (DCD, now voluntarily withdrawn from the market) is a good example of how scale affects the estimate of efficacy. Experiments at an individual urine patch level in lysimeters show reductions of N leaching up to 70% (Di & Cameron 2002b). However, this translated into an effectiveness of 20-50% when measurements were made at a grazed paddock level (Monaghan et al 2009). Effectiveness was further diluted by other leaching losses if considered at a farm level (e.g. non-treated DCD areas included at the farm level). Finally, DCD was found to be more effective in the colder South Island climates than the warmer wetter Waikato environments.

7.3 In short, efficacy of mitigations will depend on the inherent farm system and the environment, and also how far away the farm is starting from in terms of good practice.

7.4 So, if a farm is already working at good practice in terms of, say, effluent and fertiliser N management, there is less scope for improvement without moving to potentially the more expensive tier of mitigations (i.e. Best Practice or Land Use change rather than just Good Management).

7.5 Doole et al (2016) state that implementation of Good Management Practices can be assumed to lead to 5-10 % reduction in N leaching to water in the Waikato/Waipa catchments. This estimate feels intuitively correct based on other studies. By far the most common method of estimating size of effects of mitigations is through the use of modelling. Examples of the size of effects expected from mitigation measures and good management practices are provided below.

7.6 Monaghan & DeKlein (2014) estimated the reductions in farm-level N leaching from application of some individual practices:

(a) eliminating winter fertiliser N applications – 10% reduction;

(b) improved effluent management – 2-4% reduction;

(c) replacing pasture with high energy supplement – 15% reduction; and

(d) restricted grazing (or ‘duration-controlled grazing’) – 20% reduction.

7.7 Vibart et al (2015) modelled a range of sheep and beef and dairy enterprises to investigate the reductions in N leaching from applied packages of mitigations grouped as ‘improved nutrient management’, improved animal productivity’ and ‘restricted grazing’. Size of reductions in N leaching varied between enterprise and farm-type within enterprises. Deployment of improved nutrient management was estimated to decrease N leaching, as an average of case study farms, by 10% (pasture-based dairy) or 25% (intensive dairy) and

30% (sheep and beef). Application of the full suite of mitigations to dairy was estimated to decrease average N leaching by 34% for pasture-based dairy and 47% for intensive dairy.

7.8 Wilcock et al (2013) took an alternative approach to measuring change by monitoring specific catchments over 7-13 years. Long-term monitoring was able to detect some change but it was clear that catchments were slow to respond to mitigation measures and practice change initiatives. Thus, although such measurement approaches to assess impact are the ultimate evidence that mitigations work, the time-lag between action and result does make this a less than viable method for encouraging change in farm practices.

8. ACCOUNTING METHODS FOR TRACKING/MONITORING CHANGE?

8.1 The challenge, of course, is determining if a mix of mitigations applied to a mix of farm types and environments in a catchment will bring about the necessary change in water quality. Due to catchment buffering and long transit times, changes in water quality could take years or even decades to see (evidenced by the work of Wilcock et al 2013 previously cited). If we assume that reductions in nutrient leaching from farms will eventually lead to an improvement in water quality, then we may need to determine the most appropriate surrogate indicators of likely change at a farm-level.

8.2 In providing a summary of methods and their pros and cons I have relied heavily on a review paper by Cherry et al (2008) of which I was a co-author and which compares a variety of methods for assessing the effectiveness of mitigations at the farm and catchment level. This paper provided a comprehensive review, has been cited over 200 times and, although published in 2008, it is still highly relevant today. The review considers direct measurement, nutrient budgets (I will focus on farm gate budgets), risk assessment and modelling, and assesses the pros and cons of each method and their appropriateness for accounting for different types of mitigations. Appendix IV tabulates the pros and cons. I will focus on the appropriateness of the different methodologies for recognising mitigations. For context, Overseer is a model rather than a budget or risk approach.

8.3 **Farm gate budgets** quantify nutrients that enter and leave the farm gate **with no consideration of internal transfer processes** (i.e. N cycling within the farm) or of loss processes. So, of the sources described above, imported feed, fertiliser and fixation would be considered as inputs to a farm gate budget (few farms import/export manure) while soil organic matter mineralisation and effluent would be considered as internal transfers. Outputs from a farm gate budget include N in produce exported from the farm (milk and meat) and any manure, supplements sold off farm, for example.

8.4 One approach to farm gate budgeting is the determination of Farm Nitrogen Surplus (FNS). There is good evidence that FNS correlates well with N leaching estimates. Research work undertaken by Beukes et al (2012) established a correlation between N surplus and N leaching estimates of $R^2 = 0.74$ for dairy farms in the Upper Waikato catchment. Additional evidence of this strong correlation is outlined in Appendix I. Using the lines fitted by Rotz et al (2005) to their data for the relationship between N inputs and either N loss or N in produce, I re-expressed the relationship as that between N surplus and N loss. The relationship is close to a straight line (Appendix I), i.e. surplus is a key driver of N leached.

8.5 Table 2 summarises the effectiveness of different accounting approaches on recognising different mitigations. It shows that nutrient budgets are best suited to recognising mitigations that affect source.

8.6 According to Cherry et al (2008):

> Nutrient balances identify where supply exceeds demand and a nutrient surplus exists. Nutrient loss and enrichment of water bodies is often associated with excessive inputs and so a connection can be made between nutrient surpluses and potential loss … However, the relationship between N surpluses and loss is sensitive to climate, topography, land use history, soil properties and agricultural system, and it is accepted budgets predict only potential loss….
>
> Although budgeting approaches using on-farm data also provide a simpler, more communicable means of assessment but currently fail to consider the timing and transport aspects of mitigation and assume a direct causal relationship between potential and actual nutrient loss.

8.7 I note that Cherry et al (2008) include a Timing component to nutrient loss factors as well as Source and Transport, on the basis that timing is possibly captured in source and/or transport but it is important that assessment methods are able to capture timing effects of mitigation methods.

8.8 For livestock farms, farm gate N budgets are likely to capture the main source of leachable N, i.e. urine. This is because the three main inputs in the surplus calculation all influence the amount of protein eaten and urine produced. Given that the farmgate balance does not capture transport factors, this means that the surplus N leaching relationship will be more stable if farms are grouped according to rainfall/soil type (i.e. the main drivers of transport).

8.9 Mitigations that target internal transfers of N and/or transport of mineral N to water courses (e.g. timing of fertiliser N applications or rate of effluent application) generally will have no effect on the calculated farm gate N surplus. That is, unless these management practices save N from leaching that then results in a reduction in the need for fertiliser or external feed inputs to be imported into the farm – these reductions will show up as an adjustment to the farm gate N balance.

8.10 **Risk assessment** procedures quantify the risk of nutrient loss occurring based on the likelihood of nutrient availability and delivery processes coinciding (Heckrath et al 2008). A risk assessment tool identifies key source and transport processes which control nutrient losses at the field scale. Critically, therefore, this understanding supports highly targeted mitigation (Cherry et al 2008) for example, which could then be built into specific farm environment plans. McDowell et al (2018) demonstrated through modelling case studies that a targeted approach to implementing mitigations was a more effective method than a generalised approach.

8.11 Many nutrient loss **Models** exist for both N and P, ranging in complexity from simple empirical applications to comprehensive, fully process-driven models (Cherry et al 2008). Models have potential to take account of source, transport and timing effects of nutrient leaching (Appendix IV), but this will depend on the model.

8.12 However, re-iterating paragraph 4.20, the nitrogen leaching model in Overseer calculates the N available for leaching (source). It is based on a monthly timestep and so captures timing effects of management practices. It also captures transport factors to edge of farm though estimation of drainage and interaction with soil-type as described earlier.

8.13 In conclusion, no one method is perfect, but models have the potential to represent source, timing and transport mitigations. Farm gate budgets clearly also have some potential, as evidenced by the findings of a linear relationship between surplus and N leaching. I infer from this that a surplus is especially useful where:

(a) Urine-N is the primary source of N leaching from the pastoral system; and

(b) Deployed mitigations focus mainly on reducing this surplus (rather than focusing on mitigating transport).

8.14 I rely on the evidence of Gavin Sheath and Kim Hardy in relation to the implications of using certain models within Plan Change 1. I consider that if the Panel determines that it is not appropriate to use Overseer leach estimates then there are other available methods to establish a proxy baseline of nitrogen leaching and track improvements against that baseline.

Table 2. *Assessment method features for evaluation of mitigation at a range of scales (adapted from Cherry et al 2008).*

	Assessment method			
	Measurement	**Budgets**	**Risk Assessment**	**Models**
Mitigation type				
Source	x	x	x	x
Timing	x		x[1]	x
Transport	x		x	x
Scale				
Paddock	x	x	x	x
Farm	x	x	x	x
Catchment	x	x	x	x
National		x		x
Complexity				
Single mitigation	x	x	x	x
Multiple mitigations	x	x[2]	x[2]	x
Data requirements				
Paddock	Medium	Low	Low	Medium
Farm	Medium	Low	Low	Medium
Catchment	High	Medium	Medium	Medium-high[3]
National	High	Medium	High	Medium-high[3]
Uncertainty[4]				
Paddock	Low	Medium[5]	Low/medium	Medium
Farm	Low	Medium[5]	Low/medium	Medium
Catchment	Medium	Medium[5]	Medium	High
National	High	High[5]	High	High

Notes:
1. Sensitive to major changes in manure application timings
2. Gives no indication of interaction of multiple mitigation methods
3. Data requirements greater for process-based models than empirical models
4. Uncertainty also increases from source to timing to transport methods
5. Assumes loss is estimated from surplus

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Appendix I – Relationship between farm N inputs and nitrogen losses

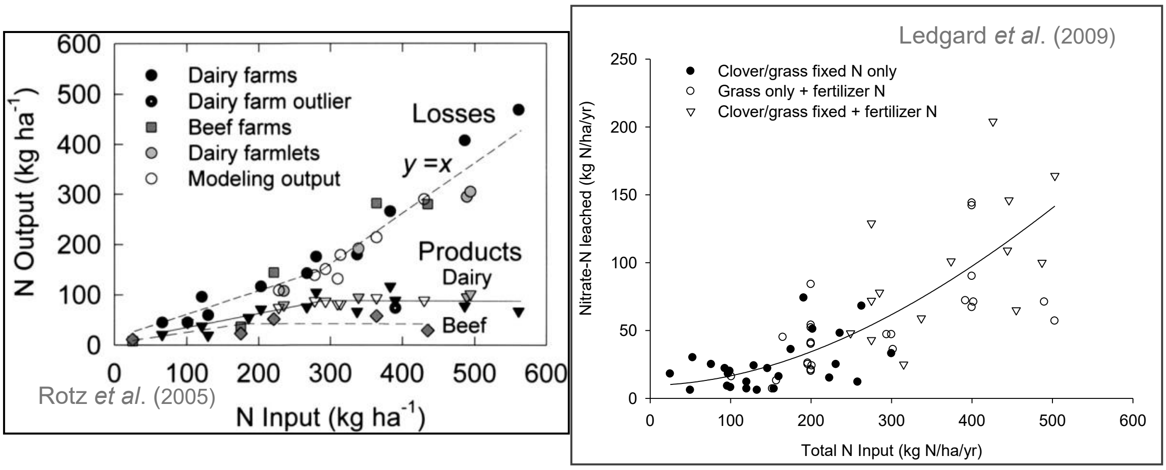

Figure A.1. *Experiments show that N losses to the environment increase as N inputs (as feed and fertiliser increase). Left hand graph: a collection of European studies showing relationship with losses of all forms of N. Right hand graph: NZ, UK, Danish and Irish studies showing the relationship with leaching*

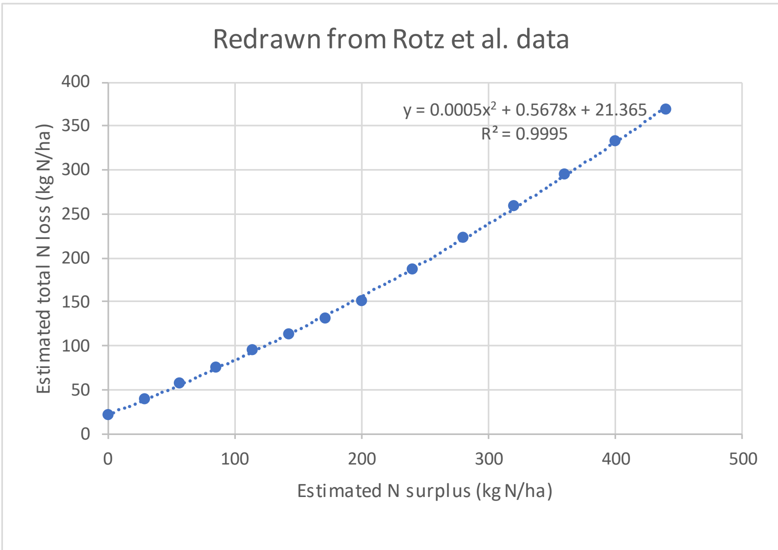

Figure A.2. *Fitted lines from Rotz et al (above) used to re-express the relationship as N loss vs N surplus.*

Appendix II - A summary of production and N leaching losses achieved in the four farm systems comparisons. In all cases comparing a 'Future' system targeting *lower nutrient losses was compared with a 'Current' system, typical of the region.*

Region	S.R. (cows/ha)	N fert. (kg N/ha)	Off-paddock?	Average production kg MS/ha	Average production % Change	kg N/ha	% Change	Method
Waikato (4 seasons)								
Current	3.2	c. 150	No	1193		54		Measured: NO_3-N, porous cups
Future	2.6	c. 50	Yes	1162	-3	31	-43	
Manawatu (3 seasons)								
Current	2.7		Part	1210		19		Measured: total N in pipe drainage
Future	2.8		Yes	1290	+7	11	-40	
Canterbury (4 seasons)								
Current	3.9	c. 300	Yes	1821		57		Modelled (OVERSEER)
Future	3.5	c. 150	Yes	1782	-2	32	-44	Milking platform only
South Otago (3 seasons)								
Current	2.9		No	963		18		Measured: soil mineral N in autumn and direct measurements of loss from winter forage crop areas
Future[1]	2.8		Yes	930, 947	-3, -2	14, 13	-24, -29	

Notes:

[1]South Otago - included two 'Future systems': values documented for a low N input and barn system, respectively

Appendix III – A summary of potential mitigations for adoption on-farm (pastoral) for decreasing N losses

NZ Mitigation description	Size of effect				Mode of action		Affects N	Comments
	NO_3-N	P-P	P-S	Z	Source	Transport	Surplus?	
Examples of Good management practice								
Deferred effluent irrigation (pond storage) - Increase the capacity of farm slurry (manure) stores to improve timing of effluent applications	L	L	M	-	Y		?	Only if changes result in a reduction in N fertiliser because more value is extracted from the effluent
Increased effluent application area - Enough land to apply agronomically sensible rates of effluent N (and other nutrients)					Y		?	Only if changes result in a reduction in N fertiliser because more value is extracted from the effluent
Use a fertiliser plan - Right fertiliser, right rate, right place, right time	L	L	L	-	Y		Y	
Better irrigation management	M	L	-	L	Y	Y	N	Source reduction if more pasture growth and N uptake from optimised irrigation. Reduction in transport due to less drainage
Examples of best management practice								
Change supplementary feed to Low N feed	L	L	L	-	Y		Y	Reduce dietary N and P intakes = less N in urine and dung
Restricted grazing (Tailored to region)	L	L	L	-		Y	N	Remove animals form paddocks at critical times for urine N deposition autumn/winter. Doesn't change the amount of N deposited, just where it is deposited
Establish riparian buffer strips	L	M	L	M		Y	N	Intercepts N on way to water course: considered a transport effect
Constructed/Facilitated wetland	L	M	L	M		Y	N	As above
Plant 'catch' crops and minimize fallow periods in rotations	M	M	L	M	Y		N	Removes leachable mineral N from the soil
Minimum till	L	M	L	M	Y		N	Adopt reduced cultivation systems
Optimise timing of cultivation practices	M	M	L	-	Y		N	Cultivate land for crops in spring rather than autumn
Fence off rivers and streams from livestock	L	L	L	-	Y		N	Avoid direct deposition into water plus protect stream edges
Examples of system change								
Decrease stocking rate to match lower N inputs (and increased per head performance)	L-M	L	L	L	Y		Y	Increase per animal production. Less N consumed per ha = less urinary N production

NZ Mitigation description	Size of effect				Mode of action		Affects N	Comments
	NO_3-N	P-P	P-S	Z	Source	Transport	Surplus?	
Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M	M	L	M	Y		Y	
Convert arable/grassland to permanent woodlands	H	M	L	M	Y		Y	
Examples of emerging mitigations								
Diverse pastures including plantain						Y		
Fodder beet					Y		Y	
New process inhibitors and targeted application machinery						Y	N	
Low N cows – bred for lower N excretion					Y		N	

[1]**Key:** L = Low = average 10% change (range 1-30%); M = Moderate = average 40% change (range 20-80%); H = High = average 70% change (range 50-90%); - = no effect; ? = uncertain effect. Farm level estimates of effectiveness are based on Newell-Price et al (2011)

Appendix IV – Pros and cons of different accounting methods (adapted from Cherry et al 2008)

Benefits	Limitations
Measurement	
• Actual not potential loss • Sensitive to all mitigation methods (N and P) • Applicable from field – catchment scale	• Long-term assessments required where delayed and buffered responses • Expensive and logistically difficult • Measurement and sampling uncertainty • Influence of site characteristics on results • Difficult to differentiate gross reductions from other confounding environmental variables • Exploitation of data limited by incomplete understanding
Nutrient budgets	
• Simple to calculate • Easy to adjust for mitigation assessment • Low data requirements (soil surface and farm gate balances) • Data readily available (esp.at farm scale) • Encourages nutrient awareness and improved nutrient use efficiency • Communicates the need to implement mitigation and increases farmer accountability • Targets mitigation • Monitors change and quantifies farm performance • Low cost • Responsive to mitigation • Applicable from field-national scale • Sensitive to source methods (N only)	• Unsuitable for P • Insensitive to timing and transport methods • Inconsistency in nutrient accounting systems • Few reference values • Input data uncertainty • Uncertainty in N content of manures and feed • Potential loss not actual loss predicted • Effect of farm system (arable vs livestock) on nutrient efficiency
Risk assessment	
• Provides rough estimate of risk/relative risk • Considers variable source areas (VSA) • Sensitive to source and transport methods (P only) • Can be adapted to suit local conditions • Encourages highly targeted mitigation • Application at field – catchment scale • Low data requirements • Data easy to obtain	• Potential loss not actual loss predicted • Unsuitable for N • Insensitive to small changes in timing • Input data uncertainty • Parameter uncertainty • Structural uncertainty • Reduction factors required. Refinement is necessary.

Benefits	Limitations
• Communicable and user friendly, engaging farmers and encouraging the adoption of mitigation	
Modelling	
• Actual not potential loss • Lower and more available data required for empirical and conceptual models • Sensitivity to all mitigation methods (Process models) • Sensitivity to source mitigation (empirical models) • Identification of principle pathways and sources, highlighting where mitigation should be targeted • Generates new knowledge and understanding • Sensitive to all mitigation methods (N and P) process models • Sensitive to source and transport methods (N and P) – conceptual models • Sensitive to source mitigation methods (N and P) – empirical models • Provides long and short-term assessments • Development of reduction factors to allow objective adjustment of parameters when simulating mitigation	• Process models are computational intense and require expertise to operate them • Large data requirements • Semi distributed therefore cannot model precise location of catchment migration • Validation required confirming prediction of actual not potential loss • Input data uncertainty • Parameter uncertainty • Structural uncertainty • Reduction factors required. Refinement is necessary • Incomplete historic land use data • Not user friends • Not communicable or engaging