Contaminant Loss Risk Index Tool

Technical document

Ministry for the Environment
Manatū Mō Te Taiao

Te Kāwanatanga o Aotearoa
New Zealand Government

Disclaimer

The information in this publication is, according to the Ministry for the Environment's best efforts, accurate at the time of publication. The Ministry will make every reasonable effort to keep it current and accurate. However, users of this publication are advised that:

- the information does not alter the laws of New Zealand, other official guidelines, or requirements
- it does not constitute legal advice, and users should take specific advice from qualified professionals before taking any action based on information in this publication
- the Ministry does not accept any responsibility or liability whatsoever whether in contract, tort, equity, or otherwise for any action taken as a result of reading, or reliance placed on this publication because of having read any part, or all, of the information in this publication or for any error, or inadequacy, deficiency, flaw in, or omission from the information in this publication
- all references to websites, organisations or people not within the Ministry are for convenience only and should not be taken as endorsement of those websites or information contained in those websites nor of organisations or people referred to.

Authors

RW McDowell, Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand and AgResearch, Lincoln Science Centre, Lincoln, New Zealand

VO Snow, AgResearch, Lincoln Science Centre, Lincoln, New Zealand

BM Jackson, BEEA Limited, Wellington, New Zealand and Victoria University of Wellington, Wellington, New Zealand

R Tamepo, Scion Research, Rotorua, New Zealand

K Muraoka, Ministry for the Environment, Wellington, New Zealand

EJC Soal, Ministry for the Environment, Wellington, New Zealand

T Cornwell, Ministry for the Environment, Wellington, New Zealand

G Rys, Ministry for Primary Industries, Wellington, New Zealand

This document may be cited as: Ministry for the Environment. 2024. *Contaminant Loss Risk Index Tool: Technical document*. Wellington: Ministry for the Environment.

Published in April 2024 by the
Ministry for the Environment
Manatū mō te Taiao
PO Box 10362, Wellington 6143, New Zealand
environment.govt.nz

ISBN: 978-1-991140-13-5
Publication number: ME 1825

Contents

Tables

Figures

Background

In response to the 2018 Overseer review,[1] a Science Advisory Panel concluded it did not have confidence in Overseer's estimates of nitrogen (N) lost from farms across the ranges of New Zealand's climate, topographies and land uses. Due to this, the Parliamentary Commissioner for the Environment declared Overseer not fit for purpose in a regulatory or catchment management context (Parliamentary Commissioner for the Environment, 2018). The government response in 2021, based on advice by an External Advisory Group, committed to the creation of a *new risk index* to provide a practical way of identifying areas of greater N-loss risk on land, to help meet freshwater outcomes (Ministry for the Environment, 2021).

In 2021 the Government committed to providing a risk index tool to councils that will, as part of a multi-evidence approach, inform freshwater decision-making. The Risk Index Tool (RIT) seeks to provide the best estimation of N-loss risk for land managers, therefore, it will:

- be evidence based
- include environmental and anthropogenic factors
- be suitable for farm-scale use.

The RIT will provide an overall risk score associated with:

- farm type
- farm practices and inputs
- biophysical characteristics: soil, slope, climate.

A priority exercise with regional councils determined that N species be the primary focus of the RIT's first iteration. With this, the Ministry for the Environment (the Ministry) acknowledges that the first iteration of the RIT would need further development to ensure it provides risk scores for a range of diffuse contaminants (eg, phosphorus, sediment and *Escherichia coli*).

The RIT was developed using the best available data. The Ministry acknowledges that further work is needed to address limitations and challenges around the assumptions of the data to the RIT.

The Ministry is leading the development of the RIT. It is supported by input from an expert panel of scientists, Māori perspectives and by the Our Land and Water National Science Challenge.[2]

---

1 The review was an independent investigation of the nutrient management model that could help inform the debate around its role in improving water quality and identify how Overseer could be improved to be better suited for use as a regulatory tool (Parliamentary Commissioner for the Environment, 2018).

2 The Our Land and Water National Science Challenge provided Agricultural Production Systems sIMulator (APSIM) modelling of biophysical data that underpins the Risk Index Tool (RIT) risk calculation service.

How the Risk Index Tool could be used in regulation

The RIT is a decision-support tool that could help inform users, as a part of a multi-evidence approach, to implement freshwater farm plans and/or the National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) to achieve better freshwater quality outcomes. However, the use of the RIT is not mandated by the Ministry.

Councils may choose to use the RIT to inform:

- freshwater farm plans
- consent applications and consent conditions
- regional plans.[3]

Freshwater farm plans are a tool to better manage the adverse effects of farming activities on freshwater and freshwater ecosystems by identifying practical actions on farm tailored to a particular farm's circumstances, its physical environment and what is important in the catchment.[4] The RIT could be used to help inform the identification of on-farm risks and actions, to help meet freshwater farm plan requirements.

Resource consents are essential for managing our natural resources and achieving freshwater outcomes. The RIT could help users prepare consent applications by identifying areas of risk of N loss from land to water and actions to mitigate this risk. The tool could also help councils determine what actions, if any, should be required in consent conditions and whether consent should be granted.

At a regional level, RIT assessments could be used to inform a review of N-loss risk 'hot spots' within catchments and receiving environments. Having this regional perspective could aid land managers in achieving freshwater outcomes. Councils should note that the first iteration of the RIT is not suitable for allocation or accounting purposes. The Ministry is capturing potential future functionality options of the RIT and these will be included for future iteration consideration.

The Ministry will provide two pieces of guidance.

1. Implementation guidance will be provided for councils on the use of the RIT in differing regulatory settings. The guidance will help councils understand the potential use of the RIT as an informative tool for regulatory-based decision-making and it provides guidance on the tool's application, including how the RIT should not be used. The guidance will include an overview of how the RIT works, including assumptions and limitations, and how the RIT can support resource consent processing and freshwater farm plans. Others can use the guidance to understand the RIT's role in environmental regulation.
2. A user guide will be provided (eg, for farmers, growers, nutrient and farm advisors) to guide them through the operational use of the tool. The guide will provide users with step-by-step instructions on how to spatially map and block their farm or orchard, enter required data and complete the risk assessment.

---

3 Councils will need to develop their own specific scenarios to determine what the risk scores mean in their catchment contexts.

4 For additional information on freshwater farm plans, visit the Ministry for the Environment website: environment.govt.nz/acts-and-regulations/freshwater-implementation-guidance/freshwater-farm-plans.

Introduction

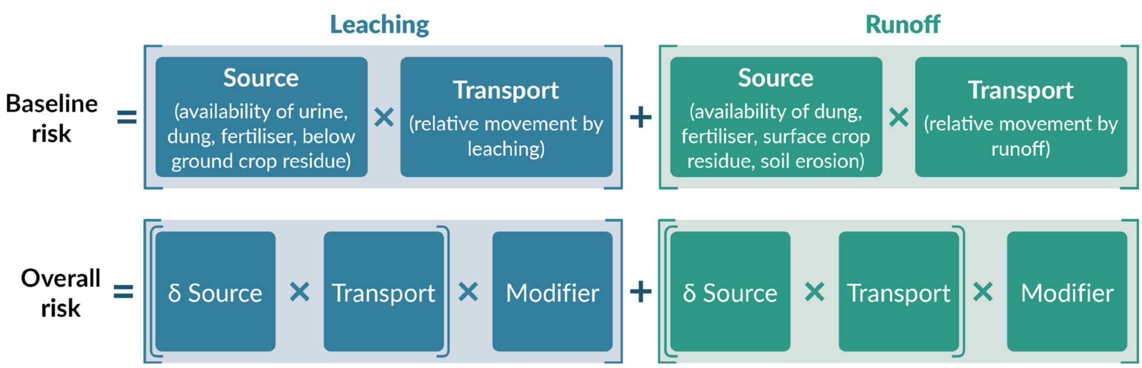
The scientific details of RIT framework described in this document are implemented to operate as a web-based application with a geographic information system- (GIS-) based graphic user interface. The framework is built on publicly available data, scientific knowledge and Agricultural Production Systems sIMulator (APSIM) modelling of robust climate, landform and land use combinations. The web-based implementation of the framework will trigger the estimation of N-loss risk when users enter their farm management information.

The approach taken in the design of the RIT was to ensure the elements most critical to N-loss risk were considered. These elements are anthropogenic N inputs (eg, fertiliser application, stocking rate) and biophysical characteristics (eg, soil, slope, climate). The RIT draws on those used in other jurisdictions to identify and manage (and namely mitigate) the risk of N loss at a property scale (Delgado et al, 2006; Figueroa-Viramontes et al, 2016; McDowell et al, 2002).[5]

The **overall risk** of N loss per hectare is determined by modification, through actions or practices, of the baseline risk. The **baseline risk** is the product of the risk associated with management of N **sources** (inputs; kilogram per hectare (ha^{-1})) and characteristics inherent in the landscape that affect N **transport** (a scaling factor) at a block level.[6] This baseline risk is then **modified** by actions or practices that can affect N-loss risk. If these actions and practices alter sources, we term them mitigations. If they act outside of sources, for example a wetland, we term them modifiers (figure 1).

Block-level risk is aggregated to the property level, but risks can also be shown to indicate more granular high-risk areas within the farm. In response to the Science and Advisory Panel's review of Overseer, we chose to estimate risk of N losses via vertical and non-vertical flow paths, which we term 'leaching' and 'runoff' respectively. Note that runoff includes surface runoff and interflow and is calculated as water lost after accounting for leaching and evapotranspiration. The forms of N considered as lost by leaching are largely nitrate-N (although this also considers transformations from non-nitrate forms) and total N (including dissolved and particulate nitrate and non-nitrate forms) in runoff.

Figure 1: Conceptual outline of the nitrogen loss risk index at a block scale for leaching and runoff



5 For an existing example, see: www.ars.usda.gov/npa/spnr/nitrogentools.

6 Due to the strong influence of management practices on N losses, a block is defined as a block or shape of land within a farm or orchard boundary that is subject to similar and consistent farm management practices over a year.

In equation form, monthly baseline risk is calculated as:

$$Leaching\ index = \sum((leach\ \times urine) + (leach \times dung) + (leach \times fert) + (leach \times bg\ residues)) \quad \text{[Eqn 1]}$$

$$Runoff\ index = \sum((runoff\ \times soil\ erosion) + (runoff \times dung) + (runoff \times fert) + (runoff \times ag\ residues)) \quad \text{[Eqn 2]}$$

Where 'leach' and 'runoff' are transport risks for leaching and runoff, and 'urine', 'dung', 'fertiliser' and 'residues' are the monthly kilograms of nitrogen per hectare (kg N ha^{-1}) input via urine and dung (as calculated in appendix A), fertiliser (including effluent contributions from appendix A) and below-ground ('bg') and above-ground ('ag') residues as calculated by appendix B, respectively.

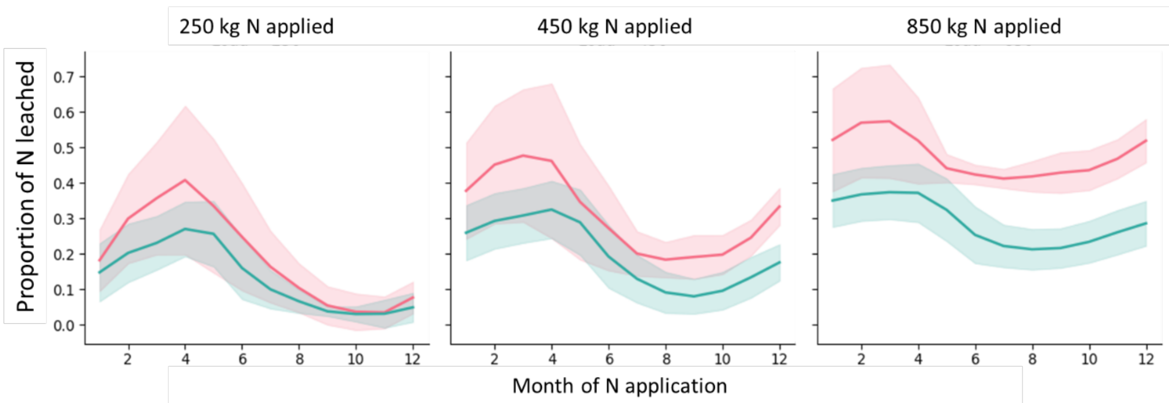
Process to estimate baseline nitrogen-loss risk

Estimating transport risk

The first part of the process is to estimate the leaching and runoff transport risks. These are inherent processes largely driven by features at the location and not under the control of the land manager. For the leaching risk, it might be expected that the risk could be modelled from the transport of a tracer (eg, chloride, bromide) through the soil to some depth, however, a tracer would miss the effect of soil processes and vegetation influencing, and mostly decreasing, the risk. Given that, we used a spike of N fertiliser rather than a tracer. This means, for example, if the growth conditions encourage high uptake of N by vegetation then the leaching risk is decreased. A scheme based on N, rather than a tracer, also allows greater differentiation of risk across the year and highlights the impacts of management actions at risky times of the year.

The next step was to select a value for the amount of N to be applied in lieu of a tracer. Figure 2 shows the relationship, generated through modelling with APSIM, between the quantity of a spike of N applied to a soil and the proportion of that N that will eventually leach by month of N application for two highly contrasting soil-location combinations. Little differentiation can be seen between soil location at low N amount and by month of application at high N amount. At intermediate values (here 450 kg N/ha) of the N spike, good differentiation is visible by both soil location and month of activity. Guided by this information, 450 kg N/ha was selected as the amount to use in the calculation of the leaching transport risk.

Figure 2: Relationship between the amount of nitrogen (N) applied as a spike with the proportion of N leached within the next two years for a shallow irrigated soil in Canterbury (blue) and a deep unirrigated soil in Waikato (orange)



Note: The shaded area shows the standard deviation across 40 years.

Source: Data from Snow et al (*in prep*)

The RIT's user will isolate the coordinates of one or more blocks of land within their property under the same management. Guidelines on what constitutes a block and what users should consider for consistent management will be articulated through the Ministry's Risk Index Tool: Phase one implementation guidance.

For each of these blocks there is a matching estimate of risk of transporting N via *leaching* (which includes the effects of N dynamics over time) and transport of water by *runoff* derived from APSIM[7] modelling (see figure 3) under either rainfed or irrigated conditions (Holzworth et al, 2014).

The vertical transport risk is calculated as the total amount of N leached over two years (to allow all N to pass through the soil profile) after the addition of a spike of N to the soil, divided by the amount of N in the spike. The horizontal transport risk is calculated as the amount of runoff in the 30 days after the 15th of the month divided by 200 (which was the 98th percentile of all runoff values). The above values are calculated for each location-irrigation-month-year combination. The transport risks for each location-irrigation-month combination are calculated as the median across the 41 years (the maximum period of climate data). Transport risks have been assessed monthly, for example the risk of eventual leaching from a N application made in April, to allow differentiation between the same action being made at more or less risky times of year.

The transport risk is aggregated to monthly risk so the underlying transport calculation reflects daily variation in, for example, climate, but management information can be input without an onerous level of day-to-day recording by the RIT user. This part of the risk is fixed by location and will not change every year unless the irrigation status is changed. The source component of the baseline risk is taken from management actions in the previous reporting year and so does have the potential to change each year.

Transport risks by leaching and runoff are then multiplied by the monthly inputs of N from different sources (discussed in 'Data sources') to yield a relative risk of N loss for each flow path and month. Note that, although inputs are in kilograms N ha^{-1} and risk is calculated per hectare, the risk of N loss cannot be assumed to be exactly the same as the mass of N loss (see appendix F).

Use of Agricultural Production Systems sIMulator

The principal APSIM models used included:

- AgPasture to simulate a ryegrass and white clover pasture (Li et al, 2011)
- Micromet to calculate radiation interception and evaporative demand in the mixed sward (Snow and Huth, 2004)
- SoilWater, which uses a layered tipping bucket to model soil water storage and movement
- SoilNitrogen to model the carbon–nitrogen cycle (both models as described by Probert et al (1998), ported to the .NET environment). APSIM has been used and validated extensively, both internationally and in New Zealand (Archontoulis et al, 2014; Cichota et al, 2010, 2018; Hoffmann et al, 2018; Vogeler et al, 2022).

---

[7] See www.apsim.info, for more information.

The combinations modelled in APSIM within and across blocks use:

(a) weather – around 10,000 locations represented by the National Institute of Water and Atmospheric Research (NIWA) Virtual Climate Station Network (VCSN)[8] (Cichota et al, 2008; Tait et al, 2006), or corrections to account for gaps around coastlines, from 1978 to 2018 (41 application-years)[9]

(b) soil – siblings within S-Map or S-Map siblings inferred from the Fundamental Soil Layer dataset (Manaaki Whenua – Landcare Research, 2014) present within each VCSN grid square

(c) irrigation – assuming a well maintained and scheduled centre-pivot irrigator.

APSIM was set up to run for each of 41 years and 12 months using the above combinations (Cichota et al, 2021; Vogeler et al, 2022). A ryegrass and white clover pasture was set as the baseline crop, and an application of 450 kg N per hectare (ha^{-1}) made on the 15th of a given month (for each month in those 41 years). Outputs from the simulations used in the RIT are the median N leached divided by 450 (refer to spike input) and the median amount of runoff (millimetres). Leaching risk is assessed for two years after N application and runoff risk for 30 days after application.

A full description of the APSIM set up above and its testing will be submitted as a journal publication in late 2023.

Calculating risk of leaching and runoff

To calculate the risk of N leaching for a block, the leaching transport risk is multiplied by the amount of N applied to the soil for each month. The sources of N input to the soil are (currently) excreta (urine and dung) from grazing animals, fertiliser (mineral and organic) and crop residues.

To calculate transport risk via runoff, we used runoff calculated by APSIM for the 30 days following the 15th of the relevant month. Runoff is driven by static and dynamic soil conditions and weather in combination with New Zealand-specific curve numbers[10] generated by Manaaki Whenua – Landcare Research (Vogeler et al, 2022). Using runoff generated from APSIM maintains a relativity, scaling transport by runoff relative to that via drainage. APSIM does not differentiate between infiltration-excess and saturation-excess runoff.

The sources of N for runoff risk are dung (we consider urine-N to be washed into the soil) from grazing animals, fertiliser (mineral and organic, including effluent), crop residues (shoots only) and soil erosion (figure3). The risk for dung from October to May is only for a 15-day period (or half a month, otherwise for all of the month from June to September), because the availability of N declines rapidly with time as dung pats crust over (McDowell et al, 2006). As with leaching, sources of N for runoff are measured as kilogram N ha^{-1}, to maintain consistency with user records (eg, fertiliser).

---

[8] National Institute of Water and Atmospheric Research. *Virtual Climate Station data and products*. Retrieved 6 December 2023.

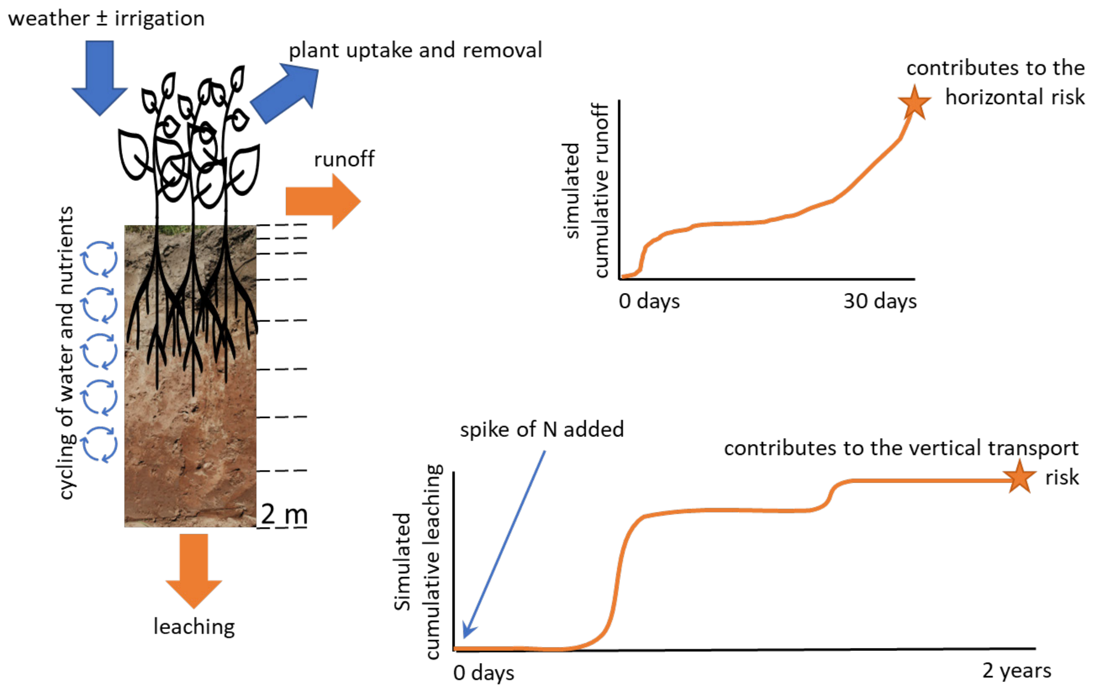
[9] It is acknowledged that gaps exist in the VCSN in (primarily) coastal areas. This will be addressed through the RIT back-end calculator functions, using proximate network data.

[10] Curve numbers define the shape of the rainfall–runoff relationship and vary from 0 (no runoff) to 100 (complete runoff).

Transport risks are a risk scaling factor (ie, multiplier) rather than the proportion of the source being transported. In addition, owing to attenuation that would change transport factors with increasing scale, the RIT output is dimensionless (figure 3).

Figure 3: How modelling is used to calculate the transport risk elements of the baseline risk

a single simulation provides data for a particular month and year in a given location (soil, climate) for either dryland or irrigated conditions



the median across all years gives the <u>transport risk</u> for a given location, month and irrigation condition

Note: Each independent simulation, as shown in the paragraph text above, was for a particular soil-climate-irrigation-month-year combination with the median across years taken to calculate transport risk.

Incorporating mitigations and modifiers

After calculating baseline risk, risk can then be adjusted (preferably down) by applying certain practices, often called mitigations; however, note our use of the term below. Incorporating these practices was a two-step process. The first step determined the range and effect of suitable practices for Aotearoa New Zealand enterprises. The second step determined how each of those practices on their own or in combination would affect N-loss risk.

For step one, practices were supplied by industry sectors and interested parties. These were parsed against published literature leading to open and transparent estimates of their effectiveness. We only included practices that had:

1. accessible and robust published literature. Grey literature was included where the report was peer reviewed and no conflict of interest existed (eg, commercial gain) with the commissioning agency
2. data were sourced from multiple, and preferentially replicated, studies
3. evidence had good geographic spread and relevance.

For step two, practices can act by changing (δ) the baseline risk **sources** or by **modifying** runoff and leaching risks after baseline risk have been calculated (figure 1). When implementing practices, they are first filtered for their relevance to the land use (cropping, dairy, deer, sheep and beef, forestry and horticulture), flow path (runoff or leaching) and then applied by either changing the baseline risk source inputs (urine, dung, fertiliser and soil mineral N) or modifying baseline risk scores.

- We term those practices that alter baseline risk by adjusting the source of N as **mitigations**.
- We term those practices that adjust the risk of N loss after calculating baseline risk as **modifiers**.

After filtering, most changes for mitigations, such as changing fertiliser inputs, or stocking rate (which alters urine and dung N inputs) will be determined by user inputs but assisted by a table of options (see table 1 for an example of its structure and appendix E for the full table). Some changes will be too complicated to fit into one table. For example, change in the risk of loss by crop residues and soil mineral N will be influenced by the crop rotation. Here, we have constructed a table of crops that enable the user to input their crop (or fallow) for each month and the effect on residues output (see appendix B). Because most source mitigations act by changing inputs, it is possible to use one or many source mitigations via this route.

Table 1: Example source mitigation table showing the filtering

Mitigation	Actioned via	Enterprise filter	Flow path filter	Soil × slope × climate filter	References
Changing stocking rate	Alter source inputs (stocking rate – dung and urine)	Dairy, deer, sheep and beef	Leaching and erosion	NA	Beukes et al, 2012; Gourley and Weaver, 2012; Silva et al, 1999
Reduction of nitrogen fertiliser	Alter source inputs (fertiliser)	All	Leaching and runoff	NA	de Klein et al, 2017; Ledgard et al, 1999
Diuretics	Alter source inputs (stocking rate – dung and urine)	Dairy, deer, sheep and beef	Leaching	NA	Ledgard et al, 2015

Note: Wetlands can only be applied to specific soil by slope by climate scenarios; see table 2) of mitigations to a land use flow path and source.

Modifiers, or practices that aim to reduce risk outside of sources, act by multiplying the risk score for runoff and leaching by a value between 0 and 1. For modifiers, it is assumed they will be presented and used in the order of most to least effective and that any subsequent modifiers would act upon the product of the previous modifier. For example, let us assume we have a block with a runoff risk of 100. If a natural wetland has the potential to reduce N loss (and therefore risk) by 20 per cent and a constructed wetland downstream but in the same block has a potential to reduce risk by 10 per cent, the calculation would be 100 × 0.8 = 80 followed by 80 * 0.9 = 72. This process reflects the diminishing returns associated with the sequential implementation of multiple edge-of-field mitigations (McDowell et al, 2021) and a strong likelihood that the remaining N will become increasingly refractory. We do not account for potential synergies or antagonisms between practices in the implementation of modifiers.

Most modifiers have variable effectiveness caused by climate, slope and soil type. User input information on these factors is used to filter out unsuitable climate-by-soil type combinations. The user inputs then select, for a set of suitable climate-by-soil type combinations, the appropriate effectiveness for a modifier (eg, table 2). We also assume that modifiers like a constructed wetland or a denitrification bed are placed in the optimal position to intercept runoff or leaching prior to exiting the block.

Table 2: **Example listings for constructed wetlands modified after filtering for enterprise (all) and flow path (leaching [L] and runoff [R])**

Description	Soil × slope × climate filter	Multiplier (0–1)	References
Constructed wetland – small **North Island:** Assumed wetland size is approximately 1% of catchment area and that catchments are approximated by a block. Assumed mean annual air temp is more than 12ºC. Excludes highly permeable soils not able to sustain a wetland.	Slope less than 15º, precipitation 800–1,600 mm	R=0.75, L=0.88	Tanner et al, 2022; Tanner and Kadlec, 2013; Tanner and Sukias, 2011
Constructed wetland – medium **North Island:** Assumed wetland size is approximately 2% of catchment area and that catchments are approximated by a block. Assumes mean annual air temp is more than 12ºC. Excludes highly permeable soils not able to sustain a wetland.	Slope less than 15º, precipitation 800–1,600 mm	R = 0.64, L= 0.82	Tanner et al, 2022; Tanner and Kadlec, 2013; Tanner and Sukias, 2011

Testing of baseline risk

A database was created containing 155 observations of N loss to freshwater from 55 studies of different land uses (Drewry et al, 2022) (figure 4). The database contained 114 measured and 41 modelled (via APSIM or SPASMO[11]) observations for known locations; 58 observations were of total N (TN) and 124 observations were of nitrate-N. Amongst land uses were three observations for beef, 31 for cropping, 47 for dairy, 8 for deer, 13 for exotic forestry, 4 for gorse, 21 for horticulture, 7 for native forest, 10 for sheep and 11 for vegetables. Fifty-one observations were of runoff (often combining leaching and surface runoff) and 104 were of leaching losses. Additional data were collated for stocking rate (46 observations) and annual N fertiliser application (97 observations).

Currently, there is a lack of coverage for whenua Māori when testing the baseline risk tool. To test the performance of the index on whenua Māori and land use capability (LUC) Class 6 and above, additional N-loss data will need to be gathered.

Figure 4: Location and dominant land use of nitrogen-loss observations

Note: Some indication is given of whether the observations were modelled or measured.

---

[11] Green, S. R., C. van den Dijssel, V. O. Snow, B. E. Clothier, T. Webb, J. Russell, N. Ironside and P. Davidson (2003). SPASMO - A risk assessment model of water, nutrient and chemical fate under agricultural lands. Tools for nutrient and pollutant management: Applications to agriculture and environmental quality. Occasional Report No. 17. L. D. Currie and J. A. Hanly. Palmerston North, New Zealand, Fertilizer and Lime Research Centre, Massey University: 321–335.

We reinspected this database and categorised the observations by land use and flow path (separating, where possible, runoff from leaching). We then augmented fertiliser data with N inputs on a monthly basis for dung and urine (converting from the stocking rate data via appendix A), soil N concentration (Stats NZ, 2022) on a soil order by land use basis, and soil N inputs via cultivation (if converting from pasture) and N inputs from crop residues (Thomas et al, 2011, 2014). Observations were filtered out where there was low confidence in N inputs, the location or where observations were recorded at an inappropriate scale (eg, a catchment greater than 10 hectares).

Using each observation's location, modelled transport risks were multiplied by our estimates of N sources (as per the baseline risk index). Risks were separated and combined across runoff and leaching, and by scale (eg, lysimeter, plot or farm) and those risks plotted against the observations. We also determined the sensitivity of sources on risk scores by increasing or decreasing inputs in the filtered and observed data by 50 per cent and expressed their effect on the overall index score relative to the mean of the original data.

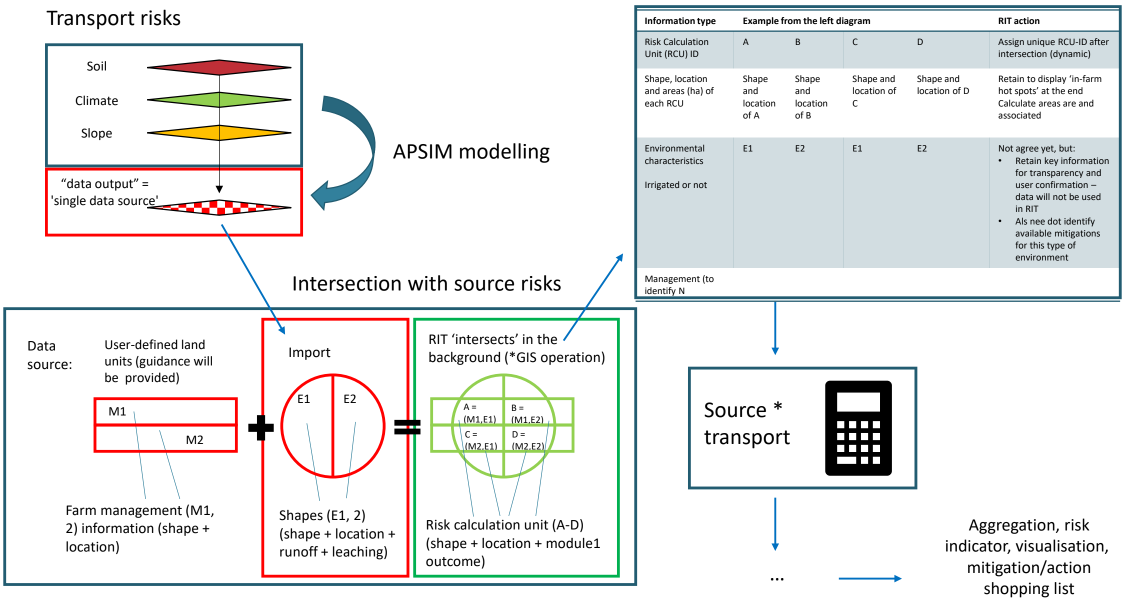
We used these plots to determine if there was good agreement between the range and response of the risk of N loss and observed losses for different land uses (and their recorded management). See appendix F for the output.

During this analysis, we noted that only two of the observations were from Māori-owned land. Furthermore, we note that, on average, Māori-owned land tends to be smaller and have less coverage in finer soil information databases like S-Map than general title land. Although this suggests the RIT may be less representative of Māori than non-Māori-owned land we have no data to say that the performance of the RIT in estimating the risk of N loss is any worse than for general title land.

Aggregating risk to greater scales

The risk scores derived at the block scale are an **area weighted average** at the finer soil type by slope by climate by management block intersection (risk calculation unit; see figure 5 for intersection). Aggregation of leaching and runoff risks is calculated **separately**. Aggregation of source mitigations is included. However, adjustment of risk scores for modifiers only occurs after block scale baseline risks have been calculated. Farm risk is calculated as the area-weighted risk of modified blocks.

Figure 5: General geographic information system workflow showing the intersection (green box) of soil by slope by climate and the subsequent calculation of risk



Note: Irrigation condition is included in Agricultural Production Systems sIMulator (APSIM) modelling.

Source: Image used with permission from the Our Land and Water National Science Challenge

Mathematically, an area weighted average risk score (*R_average*), that is, risk per hectare will be calculated as the sum of the product of risk for each of the finest spatial units (*R_rcu*; ie, soil type by slope by climate intersection intersected to farm block) and area, divided by the sum of areas:

$$R\_average = \frac{\sum(R\_rcu \times Area\_rcu)}{\sum Area\_rcu}$$

where *Area_rcu* is the area of the risk calculation spatial unit (*rcu*), and the summation operated is for the aggregation destination scale (ie, block and farm scales).

We note this aggregation has the possibility of overly discounting a very high risk from a small fraction of the farm area when reported at a block or farm scale. However, the RIT is not standalone and exists along with farm environmental planning. The *rcu*-scale transport risks and block scale baseline risks should also be considered and are presented as outputs in the tool.

Data sources

Data are input by the user or, if some sources of N are unknown, via use of data contained in, for example, the Ministry for Primary Industries' Agricultural Inventory currently used for calculating New Zealand's agricultural greenhouse gas emissions reporting (Pickering et al, 2022). These peer-reviewed and openly available methods and data give estimates of N input for dung and urine for different stock types and ages, and crop residues and the effect of tillage and pasture renewal (Pickering et al, 2022).

Data for dung and urine-N sources (via animal type and stocking rate) are available monthly and by region for different age dairy cattle, annually for drystock (sheep, beef cattle and deer) by slope and economic class, and annually (only) for other livestock classes (pigs, goats, alpacas and poultry). See appendix A for these data.

Crop residue data is calculated via yield and the percentage of N residues remaining in the soil. Residues are calculated annually for crops (eg, barley, wheat, oats, maize, onions, potatoes, brassicas, squash, peas, legumes, apples, vines and avocados) (Thomas et al, 2020). See appendix B for these data.

To calculate erosion, we employ the Revised Universal Soil Loss Equation calibrated for livestock grazing in New Zealand (Donovan, 2022). The N sourced via erosion risk is calculated as the product of sediment loss (kg ha^{-1}), for a user-defined enterprise and slope class, and soil total N concentrations (g kg^{-1}) (Stats NZ, 2022). Note that unproductive land is treated as if it were forested land with erosion considered to be the only source of N loss risk. See appendix C for how erosion risk is calculated.

In addition to these inputs, appendix D contains the N concentration of common N fertilisers.

Assumptions

General assumptions have been made in the development and for the assessment of the baseline N-loss RIT.

- Risks are for points in the landscape but are otherwise aspatial, meaning no account is made for the movement of N risks from one block to another.
- N-loss risks are relevant for the loss of nitrate by leaching, and for nitrate and non-nitrate forms of N for runoff. Nitrate was the dominant form of total N (96 per cent) lost in lysimeter to paddock- or farm-scale studies in New Zealand (Drewry, 2022), and that the slope of a regression between nitrate and total N was near to 1. We have therefore used and calibrated nitrate-N-loss by leaching to total N-loss risk, but do not claim to explicitly quantify the risk of non-nitrate N in leaching.
- For simplicity and brevity, we only considered well-implemented irrigation and generated a single layer across the country.
- We recognise that S-Map coverage on whenua Māori governed under Te Ture Whenua Māori Act 1993 (Māori Land Act 1993) is poor, therefore limitations are higher in these areas and assumptions are coarser.

Assumptions for leaching loss risks include the following.

- Bypass flow (non-equilibrium transport) is not accounted for.
- S-Map's (or analogues derived from fundamental soil layer data) soil properties are suitable for the purposes outlined here.
- APSIM's water, carbon and N processes are adequate for the purposes outlined here.
- The N applied onto a ryegrass/white clover pasture is a reasonable proxy of all land uses, although we aim to test this against shallow-rooted horticultural rotations (see appendix G).
- Risk increases linearly with the amount of N applied to the soil (in reality, the risk of leaching is only linear over particular ranges of N applied (Cichota et al, 2013)).

Assumptions for N losses in runoff are as follows.

- Runoff is assumed to be adequately modelled by a curve number approach. The curve number includes elements of infiltration-excess runoff insofar as higher daily rainfall amounts are also likely to be somewhat associated with higher rainfall intensities. Full consideration of infiltration-excess runoff is not possible because sub-daily rainfall data were not available as needed to estimate infiltration-excess runoff. The influence of infiltration-excess runoff will be looked at in subsequent iterations of the RIT.
- Modifications for the availability of N sources in runoff can vary according to the month of the year and type of source. For example, we estimate that the availability of N in dung deposited in winter is twice that deposited in summer and autumn (McDowell et al, 2006).

References

Archontoulis SV, Miguez FE, Moore KJ. 2014. Evaluating APSIM Maize, Soil Water, Soil Nitrogen, Manure, and Soil Temperature Modules in the Midwestern United States. *Agronomy Journal* 106(3): 1025–1040.

Beukes PC, Scarsbrook MR, Gregorini P, Romera AJ, Clark DA, Catto W. 2012. The relationship between milk production and farm-gate nitrogen surplus for the Waikato region, New Zealand. *Journal of Environmental Management* 93(1): 44–51.

Cichota R, Snow VO, Tait AB. 2008. A functional evaluation of virtual climate station rainfall data. *New Zealand Journal of Agricultural Research* 51(3): 317–329.

Cichota R, Snow VO, Vogeler I. 2013. Modelling nitrogen leaching from overlapping urine patches. *Environmental Modelling & Software* 41: 15–26.

Cichota R, Vogeler I, Sharp J, Verburg K, Huth N, Holzworth D, Dalgliesh N, Snow V. 2021. A protocol to build soil descriptions for APSIM simulations. *MethodsX* 8: 101566.

Cichota R, Voegler I, Snow VO, Shepperd M. 2010. Modelling the effect of a nitrification inhibitor on N leaching from grazed pastures. *Proceedings of the New Zealand Grassland Association* 72: 43–47.

Cichota R, Vogeler I, Snow V, Shepherd MA, McAuliffe R, Welten BG. 2018. Lateral spread affects nitrogen leaching from urine patches. *Science of the Total Environment* 635: 1392–1404.

De Klein CAM, Monaghan RM, Alfaro M, Gourley CJP, Oenema O, Powell, JM. 2017. Nitrogen performance indicators for dairy production systems. *Soil Research* 55(5-6): 479–488.

Delgado JA, Shaffer M, Hu C, Lavado RS, Wong JC, Joosse P, Li X, Rimski-Korsakov H, Follett R, Colon W, Sotomayor D. 2006. A decade of change in nutrient management: A new nitrogen index. *Journal of Soil and Water Conservation* 61(2): 62A–71A.

Donovan M. 2022. Modelling soil loss from surface erosion at high-resolution to better understand sources and drivers across land uses and catchments: A national-scale assessment of Aotearoa, New Zealand. *Environmental Modelling & Software* 147: 105228.

Drewry JJ, McDowell RW, Ghimire C, Noble A. 2022. *Collation of nutrient, sediment, and* E. coli *losses from land uses to freshwater, and an initial analysis of some factors contributing to nitrogen loss*. Palmerston North: Manaaki Whenua Landcare Research.

Figueroa-Viramontes U, Delgado JA, Sánchez-Duarte JI, Ochoa-Martínez E, Núñez-Hernández G. 2016. A nitrogen index for improving nutrient management within commercial Mexican dairy operations. *International Soil and Water Conservation Research* 4(1): 1–5.

Gourley CJP, Weaver DM. 2012. Nutrient surpluses in Australian grazing systems: management practices, policy approaches, and difficult choices to improve water quality. *Crop and Pasture Science* 63(9): 805–818.

Hoffmann MP, Isselstein J, Rötter RP, Kayser M. 2018. Nitrogen management in crop rotations after the break-up of grassland: Insights from modelling. *Agriculture, Ecosystems & Environment* 259: 28–44.

Holzworth DP, Huth NI, deVoil PG, Zurcher EJ, Herrmann NI, McLean G, Chenu K, van Oosterom EJ, Snow V, Murphy C, Moore AD, Brown H, Whish JPM, Verrall S, Fainges J, Bell LW, Peake AS, Poulton PL, Hochman Z, Thorburn Peter J, Keating BA. 2014. APSIM – Evolution towards a new generation of agricultural systems simulation. *Environmental Modelling & Software* 62: 327–350.

Ledgard SF, Penno JW, Sprosen MS. 1999. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *The Journal of Agricultural Science* 132(2): 215–225.

Ledgard SF, Welten B, Betteridge K. 2015. Salt as a mitigation option for decreasing nitrogen leaching losses from grazed pastures. *Journal of the Science of Food and Agriculture* 95(15): 3033–3040.

Li FY, Snow VO, Holzworth DP. 2011. Modelling the seasonal and geographical pattern of pasture production in New Zealand. *New Zealand Journal of Agricultural Research* 54(4): 331–352.

Manaaki Whenua – Landcare Research. *S-Map Online* 2014. Retrieved 13 February 2017.

McDowell RW, Monaghan RM, Smith C, Manderson A, Basher L, Burger DF, Laurenson S, Pletnyakov P, Spiekermann R, Depree C. 2021. Quantifying contaminant losses to water from pastoral land uses in New Zealand III. What could be achieved by 2035? *New Zealand Journal of Agricultural Research* 64(3): 390–410.

McDowell RW, Muirhead RW, Monaghan RM. 2006. Nutrient, sediment, and bacterial losses in overland flow from pasture and cropping soils following cattle dung deposition. *Communications in Soil Science and Plant Analysis* 37(1-2): 93–108.

McDowell RW, Sharpley AN, Kleinman PJ. 2002. Integrating phosphorus and nitrogen decision management at watershed scales. *Journal of the American Water Resources Association* 38(2): 479–491.

Ministry for the Environment. 2021. *Government response to the findings of the Overseer peer review report*. Wellington: Ministry for the Environment.

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

Pickering A, Gibbs J, Wear S, Fick J, Tomlin H. 2022. *Methodology for calculation of New Zealand's agricultural greenhouse gas emissions*. MPI Technical Paper. Version 8. Wellington: Ministry for Primary Industries.

Probert ME, Dimes JP, Keating BA, Dalal RC, Strong WM. 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems* 56(1): 1–28.

Silva RG, Cameron KC, Di HJ, Hendry T. 1999. A lysimeter study of the impact of cow urine, dairy shed euent, and nitrogen fertiliser on nitrate leaching. *Soil Research* 37(2): 357–370.

Stats NZ. 2022. *Soil quality and land use*. Retrieved 20 May 2022.

Snow VO, Cichota R, Lilburne L, McDowell RM, Tait A, et al (in preparation) Deriving Transport Risk Factors for New Zealand's Agricultural Lands. For submission to *Environmental Modelling and Software*.

Snow VO, Huth NI. 2004. *The APSIM–MICROMET module*. HortResearch Internal Report No. 2004/12848. Auckland: HortResearch.

Tait A, Henderson R, Turner R, Zheng X. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology* 26(14): 2097–2115.

Tanner CC, Depree C, Sukias J, Wright-Stow A, Burger D, Goeller B. 2022. *Constructed wetland practitioners guide: Design and performance estimates*. Hamilton: DairyNZ and NIWA.

Tanner CC, Kadlec RH. 2013. Influence of hydrological regime on wetland attenuation of diffuse agricultural nitrate losses. *Ecological Engineering* 56: 79–88.

Tanner CC, Sukias JPS. 2011. Multiyear nutrient removal performance of three constructed wetlands intercepting tile drain flows from grazed pastures. *Journal of Environmental Quality* 40(2): 620–633.

Thomas S, Ausseil A-G, Guo J, Herzig A, Khaembah E, Palmer D, Renwick A, Teixeira E, van der Weerden T, Wakelin SJ. 2020. *Evaluation of profitability and future potential for low emission productive uses of land that is currently used for livestock*. MPI Technical Paper No: 2021/13. Wellington: Ministry for Primary Industries.

Thomas S, Fraser T, Curtin D, Brown H, Lawrence E. 2011. *Review of nitrous oxide emission factors and activity data for crops*. Prepared for Ministry of Agriculture and Forestry by Crop and Food Research (Report No. 2240) August 2008. Wellington: Ministry of Agriculture and Forestry.

Thomas S, Wallace D, Beare M. 2014. *Pasture renewal activity data and factors for New Zealand*. Wellington: Plant and Food Research.

Vogeler I, Lilburne L, Webb T, Cichota R, Sharp J, Carrick S, Brown H, Snow V. 2022. S-map parameters for APSIM. *MethodsX* 9: 101632.

Vogeler I, Thomsen IK, Taube F, Poulsen HV, Loges R, Hansen EM. 2022. Effect of winter cereal sowing time on yield and nitrogen leaching based on experiments and modelling. *Soil Use and Management* 38(1): 663–675.

Appendix A: Animal nitrogen inputs via urine and faeces

RW McDowell[1, 2], EJC Soal[3]

[1] *Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand*

[2] *AgResearch, Lincoln Science Centre, Lincoln, New Zealand*

[3] *Ministry for the Environment, Wellington*

The following tables outline the nitrogen (N) excretion rates for livestock to be used as input values for different stock classes, ages and rates for leaching and runoff.

If a block is identified as receiving effluent, the quantity of fertiliser N is boosted by the N contained in the effluent (Luo et al, 2022) and the daily volume of wash down water (Stewart and Rout, 2007) (summed to 30 days from September to May) cycled through the effluent system and applied to land (assumes a travelling irrigator) where:

$$\text{Effluent N (kg month}^{-1}) = \text{Number of dairy cows} \times 70 \text{ L cow}^{-1}\text{ day}^{-1} \times 0.2 \text{ g N L}^{-1} \times 30 \text{ (days/month)/1,000 (g/kg)}$$

No data are currently available for effluent from dairy sheep or goats.

The tables are based on the New Zealand Agricultural Inventory Model (AIM). AIM is designed for inventory purposes and contains some features not consistent with the Risk Index Tool (RIT). The inconsistencies (less than 2 per cent of values) are entries of zero excreta values for some months where, at a regional or national scale, an animal class is not present. The RIT is applied at a sub-farm level, and so these assumptions can be problematic. In these cases, the excreta values were estimated from the existing data.

Dairy cattle

Table A.1: Nitrogen (N) excretion rates for different age classes of dairy cattle by region (2021–22)

Note: Estimated values are in italics with the method indicated in a footnote to the table.

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Auckland	Milking cows – mature	Jan	9.06	6.63	2.43
Auckland	Milking cows – mature	Feb	7.85	5.75	2.1
Auckland	Milking cows – mature	Mar	9.6	7.03	2.57
Auckland	Milking cows – mature	Apr	8.73	6.4	2.34
Auckland	Milking cows – mature	May	8.14	5.96	2.18
Auckland	Milking cows – mature	Jun	7.22	5.29	1.93
Auckland	Milking cows – mature	Jul	9.16	6.71	2.45
Auckland	Milking cows – mature	Aug	8.33	6.1	2.23
Auckland	Milking cows – mature	Sep	10.97	8.03	2.94

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Auckland	Milking cows – mature	Oct	10.78	7.89	2.89
Auckland	Milking cows – mature	Nov	10.05	7.36	2.69
Auckland	Milking cows – mature	Dec	9.78	7.16	2.62
Auckland	Growing heifers – 0–1	Jan	2.89	2.12	0.77
Auckland	Growing heifers – 0–1	Feb	2.86	2.1	0.77
Auckland	Growing heifers – 0–1	Mar	4.04	2.96	1.08
Auckland	Growing heifers – 0–1	Apr	4.23	3.09	1.13
Auckland	Growing heifers – 0–1	May	4.81	3.52	1.29
Auckland	Growing heifers – 0–1	Jun	4.76	3.49	1.27
Auckland	Growing heifers – 0–1	Jul	3.56	2.6	*0.95**
Auckland	Growing heifers – 0–1	Aug	3.56	2.6	*0.95**
Auckland	Growing heifers – 0–1	Sep	3.56	2.6	*0.95**
Auckland	Growing heifers – 0–1	Oct	1.87	1.37	0.5
Auckland	Growing heifers – 0–1	Nov	2.12	1.55	0.57
Auckland	Growing heifers – 0–1	Dec	2.5	1.83	0.67
Auckland	Growing heifers – 1–2	Jan	6.42	4.7	1.72
Auckland	Growing heifers – 1–2	Feb	6.04	4.42	1.62
Auckland	Growing heifers – 1–2	Mar	8.01	5.86	2.14
Auckland	Growing heifers – 1–2	Apr	7.88	5.77	2.11
Auckland	Growing heifers – 1–2	May	6.67	4.88	*1.79†*
Auckland	Growing heifers – 1–2	Jun	6.67	4.88	*1.79†*
Auckland	Growing heifers – 1–2	Jul	5.27	3.86	1.41
Auckland	Growing heifers – 1–2	Aug	5.52	4.04	1.48
Auckland	Growing heifers – 1–2	Sep	5.58	4.08	1.49
Auckland	Growing heifers – 1–2	Oct	5.32	3.9	1.43
Auckland	Growing heifers – 1–2	Nov	5.49	4.02	1.47
Auckland	Growing heifers – 1–2	Dec	6	4.39	1.61
Auckland	Breeding bulls	Jan	8.13	5.96	2.18
Auckland	Breeding bulls	Feb	7.38	5.4	1.98
Auckland	Breeding bulls	Mar	9.42	6.9	2.52
Auckland	Breeding bulls	Apr	8.94	6.55	2.39
Auckland	Breeding bulls	May	9.36	6.86	2.51
Auckland	Breeding bulls	Jun	8.6	6.3	2.3
Auckland	Breeding bulls	Jul	8.93	6.54	2.39
Auckland	Breeding bulls	Aug	8.77	6.42	2.35
Auckland	Breeding bulls	Sep	8.37	6.13	2.24
Auckland	Breeding bulls	Oct	7.63	5.59	2.04
Auckland	Breeding bulls	Nov	7.51	5.5	2.01
Auckland	Breeding bulls	Dec	7.84	5.74	2.1
Bay of Plenty (BOP)	Milking cows – mature	Jan	11.14	8.16	2.98
BOP	Milking cows – mature	Feb	9.53	6.98	2.55
BOP	Milking cows – mature	Mar	11.52	8.43	3.08
BOP	Milking cows – mature	Apr	10.19	7.47	2.73

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
BOP	Milking cows – mature	May	8.89	6.51	2.38
BOP	Milking cows – mature	Jun	7.37	5.39	1.97
BOP	Milking cows – mature	Jul	9.4	6.88	2.52
BOP	Milking cows – mature	Aug	9.72	7.11	2.6
BOP	Milking cows – mature	Sep	13.81	10.12	3.7
BOP	Milking cows – mature	Oct	13.74	10.06	3.68
BOP	Milking cows – mature	Nov	12.86	9.42	3.44
BOP	Milking cows – mature	Dec	12.33	9.03	3.3
BOP	Growing heifers – 0–1	Jan	2.9	2.13	0.78
BOP	Growing heifers – 0–1	Feb	2.88	2.11	0.77
BOP	Growing heifers – 0–1	Mar	4.06	2.97	1.09
BOP	Growing heifers – 0–1	Apr	4.25	3.11	1.14
BOP	Growing heifers – 0–1	May	4.84	3.54	1.3
BOP	Growing heifers – 0–1	Jun	4.79	3.51	1.28
BOP	Growing heifers – 0–1	Jul	3.58	2.62	*0.96**
BOP	Growing heifers – 0–1	Aug	3.58	2.62	*0.96**
BOP	Growing heifers – 0–1	Sep	3.58	2.62	*0.96**
BOP	Growing heifers – 0–1	Oct	1.88	1.38	0.5
BOP	Growing heifers – 0–1	Nov	2.13	1.56	0.57
BOP	Growing heifers – 0–1	Dec	2.52	1.84	0.67
BOP	Growing heifers – 1–2	Jan	6.45	4.73	1.73
BOP	Growing heifers – 1–2	Feb	6.07	4.44	1.62
BOP	Growing heifers – 1–2	Mar	8.05	5.89	2.15
BOP	Growing heifers – 1–2	Apr	7.92	5.8	2.12
BOP	Growing heifers – 1–2	May	6.71	4.91	*1.79†*
BOP	Growing heifers – 1–2	Jun	6.71	4.91	*1.79†*
BOP	Growing heifers – 1–2	Jul	5.3	3.88	1.42
BOP	Growing heifers – 1–2	Aug	5.55	4.06	1.48
BOP	Growing heifers – 1–2	Sep	5.61	4.11	1.5
BOP	Growing heifers – 1–2	Oct	5.35	3.92	1.43
BOP	Growing heifers – 1–2	Nov	5.52	4.04	1.48
BOP	Growing heifers – 1–2	Dec	6.03	4.41	1.61
BOP	Breeding bulls	Jan	8.13	5.96	2.18
BOP	Breeding bulls	Feb	7.38	5.4	1.98
BOP	Breeding bulls	Mar	9.42	6.9	2.52
BOP	Breeding bulls	Apr	8.94	6.55	2.39
BOP	Breeding bulls	May	9.36	6.86	2.51
BOP	Breeding bulls	Jun	8.6	6.3	2.3
BOP	Breeding bulls	Jul	8.93	6.54	2.39
BOP	Breeding bulls	Aug	8.77	6.42	2.35
BOP	Breeding bulls	Sep	8.37	6.13	2.24
BOP	Breeding bulls	Oct	7.63	5.59	2.04
BOP	Breeding bulls	Nov	7.51	5.5	2.01

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
BOP	Breeding bulls	Dec	7.84	5.74	2.1
Canterbury	Milking cows – mature	Jan	12.59	9.22	3.37
Canterbury	Milking cows – mature	Feb	10.71	7.84	2.87
Canterbury	Milking cows – mature	Mar	12.87	9.43	3.45
Canterbury	Milking cows – mature	Apr	11.23	8.22	3.01
Canterbury	Milking cows – mature	May	9.53	6.98	2.55
Canterbury	Milking cows – mature	Jun	7.49	5.48	2
Canterbury	Milking cows – mature	Jul	9.48	6.94	2.54
Canterbury	Milking cows – mature	Aug	10.17	7.45	2.72
Canterbury	Milking cows – mature	Sep	14.74	10.79	3.95
Canterbury	Milking cows – mature	Oct	14.68	10.75	3.93
Canterbury	Milking cows – mature	Nov	13.76	10.08	3.68
Canterbury	Milking cows – mature	Dec	13.15	9.63	3.52
Canterbury	Growing heifers – 0–1	Jan	2.91	2.13	0.78
Canterbury	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Canterbury	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Canterbury	Growing heifers – 0–1	Apr	4.26	3.12	1.14
Canterbury	Growing heifers – 0–1	May	4.86	3.56	1.3
Canterbury	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Canterbury	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Canterbury	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Canterbury	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Canterbury	Growing heifers – 0–1	Oct	1.88	1.38	0.5
Canterbury	Growing heifers – 0–1	Nov	2.14	1.56	0.57
Canterbury	Growing heifers – 0–1	Dec	2.53	1.85	0.68
Canterbury	Growing heifers – 1–2	Jan	6.48	4.74	1.73
Canterbury	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Canterbury	Growing heifers – 1–2	Mar	8.08	5.91	2.16
Canterbury	Growing heifers – 1–2	Apr	7.94	5.82	2.13
Canterbury	Growing heifers – 1–2	May	6.73	4.93	*1.8†*
Canterbury	Growing heifers – 1–2	Jun	6.73	4.93	*1.8†*
Canterbury	Growing heifers – 1–2	Jul	5.32	3.89	1.42
Canterbury	Growing heifers – 1–2	Aug	5.57	4.08	1.49
Canterbury	Growing heifers – 1–2	Sep	5.63	4.12	1.51
Canterbury	Growing heifers – 1–2	Oct	5.37	3.93	1.44
Canterbury	Growing heifers – 1–2	Nov	5.54	4.06	1.48
Canterbury	Growing heifers – 1–2	Dec	6.05	4.43	1.62
Canterbury	Breeding bulls	Jan	8.13	5.96	2.18
Canterbury	Breeding bulls	Feb	7.38	5.4	1.98
Canterbury	Breeding bulls	Mar	9.42	6.9	2.52
Canterbury	Breeding bulls	Apr	8.94	6.55	2.39
Canterbury	Breeding bulls	May	9.36	6.86	2.51
Canterbury	Breeding bulls	Jun	8.6	6.3	2.3

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Canterbury	Breeding bulls	Jul	8.93	6.54	2.39
Canterbury	Breeding bulls	Aug	8.77	6.42	2.35
Canterbury	Breeding bulls	Sep	8.37	6.13	2.24
Canterbury	Breeding bulls	Oct	7.63	5.59	2.04
Canterbury	Breeding bulls	Nov	7.51	5.5	2.01
Canterbury	Breeding bulls	Dec	7.84	5.74	2.1
Gisborne	Milking cows – mature	Jan	9.23	6.76	2.47
Gisborne	Milking cows – mature	Feb	7.99	5.85	2.14
Gisborne	Milking cows – mature	Mar	9.77	7.15	2.61
Gisborne	Milking cows – mature	Apr	8.86	6.49	2.37
Gisborne	Milking cows – mature	May	8.25	6.04	2.21
Gisborne	Milking cows – mature	Jun	7.26	5.31	1.94
Gisborne	Milking cows – mature	Jul	9.11	6.67	2.44
Gisborne	Milking cows – mature	Aug	7.88	5.77	2.11
Gisborne	Milking cows – mature	Sep	10.02	7.34	2.68
Gisborne	Milking cows – mature	Oct	9.78	7.16	2.62
Gisborne	Milking cows – mature	Nov	9.1	6.66	2.44
Gisborne	Milking cows – mature	Dec	8.92	6.53	2.39
Gisborne	Growing heifers – 0–1	Jan	2.9	2.13	0.78
Gisborne	Growing heifers – 0–1	Feb	2.88	2.11	0.77
Gisborne	Growing heifers – 0–1	Mar	4.06	2.97	1.09
Gisborne	Growing heifers – 0–1	Apr	4.25	3.11	1.14
Gisborne	Growing heifers – 0–1	May	4.84	3.54	1.3
Gisborne	Growing heifers – 0–1	Jun	4.79	3.51	1.28
Gisborne	Growing heifers – 0–1	Jul	3.58	2.62	*0.96**
Gisborne	Growing heifers – 0–1	Aug	3.58	2.62	*0.96**
Gisborne	Growing heifers – 0–1	Sep	3.58	2.62	*0.96**
Gisborne	Growing heifers – 0–1	Oct	1.88	1.38	0.5
Gisborne	Growing heifers – 0–1	Nov	2.13	1.56	0.57
Gisborne	Growing heifers – 0–1	Dec	2.52	1.84	0.67
Gisborne	Growing heifers – 1–2	Jan	6.45	4.73	1.73
Gisborne	Growing heifers – 1–2	Feb	6.07	4.44	1.62
Gisborne	Growing heifers – 1–2	Mar	8.05	5.89	2.15
Gisborne	Growing heifers – 1–2	Apr	7.92	5.8	2.12
Gisborne	Growing heifers – 1–2	May	6.71	4.91	*1.79†*
Gisborne	Growing heifers – 1–2	Jun	6.71	4.91	*1.79†*
Gisborne	Growing heifers – 1–2	Jul	5.3	3.88	1.42
Gisborne	Growing heifers – 1–2	Aug	5.55	4.06	1.48
Gisborne	Growing heifers – 1–2	Sep	5.61	4.11	1.5
Gisborne	Growing heifers – 1–2	Oct	5.35	3.92	1.43
Gisborne	Growing heifers – 1–2	Nov	5.52	4.04	1.48
Gisborne	Growing heifers – 1–2	Dec	6.03	4.41	1.61
Gisborne	Breeding bulls	Jan	8.13	5.96	2.18

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Gisborne	Breeding bulls	Feb	7.38	5.4	1.98
Gisborne	Breeding bulls	Mar	9.42	6.9	2.52
Gisborne	Breeding bulls	Apr	8.94	6.55	2.39
Gisborne	Breeding bulls	May	9.36	6.86	2.51
Gisborne	Breeding bulls	Jun	8.6	6.3	2.3
Gisborne	Breeding bulls	Jul	8.93	6.54	2.39
Gisborne	Breeding bulls	Aug	8.77	6.42	2.35
Gisborne	Breeding bulls	Sep	8.37	6.13	2.24
Gisborne	Breeding bulls	Oct	7.63	5.59	2.04
Gisborne	Breeding bulls	Nov	7.51	5.5	2.01
Gisborne	Breeding bulls	Dec	7.84	5.74	2.1
Hawke's Bay	Milking cows – mature	Jan	11.97	8.77	3.2
Hawke's Bay	Milking cows – mature	Feb	10.21	7.47	2.73
Hawke's Bay	Milking cows – mature	Mar	12.29	9	3.29
Hawke's Bay	Milking cows – mature	Apr	10.79	7.9	2.89
Hawke's Bay	Milking cows – mature	May	9.1	6.66	2.44
Hawke's Bay	Milking cows – mature	Jun	7.41	5.43	1.98
Hawke's Bay	Milking cows – mature	Jul	9.59	7.02	2.57
Hawke's Bay	Milking cows – mature	Aug	10.73	7.86	2.87
Hawke's Bay	Milking cows – mature	Sep	15.89	11.63	4.25
Hawke's Bay	Milking cows – mature	Oct	15.88	11.63	4.25
Hawke's Bay	Milking cows – mature	Nov	14.91	10.92	3.99
Hawke's Bay	Milking cows – mature	Dec	14.19	10.39	3.8
Hawke's Bay	Growing heifers – 0–1	Jan	2.91	2.13	0.78
Hawke's Bay	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Hawke's Bay	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Hawke's Bay	Growing heifers – 0–1	Apr	4.26	3.12	1.14
Hawke's Bay	Growing heifers – 0–1	May	4.86	3.56	1.3
Hawke's Bay	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Hawke's Bay	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Hawke's Bay	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Hawke's Bay	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Hawke's Bay	Growing heifers – 0–1	Oct	1.89	1.38	0.51
Hawke's Bay	Growing heifers – 0–1	Nov	2.14	1.57	0.57
Hawke's Bay	Growing heifers – 0–1	Dec	2.54	1.86	0.68
Hawke's Bay	Growing heifers – 1–2	Jan	6.48	4.74	1.73
Hawke's Bay	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Hawke's Bay	Growing heifers – 1–2	Mar	8.08	5.91	2.16
Hawke's Bay	Growing heifers – 1–2	Apr	7.94	5.82	2.13
Hawke's Bay	Growing heifers – 1–2	May	6.74	4.93	*1.81*†
Hawke's Bay	Growing heifers – 1–2	Jun	6.74	4.93	*1.81*†
Hawke's Bay	Growing heifers – 1–2	Jul	5.34	3.91	1.43
Hawke's Bay	Growing heifers – 1–2	Aug	5.59	4.09	1.5

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Hawke's Bay	Growing heifers – 1–2	Sep	5.65	4.14	1.51
Hawke's Bay	Growing heifers – 1–2	Oct	5.39	3.95	1.44
Hawke's Bay	Growing heifers – 1–2	Nov	5.56	4.07	1.49
Hawke's Bay	Growing heifers – 1–2	Dec	6.07	4.45	1.63
Hawke's Bay	Breeding bulls	Jan	8.13	5.96	2.18
Hawke's Bay	Breeding bulls	Feb	7.38	5.4	1.98
Hawke's Bay	Breeding bulls	Mar	9.42	6.9	2.52
Hawke's Bay	Breeding bulls	Apr	8.94	6.55	2.39
Hawke's Bay	Breeding bulls	May	9.36	6.86	2.51
Hawke's Bay	Breeding bulls	Jun	8.6	6.3	2.3
Hawke's Bay	Breeding bulls	Jul	8.93	6.54	2.39
Hawke's Bay	Breeding bulls	Aug	8.77	6.42	2.35
Hawke's Bay	Breeding bulls	Sep	8.37	6.13	2.24
Hawke's Bay	Breeding bulls	Oct	7.63	5.59	2.04
Hawke's Bay	Breeding bulls	Nov	7.51	5.5	2.01
Hawke's Bay	Breeding bulls	Dec	7.84	5.74	2.1
Manawatu Wanganui	Milking cows – mature	Jan	10.79	7.9	2.89
Manawatu Wanganui	Milking cows – mature	Feb	9.25	6.77	2.48
Manawatu Wanganui	Milking cows – mature	Mar	11.2	8.2	3
Manawatu Wanganui	Milking cows – mature	Apr	9.96	7.29	2.67
Manawatu Wanganui	Milking cows – mature	May	8.77	6.42	2.35
Manawatu Wanganui	Milking cows – mature	Jun	7.36	5.39	1.97
Manawatu Wanganui	Milking cows – mature	Jul	9.4	6.88	2.52
Manawatu Wanganui	Milking cows – mature	Aug	9.58	7.01	2.56
Manawatu Wanganui	Milking cows – mature	Sep	13.49	9.88	3.61
Manawatu Wanganui	Milking cows – mature	Oct	13.4	9.81	3.59
Manawatu Wanganui	Milking cows – mature	Nov	12.54	9.18	3.36
Manawatu Wanganui	Milking cows – mature	Dec	12.04	8.82	3.22
Manawatu Wanganui	Growing heifers – 0–1	Jan	2.91	2.13	0.78
Manawatu Wanganui	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Manawatu Wanganui	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Manawatu Wanganui	Growing heifers – 0–1	Apr	4.26	3.12	1.14
Manawatu Wanganui	Growing heifers – 0–1	May	4.86	3.56	1.3
Manawatu Wanganui	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Manawatu Wanganui	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Manawatu Wanganui	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Manawatu Wanganui	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Manawatu Wanganui	Growing heifers – 0–1	Oct	1.89	1.38	0.51
Manawatu Wanganui	Growing heifers – 0–1	Nov	2.14	1.57	0.57
Manawatu Wanganui	Growing heifers – 0–1	Dec	2.54	1.86	0.68
Manawatu Wanganui	Growing heifers – 1–2	Jan	6.48	4.74	1.73
Manawatu Wanganui	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Manawatu Wanganui	Growing heifers – 1–2	Mar	8.08	5.91	2.16

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Manawatu Wanganui	Growing heifers – 1–2	Apr	7.94	5.82	2.13
Manawatu Wanganui	Growing heifers – 1–2	May	6.74	4.93	*1.81*†
Manawatu Wanganui	Growing heifers – 1–2	Jun	6.74	4.93	*1.81*†
Manawatu Wanganui	Growing heifers – 1–2	Jul	5.34	3.91	1.43
Manawatu Wanganui	Growing heifers – 1–2	Aug	5.59	4.09	1.5
Manawatu Wanganui	Growing heifers – 1–2	Sep	5.65	4.14	1.51
Manawatu Wanganui	Growing heifers – 1–2	Oct	5.39	3.95	1.44
Manawatu Wanganui	Growing heifers – 1–2	Nov	5.56	4.07	1.49
Manawatu Wanganui	Growing heifers – 1–2	Dec	6.07	4.45	1.63
Manawatu Wanganui	Breeding bulls	Jan	8.13	5.96	2.18
Manawatu Wanganui	Breeding bulls	Feb	7.38	5.4	1.98
Manawatu Wanganui	Breeding bulls	Mar	9.42	6.9	2.52
Manawatu Wanganui	Breeding bulls	Apr	8.94	6.55	2.39
Manawatu Wanganui	Breeding bulls	May	9.36	6.86	2.51
Manawatu Wanganui	Breeding bulls	Jun	8.6	6.3	2.3
Manawatu Wanganui	Breeding bulls	Jul	8.93	6.54	2.39
Manawatu Wanganui	Breeding bulls	Aug	8.77	6.42	2.35
Manawatu Wanganui	Breeding bulls	Sep	8.37	6.13	2.24
Manawatu Wanganui	Breeding bulls	Oct	7.63	5.59	2.04
Manawatu Wanganui	Breeding bulls	Nov	7.51	5.5	2.01
Manawatu Wanganui	Breeding bulls	Dec	7.84	5.74	2.1
Marlborough	Milking cows – mature	Jan	12.99	9.51	3.48
Marlborough	Milking cows – mature	Feb	11.03	8.08	2.95
Marlborough	Milking cows – mature	Mar	13.23	9.68	3.54
Marlborough	Milking cows – mature	Apr	11.5	8.42	3.08
Marlborough	Milking cows – mature	May	9.65	7.06	2.58
Marlborough	Milking cows – mature	Jun	7.51	5.5	2.01
Marlborough	Milking cows – mature	Jul	9.52	6.97	2.55
Marlborough	Milking cows – mature	Aug	10.4	7.62	2.79
Marlborough	Milking cows – mature	Sep	15.22	11.15	4.08
Marlborough	Milking cows – mature	Oct	15.21	11.14	4.07
Marlborough	Milking cows – mature	Nov	14.26	10.44	3.82
Marlborough	Milking cows – mature	Dec	13.6	9.96	3.64
Marlborough	Growing heifers – 0–1	Jan	2.91	2.13	0.78
Marlborough	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Marlborough	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Marlborough	Growing heifers – 0–1	Apr	4.26	3.12	1.14
Marlborough	Growing heifers – 0–1	May	4.86	3.56	1.3
Marlborough	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Marlborough	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Marlborough	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Marlborough	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Marlborough	Growing heifers – 0–1	Oct	1.88	1.38	0.5

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Marlborough	Growing heifers – 0–1	Nov	2.14	1.56	0.57
Marlborough	Growing heifers – 0–1	Dec	2.53	1.85	0.68
Marlborough	Growing heifers – 1–2	Jan	6.48	4.74	1.73
Marlborough	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Marlborough	Growing heifers – 1–2	Mar	8.08	5.91	2.16
Marlborough	Growing heifers – 1–2	Apr	7.94	5.82	2.13
Marlborough	Growing heifers – 1–2	May	6.73	4.93	*1.8*†
Marlborough	Growing heifers – 1–2	Jun	6.73	4.93	*1.8*†
Marlborough	Growing heifers – 1–2	Jul	5.32	3.89	1.42
Marlborough	Growing heifers – 1–2	Aug	5.57	4.08	1.49
Marlborough	Growing heifers – 1–2	Sep	5.63	4.12	1.51
Marlborough	Growing heifers – 1–2	Oct	5.37	3.93	1.44
Marlborough	Growing heifers – 1–2	Nov	5.54	4.06	1.48
Marlborough	Growing heifers – 1–2	Dec	6.05	4.43	1.62
Marlborough	Breeding bulls	Jan	8.13	5.96	2.18
Marlborough	Breeding bulls	Feb	7.38	5.4	1.98
Marlborough	Breeding bulls	Mar	9.42	6.9	2.52
Marlborough	Breeding bulls	Apr	8.94	6.55	2.39
Marlborough	Breeding bulls	May	9.36	6.86	2.51
Marlborough	Breeding bulls	Jun	8.6	6.3	2.3
Marlborough	Breeding bulls	Jul	8.93	6.54	2.39
Marlborough	Breeding bulls	Aug	8.77	6.42	2.35
Marlborough	Breeding bulls	Sep	8.37	6.13	2.24
Marlborough	Breeding bulls	Oct	7.63	5.59	2.04
Marlborough	Breeding bulls	Nov	7.51	5.5	2.01
Marlborough	Breeding bulls	Dec	7.84	5.74	2.1
Nelson	Milking cows – mature	Jan	9.98	7.31	2.67
Nelson	Milking cows – mature	Feb	8.58	6.28	2.3
Nelson	Milking cows – mature	Mar	10.42	7.63	2.79
Nelson	Milking cows – mature	Apr	9.35	6.85	2.5
Nelson	Milking cows – mature	May	8.47	6.2	2.27
Nelson	Milking cows – mature	Jun	7.22	5.28	1.93
Nelson	Milking cows – mature	Jul	9.13	6.68	2.44
Nelson	Milking cows – mature	Aug	8.47	6.2	2.27
Nelson	Milking cows – mature	Sep	11.35	8.31	3.04
Nelson	Milking cows – mature	Oct	11.19	8.19	2.99
Nelson	Milking cows – mature	Nov	10.42	7.63	2.79
Nelson	Milking cows – mature	Dec	10.1	7.4	2.7
Nelson	Growing heifers – 0–1	Jan	2.83	2.08	0.76
Nelson	Growing heifers – 0–1	Feb	2.81	2.06	0.75
Nelson	Growing heifers – 0–1	Mar	3.96	2.9	1.06
Nelson	Growing heifers – 0–1	Apr	4.14	3.03	1.11
Nelson	Growing heifers – 0–1	May	4.72	3.45	1.26

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Nelson	Growing heifers – 0–1	Jun	4.67	3.42	1.25
Nelson	Growing heifers – 0–1	Jul	3.49	2.55	*0.93**
Nelson	Growing heifers – 0–1	Aug	3.49	2.55	*0.93**
Nelson	Growing heifers – 0–1	Sep	3.49	2.55	*0.93**
Nelson	Growing heifers – 0–1	Oct	1.83	1.34	0.49
Nelson	Growing heifers – 0–1	Nov	2.08	1.52	0.56
Nelson	Growing heifers – 0–1	Dec	2.46	1.8	0.66
Nelson	Growing heifers – 1–2	Jan	6.3	4.61	1.69
Nelson	Growing heifers – 1–2	Feb	5.92	4.34	1.59
Nelson	Growing heifers – 1–2	Mar	7.86	5.75	2.1
Nelson	Growing heifers – 1–2	Apr	7.74	5.67	2.07
Nelson	Growing heifers – 1–2	May	6.54	4.79	*1.75*†
Nelson	Growing heifers – 1–2	Jun	6.54	4.79	*1.75*†
Nelson	Growing heifers – 1–2	Jul	5.16	3.78	1.38
Nelson	Growing heifers – 1–2	Aug	5.4	3.95	1.45
Nelson	Growing heifers – 1–2	Sep	5.46	4	1.46
Nelson	Growing heifers – 1–2	Oct	5.21	3.82	1.4
Nelson	Growing heifers – 1–2	Nov	5.38	3.94	1.44
Nelson	Growing heifers – 1–2	Dec	5.87	4.3	1.57
Nelson	Breeding bulls	Jan	8.13	5.96	2.18
Nelson	Breeding bulls	Feb	7.38	5.4	1.98
Nelson	Breeding bulls	Mar	9.42	6.9	2.52
Nelson	Breeding bulls	Apr	8.94	6.55	2.39
Nelson	Breeding bulls	May	9.36	6.86	2.51
Nelson	Breeding bulls	Jun	8.6	6.3	2.3
Nelson	Breeding bulls	Jul	8.93	6.54	2.39
Nelson	Breeding bulls	Aug	8.77	6.42	2.35
Nelson	Breeding bulls	Sep	8.37	6.13	2.24
Nelson	Breeding bulls	Oct	7.63	5.59	2.04
Nelson	Breeding bulls	Nov	7.51	5.5	2.01
Nelson	Breeding bulls	Dec	7.84	5.74	2.1
Northland	Milking cows – mature	Jan	10.42	7.63	2.79
Northland	Milking cows – mature	Feb	8.95	6.55	2.4
Northland	Milking cows – mature	Mar	10.85	7.95	2.91
Northland	Milking cows – mature	Apr	9.69	7.09	2.59
Northland	Milking cows – mature	May	8.61	6.3	2.3
Northland	Milking cows – mature	Jun	7.3	5.35	1.95
Northland	Milking cows – mature	Jul	9.31	6.82	2.49
Northland	Milking cows – mature	Aug	9.17	6.72	2.46
Northland	Milking cows – mature	Sep	12.7	9.3	3.4
Northland	Milking cows – mature	Oct	12.57	9.21	3.37
Northland	Milking cows – mature	Nov	11.76	8.61	3.15
Northland	Milking cows – mature	Dec	11.33	8.3	3.03

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Northland	Growing heifers – 0–1	Jan	2.89	2.12	0.77
Northland	Growing heifers – 0–1	Feb	2.87	2.1	0.77
Northland	Growing heifers – 0–1	Mar	4.04	2.96	1.08
Northland	Growing heifers – 0–1	Apr	4.23	3.1	1.13
Northland	Growing heifers – 0–1	May	4.81	3.53	1.29
Northland	Growing heifers – 0–1	Jun	4.76	3.49	1.28
Northland	Growing heifers – 0–1	Jul	3.56	2.61	*0.95**
Northland	Growing heifers – 0–1	Aug	3.56	2.61	*0.95**
Northland	Growing heifers – 0–1	Sep	3.56	2.61	*0.95**
Northland	Growing heifers – 0–1	Oct	1.88	1.37	0.5
Northland	Growing heifers – 0–1	Nov	2.13	1.56	0.57
Northland	Growing heifers – 0–1	Dec	2.51	1.84	0.67
Northland	Growing heifers – 1–2	Jan	6.42	4.7	1.72
Northland	Growing heifers – 1–2	Feb	6.04	4.42	1.62
Northland	Growing heifers – 1–2	Mar	8.01	5.87	2.14
Northland	Growing heifers – 1–2	Apr	7.88	5.77	2.11
Northland	Growing heifers – 1–2	May	6.68	4.89	*1.79†*
Northland	Growing heifers – 1–2	Jun	6.68	4.89	*1.79†*
Northland	Growing heifers – 1–2	Jul	5.29	3.87	1.42
Northland	Growing heifers – 1–2	Aug	5.54	4.05	1.48
Northland	Growing heifers – 1–2	Sep	5.6	4.1	1.5
Northland	Growing heifers – 1–2	Oct	5.34	3.91	1.43
Northland	Growing heifers – 1–2	Nov	5.51	4.04	1.48
Northland	Growing heifers – 1–2	Dec	6.02	4.41	1.61
Northland	Breeding bulls	Jan	8.13	5.96	2.18
Northland	Breeding bulls	Feb	7.38	5.4	1.98
Northland	Breeding bulls	Mar	9.42	6.9	2.52
Northland	Breeding bulls	Apr	8.94	6.55	2.39
Northland	Breeding bulls	May	9.36	6.86	2.51
Northland	Breeding bulls	Jun	8.6	6.3	2.3
Northland	Breeding bulls	Jul	8.93	6.54	2.39
Northland	Breeding bulls	Aug	8.77	6.42	2.35
Northland	Breeding bulls	Sep	8.37	6.13	2.24
Northland	Breeding bulls	Oct	7.63	5.59	2.04
Northland	Breeding bulls	Nov	7.51	5.5	2.01
Northland	Breeding bulls	Dec	7.84	5.74	2.1
Otago	Milking cows – mature	Jan	11.59	8.48	3.1
Otago	Milking cows – mature	Feb	9.89	7.25	2.65
Otago	Milking cows – mature	Mar	11.95	8.75	3.2
Otago	Milking cows – mature	Apr	10.52	7.71	2.82
Otago	Milking cows – mature	May	9.16	6.71	2.45
Otago	Milking cows – mature	Jun	7.43	5.44	1.99
Otago	Milking cows – mature	Jul	9.39	6.88	2.52

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Otago	Milking cows – mature	Aug	9.59	7.02	2.57
Otago	Milking cows – mature	Sep	13.53	9.91	3.62
Otago	Milking cows – mature	Oct	13.43	9.83	3.6
Otago	Milking cows – mature	Nov	12.57	9.2	3.37
Otago	Milking cows – mature	Dec	12.07	8.84	3.23
Otago	Growing heifers – 0–1	Jan	2.92	2.14	0.78
Otago	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Otago	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Otago	Growing heifers – 0–1	Apr	4.27	3.13	1.14
Otago	Growing heifers – 0–1	May	4.86	3.56	1.3
Otago	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Otago	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Otago	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Otago	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Otago	Growing heifers – 0–1	Oct	1.89	1.38	0.5
Otago	Growing heifers – 0–1	Nov	2.14	1.57	0.57
Otago	Growing heifers – 0–1	Dec	2.53	1.85	0.68
Otago	Growing heifers – 1–2	Jan	6.48	4.75	1.74
Otago	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Otago	Growing heifers – 1–2	Mar	8.08	5.92	2.16
Otago	Growing heifers – 1–2	Apr	7.95	5.82	2.13
Otago	Growing heifers – 1–2	May	6.73	4.93	*1.8†*
Otago	Growing heifers – 1–2	Jun	6.73	4.93	*1.8†*
Otago	Growing heifers – 1–2	Jul	5.32	3.9	1.43
Otago	Growing heifers – 1–2	Aug	5.57	4.08	1.49
Otago	Growing heifers – 1–2	Sep	5.63	4.13	1.51
Otago	Growing heifers – 1–2	Oct	5.38	3.94	1.44
Otago	Growing heifers – 1–2	Nov	5.55	4.06	1.49
Otago	Growing heifers – 1–2	Dec	6.05	4.43	1.62
Otago	Breeding bulls	Jan	8.13	5.96	2.18
Otago	Breeding bulls	Feb	7.38	5.4	1.98
Otago	Breeding bulls	Mar	9.42	6.9	2.52
Otago	Breeding bulls	Apr	8.94	6.55	2.39
Otago	Breeding bulls	May	9.36	6.86	2.51
Otago	Breeding bulls	Jun	8.6	6.3	2.3
Otago	Breeding bulls	Jul	8.93	6.54	2.39
Otago	Breeding bulls	Aug	8.77	6.42	2.35
Otago	Breeding bulls	Sep	8.37	6.13	2.24
Otago	Breeding bulls	Oct	7.63	5.59	2.04
Otago	Breeding bulls	Nov	7.51	5.5	2.01
Otago	Breeding bulls	Dec	7.84	5.74	2.1
Southland	Milking cows – mature	Jan	13.56	9.93	3.63
Southland	Milking cows – mature	Feb	11.5	8.42	3.08

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Southland	Milking cows – mature	Mar	13.77	10.08	3.69
Southland	Milking cows – mature	Apr	11.91	8.72	3.19
Southland	Milking cows – mature	May	9.97	7.3	2.67
Southland	Milking cows – mature	Jun	7.57	5.54	2.03
Southland	Milking cows – mature	Jul	9.53	6.98	2.55
Southland	Milking cows – mature	Aug	10.47	7.67	2.8
Southland	Milking cows – mature	Sep	15.36	11.25	4.11
Southland	Milking cows – mature	Oct	15.33	11.22	4.1
Southland	Milking cows – mature	Nov	14.37	10.52	3.85
Southland	Milking cows – mature	Dec	13.7	10.03	3.67
Southland	Growing heifers – 0–1	Jan	2.92	2.14	0.78
Southland	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Southland	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Southland	Growing heifers – 0–1	Apr	4.27	3.13	1.14
Southland	Growing heifers – 0–1	May	4.86	3.56	1.3
Southland	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Southland	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Southland	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Southland	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Southland	Growing heifers – 0–1	Oct	1.89	1.38	0.5
Southland	Growing heifers – 0–1	Nov	2.14	1.57	0.57
Southland	Growing heifers – 0–1	Dec	2.53	1.85	0.68
Southland	Growing heifers – 1–2	Jan	6.48	4.75	1.74
Southland	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Southland	Growing heifers – 1–2	Mar	8.08	5.92	2.16
Southland	Growing heifers – 1–2	Apr	7.95	5.82	2.13
Southland	Growing heifers – 1–2	May	6.73	4.93	*1.8†*
Southland	Growing heifers – 1–2	Jun	6.73	4.93	*1.8†*
Southland	Growing heifers – 1–2	Jul	5.32	3.9	1.43
Southland	Growing heifers – 1–2	Aug	5.57	4.08	1.49
Southland	Growing heifers – 1–2	Sep	5.63	4.13	1.51
Southland	Growing heifers – 1–2	Oct	5.38	3.94	1.44
Southland	Growing heifers – 1–2	Nov	5.55	4.06	1.49
Southland	Growing heifers – 1–2	Dec	6.05	4.43	1.62
Southland	Breeding bulls	Jan	8.13	5.96	2.18
Southland	Breeding bulls	Feb	7.38	5.4	1.98
Southland	Breeding bulls	Mar	9.42	6.9	2.52
Southland	Breeding bulls	Apr	8.94	6.55	2.39
Southland	Breeding bulls	May	9.36	6.86	2.51
Southland	Breeding bulls	Jun	8.6	6.3	2.3
Southland	Breeding bulls	Jul	8.93	6.54	2.39
Southland	Breeding bulls	Aug	8.77	6.42	2.35
Southland	Breeding bulls	Sep	8.37	6.13	2.24

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Southland	Breeding bulls	Oct	7.63	5.59	2.04
Southland	Breeding bulls	Nov	7.51	5.5	2.01
Southland	Breeding bulls	Dec	7.84	5.74	2.1
Taranaki	Milking cows – mature	Jan	11.54	8.45	3.09
Taranaki	Milking cows – mature	Feb	9.86	7.22	2.64
Taranaki	Milking cows – mature	Mar	11.89	8.7	3.18
Taranaki	Milking cows – mature	Apr	10.47	7.67	2.8
Taranaki	Milking cows – mature	May	8.98	6.57	2.4
Taranaki	Milking cows – mature	Jun	7.35	5.38	1.97
Taranaki	Milking cows – mature	Jul	9.45	6.92	2.53
Taranaki	Milking cows – mature	Aug	10.21	7.48	2.73
Taranaki	Milking cows – mature	Sep	14.88	10.9	3.98
Taranaki	Milking cows – mature	Oct	14.85	10.87	3.97
Taranaki	Milking cows – mature	Nov	13.91	10.18	3.72
Taranaki	Milking cows – mature	Dec	13.28	9.72	3.55
Taranaki	Growing heifers – 0–1	Jan	2.88	2.11	0.77
Taranaki	Growing heifers – 0–1	Feb	2.86	2.09	0.76
Taranaki	Growing heifers – 0–1	Mar	4.03	2.95	1.08
Taranaki	Growing heifers – 0–1	Apr	4.21	3.08	1.13
Taranaki	Growing heifers – 0–1	May	4.8	3.51	1.28
Taranaki	Growing heifers – 0–1	Jun	4.75	3.48	1.27
Taranaki	Growing heifers – 0–1	Jul	3.55	2.6	*0.95**
Taranaki	Growing heifers – 0–1	Aug	3.55	2.6	*0.95**
Taranaki	Growing heifers – 0–1	Sep	3.55	2.6	*0.95**
Taranaki	Growing heifers – 0–1	Oct	1.87	1.37	0.5
Taranaki	Growing heifers – 0–1	Nov	2.11	1.55	0.57
Taranaki	Growing heifers – 0–1	Dec	2.5	1.83	0.67
Taranaki	Growing heifers – 1–2	Jan	6.4	4.69	1.71
Taranaki	Growing heifers – 1–2	Feb	6.02	4.41	1.61
Taranaki	Growing heifers – 1–2	Mar	7.98	5.84	2.14
Taranaki	Growing heifers – 1–2	Apr	7.85	5.75	2.1
Taranaki	Growing heifers – 1–2	May	6.65	4.87	*1.78†*
Taranaki	Growing heifers – 1–2	Jun	6.65	4.87	*1.78†*
Taranaki	Growing heifers – 1–2	Jul	5.26	3.85	1.41
Taranaki	Growing heifers – 1–2	Aug	5.5	4.03	1.47
Taranaki	Growing heifers – 1–2	Sep	5.57	4.08	1.49
Taranaki	Growing heifers – 1–2	Oct	5.31	3.89	1.42
Taranaki	Growing heifers – 1–2	Nov	5.48	4.01	1.47
Taranaki	Growing heifers – 1–2	Dec	5.98	4.38	1.6
Taranaki	Breeding bulls	Jan	8.13	5.96	2.18
Taranaki	Breeding bulls	Feb	7.38	5.4	1.98
Taranaki	Breeding bulls	Mar	9.42	6.9	2.52
Taranaki	Breeding bulls	Apr	8.94	6.55	2.39

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Taranaki	Breeding bulls	May	9.36	6.86	2.51
Taranaki	Breeding bulls	Jun	8.6	6.3	2.3
Taranaki	Breeding bulls	Jul	8.93	6.54	2.39
Taranaki	Breeding bulls	Aug	8.77	6.42	2.35
Taranaki	Breeding bulls	Sep	8.37	6.13	2.24
Taranaki	Breeding bulls	Oct	7.63	5.59	2.04
Taranaki	Breeding bulls	Nov	7.51	5.5	2.01
Taranaki	Breeding bulls	Dec	7.84	5.74	2.1
Tasman	Milking cows – mature	Jan	11.39	8.34	3.05
Tasman	Milking cows – mature	Feb	9.72	7.12	2.6
Tasman	Milking cows – mature	Mar	11.72	8.58	3.14
Tasman	Milking cows – mature	Apr	10.34	7.57	2.77
Tasman	Milking cows – mature	May	8.9	6.51	2.38
Tasman	Milking cows – mature	Jun	7.29	5.34	1.95
Tasman	Milking cows – mature	Jul	9.3	6.81	2.49
Tasman	Milking cows – mature	Aug	9.66	7.08	2.59
Tasman	Milking cows – mature	Sep	13.82	10.12	3.7
Tasman	Milking cows – mature	Oct	13.76	10.08	3.68
Tasman	Milking cows – mature	Nov	12.86	9.42	3.44
Tasman	Milking cows – mature	Dec	12.32	9.02	3.3
Tasman	Growing heifers – 0–1	Jan	2.83	2.08	0.76
Tasman	Growing heifers – 0–1	Feb	2.81	2.06	0.75
Tasman	Growing heifers – 0–1	Mar	3.96	2.9	1.06
Tasman	Growing heifers – 0–1	Apr	4.14	3.03	1.11
Tasman	Growing heifers – 0–1	May	4.72	3.45	1.26
Tasman	Growing heifers – 0–1	Jun	4.67	3.42	1.25
Tasman	Growing heifers – 0–1	Jul	3.49	2.55	*0.93**
Tasman	Growing heifers – 0–1	Aug	3.49	2.55	*0.93**
Tasman	Growing heifers – 0–1	Sep	3.49	2.55	*0.93**
Tasman	Growing heifers – 0–1	Oct	1.83	1.34	0.49
Tasman	Growing heifers – 0–1	Nov	2.08	1.52	0.56
Tasman	Growing heifers – 0–1	Dec	2.46	1.8	0.66
Tasman	Growing heifers – 1–2	Jan	6.3	4.61	1.69
Tasman	Growing heifers – 1–2	Feb	5.92	4.34	1.59
Tasman	Growing heifers – 1–2	Mar	7.86	5.75	2.1
Tasman	Growing heifers – 1–2	Apr	7.74	5.67	2.07
Tasman	Growing heifers – 1–2	May	6.54	4.79	*1.75†*
Tasman	Growing heifers – 1–2	Jun	6.54	4.79	*1.75†*
Tasman	Growing heifers – 1–2	Jul	5.16	3.78	1.38
Tasman	Growing heifers – 1–2	Aug	5.4	3.95	1.45
Tasman	Growing heifers – 1–2	Sep	5.46	4	1.46
Tasman	Growing heifers – 1–2	Oct	5.21	3.82	1.4
Tasman	Growing heifers – 1–2	Nov	5.38	3.94	1.44

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Tasman	Growing heifers – 1–2	Dec	5.87	4.3	1.57
Tasman	Breeding bulls	Jan	8.13	5.96	2.18
Tasman	Breeding bulls	Feb	7.38	5.4	1.98
Tasman	Breeding bulls	Mar	9.42	6.9	2.52
Tasman	Breeding bulls	Apr	8.94	6.55	2.39
Tasman	Breeding bulls	May	9.36	6.86	2.51
Tasman	Breeding bulls	Jun	8.6	6.3	2.3
Tasman	Breeding bulls	Jul	8.93	6.54	2.39
Tasman	Breeding bulls	Aug	8.77	6.42	2.35
Tasman	Breeding bulls	Sep	8.37	6.13	2.24
Tasman	Breeding bulls	Oct	7.63	5.59	2.04
Tasman	Breeding bulls	Nov	7.51	5.5	2.01
Tasman	Breeding bulls	Dec	7.84	5.74	2.1
Waikato	Milking cows – mature	Jan	10.81	7.92	2.89
Waikato	Milking cows – mature	Feb	9.27	6.79	2.48
Waikato	Milking cows – mature	Mar	11.21	8.21	3
Waikato	Milking cows – mature	Apr	9.96	7.29	2.67
Waikato	Milking cows – mature	May	8.79	6.43	2.35
Waikato	Milking cows – mature	Jun	7.33	5.37	1.96
Waikato	Milking cows – mature	Jul	9.33	6.83	2.5
Waikato	Milking cows – mature	Aug	9.42	6.9	2.52
Waikato	Milking cows – mature	Sep	13.23	9.69	3.54
Waikato	Milking cows – mature	Oct	13.13	9.62	3.52
Waikato	Milking cows – mature	Nov	12.29	9	3.29
Waikato	Milking cows – mature	Dec	11.8	8.64	3.16
Waikato	Growing heifers – 0–1	Jan	2.89	2.12	0.77
Waikato	Growing heifers – 0–1	Feb	2.86	2.1	0.77
Waikato	Growing heifers – 0–1	Mar	4.04	2.96	1.08
Waikato	Growing heifers – 0–1	Apr	4.23	3.09	1.13
Waikato	Growing heifers – 0–1	May	4.81	3.52	1.29
Waikato	Growing heifers – 0–1	Jun	4.76	3.49	1.27
Waikato	Growing heifers – 0–1	Jul	3.56	2.6	*0.95**
Waikato	Growing heifers – 0–1	Aug	3.56	2.6	*0.95**
Waikato	Growing heifers – 0–1	Sep	3.56	2.6	*0.95**
Waikato	Growing heifers – 0–1	Oct	1.87	1.37	0.5
Waikato	Growing heifers – 0–1	Nov	2.12	1.55	0.57
Waikato	Growing heifers – 0–1	Dec	2.5	1.83	0.67
Waikato	Growing heifers – 1–2	Jan	6.42	4.7	1.72
Waikato	Growing heifers – 1–2	Feb	6.04	4.42	1.62
Waikato	Growing heifers – 1–2	Mar	8.01	5.86	2.14
Waikato	Growing heifers – 1–2	Apr	7.88	5.77	2.11
Waikato	Growing heifers – 1–2	May	6.67	4.88	*1.79†*
Waikato	Growing heifers – 1–2	Jun	6.67	4.88	*1.79†*

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Waikato	Growing heifers – 1–2	Jul	5.27	3.86	1.41
Waikato	Growing heifers – 1–2	Aug	5.52	4.04	1.48
Waikato	Growing heifers – 1–2	Sep	5.58	4.08	1.49
Waikato	Growing heifers – 1–2	Oct	5.32	3.9	1.43
Waikato	Growing heifers – 1–2	Nov	5.49	4.02	1.47
Waikato	Growing heifers – 1–2	Dec	6	4.39	1.61
Waikato	Breeding bulls	Jan	8.13	5.96	2.18
Waikato	Breeding bulls	Feb	7.38	5.4	1.98
Waikato	Breeding bulls	Mar	9.42	6.9	2.52
Waikato	Breeding bulls	Apr	8.94	6.55	2.39
Waikato	Breeding bulls	May	9.36	6.86	2.51
Waikato	Breeding bulls	Jun	8.6	6.3	2.3
Waikato	Breeding bulls	Jul	8.93	6.54	2.39
Waikato	Breeding bulls	Aug	8.77	6.42	2.35
Waikato	Breeding bulls	Sep	8.37	6.13	2.24
Waikato	Breeding bulls	Oct	7.63	5.59	2.04
Waikato	Breeding bulls	Nov	7.51	5.5	2.01
Waikato	Breeding bulls	Dec	7.84	5.74	2.1
Wellington	Milking cows – mature	Jan	11.88	8.7	3.18
Wellington	Milking cows – mature	Feb	10.14	7.42	2.71
Wellington	Milking cows – mature	Mar	12.21	8.94	3.27
Wellington	Milking cows – mature	Apr	10.73	7.86	2.87
Wellington	Milking cows – mature	May	9.41	6.89	2.52
Wellington	Milking cows – mature	Jun	7.47	5.47	2
Wellington	Milking cows – mature	Jul	9.33	6.83	2.5
Wellington	Milking cows – mature	Aug	9.15	6.7	2.45
Wellington	Milking cows – mature	Sep	12.61	9.24	3.38
Wellington	Milking cows – mature	Oct	12.48	9.14	3.34
Wellington	Milking cows – mature	Nov	11.67	8.54	3.12
Wellington	Milking cows – mature	Dec	11.25	8.24	3.01
Wellington	Growing heifers – 0–1	Jan	2.91	2.13	0.78
Wellington	Growing heifers – 0–1	Feb	2.89	2.12	0.77
Wellington	Growing heifers – 0–1	Mar	4.08	2.99	1.09
Wellington	Growing heifers – 0–1	Apr	4.26	3.12	1.14
Wellington	Growing heifers – 0–1	May	4.86	3.56	1.3
Wellington	Growing heifers – 0–1	Jun	4.81	3.52	1.29
Wellington	Growing heifers – 0–1	Jul	3.59	2.63	*0.96**
Wellington	Growing heifers – 0–1	Aug	3.59	2.63	*0.96**
Wellington	Growing heifers – 0–1	Sep	3.59	2.63	*0.96**
Wellington	Growing heifers – 0–1	Oct	1.89	1.38	0.51
Wellington	Growing heifers – 0–1	Nov	2.14	1.57	0.57
Wellington	Growing heifers – 0–1	Dec	2.54	1.86	0.68
Wellington	Growing heifers – 1–2	Jan	6.48	4.74	1.73

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Wellington	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Wellington	Growing heifers – 1–2	Mar	8.08	5.91	2.16
Wellington	Growing heifers – 1–2	Apr	7.94	5.82	2.13
Wellington	Growing heifers – 1–2	May	6.74	4.93	*1.81*†
Wellington	Growing heifers – 1–2	Jun	6.74	4.93	*1.81*†
Wellington	Growing heifers – 1–2	Jul	5.34	3.91	1.43
Wellington	Growing heifers – 1–2	Aug	5.59	4.09	1.5
Wellington	Growing heifers – 1–2	Sep	5.65	4.14	1.51
Wellington	Growing heifers – 1–2	Oct	5.39	3.95	1.44
Wellington	Growing heifers – 1–2	Nov	5.56	4.07	1.49
Wellington	Growing heifers – 1–2	Dec	6.07	4.45	1.63
Wellington	Breeding bulls	Jan	8.13	5.96	2.18
Wellington	Breeding bulls	Feb	7.38	5.4	1.98
Wellington	Breeding bulls	Mar	9.42	6.9	2.52
Wellington	Breeding bulls	Apr	8.94	6.55	2.39
Wellington	Breeding bulls	May	9.36	6.86	2.51
Wellington	Breeding bulls	Jun	8.6	6.3	2.3
Wellington	Breeding bulls	Jul	8.93	6.54	2.39
Wellington	Breeding bulls	Aug	8.77	6.42	2.35
Wellington	Breeding bulls	Sep	8.37	6.13	2.24
Wellington	Breeding bulls	Oct	7.63	5.59	2.04
Wellington	Breeding bulls	Nov	7.51	5.5	2.01
Wellington	Breeding bulls	Dec	7.84	5.74	2.1
West Coast	Milking cows – mature	Jan	12.01	8.79	3.21
West Coast	Milking cows – mature	Feb	10.22	7.48	2.74
West Coast	Milking cows – mature	Mar	12.3	9	3.29
West Coast	Milking cows – mature	Apr	10.77	7.89	2.88
West Coast	Milking cows – mature	May	9.29	6.81	2.49
West Coast	Milking cows – mature	Jun	7.36	5.39	1.97
West Coast	Milking cows – mature	Jul	9.26	6.78	2.48
West Coast	Milking cows – mature	Aug	9.44	6.91	2.53
West Coast	Milking cows – mature	Sep	13.35	9.78	3.58
West Coast	Milking cows – mature	Oct	13.27	9.72	3.55
West Coast	Milking cows – mature	Nov	12.4	9.08	3.32
West Coast	Milking cows – mature	Dec	11.89	8.71	3.18
West Coast	Growing heifers – 0–1	Jan	2.83	2.08	0.76
West Coast	Growing heifers – 0–1	Feb	2.81	2.06	0.75
West Coast	Growing heifers – 0–1	Mar	3.96	2.9	1.06
West Coast	Growing heifers – 0–1	Apr	4.14	3.03	1.11
West Coast	Growing heifers – 0–1	May	4.72	3.45	1.26
West Coast	Growing heifers – 0–1	Jun	4.67	3.42	1.25
West Coast	Growing heifers – 0–1	Jul	3.49	2.55	*0.93**
West Coast	Growing heifers – 0–1	Aug	3.49	2.55	*0.93**

Region	Class	Month	Total excreta kg N/head per month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
West Coast	Growing heifers – 0–1	Sep	3.49	2.55	*0.93**
West Coast	Growing heifers – 0–1	Oct	1.83	1.34	0.49
West Coast	Growing heifers – 0–1	Nov	2.08	1.52	0.56
West Coast	Growing heifers – 0–1	Dec	2.46	1.8	0.66
West Coast	Growing heifers – 1–2	Jan	6.3	4.61	1.69
West Coast	Growing heifers – 1–2	Feb	5.92	4.34	1.59
West Coast	Growing heifers – 1–2	Mar	7.86	5.75	2.1
West Coast	Growing heifers – 1–2	Apr	7.74	5.67	2.07
West Coast	Growing heifers – 1–2	May	6.54	4.79	*1.75†*
West Coast	Growing heifers – 1–2	Jun	6.54	4.79	*1.75†*
West Coast	Growing heifers – 1–2	Jul	5.16	3.78	1.38
West Coast	Growing heifers – 1–2	Aug	5.4	3.95	1.45
West Coast	Growing heifers – 1–2	Sep	5.46	4	1.46
West Coast	Growing heifers – 1–2	Oct	5.21	3.82	1.4
West Coast	Growing heifers – 1–2	Nov	5.38	3.94	1.44
West Coast	Growing heifers – 1–2	Dec	5.87	4.3	1.57
West Coast	Breeding bulls	Jan	8.13	5.96	2.18
West Coast	Breeding bulls	Feb	7.38	5.4	1.98
West Coast	Breeding bulls	Mar	9.42	6.9	2.52
West Coast	Breeding bulls	Apr	8.94	6.55	2.39
West Coast	Breeding bulls	May	9.36	6.86	2.51
West Coast	Breeding bulls	Jun	8.6	6.3	2.3
West Coast	Breeding bulls	Jul	8.93	6.54	2.39
West Coast	Breeding bulls	Aug	8.77	6.42	2.35
West Coast	Breeding bulls	Sep	8.37	6.13	2.24
West Coast	Breeding bulls	Oct	7.63	5.59	2.04
West Coast	Breeding bulls	Nov	7.51	5.5	2.01
West Coast	Breeding bulls	Dec	7.84	5.74	2.1

* Applied an average of Apr–Jun and Oct–Nov.

† Applied an average of Mar–Apr and Jul–Aug.

Source: Pickering et al, 2022

Beef cattle

Table A.2: Nitrogen (N) excretion rates for different age classes of beef cattle (2021–22)

Note: Estimated values are in italics with the method indicated in a footnote to the table.

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Breeding growing cows 0–1	Jan	1.11	0.83	0.28
Breeding growing cows 0–1	Feb	1.24	0.93	0.31
Breeding growing cows 0–1	Mar	3.39	2.54	0.85
Breeding growing cows 0–1	Apr	3.56	2.67	0.89
Breeding growing cows 0–1	May	4.12	3.08	1.03
Breeding growing cows 0–1	Jun	4	3	1.01
Breeding growing cows 0–1	Jul	4.34	3.25	1.09
Breeding growing cows 0–1	Aug	4.53	3.39	1.14
Breeding growing cows 0–1	Sep	5	3.74	*1.26‡*
Breeding growing cows 0–1	Oct	5	3.74	*1.26‡*
Breeding growing cows 0–1	Nov	5	3.74	*1.26‡*
Breeding growing cows 0–1	Dec	5	3.74	*1.26‡*
Breeding growing cows 1–2	Jan	5.3	3.97	1.33
Breeding growing cows 1–2	Feb	5.07	3.8	1.27
Breeding growing cows 1–2	Mar	6.73	5.04	1.69
Breeding growing cows 1–2	Apr	6.71	5.03	1.69
Breeding growing cows 1–2	May	7.43	5.56	1.86
Breeding growing cows 1–2	Jun	6.93	5.19	1.74
Breeding growing cows 1–2	Jul	7.25	5.43	1.82
Breeding growing cows 1–2	Aug	7.31	5.48	1.84
Breeding growing cows 1–2	Sep	4.49	3.36	1.13
Breeding growing cows 1–2	Oct	4.22	3.16	1.06
Breeding growing cows 1–2	Nov	4.33	3.24	1.09
Breeding growing cows 1–2	Dec	4.73	3.55	1.19
Breeding bulls mixed age	Jan	10.17	7.62	2.55
Breeding bulls mixed age	Feb	9.47	7.1	2.38
Breeding bulls mixed age	Mar	12.12	9.08	3.04
Breeding bulls mixed age	Apr	11.39	8.53	2.86
Breeding bulls mixed age	May	12.07	9.04	3.03
Breeding bulls mixed age	Jun	10.79	8.08	2.71
Breeding bulls mixed age	Jul	11.19	8.38	2.81
Breeding bulls mixed age	Aug	10.89	8.16	2.74
Breeding bulls mixed age	Sep	10.36	7.76	2.6
Breeding bulls mixed age	Oct	9.31	6.98	2.34
Breeding bulls mixed age	Nov	9.28	6.95	2.33
Breeding bulls mixed age	Dec	9.74	7.29	2.44
Slaughter heifers 0–1	Jan	1.62	1.21	0.41
Slaughter heifers 0–1	Feb	1.8	1.35	0.45
Slaughter heifers 0–1	Mar	4.22	3.16	1.06

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Slaughter heifers 0–1	Apr	4.46	3.34	1.12
Slaughter heifers 0–1	May	5.2	3.89	1.3
Slaughter heifers 0–1	Jun	5.06	3.79	1.27
Slaughter heifers 0–1	Jul	5.69	4.26	1.43
Slaughter heifers 0–1	Aug	5.95	4.46	1.49
Slaughter heifers 0–1	Sep	6.49	4.86	*1.63‡*
Slaughter heifers 0–1	Oct	6.49	4.86	*1.63‡*
Slaughter heifers 0–1	Nov	6.49	4.86	*1.63‡*
Slaughter heifers 0–1	Dec	6.49	4.86	*1.63‡*
Slaughter heifers 1–2	Jan	6.87	5.15	1.73
Slaughter heifers 1–2	Feb	6.6	4.95	1.66
Slaughter heifers 1–2	Mar	8.77	6.57	2.2
Slaughter heifers 1–2	Apr	8.66	6.48	2.17
Slaughter heifers 1–2	May	9.53	7.14	2.39
Slaughter heifers 1–2	Jun	8.81	6.6	2.21
Slaughter heifers 1–2	Jul	9.49	7.11	2.38
Slaughter heifers 1–2	Aug	9.51	7.12	2.39
Slaughter heifers 1–2	Sep	5.92	4.44	1.49
Slaughter heifers 1–2	Oct	5.58	4.18	1.4
Slaughter heifers 1–2	Nov	5.78	4.33	1.45
Slaughter heifers 1–2	Dec	6.34	4.75	1.59
Slaughter steers 0–1	Jan	2.31	1.73	0.58
Slaughter steers 0–1	Feb	2.54	1.9	0.64
Slaughter steers 0–1	Mar	5.32	3.98	1.34
Slaughter steers 0–1	Apr	5.63	4.21	1.41
Slaughter steers 0–1	May	6.58	4.93	1.65
Slaughter steers 0–1	Jun	6.4	4.79	1.61
Slaughter steers 0–1	Jul	7.15	5.36	1.8
Slaughter steers 0–1	Aug	7.48	5.6	1.88
Slaughter steers 0–1	Sep	8.32	6.23	*2.09‡*
Slaughter steers 0–1	Oct	8.32	6.23	*2.09‡*
Slaughter steers 0–1	Nov	8.32	6.23	*2.09‡*
Slaughter steers 0–1	Dec	8.32	6.23	*2.09‡*
Slaughter steers 1–2	Jan	8.86	6.64	2.23
Slaughter steers 1–2	Feb	8.58	6.43	2.15
Slaughter steers 1–2	Mar	11.45	8.57	2.87
Slaughter steers 1–2	Apr	11.19	8.38	2.81
Slaughter steers 1–2	May	12.29	9.2	3.09
Slaughter steers 1–2	Jun	11.26	8.44	2.83
Slaughter steers 1–2	Jul	12	8.99	3.01
Slaughter steers 1–2	Aug	11.99	8.98	3.01
Slaughter steers 1–2	Sep	7.45	5.58	1.87
Slaughter steers 1–2	Oct	7.03	5.26	1.76

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Slaughter steers 1–2	Nov	7.35	5.5	1.84
Slaughter steers 1–2	Dec	8.08	6.05	2.03
Slaughter bulls 0–1	Jan	2.35	1.76	0.59
Slaughter bulls 0–1	Feb	2.55	1.91	0.64
Slaughter bulls 0–1	Mar	5.29	3.96	1.33
Slaughter bulls 0–1	Apr	5.59	4.18	1.4
Slaughter bulls 0–1	May	6.51	4.87	1.63
Slaughter bulls 0–1	Jun	6.34	4.75	1.59
Slaughter bulls 0–1	Jul	7.14	5.35	1.79
Slaughter bulls 0–1	Aug	7.47	5.6	1.88
Slaughter bulls 0–1	Sep	8.28	6.2	*2.08‡*
Slaughter bulls 0–1	Oct	8.28	6.2	*2.08‡*
Slaughter bulls 0–1	Nov	8.28	6.2	*2.08‡*
Slaughter bulls 0–1	Dec	8.28	6.2	*2.08‡*
Slaughter bulls 1–2	Jan	8.79	6.59	2.21
Slaughter bulls 1–2	Feb	8.52	6.38	2.14
Slaughter bulls 1–2	Mar	11.39	8.53	2.86
Slaughter bulls 1–2	Apr	11.23	8.41	2.82
Slaughter bulls 1–2	May	12.39	9.28	3.11
Slaughter bulls 1–2	Jun	11.46	8.58	2.88
Slaughter bulls 1–2	Jul	12.37	9.26	3.1
Slaughter bulls 1–2	Aug	12.41	9.29	3.12
Slaughter bulls 1–2	Sep	7.44	5.57	1.87
Slaughter bulls 1–2	Oct	7.03	5.27	1.77
Slaughter bulls 1–2	Nov	7.33	5.49	1.84
Slaughter bulls 1–2	Dec	8.07	6.05	2.03
Breeding growing cows 2–3	Jan	7.09	5.31	1.78
Breeding growing cows 2–3	Feb	6.66	4.99	1.67
Breeding growing cows 2–3	Mar	8.72	6.53	2.19
Breeding growing cows 2–3	Apr	8.68	6.5	2.18
Breeding growing cows 2–3	May	9.66	7.24	2.43
Breeding growing cows 2–3	Jun	9.39	7.03	2.36
Breeding growing cows 2–3	Jul	10.52	7.88	2.64
Breeding growing cows 2–3	Aug	11.88	8.9	2.98
Breeding growing cows 2–3	Sep	6.8	5.09	1.71
Breeding growing cows 2–3	Oct	6.23	4.66	1.56
Breeding growing cows 2–3	Nov	6.15	4.61	1.54
Breeding growing cows 2–3	Dec	6.57	4.92	1.65
Breeding mature cows	Jan	8.72	6.53	2.19
Breeding mature cows	Feb	8.27	6.2	2.08
Breeding mature cows	Mar	7.6	5.69	1.91
Breeding mature cows	Apr	7.39	5.54	1.86
Breeding mature cows	May	8.08	6.05	2.03

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Breeding mature cows	Jun	7.78	5.83	1.95
Breeding mature cows	Jul	8.72	6.53	2.19
Breeding mature cows	Aug	9.95	7.45	2.5
Breeding mature cows	Sep	9.07	6.79	2.28
Breeding mature cows	Oct	8.14	6.09	2.04
Breeding mature cows	Nov	8	5.99	2.01
Breeding mature cows	Dec	8.3	6.21	2.08

‡ Applied an average of Jun–Aug and Jan–Mar.

Source: Pickering et al, 2022

Sheep

Table A.3: Nitrogen (N) excretion rates for different age classes of sheep (2021–22)

Note: Estimated values are in italics with the method indicated in a footnote to the table.

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Dry ewes	Jan	0.987	0.694	*0.294§*
Dry ewes	Feb	0.698	0.49	*0.207§*
Dry ewes	Mar	0.892	0.626	*0.265§*
Dry ewes	Apr	0.857	0.602	*0.255§*
Dry ewes	May	0.927	0.651	*0.276§*
Dry ewes	Jun	0.893	0.627	*0.266§*
Dry ewes	Jul	1.094	0.769	*0.326§*
Dry ewes	Aug	1.392	0.978	*0.414§*
Dry ewes	Sep	1.971	1.385	*0.586§*
Dry ewes	Oct	1.417	0.995	*0.422§*
Dry ewes	Nov	1.379	0.969	*0.41§*
Dry ewes	Dec	1.44	1.012	*0.429§*
Mature breeding ewes	Jan	1.229	0.864	0.366
Mature breeding ewes	Feb	0.869	0.61	0.258
Mature breeding ewes	Mar	1.11	0.779	0.33
Mature breeding ewes	Apr	1.067	0.749	0.317
Mature breeding ewes	May	1.154	0.811	0.343
Mature breeding ewes	Jun	1.112	0.781	0.331
Mature breeding ewes	Jul	1.362	0.957	0.405
Mature breeding ewes	Aug	1.733	1.217	0.516
Mature breeding ewes	Sep	2.454	1.724	0.73
Mature breeding ewes	Oct	1.764	1.239	0.525
Mature breeding ewes	Nov	1.717	1.206	0.511
Mature breeding ewes	Dec	1.793	1.26	0.534
Growing breeding sheep	Jan	1.409	0.99	0.419
Growing breeding sheep	Feb	1.059	0.744	0.315

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Growing breeding sheep	Mar	1.387	0.974	0.413
Growing breeding sheep	Apr	1.01	0.71	0.3
Growing breeding sheep	May	1.132	0.795	0.337
Growing breeding sheep	Jun	1.126	0.791	0.335
Growing breeding sheep	Jul	1.408	0.989	0.419
Growing breeding sheep	Aug	1.806	1.268	0.537
Growing breeding sheep	Sep	2.545	1.788	0.757
Growing breeding sheep	Oct	1.869	1.313	0.556
Growing breeding sheep	Nov	1.834	1.288	0.546
Growing breeding sheep	Dec	1.94	1.363	0.577
Growing non-breeding sheep	Jan	1.229	0.863	0.366
Growing non-breeding sheep	Feb	1.156	0.812	0.344
Growing non-breeding sheep	Mar	1.516	1.065	0.451
Growing non-breeding sheep	Apr	1.099	0.772	0.327
Growing non-breeding sheep	May	1.21	0.85	0.36
Growing non-breeding sheep	Jun	1.125	0.79	0.335
Growing non-breeding sheep	Jul	1.221	0.858	0.363
Growing non-breeding sheep	Aug	1.225	0.861	0.365
Growing non-breeding sheep	Sep	1.195	0.839	0.356
Growing non-breeding sheep	Oct	1.094	0.769	0.326
Growing non-breeding sheep	Nov	1.099	0.772	0.327
Growing non-breeding sheep	Dec	1.176	0.826	0.35
Wethers	Jan	0.951	0.668	0.283
Wethers	Feb	0.869	0.61	0.258
Wethers	Mar	1.11	0.779	0.33
Wethers	Apr	1.063	0.747	0.316
Wethers	May	1.133	0.796	0.337
Wethers	Jun	1.034	0.726	0.308
Wethers	Jul	1.094	0.769	0.326
Wethers	Aug	1.074	0.754	0.319
Wethers	Sep	1.024	0.72	0.305
Wethers	Oct	0.922	0.648	0.274
Wethers	Nov	0.894	0.628	0.266
Wethers	Dec	0.934	0.656	0.278
Lambs-Sl1	Jan	1.195	0.84	0.356
Lambs-Sl1	Feb	1.296	0.91	0.386
Lambs-Sl1	Mar	1.028	0.722	0.306
Lambs-Sl1	Apr	0.796	0.559	0.237
Lambs-Sl1	May	0.903	0.634	0.269
Lambs-Sl1	Jun	0.876	0.615	0.261
Lambs-Sl1	Jul	0.966	0.679	*0.287ϕ*
Lambs-Sl1	Aug	0.997	0.7	*0.297ϕ*

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Lambs-Sl1	Sep	0.047	0.033	*0.014ϕ*
Lambs-Sl1	Oct	0.047	0.033	0.014
Lambs-Sl1	Nov	0.277	0.195	0.083
Lambs-Sl1	Dec	0.628	0.441	0.187
Lambs-Sl2	Jan	1.195	0.84	*0.356ϕ*
Lambs-Sl2	Feb	1.296	0.91	*0.386ϕ*
Lambs-Sl2	Mar	1.028	0.722	*0.306ϕ*
Lambs-Sl2	Apr	0.796	0.559	*0.237ϕ*
Lambs-Sl2	May	0.903	0.634	*0.269ϕ*
Lambs-Sl2	Jun	0.876	0.615	*0.261ϕ*
Lambs-Sl2	Jul	0.966	0.679	0.287
Lambs-sl2	Aug	0.997	0.7	0.297
Lambs-Sl2	Sep	0.047	0.033	*0.014ϕ*
Lambs-Sl2	Oct	0.047	0.033	*0.014ϕ*
Lambs-Sl2	Nov	0.277	0.195	*0.083ϕ*
Lambs-Sl2	Dec	0.628	0.441	*0.187ϕ*
Rams	Jan	1.766	1.241	0.525
Rams	Feb	1.65	1.159	0.491
Rams	Mar	2.123	1.492	0.632
Rams	Apr	1.978	1.39	0.588
Rams	May	2.092	1.47	0.622
Rams	Jun	1.864	1.31	0.555
Rams	Jul	1.954	1.373	0.581
Rams	Aug	1.901	1.335	0.565
Rams	Sep	1.804	1.267	0.537
Rams	Oct	1.624	1.141	0.483
Rams	Nov	1.623	1.14	0.483
Rams	Dec	1.71	1.201	0.509

§ Applied MatureBreedingEwe_month * DryEwe_July / MatureBreedingEwe_July.
ϕ Applied values from the other lamb class for the same month.

Source: Pickering et al, 2022

Deer

Table A.4: Nitrogen (N) excretion rates for different age classes of deer (2021–22)

Note: Estimated values are in italics with the method indicated in a footnote to the table.

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Breeding Hinds 2+ years	Jan	3.326	2.46	0.866
Breeding hinds 2+	Feb	2.953	2.184	0.769
Breeding hinds 2+	Mar	3.06	2.263	0.797
Breeding hinds 2+	Apr	2.223	1.644	0.579
Breeding hinds 2+	May	2.388	1.766	0.622
Breeding hinds 2+	Jun	2.543	1.881	0.662
Breeding hinds 2+	Jul	2.686	1.986	0.699
Breeding hinds 2+	Aug	2.973	2.199	0.774
Breeding hinds 2+	Sep	3.162	2.339	0.823
Breeding hinds 2+	Oct	2.859	2.115	0.745
Breeding hinds 2+	Nov	3.37	2.492	0.878
Breeding hinds 2+	Dec	3.302	2.442	0.86
Hinds 0–1	Jan	0.112	0.083	0.029
Hinds 0–1	Feb	0.232	0.171	0.06
Hinds 0–1	Mar	0.723	0.535	0.188
Hinds 0–1	Apr	1.201	0.888	0.313
Hinds 0–1	May	0.974	0.72	0.254
Hinds 0–1	Jun	1.489	1.101	0.388
Hinds 0–1	Jul	1.7	1.257	0.443
Hinds 0–1	Aug	1.824	1.349	0.475
Hinds 0–1	Sep	1.884	1.394	0.491
Hinds 0–1	Oct	1.792	1.325	0.467
Hinds 0–1	Nov	1.813	1.341	0.472
Hinds 0–1	Dec	1.92	1.42	*0.5e*
Hinds 1–2	Jan	2.099	1.552	0.547
Hinds 1–2	Feb	1.967	1.455	0.512
Hinds 1–2	Mar	2.521	1.864	0.656
Hinds 1–2	Apr	2.562	1.895	0.667
Hinds 1–2	May	2.835	2.097	0.738
Hinds 1–2	Jun	2.932	2.168	0.763
Hinds 1–2	Jul	3.174	2.347	0.826
Hinds 1–2	Aug	3.489	2.581	0.909
Hinds 1–2	Sep	3.71	2.744	0.966
Hinds 1–2	Oct	3.417	2.527	0.89
Hinds 1–2	Nov	4.016	2.97	1.046
Hinds 1–2	Dec	1.931	1.428	0.503
Stags 0–1	Jan	0.3	0.222	0.078
Stags 0–1	Feb	0.412	0.305	0.107

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Stags 0–1	Mar	0.964	0.713	0.251
Stags 0–1	Apr	1.456	1.077	0.379
Stags 0–1	May	1.129	0.835	0.294
Stags 0–1	Jun	1.777	1.314	0.463
Stags 0–1	Jul	1.996	1.476	0.52
Stags 0–1	Aug	2.137	1.58	0.556
Stags 0–1	Sep	2.205	1.631	0.574
Stags 0–1	Oct	2.1	1.553	0.547
Stags 0–1	Nov	2.118	1.567	0.552
Stags 0–1	Dec	0.107	0.079	0.028
Stags 1–2	Jan	2.482	1.836	0.646
Stags 1–2	Feb	2.329	1.723	0.607
Stags 1–2	Mar	2.603	1.925	0.678
Stags 1–2	Apr	2.637	1.95	0.687
Stags 1–2	May	2.89	2.137	0.752
Stags 1–2	Jun	2.755	2.038	0.717
Stags 1–2	Jul	2.916	2.157	0.759
Stags 1–2	Aug	2.946	2.179	0.767
Stags 1–2	Sep	2.535	1.875	0.66
Stags 1–2	Oct	2.29	1.693	0.596
Stags 1–2	Nov	2.479	1.833	0.646
Stags 1–2	Dec	2.256	1.669	0.588
Stags 2–3	Jan	2.709	2.003	0.705
Stags 2–3	Feb	2.461	1.82	0.641
Stags 2–3	Mar	3.129	2.314	0.815
Stags 2–3	Apr	3.15	2.33	0.82
Stags 2–3	May	3.432	2.538	0.894
Stags 2–3	Jun	3.258	2.409	0.848
Stags 2–3	Jul	3.44	2.544	0.896
Stags 2–3	Aug	3.459	2.559	0.901
Stags 2–3	Sep	3.023	2.236	0.787
Stags 2–3	Oct	2.724	2.015	0.709
Stags 2–3	Nov	2.575	1.904	0.671
Stags 2–3	Dec	2.586	1.912	0.673
Breeding stags 3+	Jan	2.606	1.928	0.679
Breeding stags 3+	Feb	2.368	1.751	0.617
Breeding stags 3+	Mar	3.012	2.228	0.784
Breeding stags 3+	Apr	3.032	2.242	0.789
Breeding stags 3+	May	3.302	2.442	0.86
Breeding stags 3+	Jun	3.133	2.317	0.816
Breeding stags 3+	Jul	3.308	2.447	0.861
Breeding stags 3+	Aug	3.326	2.46	0.866

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
Breeding stags 3+	Sep	2.982	2.206	0.777
Breeding stags 3+	Oct	2.694	1.993	0.702
Breeding stags 3+	Nov	2.551	1.887	0.664
Breeding stags 3+	Dec	2.488	1.84	0.648

ɵ Applied an average of Oct–Nov and Jan–Feb.

Source: Pickering et al, 2022

All other livestock equations calculate annual dung N excretion. This is to be distributed evenly, and proportional to the months these livestock types are present.

Outdoor pigs

Total N_{ex} = head x N_{ex} factor

where:

- Total N_{ex} Excreted nitrogen in kilograms per year – listed as 11.05 kg $head^{-1}$ yr^{-1} (Hill, 2012)
- Head Number of animals – **a user-inputted figure**
- N_{ex} factor Nitrogen excretion rate (N/head/year)

Note that NZPork has advised that the Ministry for Primary Industries inventory equation for swine is not appropriate because the Intergovernmental Panel on Climate Change calculations are for an 'average' pig. Outdoor sows deposit more N than an average pig. The replacement calculation could be updated once provided.

Poultry

These equations refer to the combined annual excretion of N in urine and dung. We split N inputs equally between urine and dung when applying an index.

Total N_{ex} = head x N_{ex} factor

where:

- Total N_{ex} Excreted nitrogen in kilograms per year
- Head Number of animals – **a user-inputted figure**
- N_{ex} factor Nitrogen excretion rate (N/head/year)

Poultry type	Equation
Broilers	Total N_{ex} = head x 0.39
Layers	Total N_{ex} = head x 0.42
Other (including ducks, turkeys, emus, ostriches)	Total N_{ex} = head x 0.60

Goats

These equations refer to the combined annual excretion of N in urine and dung. We split N inputs equally between urine and dung when applying an index. We suspect that meat goats and dairy goats may excrete different amounts of N in urine, but have no data on this so treat them as equal.

Total N_{ex} = head x N_{ex} factor

where:

- Total N_{ex} Excreted nitrogen in kilograms per year
- Head Number of animals – **a user-inputted figure**
- N_{ex} factor Nitrogen excretion rate (N/head/year)

Goat type	Equation
Dairy	Total N_{ex} = head x 12.7
Non-dairy	Total N_{ex} = head x 10.6

Horses, mules and asses

These equations refer to the combined annual excretion of N in urine and dung. We split N inputs equally between urine and dung when applying an index.

Total N_{ex} = head x N_{ex} factor

where:

- Total N_{ex} Excreted nitrogen in kilograms per year
- Head Number of animals – **a user-inputted figure**
- N_{ex} factor Nitrogen excretion rate (25 N/head/year)

Alpacas

Use values for mature breeding ewes.

References

Hill J. 2012. *Recalculate Pork Industry Emissions Inventory*. MAF Technical Paper No: 2012/05. Prepared for Ministry of Agriculture and Forestry by Massey University College of Sciences. Wellington: Ministry of Agriculture and Forestry.

Luo J, Sagger S, van der Weerden T, de Klein C, Sprosen M. 2022. Review and revision of the methane conversion factor (MCF) for dairy cattle manure. 34.

Pickering A, Gibbs J, Wear S, Fick J, Tomlin H. 2022. *Methodology for calculation of New Zealand's agricultural greenhouse gas emissions*. MPI Technical Paper. Version 8. Wellington: Ministry for Primary Industries.

Stewart DPC, Rout R. 2007. *Reasonable Stock Water Requirements Guidelines for Resource Consent Applications*. Technical report prepared for Horizons Regional Council. Palmerston North: Horizons Regional Council.

Appendix B: Soil residue nitrogen inputs

S Trolove[1], VO Snow[2], RW McDowell[2,3]

[1] Plant & Food Research, 30 Crosses Rd, Havelock North 4130, New Zealand

[2] AgResearch, Lincoln Science Centre, Lincoln, New Zealand

[3] Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand

The total mineral nitrogen (N) inputs (the amount of N per hectare to be multiplied by the transport factor) is calculated by summing total mineral N inputs from fertiliser, composts and residues for the month.

Users will be requested to input a crop type (including fallow) for every month from a drop-down box and a yield for the month of harvest.

To estimate N losses from **runoff**, only use estimates for above-ground residues (ie, Eqn 1).

To estimate N losses from **leaching** use above- and below-ground residues (after removing N that is immobilised) and any modifications from sections 2 to 5 (ie, Eqn 2 plus Eqn 3 onwards).

Mineral N inputs from residues, and monthly crop uptake, are calculated as described below.

1. Estimating average soil mineral nitrogen inputs from crop residues

The amount of N in crop residues is based on the work of Pickering et al (2022), who calculated N content for the purposes of calculating nitrous oxide emissions. The fact that some residues immobilise N and some release N is crudely accounted for by assuming mineralisation in residues with a C:N ratio below a critical value of 25 (Paul and Clark, 1989), and immobilisation (mineral N taken up from the soil) by residues with a high C:N ratio. This agrees with the critical C:N ratio of 24 found by Trinsoutrot et al (2000). But a lower critical C:N ratio of 18 (Bolger et al, 2001) or higher critical C:N ratios of 37 (Chaves et al, 2004), 40 (Vigil and Kissel, 1991) and 44 (De Neve and Hofman, 1996) have been found in other studies. This indicates that the C:N ratio alone is not particularly accurate, and better relationships have been found by including lignin content into decomposition equations (Chaves et al, 2004; De Neve and Hofman, 1996), which include the rate of N release. However, this information is not available for all crops, so the C:N ratio has been used in this instance. It is assumed that N supply from burnt residues is small, so is not accounted for in this version but can be included in later versions if needed. Immobilisation is reduced according to the proportion of unburnt residues (a value entered by the user).

The amount of N supplied by crop residues (if the C:N ratio is less than 25) is calculated according to equation 1 below.

$$AGNR,c = DMFc \times (Prodc \;/\; HIc - Prodc) \times NAG,\text{c} \qquad \text{[Eqn 1]}$$

Where:

- AGNR,c = Amount of above-ground nitrogen returned to soils through incorporation of crop residues for crop type c (kg N ha^{-1})

- DMFc = Dry matter factor, used to convert the tonnes of fresh residues produced to tonnes of dry matter produced for crop type c (see table B.1 for values)
- Prodc = Annual production of crop type, c (kg ha^{-1}). This is entered by the grower
- Hic = Harvest index, fraction of the crop (c) that is harvested for the primary purpose of growing the crop (see table B.1 for values)
- NAG,c = Nitrogen content of above-ground residue for crop type c (kg N kg^{-1} dry matter) (see table B.1 for values)

Above-ground N is assumed to be available to runoff, whereas both above- and below-ground N from residues are assumed to be available to leaching.

The amount of N supplied by roots from crop residues is calculated according to equation 2 below.

$BGN,c = DMFc \times (Prodc \,/\, HIc) \times RSc \times NBG,c$ [Eqn 2]

Where:

- BGN,c = Amount of below-ground nitrogen returned to soils after the crop through incorporation of crop residues for crop type c (kg N ha^{-1})
- DMFc = Dry matter factor, used to convert total production to dry matter crop production for crop type c (see table B.1 for values)
- Prodc = Annual production of crop type, c (kg/ha). This is entered by the grower
- Hic = Harvest index, fraction of the crop (c) that is harvested for the primary purpose of growing the crop (see table B.1 for values)
- RSc = Root:shoot ratio for crop type c, assumed to be 0.1 for all crops (Thomas et al, 2011)
- NBG,c = Nitrogen content of below-ground residue for crop type c (kg N/kg DM) (see table B.1 for values).

The amount of mineral N (in kilograms of nitrogen per hectare (kg N/ha)) supplied by mineralisation of above-ground (NminAGR) and below-ground (NminBGR) crop residues (if the C:N ratio is less than 25) is calculated by the formulae below (equations 3 and 4). If C:N is between 25 and 40, it is assumed that no N is released from residues. The N content of the residues is multiplied by 0.6, because approximately 60 per cent of the N in the residues is released by mineralisation in the short term (De Neve and Hofman, 1996). This is a crude approximation that in future versions could be made to vary with residue type. The remaining 40 per cent of the N becomes part of the organic N pool, which is slowly released over many years and not considered in this N leaching risk index tool.

If $C{:}N_{AG}<25$, NminAGR = $AGNR_c$ x 0.6 [Eqn 3]

Where:

- $C{:}N_{AG}$ = the carbon to nitrogen ratio of the above-ground biomass (see table B.1 for values).

NminBGR = $BGNR_c$ x 0.6 [Eqn 4]

Data for C:N ratios for roots of each crop is difficult to find. For crops where data were available, the values were often between 30 and 40 (Nicolardot et al, 2001), and the amounts of mineral N either immobilised or released were variable. However, root N only comprises a small amount of the N contribution of crop residues, so N release has been assumed.

The total amount (kg N ha^{-1}) of N mineralised (NminT) is the sum of that supplied from mineralisation the above- and below-ground residues.

(NminT) = NminAGR + NminBGR

For forage cereals, stock numbers are input and NminBGR are calculated but NminAGR is assumed to be zero due to grazing. For crops that are grazed, values yield values as for any crop and stock numbers in the appropriate months. Stock numbers should be a maximum number in the month, that is, not averaged for part of a month or across the farm.

Table B.1: Parameters for the calculation of crop residue nitrogen (N) content and crop N uptake

These are rooting depth, harvest index (HI), the N concentration in the above-ground residues (NAGR) and below-ground residues (NBG), the dry matter factor (DMF), and the carbon to nitrogen ratio (C:N). Most of the data for HI, NAGR, NBG and DMF are from Pickering et al (2022). Rooting depths are from Lott and Hammond (2013) and Alberta Agriculture and Forestry (2016) and apply only to leaching. Other data are as listed in the references column.

Species	Rooting depth	HI	NAGR (kg N/kg DM)	NBG (kg N/kg DM)	DMF residues	C:N	References
Wheat	Deep	0.41	0.005	0.009	0.86	58	Rahn and Lillywhite, 2002
Barley	Deep	0.46	0.005	0.009	0.86	58	Curtin et al, 2022
Oats	Deep	0.30	0.005	0.009	0.86	58	Carranca et al, 2009
Forage cereal	Deep	0.37	NA	0.009	0.13	20	Muldoon, 1986
Maize (grain)	Deep	0.50	0.007	0.007	0.86	79	Kucharik and Brye, 2003
Field seed peas	Intermediate	0.50	0.020	0.015	0.86	28	Rezgui et al, 2021
Peas fresh and processed	Intermediate	0.45	0.030	0.015	0.21	12*	
Potatoes	Intermediate	0.90	0.020	0.010	0.22	22	Chatterjee and Acharya, 2020
Onions	Shallow	0.80	0.020	0.010	0.11	23	Thiébeau et al, 2021
Sweet corn	Intermediate	0.55	0.009	0.007	0.24	32	University of Minnesota Extension, 2021
Squash	Intermediate	0.80	0.020	0.010	0.20	12*	
Herbage seeds	Intermediate	0.11	0.015	0.010	0.85	30*	
Legume seeds	Intermediate	0.09	0.040	0.010	0.85	30*	
Brassica seeds	Intermediate	0.20	0.010	0.008	0.85	30*	
Cauliflower	Intermediate	0.24	0.023	0.010	0.12	17	Kage and Stützel, 1999; Nett et al, 2016
Broccoli	Intermediate	0.35	0.015	0.010	0.20	26	Curtin et al, 2022; Jett et al, 1995
Beans	Intermediate	0.37	0.033	0.010	0.17	11	Bending et al, 1998; Trolove et al, 2021
Carrots	Intermediate	0.77	0.022	0.010	0.18	24	Trolove et al, 2021
Beetroot	Intermediate	0.85	0.030	0.010	0.28	10	Trolove et al, 2021
Tomatoes	Intermediate	0.67	0.022	0.010	0.19	10	Trolove et al, 2021

Species	Rooting depth	HI	NAGR (kg N/kg DM)	NBG (kg N/kg DM)	DMF residues	C:N	References
Lettuce	Shallow	0.38	0.024	0.041	0.07	12	Hamilton and Bernier, 1975; Paterson and Rahn, 1996; Rahn and Lillywhite, 2002
Cabbage	Intermediate	0.70	0.029	0.013	0.15	14	Duarte et al, 2019; Mitchell et al, 2001
Brussels sprouts	Intermediate	0.35	0.021	0.009	0.18	15	Nicolardot et al, 2001; Turan et al, 2009
Celery	Shallow	0.50	0.024	0.020	0.17	15	De Neve and Hofman, 1996; Hamilton and Bernier, 1975; Turan et al, 2009
Grey pumpkin	Intermediate	0.86	0.014	0.010*	0.12	30*	Nett et al, 2016
Asian greens (eg, pak choi)	Shallow	0.60*	0.024*	0.030*	0.08*	12*	
Leeks	Shallow	0.70*	0.029	0.036	0.11	12	Chaves et al, 2004; ; Rahn and Lillywhite, 2002
Spinach	Shallow	0.70*	0.025*	0.010*	0.12*	12*	
Long-term pasture – dairy (prior to cultivation)		See section 3 below.					
Long-term pasture – sheep, beef, deer (prior to cultivation)		See section 3 below.					
Short-term pastures (prior to cultivation)		See section 3 below.					
Green manure		See section 4 below.					
Fallow		See section 5 below.					

*Estimated values.

The monthly release of this amount of nitrogen will be apportioned as described in table B.2.

Table B.1: Proportion of crop residue nitrogen released per month after incorporation into the soil

1st month	2nd month	3rd month
70%	20%	10%

This is a crude approximation of the release rates provided by De Neve and Hofman (1996). Greater accuracy may be achieved in future iterations of the index by providing different release rates for different seasons. Rates of N release or immobilisation will be slower if the residues remain on the soil surface, because N release can only occur if there is adequate soil moisture, and immobilisation of soil N only occurs when the residues are in contact with soil N (Chen et al, 2014).

Immobilisation by residues with C:N>40 may be crudely estimated according to the relationship from Trinsoutrot et al (2000).

N immobilised = 14.6 x $N_{residues}$ – 24.6

Where N immobilised is g N kg^{-1} residual C and $N_{residues}$ is organic N in residues (g kg^{-1} dry matter)

Rearranging this becomes:

N immobilised (kg ha^{-1}) = kg residual C ha^{-1} x (14.6 x NAG x 1000 – 24.6)/1000

And kg residual C ha^{-1} = $AGNR,c$ x C:N ratio

This immobilisation could be assumed to occur within a month of incorporation after harvest, because laboratory studies show that immobilisation by crop residues is often rapid (Trinsoutrot et al, 2000), although again there is much variability depending on factors such as residue type, temperature and degree of incorporation into the soil. If sufficient immobilisation occurs, the risk for the month of immobilisation can be zero.

Nitrogen inputs from perennial crop prunings are not included in table B.1 because they are not likely to contribute to increased risk of N leaching in the short term. They are considered to enter the slow-release organic N pool, which is not covered in this RIT, except to highlight N risk during periods of fallow and crop establishment (Thomas et al, 2014).

2. Effect of rooting depth on the risk of nitrate leaching

Nitrogen applied to deep-rooting crops that have a high N requirement typically have a lower risk of leaching than N applied to shallow-rooting crops. To account for this, the sum of monthly N leaching risk for the different crops in table B.1 is multiplied by a rooting depth factor (table B.2). The N leaching risk for deep-rooting crops will be multiplied by 0.7 (ie, N leaching is reduced relative to pasture at 60cm rooting depth), and for shallow-rooting crops the N leaching risk will be multiplied by 1.4 (ie, risk is increased relative to pasture). For crops with intermediate-rooting depths, the multiplier is 1, that is, the risk is like to pasture. This is summarised in table B.3. For fallow, the multiplier is 1.8.

Table B.3: Multiplier to apply to the sum of monthly nitrogen (N) loss during the months where each crop is grown

Rooting depth	N leaching risk multiplier
Shallow	1.4
Intermediate	1.0
Deep	0.7

3. Estimating average soil mineral nitrogen inputs to leaching from cultivation of long- and short-term pasture residues

Soil mineral N inputs from pasture residues are calculated based on the methodology of Thomas et al (2014). Users indicate pasture as the crop type for all months from January preceding a new crop or fallow.

The N supplied from long-term dairy, sheep, beef or deer pastures, whereby pasture residues N_p (kg ha^{-1}) is calculated as:

$$N,p = (AG_{DM} \times N_{AG}) + (BG_{DM} \times N_{BG}) \qquad \text{[Eqn 5]}$$

Where:

- AG_{DM} is the above-ground dry matter, which in dairy pastures, is taken to be 1.4 Mg DM/ha, and in sheep and beef pastures is 0.75 Mg DM/ha
- N_{AG} is assumed to be 2 per cent for both sheep and beef and dairy pastures
- BG_{DM} for sheep and beef pastures is taken to be 7.2 Mg DM/ha, and 2.8 Mg DM/ha for dairy pastures
- N_{BG} is taken to be 1.2 per cent for sheep and beef pastures and 1.6 per cent for dairy pastures.

For short-term pastures (ie, those only present in the system for less than two years), AG_{DM} is 1.2 Mg DM/ha, BG_{DM} is 2 Mg DM/ha N_{BG} is 1.4 per cent and N_{AG} is 2 per cent.

This N is assumed to be converted to mineral N distributed according to the pattern shown in table B.4. Note that much variation occurs in the rate of conversion of these pastoral N residues into mineral N (Bending et al, 1998; Chaves et al, 2004), because this depends on numerous factors such as soil temperature, degree of incorporation, soil moisture and pasture composition, which would be much more accurately described by a model.

Table B.4: Percentage of pasture residue nitrogen (N) converted to mineral N per month following incorporation into soil

Note: Twenty per cent is assumed to be mineralised over the next nine months at a rate of 1.9 per cent per month (looping back to the start of the year if less than nine months since harvest) but this has not been included in the first release of the tool. The remaining 20 per cent is assumed to go into the long-term N pool that is not at risk of leaching in the short term.

1st month	2nd month	3rd month
40	15	5

4. Green manure crops

Green manure crops are defined as short-term crops (commonly three months or less) planted for the purpose of supplying nutrients (eg, N) to the subsequent crop, so they typically have a high leaf N concentration. Green manure crops are distinct from catch crops, which have an extensive, deep-root system, a longer growing period and a lower leaf N concentration.

The amount of mineral N from green manures (GMN) available for leaching is estimated according to equation 6.

$$GMN = Prodc \times NAG \text{ X } 0.8 \qquad \text{[Eqn 6]}$$

The N supplied by green manure crops is multiplied by 0.8, because approximately 70 per cent of the crop N is released by mineralisation, with an additional 10 per cent N added to account for mineral N supply from the roots. The remaining 20 per cent of the crop N is assumed to go into the slow-release organic N pool. The green manure N would be distributed according to the pattern in table B.2. For simplicity, only two categories of green manure crops are considered:

1) grass and cereal green manure crops, with a NAG concentration of 0.012 kg N kg^{-1} DM
2) all other green manure crops, with a NAG concentration of 0.03 kg N kg^{-1} DM (Wheeler, 2018).

Note that, in this instance, *Prodc* has the units of kg DM ha^{-1}, because it is assumed growers will be more familiar with this unit for green manure crop yield than with kg FW ha^{-1}.

5. Process for handling fallow periods and crop establishment

The risk of leaching N losses is greatly increased during fallow periods, when N uptake and crop cover is non-existent or very small. To account for this, soil N mineralisation is added in. This rate varies with factors such as temperature and paddock management history. We have crudely estimated the supply of mineral N from mineralisation (Nmin) as 0.5 kg N ha^{-1} day^{-1} in the summer and 0.25 kg N ha^{-1} day^{-1} in the winter, with intermediate values for September and April (table B.5). Soil N mineralisation will be included as a N input for the months of fallow plus the first month after sowing a crop.

Table B.5: Table of soil nitrogen (N) mineralisation values (Nmin, kg N ha^{-1} $month^{-1}$) to be added as an N input during fallow periods, starting with the first month after harvest of a crop and up to (ie, including) the first month of the subsequent crop

Month	J	F	M	A	M	J	J	A	S	O	N	D
Nmin	15.5	14	15.5	10	7.75	7.5	7.75	7.75	10	15.5	15	15.5

References

Alberta Agriculture and Forestry. 2016. *Alberta Irrigation Management Manual 2016*. Alberta: Alberta Agriculture and Forestry.

Bending GD, Turner MK, Burns IG. 1998. Fate of nitrogen from crop residues as affected by biochemical quality and the microbial biomass. *Soil Biology and Biochemistry* 30(14): 2055–2065.

Bolger TP, Reid BM, Peoples MB, Angus AF. 2001. *Nitrogen mineralisation from shoot and root residues of crop and pasture species*. Canberra: CSIRO Plant Industry.

Carranca C, Oliveira A, Pampulha E, Torres MO. 2009. Temporal dynamics of soil nitrogen, carbon and microbial activity in conservative and disturbed fields amended with mature white lupine and oat residues. *Geoderma* 151(1): 50–59.

Chatterjee A, Acharya U. 2020. Controls of carbon and nitrogen releases during crops' residue decomposition in the Red River Valley, USA. *Archives of Agronomy and Soil Science* 66(5): 614–624.

Chaves B, De Neve S, Hofman G, Boeckx P, Van Cleemput O. 2004. Nitrogen mineralization of vegetable root residues and green manures as related to their (bio)chemical composition. *European Journal of Agronomy* 21(2): 161–170.

Chen D, Huang H, Hu M, Dahlgren RA. 2014. Influence of lag effect, soil release, and climate change on watershed anthropogenic nitrogen inputs and riverine export dynamics. *Environmental Science & Technology* 48(10): 5683–5690.

De Neve S, Hofman G. 1996. Modelling N mineralization of vegetable crop residues during laboratory incubations. *Soil Biology and Biochemistry* 28(10): 1451–1457.

Duarte LO, Clemente JM, Caixeta IAB, Senoski M, Aquino LA. 2019. Dry matter and nutrient accumulation curve in cabbage crop. *Agronmia Revista Caatinga* 32(3): 679–689.

Hamilton HA, Bernier R. 1975. N–P–K Fertilizer effects in yield, composition and residues of lettuce, celery, carrot and onion grown in an organic soil in Quebec*. Canadian Journal of Plant Science* 55(2): 453–461.

Jett LW, Morse RD, O'Dell CR. 1995. Plant density effects on single-head broccoli production. *HortScience HortSci* 30(1): 50–52.

Kage H, Stützel H. 1999. A simple empirical model for predicting development and dry matter partitioning in cauliflower (*Brassica oleracea L. botrytis*). *Scientia Horticulturae* 80(1): 19–38.

Kucharik CJ, Brye KR. 2003. Integrated Biosphere Simulator (IBIS) Yield and Nitrate Loss Predictions for Wisconsin Maize Receiving Varied Amounts of Nitrogen Fertilizer. *Journal of Environmental Quality* 32(1): 247–268.

Lott DE, Hammond VE. 2013. *Water Wise: Vegetable and Fruit Production*. NebGuide. University of Nebraska–Lincoln Extension.

Mitchell R, Webb J, Harrison R. 2001. Crop residues can affect N leaching over at least two winters. *European Journal of Agronomy* 15(1): 17–29.

Muldoon D. 1986. Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. *Australian Journal of Experimental Agriculture* 26(1): 87–98.

Nett L, Sradnick A, Fuß R, Flessa H, Fink M. 2016. Emissions of nitrous oxide and ammonia after cauliflower harvest are influenced by soil type and crop residue management. *Nutrient Cycling in Agroecosystems* 106(2): 217–231.

Nicolardot B, Recous S, Mary B. 2001. Simulation of C and N mineralisation during crop residue decomposition: A simple dynamic model based on the C:N ratio of the residues. *Plant and Soil* 228(1): 83–103.

Paterson CD, Rahn CR. 1996. The nitrogen contribution of lettuce crop residues intensive vegetable rotations. *Acta Horticulturae* 428: 105–114.

Paul EA, FE Clark. 1989. *Soil Microbiology and Biochemistry*. San Diego, CA: Academic Press Inc.

Pickering A, Gibbs J, Wear S, Fick J, Tomlin H. 2022. *Methodology for calculation of New Zealand's agricultural greenhouse gas emissions*. MPI Technical Paper. Version 8. Wellington: Ministry for Primary Industries.

Rahn CR, Lillywhite RD. 2002. A study of the quality factors affecting the short-term decomposition of field vegetable residues. *Journal of the Science of Food and Agriculture* 82(1): 19–26.

Rezgui C, Trinsoutrot-Gattin I, Benoit M, Laval K, Riah-Anglet W. 2021. Linking changes in the soil microbial community to C and N dynamics during crop residue decomposition. *Journal of Integrative Agriculture* 20(11): 3039–3059.

Thiébeau P, Jensen LS, Ferchaud F, Recous S. 2021. Dataset of biomass and chemical quality of crop residues from European areas. *Data in Brief* 37: 107227.

Thomas S, Fraser T, Curtin D, Brown H, Lawrence E. 2011. *Review of nitrous oxide emission factors and activity data for crops*. MAF Technical Paper No: 2011/25. Prepared for the Ministry of Agriculture and Forestry by Crop and Food Research August 2008. Wellington: Ministry of Agriculture and Forestry.

Thomas S, Wallace D, Beare M. 2014. *Pasture renewal activity data and factors for New Zealand*. Wellington: Plant and Food Research.

Trinsoutrot I, Recous S, Bentz B, Linères M, Chèneby D, Nicolardot B. 2000. Biochemical Quality of Crop Residues and Carbon and Nitrogen Mineralization Kinetics under Nonlimiting Nitrogen Conditions. *Soil Science Society of America Journal* 64(3): 918–926.

Trolove S, Wallace D, Johnstone P, Sorensen I, Arnold N, van der Weyden J, van den Dijssel C, Dellow S, Wright P, Clark G, Cummins M, Green S. 2021. *Protecting our groundwater: Fluxmeter network summary report*. Plant & Food Research Report No. 20648. Auckland: Plant and Food Research.

Turan M, Ataoglu N, Gunes A, Oztas T, Dursun A, Ekinci M, Ketterings QM, Huang M. 2009. Yield and chemical composition of brussels sprout (*Brassica oleracea L. gemmifera*) as affected by boron management. *HortScience HortSci* 44(1): 176–182.

University of Minnesota Extension. 2021. *Can you take a nitrogen credit following sweet corn? Minnesota Crop News*. Retrieved 28 November 2023.

Vigil MF, Kissel DE. 1991. Equations for Estimating the Amount of Nitrogen Mineralized from Crop Residues. *Soil Science Society of America Journal* 55(3): 757–761.

Wheeler DM. 2018. *OVERSEER® Technical Manual: Technical Manual for the description of the OVERSEER® Nutrient Budgets engine*. OVERSEER Limited.

Zink FW. 1966. Celery growth and nutrient absorption studies. *Hilgardia* 20(7): 10–10.

Appendix C: Erosion losses associated with land use and management

RW McDowell[1,2], RA Benavidez[3,4], BM Jackson[3,4]

[1] Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand

[2] AgResearch, Lincoln Science Centre, Lincoln, New Zealand

[3] BEEA Limited, Wellington, New Zealand

[4] Victoria University of Wellington, Wellington, New Zealand

We estimated nitrogen (N) losses at the polygon level from soil erosion from erosion estimates of sediment and soil N concentrations for different soil orders, land uses and annual rainfall amounts. Appendix G discusses how we suggest bringing in more drivers, such as topography, more sophisticated rainfall erosivity estimates and break out cover and management factors, to improve potential further development of erosion losses to support future iterations of the Risk Index Tool (RIT).

Estimating soil erosion losses

Observations for sediment loss were obtained from the literature (table C.1). These were used to generate mean observed sediment losses for land use and slope classes (flat, rolling, easy and steep corresponding to less than 7, 7–15, 15.01–25, and more than 25 degrees, respectively) where there were three or more studies (table C.2). Too few data were available to make any further inferences on the role of different practices or land use intensity within each of these land use by slope classes. The only exception was grazed winter forage cropping (as a land use management), which has been well studied owing to its higher sediment loss compared with pasture grazed in winter (McDowell and Houlbrooke, 2009).

Table C.1: Sediment yields and mean annual rainfall observed for farm to catchment scale studies of different land uses (and grazed winter forage crops) and slope classes across New Zealand

Land use and management	Sediment yield (kg ha^{-1} yr^{-1})	Mean annual rainfall (mm)	Slope class (degrees)	References
Arable	130	1,100	11.5	Muller et al, 2002
Arable	230	800	3.5	Worrall et al, 2013[1]
Dairy	1,250	780	11.5	McDowell, 2006b
Dairy	142	1,132	3.5	Wilcock et al, 1999
Dairy	58	850	3.5	Monaghan et al, 2007
Dairy	67	1,132	3.5	Wilcock et al, 2006
Dairy	38	1,160	3.5	Davies-Colley and Nagels, 2002; Wilcock et al, 2007
Dairy	149	1,250	3.5	Davies-Colley and Nagels, 2002; Wilcock et al, 2007
Dairy	72	1,330	3.5	Davies-Colley and Nagels, 2002; Wilcock et al, 2007

Land use and management	Sediment yield (kg ha^{-1} yr^{-1})	Mean annual rainfall (mm)	Slope class (degrees)	References
Dairy	883	4,830	3.5	Davies-Colley and Nagels, 2002; Wilcock et al, 2007
Dairy	32	900	3.5	Davies-Colley and Nagels, 2002; Wilcock et al, 2007
Deer (drystock)	4,480	687	19	McDowell, 2007
Deer (drystock)	3,950	944	11.5	McDowell, 2007
Deer (drystock)	3,356	687	19	McDowell, 2008
Deer (drystock)	158	1,100	3.5	McDowell, 2006a
Deer (drystock)	850	1,300	19	McDowell, 2009
Deer (drystock)	2,068	800	11.5	McDowell, 2009
Deer (drystock)	398	800	19	McDowell, 2009
Exotic forest	140	1,300	35	Fahey and Marden, 2000
Exotic forest	40	1,550	19	Dons, 1987
Native forest	320	1,600	35	Quinn and Stroud, 2002
Native forest	320	1,600	35	Quinn and Stroud, 2002
Native forest	27	1,500	19	Cooper and Thomsen, 1988
Native forest	600	1,664	35	Hughes et al, 2012
Native forest	240	2,600	35	O'Loughlin et al, 1978
Native forest	270	1,550	19	Dons, 1987
Sheep and beef (drystock)	700	1,200	19	Cooke and Dons, 1988
Sheep and beef (drystock)	1,220	1,200	19	Lambert et al, 1985
Sheep and beef (drystock)	97	690	19	McDowell et al, 2004
Sheep and beef (drystock)	374	1,401	19	Smith, 1987
Sheep and beef (drystock)	1,400	1,000	35	Bargh, 1978
Sheep and beef (drystock)	22	1,500	19	Cooper and Thomsen, 1988
Sheep and beef (drystock)	2,632	1,600	35	Quinn and Stroud, 2002
Sheep and beef (drystock)	128	1,923	11.5	Williamson et al, 1996
Sheep and beef (drystock)	2,740	1,200	19	Lambert et al, 1985
Sheep and beef (drystock)	183	1,006	11.5	Thorrold et al, 1997
Sheep and beef (drystock)	970	1,664	35	Hughes et al, 2012
Sheep and beef (drystock)	430	1,300	19	Fahey and Marden, 2000
Sheep and beef (drystock)	220	1,550	19	Dons, 1987
Horticulture (vegetables)[2]	7,000	1,200	19	Basher et al, 2004
Horticulture (vegetables)[2]	16,000	1,200	19	Basher and Ross, 2002
Horticulture (vegetables)	490	1,200	3.5	Hicks, 1994
Winter forage crop (grazed)	1,012	800	11.5	McDowell and Stevens, 2008
Winter forage crop (grazed)	1,980	700	11.5	Monaghan et al, 2017
Winter forage crop (grazed)	1,100	1,100	11.5	Burkitt et al, 2017
Winter forage crop (grazed)	204	1,100	11.5	Burkitt et al, 2017
Winter forage crop (grazed)	640	1,083	11.5	McDowell and Houlbrooke, 2009
Winter forage crop (grazed)	400	1,083	11.5	McDowell and Houlbrooke, 2009

1 Data taken for catchments in the United Kingdom dominated by arable cropping (greater than 70 per cent) where the rainfall (600–900 mm), soil texture (silt loam) and slope (flat) were considered similar to those likely in New Zealand.

2 Data not included as vegetable growing on slopes is likely to be an unjustifiable intensive use of high erosion risk land.

Table C.2: Mean observed annual sediment yields (kg ha-1) from different land uses at each slope

Land use and management	Flat	Rolling	Easy	Steep
Arable	180	180		
Dairy	180	1,250		
Deer (drystock)	158	2,517[1]	2,517[1]	
Exotic forest			167	167
Native forest			296	296
Sheep and Beef (drystock)		156	725	1,667
Horticultural (vegetables)	490			
Winter forage crop (grazed)		889		

1 These observations were excluded from the analysis owing to the bias caused by the large influence of wallows on the data compared with the presence of wallowing in a normal deer farm.

Estimates for seasonal cover factors used in the Revised Universal Soil Loss Equation (RUSLE) were taken from Donovan (2022) for New Zealand, see appendix G for more information and references to the RUSLE approach and how we might use it more fully in later iterations of the RIT. Because no New Zealand data were available for vegetables, these were sourced from a study of European soils (Bakker et al, 2008) and the data for temperate soils from a study of global soils (Nendel et al, 2019) (table C.3). These data were then adjusted by multipliers (from 70–800) to yield values that were like annual sediment yields (table C.4; figure C.1). We have isolated the cover factor as the dominant human-influenced factor within RUSLE. No data are readily available for practice values but, through prior calibration in New Zealand, land management practices are bundled within cover factors, for example, see Dymond 2010 and Dymond et al, 2010. We outline how RUSLE can replace our estimates in appendix G. However, we have produced these estimates to make use of user-supplied data on land use and slope (also used for the filtering of mitigations and modifiers).

Table C.3: Seasonal cover factors and soil total nitrogen (N) concentration by land use management

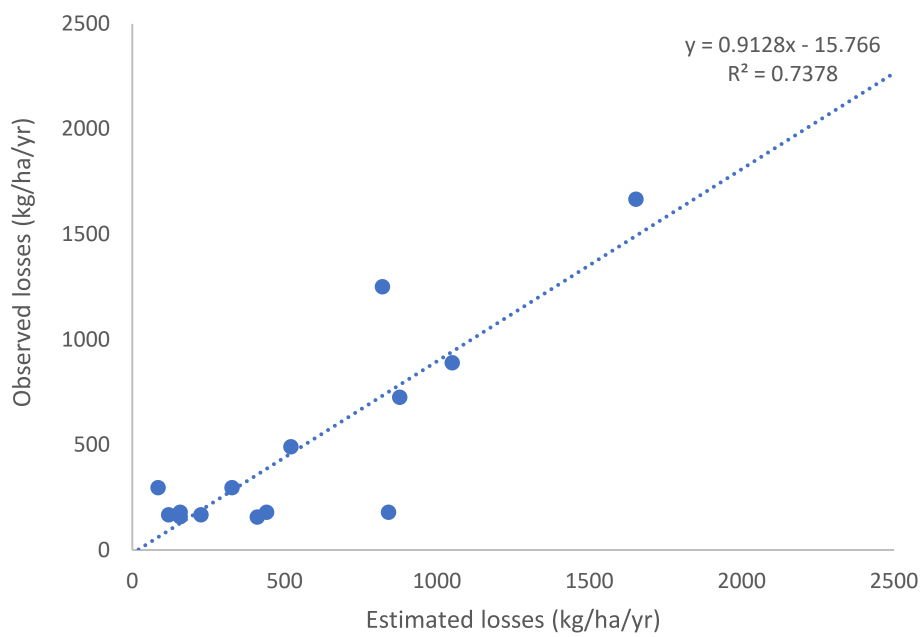
Land use and management	Total N (g kg^{-1})	Spring	Summer	Autumn	Winter
Native forest	3.20	0.002	0.0012	0.0012	0.003
Exotic forest	3.20	0.005	0.004	0.004	0.007
Dairy	6.18	0.04	0.03	0.03	0.05
Drystock	5.00	0.04	0.03	0.03	0.05
Arable (incl perennial horticulture)	3.50	0.3	0.28	0.33	0.35
Horticultural (vegetables)	8.40	0.35	0.28	0.43	0.43
Winter forage crop (grazed)	5.00	0.05	0.04	0.04	0.06

Table C.4: Values of sediment loss derived using New Zealand cover factors, adjusted for different slope classes

Note: Values for adjustment are in parentheses and are derived using expert opinion. We adjusted cover factors based on empirical evidence that erosion rates increase with slope. However, we did not adjust cover factors where empirical evidence did not exist or because the land use was unlikely, such as for arable, horticultural, dairy and winter forage crops on easy and steep slopes. Values in bold have corresponding observations.

Land use and management	Flat	Rolling	Easy	Steep
Native forest	21 (800)	53 (800)	**85 (800)**	**328 (1600)**
Exotic forest	28 (400)	75 (400)	120 (400)	226 (400)
Dairy	**158 (300)**	**822 (600)**	1,317 (600)	2,481 (600)
Drystock	**158 (300)**	**411 (300)**	**878 (400)**	**1,654 (400)**
Arable (incl perennial horticulture)	**441 (100)**	**841 (70)**	1,358 (70)	2,505 (70)
Horticultural (vegetables)	**522 (100)**	**1,409 (100)**	2,317 (100)	4,255 (100)
Winter forage crop (grazed)	**399 (600)**	**1,050 (600)**	1,680 (600)	3,150 (600)

Figure C.1: Plot of observed versus expected annual losses of sediment



Estimated sediment losses by land use (and management) and slope class were then multiplied by total soil N concentrations sourced from sampling conducted by regional authorities from 1995 to 2017 and reported to the Ministry for the Environment and Stats NZ as part of state of the environment reporting (Stats NZ, 2022). No significant differences were noted for soil N concentrations between authorities nor by year. Median total soil N concentrations are reported at the land use by soil order level (table C.5) but are used in the calculation of eroded soil N by land use because freely accessible data for soil order were unavailable at the time. The resulting estimates of seasonal soil N losses via erosion are given in table C.6 by land use (and management) and slope class. Seasonal losses are split evenly across the three months of the season: for example, if a value of 1 kg ha^{-1} is given for spring, the months of September, October and November are each allocated a soil erosion N source of a third of the kilogram of N loss per hectare. Note that unproductive land is handled within the RIT as if it was forested land use.

Table C.5: Mean, standard deviation, median and count of soil samples used to calculate soil total nitrogen (N) concentrations for different land use by soil order combinations

Land use by soil order	Mean soil total N concentration (g kg^{-1})	Standard deviation of soil total N (g kg^{-1})	Median soil total N concentration (g kg^{-1})	Count
Crop_Hort	4.91	6.14	3.50	311
Allophanic	10.43	12.26	6.57	57
Brown	3.91	1.61	3.30	32
Gley	3.58	1.93	3.19	41
Granular	3.10	1.24	2.85	31
Organic	10.22	4.47	9.47	10
Pallic	3.21	0.87	2.96	35
Pumice	5.32	1.18	5.60	5
Recent	3.18	1.42	3.07	87
Ultic	3.50	0.63	3.71	13
Dairy	10.34	14.29	6.18	340
Allophanic	13.37	15.17	8.29	49
Brown	11.80	17.08	5.78	72
Gley	5.94	1.64	5.79	43
Granular	26.72	28.88	7.33	23
Melanic	6.60	–	6.60	1
Organic	15.23	6.21	14.28	16
Pallic	4.27	1.39	3.80	14
Podzol	5.62	1.28	5.49	4
Pumice	5.96	1.93	6.06	49
Recent	4.71	1.29	4.78	52
Ultic	15.90	20.60	6.85	17
Drystock	7.01	8.80	5.00	407
Allophanic	11.86	13.38	9.07	46
Brown	7.09	9.71	4.50	115
Gley	4.56	1.50	4.35	28
Granular	9.12	10.09	6.43	35
Melanic	6.75	1.70	6.80	5
Organic	12.56	5.35	14.80	5
Pallic	4.35	1.33	3.90	62
Podzol	6.45	1.82	5.78	4
Pumice	5.86	1.48	5.90	34
Recent	3.60	1.12	3.67	49
Ultic	11.55	15.66	5.81	24
Forestry	7.21	10.28	3.20	120
Allophanic	11.69	7.24	11.01	12
Brown	7.75	10.42	3.26	40
Gley	6.47	1.51	6.47	2
Granular	30.58	18.67	35.75	4
Pallic	3.12	0.82	3.30	9
Podzol	3.68	0.51	3.90	3
Pumice	3.51	1.17	3.33	14
Recent	0.85	0.73	0.60	9
Ultic	6.83	11.60	2.90	27

Table C.6: Estimates of seasonal soil nitrogen (N) losses via erosion (kg N ha^{-1}) by land use (and management) and slope class

Season	Slope class	Native forest	Exotic forest	Dairy	Drystock	Arable (incl perennial horticulture)	Horticultural (vegetables)	Winter forage crop (grazed)
Spring	Flat	0.04	0.05	0.43	0.43	0.52	1.27	0.91
	Rolling	0.02	0.04	0.65	0.33	0.34	1.02	0.73
	Easy	0.02	0.04	0.65	0.43	0.40	1.57	0.73
	Steep	0.12	0.07	1.09	0.72	0.42	1.57	1.09
Summer	Flat	0.02	0.04	0.33	0.33	0.48	1.02	0.73
	Rolling	0.08	0.13	2.14	1.07	1.11	3.35	2.39
	Easy	0.13	0.22	3.53	2.36	1.83	5.53	3.95
	Steep	0.50	0.42	6.70	4.47	3.46	10.48	7.49
Autumn	Flat	0.02	0.04	0.33	0.33	0.57	1.57	0.73
	Rolling	0.08	0.13	2.14	1.07	1.30	5.14	2.39
	Easy	0.13	0.22	3.53	2.36	2.15	8.50	3.95
	Steep	0.50	0.42	6.70	4.47	4.08	16.10	7.49
Winter	Flat	0.06	0.07	0.54	0.54	0.60	1.57	1.09
	Rolling	0.20	0.23	3.57	1.78	1.38	5.14	3.59
	Easy	0.33	0.38	5.89	3.93	2.28	8.50	5.93
	Steep	1.25	0.73	11.16	7.44	4.33	16.10	11.24

Note: Some land uses (such as dairy, arable, horticultural and winter forage cropping) are highly unlikely on easy or steep slopes.

References

Bakker MM, Govers G, van Doorn A, Quetier F, Chouvardas D, Rounsevell M. 2008. The response of soil erosion and sediment export to land-use change in four areas of Europe: The importance of landscape pattern. *Geomorphology* 98(3): 213–226.

Bargh BJ. 1978. Output of water, suspended sediment, and phosphorus and nitrogen forms from a small agricultural catchment. *New Zealand Journal of Agricultural Research* 21(1): 29–38.

Basher LR, Ross CW. 2002. Soil erosion rates under intensive vegetable production on clay loam, strongly structured soils at Pukekohe, New Zealand. *Soil Research* 40(6): 947–961.

Basher LR, Ross CW, Dando J. 2004. Effects of carrot growing on volcanic ash soils in the Ohakune area, New Zealand. *Soil Research* 42(3): 259–272.

Burkitt LL, Winters JL, Horne DJ. 2017. Sediment and nutrient losses under winter cropping on two Manawatu hill country soils. *Proceedings of the New Zealand Grassland Association* 79: 19–26.

Cooke JG, Dons T. 1988. Source and sinks of nutrients in a New Zealand hill pasture catchment I. Stormflow generation. *Hydrological Processes* 2: 109–122.

Cooper AB, Thomsen CE. 1988. Nitrogen and phosphorus in streamwaters from adjacent pasture, pine, and native forest catchments. *New Zealand Journal of Marine and Freshwater Research* 22: 279–291.

Davies-Colley RJ, Nagels JW. 2002. Effects of dairying on water quality of lowland streams in Westland and Waikato. *Proceedings of the New Zealand Grassland Association* 64: 107–114.

Donovan M. 2022. Modelling soil loss from surface erosion at high-resolution to better understand sources and drivers across land uses and catchments: A national-scale assessment of Aotearoa, New Zealand. *Environmental Modelling & Software* 147: 105228.

Dons A. 1987. Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the Central North Island, New Zealand. *New Zealand Journal of Forestry Science* 17(2/3): 161–178.

Dymond JR. 2010. Soil erosion in New Zealand is a net sink of CO_2. *Earth Surface Processes and Landforms* 35(15): 1763–1772.

Dymond JR, Betts HD, Schierlitz CS. 2010. An erosion model for evaluating regional land-use scenarios. *Environmental Modelling & Software* 25(3): 289–298.

Fahey BD, Marden M. 2000. Sediment yields from a forested and a pasture catchment, coastal Hawke's Bay, North Island, New Zealand. *Journal of Hydrology (NZ)* 39(1): 49–63.

Hicks DM. 1994. *Storm Sediment Yields from Basins with Various Landscapes in Auckland Area*. NIWA: Christchurch.

Hughes AO, Quinn JM, McKergow LA. 2012. Land use influences on suspended sediment yields and event sediment dynamics within two headwater catchments, Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 46(3): 315–333.

Lambert MG, Devantier BP, Nes P, Penny PE. 1985. Losses of nitrogen, phosphorus, and sediment in runoff from hill country under different fertiliser and grazing management regimes. *New Zealand Journal of Agricultural Research* 28: 371–379.

McDowell RW. 2006a. Contaminant losses in overland flow from cattle, deer and sheep dung. *Water, Air, and Soil Pollution* 174(1-4): 211–222.

McDowell RW. 2006b. Phosphorus and sediment loss in a catchment with winter forage grazing of cropland by dairy cattle. *Journal of Environmental Quality* 35(2): 575–583.

McDowell RW. 2007. Water quality in headwater catchments with deer wallows. *Journal of Environmental Quality* 36(5): 1377–1382.

McDowell RW. 2008. Water quality of a stream recently fenced-off from deer. *New Zealand Journal of Agricultural Research* 51(3): 291–298.

McDowell RW. 2009. Maintaining good water and soil quality in catchments containing deer farms. *International Journal of River Basin Management* 7(3): 187–195.

McDowell RW, Drewry JJ, Paton RJ. 2004. Effects of deer grazing and fence-line pacing on water and soil quality. *Soil Use and Management* 20(3): 302–307.

McDowell RW, Houlbrooke DJ. 2009. Management options to decrease phosphorus and sediment losses from irrigated cropland grazed by cattle and sheep. *Soil Use and Management* 25(3): 224–233.

McDowell RW, Stevens DR. 2008. Potential waterway contamination associated with wintering deer on pastures and forage crops. *New Zealand Journal of Agricultural Research* 51(3): 287–290.

Ministry for the Environment. 2020. *National Policy Statement for Freshwater Management 2020*. Wellington: Ministry for the Environment.

Monaghan RM, Laurenson S, Dalley DE, Orchiston TS. 2017. Grazing strategies for reducing contaminant losses to water from forage crop fields grazed by cattle during winter. *New Zealand Journal of Agricultural Research* 60(3): 333–348.

Monaghan RM, Wilcock RJ, Smith LC, Tikkisetty B, Thorrold BS, Costall D. 2007. Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand. *Agriculture, Ecosystems & Environment* 118(1–4): 211–222.

Muller K, Trolove M, James TK, Rahman A. 2002. Herbicide runoff studies in an arable soil under simulated rainfall. *New Zealand Plant Protection* 55: 172–176.

Nendel C, Melzer D, Thorburn PJ. 2019. The nitrogen nutrition potential of arable soils. *Scientific Reports* 9(1): 5851.

O'Loughlin CL, Rowe LK, Rearce AJ. 1978. Sediment yields from small forested catchments North wetland – Nelson, New Zealand. *Journal of Hydrology (NZ)* 17(1): 1–15.

Quinn JM, Stroud MJ. 2002. Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research* 36(2): 409–429.

Smith CM. 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.

Stats NZ. 2022. *Soil quality and land use*. Retrieved 20 May 2022.

Thorrold BS, Hamill KD, Monaghan RM, Rekker J, Rodda HJ, Ryder G. Oteramika catchment study. In: *Proceedings of the New Zealand Fertiliser Manufacturers' Research Association Inc. Conference*. Invercargill: New Zealand Fertiliser Manufacturers' Research Association Inc, Auckland, New Zealand. Pp 119–128.

Wilcock RJ, Monaghan RM, Quinn JM, Campbell AM, Thorrold BS, Duncan MJ, McGowan AW, Betteridge K. 2006. Land-use impacts and water quality targets in the intensive dairying catchment of the Toenepi Stream, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 40(1): 123–140.

Wilcock RJ, Monaghan RM, Thorrold BS, Meredith AS, Betteridge K, Duncan M. 2007. Land-water interactions in five contrasting dairying catchments: Issues and solutions. *Land Use and Water Resources Research* 7: 2.1–2.10.

Wilcock RJ, Nagels JW, Rodda Harvey JE, O'Connor MB, Thorrold BS, Barnett JW. 1999. Water quality of a lowland stream in a New Zealand dairy farming catchment. *New Zealand Journal of Marine and Freshwater Research* 33(4): 683–696.

Williamson RB, Smith CM, Cooper AB. 1996. Watershed riparian management and its benefits to a eutrophic lake. *Journal of Water Resources Planning and Management* 122: 24–32.

Worrall F, Burt TP, Howden NJK. 2013. The flux of suspended sediment from the UK 1974 to 2010. *Journal of Hydrology* 504: 29–39.

Appendix D: Nitrogen concentrations for common fertilisers and manures

RW McDowell[1,2]

[1] *Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand*

[2] *AgResearch, Lincoln Science Centre, Lincoln, New Zealand*

These data are to be offered to the user if they do not know the nitrogen (N) concentration of their product. Additional fertilisers from other suppliers can be added as needed, provided they supply an analysis of N concentration and that the concentration for the product is consistent with time.

Nitrogen application rates are calculated as the kilogram of product by the %N/100.

Table D.1: Representative nitrogen (N) fertiliser concentrations from Ballance Agri-Nutrients and Ravensdown Fertiliser Co-operative, effective 19 August and 16 August, respectively.

Ballance fertiliser	%N	Ravensdown fertiliser	%N
SustaiN	45.9	N-Protect	45.9
SustaiN 15K	32.1	Urea	46
SustaiN 20K	27.5	Granular Ammonium Sulphate	20
SustaiN 25K	23.0	Nitrogen Super	6
SustaiN Ammo 30N	29.8	Calcium Ammonium Nitrate (CAN)	27
SustaiN Ammo 36N	35.4	Ammo 31	30.4
PhaSedN	25.3	Ammo 36	35.6
PhaSedN Quick Start	31.3	Nitro S™	29.9
PastureSure 5K	9.5	N-Protect S™	29.8
PastureSure 10K	7.6	Ureammopot	25.7
PastureSure 15K	7.6	Flexi-N (South Island only)	43.2
PastureSure 15S	9.5	Flexi-N (North Island only)	45.3
PastureSure Boost	9.1	Flowfert N (South Island only)	18
PastureSure Balancer	6.0	Super Mag N	6.9
PastureSure Impact	12.1	15% Granular Potash Super Mag N	5.9
PasturemagPlus (with SustaiN)	6.9	20% Granular Potash Super Mag N	5.5
PasturemagPlus 5K (with SustaiN)	6.2	Dairy Pasture Boost 4	4
PasturemagPlus 10K (with SustaiN)	5.5	Dairy Pasture Boost 6	4
PasturemagPlus 15K (with SustaiN)	4.8	Dairy Pasture Boost 10	4
PasturemagPlus 12N (with SustaiN)	11.5	Dairy Pasture Boost 12	4
PasturemagPlus Hay & Silage (with SustaiN)	9.2	Pasture 6 Ravensdown Bulk	5.5
Nrich Urea	46.0	Cropmaster® DAP	17.6
Nrich SOA	19.5	DAP 13 S	10.6
Nrich Ammo 30N	29.8	Cropmaster® 11	10.6
Nrich Ammo 36N	35.4	Cropmaster® 13	12.3
Cropzeal 15P	13.2	Cropmaster® 15	14.8

Ballance fertiliser	%N	Ravensdown fertiliser	%N
Cropzeal 16N	15.2	Cropmaster® 16 High K Bulk	15.4
Cropzeal 20N	19.1	Cropmaster® 20	18.8
Cropzeal Boron Boost	16.0	Cropmaster® Brassica mix	14.1
DAP	17.6	Cropmaster® Brassica + Boron Blend	13.6
DAP Sulphur Super	10.6	Ammo-Phos® MAP	10
20% Potash DAP Sulphur Super	8.5	Ammo-Phos® / Hycrop 7-15-15	7
YaraMila Actyva S 15-7-12.5	15.0	Ammo-Phos® / Hycrop 9-19-7	8.5
YaraMila 12-10-10	13.0	Nitrophoska® Select	15
YaraMila 8-11-20	8.0	Nitrophosak Extra (North Island only)	12
YaraMila Complex	12.0	Cropstart 12-5-14	12
YaraMila GrowerNZ	13.0	Compound Extra	12
YaraBela CAN	27	Cropstart Select	15
YaraLiva Nitrabor	15.4	Potash Gold 7-15-13	7
YaraRega 9-0-30	9.0	Potash Gold 15-10-10	14.2
Pure Protamin	13	Potash Gold 14-7-14	14.3
		Urea	46
		Granular Ammonium Sulphate	20
		Calcium Ammonium Nitrate (CAN)	27
		Cropmaster® DAP	17.6
		Cropmaster® 15	14.8
		Cropmaster® 20	18.8
		Garden Fertiliser	6.6
		Lawn Fertiliser	14.5
		Avocado Regular Mix + TE	9.6
		Cropstart Select	15

Source: Ballance Agri-Nutrients, 2023; Ravensdown Fertiliser Co-operative, 2023

Table D.2: Dry matter and nitrogen (N) content of dairy slurry, manures and poultry manures to be considered as fertiliser N inputs (these are separate from farm dairy effluent applied up to nine months of the year)

Manure type	Dry matter content (%)	N content (%)
Scraped solids	25.9	5.9
Bunker manure	23.1	5.6
Manure plus residues scraped from carbon-rich pads	38.2	3.7
Solids behind a weeping wall	22.5	2.4
Mechanically separated solids	25.9	5.9
Farm dairy effluent slurry from a stirred pond	1.7	0.6
Poultry manure	66	1.9
Poultry compost	56	2.5

Source: Data from BioRich, 2022; Department for Environment, Food and Rural Affairs, 2010; Houlbrooke et al, 2011; Parker et al, 1959; Sims and Wolf, 1994

References

Ballance Agri-Nutrients. 2023. *Ballance product price list*. Retrieved 28 November 2023.

BioRich. 2022. *BioRich Conventional Compost Analysis*. Retrieved 29 November 2023.

Department for Environment, Food and Rural Affairs. 2010. *The Fertiliser Manual*. United Kingdom Government Publications.

Houlbrooke D, Longhurst B, Orchiston T, Muirhead R. 2011. *Characterising dairy manures and slurries*. Mosgiel: AgResearch.

Parker MB, Perkins HF, Fuller HL. 1959. Nitrogen, phosphorus and potassium content of poultry manure and some factors influencing its composition. *Poultry Science* 38(5): 1154–1158.

Ravensdown Fertiliser Co-operative. 2023. *Fertiliser prices*. Retrieved 28 November 2023.

Sims JT, Wolf DC. 1994. Poultry Waste Management: Agricultural and Environmental Issues. In: DL Sparks (ed.) *Advances in Agronomy.* London: Academic Press. Pp 1–83.

Appendix E: Mitigations and modifiers

RW McDowell[1,2], CC Tanner[3], B Malcolm[4], S Trolove[5], L McKergow[3], FE Matheson[3], S Carrick[6]

[1] *Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand*

[2] *AgResearch, Lincoln Science Centre, Lincoln, New Zealand*

[3] *National Institute of Water and Atmospheric Research, Gate 10, Silverdale Rd, Hamilton 3216, New Zealand*

[4] *Plant and Food Research, 74 Gerald St, Lincoln 7608, New Zealand*

[5] *Plant and Food Research, 30 Crosses Rd, Havelock North 4130, New Zealand*

[6] *Manaaki Whenua, Landcare Research, Lincoln, New Zealand*

Preamble

This appendix gives the description of data filters and descriptive text for how mitigations are to be used to reduce baseline risk by altering source inputs (eg, the user uses the data contained in appendices A–D to change source inputs), or baseline risk is reduced via a modifier multiplier between 0–1 (table E.1).

References are given, where possible, for the original source for the magnitude of a modification multiplier (ie, reduction effect) but are checked against four sources who have independently collated, interpreted and summarised ranges for some modifiers (Edkins et al, 2022; Matheson et al, 2018; McDowell et al, 2013, 2021). Note that runoff here is interpreted as surface/near-surface runoff (overland flow and throughflow) and interflow.

Modifiers are presented to the user in order of effectiveness. After selection, modifiers are applied in order of most to the least effective, reducing risk by the modified amount prior to the application of the next modification. Modifiers assume full effectiveness and good implementation.

The following internal Risk Index Tool (RIT) data will be used to filter the modifiers or mitigations to each block:

- enterprise type – arable, beef, dairy, deer, forestry, grazed forage crop, horticulture annual (incl veg), horticulture perennial, outdoor pigs, sheep, livestock – other
- flow path (leaching or runoff)
- slope (flat, rolling, easy or steep)
- climate (annual rainfall less than 800 mm, 800–1,600 mm, and more than 1,600 mm)[12]
- soil composition (relevant types being silt loam texture, sandy texture, sandy or not sandy textured). The filtering will be handled by two specific data fields that will enable modifiers 1, 2, 3 and 4:
  - riparian filter (value can be True or False)
  - riparian buffer (value can be True or False)

    If riparian filter = True; soil composition is relevant for modifier 1 and 2

    If riparian buffer = True; soil composition is relevant for modifier 3

    If riparian buffer = False; soil composition is relevant for modifier 4.

[12] Climate being precipitation.

Table E.1: Reduction efficiencies (at a block scale) for mitigation actions and modifiers, relevant to flow paths and soil (riparian filter/riparian buffer) x slope x climate combinations

Note: The description applies to the implementation of the mitigation or modifier in the right place and at the right time. If actioned via a source mitigation, advice is given on which sources to alter. Modifier values are listed as the median for studies with a range given, where available. All refers to all land uses except forestry. R = runoff and L = leaching. Values in parentheses are ranges but only given to the user for reference (ie, not used int the calculation). Confidence intervals are given where evidence permits (eg, 0.80 ± 0.18).

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
1.	Riparian management	Narrow riparian filter (2% to 5% of hillslope length)	**Medium performance:** Dense grass or other vegetation at ground level. Average filter width is 2% to 5% of hillslope length. Assumes silt loam to sandy soil texture.	**Modifier**	All	Runoff	True		Flat		0.49 (0.18–0.90)	McKergow et al, 2020
2.	Riparian management	Wide riparian filter (greater than 5% of hillslope length)	**High performance:** Dense grass or other vegetation at ground level. Average filter width greater than 5% of hillslope length. Assumes silt loam to sandy soil texture.	**Modifier**	All	Runoff	True		Flat		0.32 (0.24–0.70)	McKergow et al, 2020
3.	Riparian management	Planted riparian buffer – coarser than sandy loam	**Medium performance:** Buffer with trees and shrubs. Installed into farms where there is a shallow confining layer (less than 2 m depth below surface). Assumes sandy soil texture. Note: riparian filters cannot effectively intercept artificial drainage waters.	**Modifier**	All	Leaching		True			0.45 (0.30-0.60)	McKergow et al, 2020
4.	Riparian management	Planted riparian buffer – sandy loam or finer	**High performance:** Buffer with trees and shrubs. Installed into farms where there is a shallow confining layer (less than 2 m depth below surface). Assumes soils are not sand texture. Note: riparian filters cannot effectively intercept artificial drainage waters.	**Modifier**	All	Leaching		False			0.25 (0.00–0.30)	McKergow et al, 2020
5.	Riparian management	Stock exclusion	Preventing direct deposition of excreta and streambank damage. Assumes 100% connectivity for red deer due to wallowing and that farms comply with current stock exclusion regulations. Remaining effect estimated for catchments with high stream density.	**Modifier**	Dairy, deer, sheep and beef	Runoff				NA	0.80	Daigneault et al, 2017; Low et al, 2017; McDowell, 2008; O'Callaghan et al, 2019
6.	Edge of field	Preserve and restore 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. Seepage of nitrate-rich water through organic soils promotes effective nitrate–nitrogen removal via denitrification. Assumes that catchments are approximated by a block. For leaching, reductions assume that seepage wetlands receive 20% of leached N of which 75% is removed.	**Modifier**	All	Runoff Leaching				All	R=0.5, L=0.85	McKergow et al, 2017; Rutherford et al, 2009

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
7.	Edge of field	Constructed wetland – small – North Island	Assumed wetland size is approximately 1% of catchment area and that catchments are approximated by a block. Assumed mean annual air temperature greater than 12°C. Excludes highly permeable soils not able to sustain a wetland.	**Modifier**	All	Runoff Leaching			Flat, rolling	800–1,600 mm	R=0.75, L=0.88	Tanner and Kadlec, 2013; Tanner and Sukias, 2011; Tanner et al, 2022
8.	Edge of field	Constructed wetland – medium – North Island	Assumed wetland size is approximately 2% of catchment area and that catchments are approximated by a block. Assumes mean annual air temperature greater than 12°C. Excludes highly permeable soils not able to sustain a wetland.	**Modifier**	All	Runoff Leaching			Flat, rolling	800–1,600 mm	R = 0.64, L= 0.82	Tanner and Kadlec, 2013; Tanner and Sukias, 2011; Tanner et al, 2022
9.	Edge of field	Constructed wetland – large – North Island	Assumed wetland size is approximately 4% of catchment area and that catchments are approximated by a block. Assumes mean annual air temperature greater than 12°C. Excludes highly permeable soils not able to sustain a wetland.	**Modifier**	All	Runoff Leaching			Flat, rolling	800–1,600 mm	R= 0.52, L= 0.76	Tanner and Kadlec, 2013; Tanner and Sukias, 2011; Tanner et al, 2022
10.	Edge of field	Constructed wetland – small – South Island	Assumed wetland size is approximately 1% of catchment area and that catchments are approximated by a block. Assumes mean annual air temperature 8–12°C. Excludes highly permeable soils not able to sustain a wetland.	**Modifier**	All	Runoff Leaching			Flat, rolling	800–1,600 mm	R=0.82, L=0.91	Tanner and Kadlec, 2013; Tanner and Sukias, 2011; Tanner et al, 2022
11.	Edge of field	Constructed wetland – medium – South Island	Assumed wetland size is approximately 2% of catchment area and that catchments are approximated by a block. Assumes mean annual air temperature 8–12°C. Excludes highly permeable soils not able to sustain a wetland.	**Modifier**	All	Runoff Leaching			Flat, rolling	800–1,600 mm	R=0.74, L=0.87	Tanner and Kadlec, 2013; Tanner and Sukias, 2011; Tanner et al, 2022
12.	Edge of field	Constructed wetland – large – South Island	Assumed wetland size is approximately 4% of catchment area and that catchments are approximated by a block. Assumes mean annual air temperature 8–12°C. Excludes highly permeable soils not able to sustain a wetland.	**Modifier**	All	Runoff Leaching			Flat, rolling	800–1,600 mm	R=0.64, L=0.82	Tanner and Kadlec, 2013; Tanner and Sukias, 2011; Tanner et al, 2022
13.	Edge of field	Detainment bund on free-draining soil	An engineered structure to slow water flows and allow sedimentation and infiltration. Storage volume of 120 m^3 per ha of contributing catchment, ie, 1.5% of catchment with a 0.8 m average pond depth. Assumes that catchments are approximated by a block. Total N reductions are estimated from reductions in sediment loss (approximately 50% to 60% from 17 ha to 55 ha catchment). We assume 30% of total N was lost in particulate form.	**Modifier**	All	Runoff			Rolling, easy, steep		0.50	Levine, 2020; Levine et al, 2021

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
14.	Edge of field	Woodchip denitrification beds intercepting tile drains	Denitrification beds comprise basins filled with woodchips that intercept drain flow before discharge to surface waters. The wood chips provide organic carbon that fuels the microbial conversion of nitrate in water to nitrogen gas, which is released to the atmosphere. Assumes denitrification bed 1 m deep approximately 1% of catchment area. Assumes that catchments are approximated by a block. Removal range is 0.1–0.8 (mid-point) of 0.5, but we assume artificial drainage captures half of the N leached.	**Modifier**	All	Leaching			Flat	800–1,600 mm	0.75	Hudson et al, 2019; Maxwell et al, 2020; McDowell et al, 2013; Rivas et al, 2020; Schipper et al, 2010
15.	Edge of field	Cut outs or berms to direct laneway or stockyard runoff away from waterways	Direct water off laneways, near stockyards or recently cultivated paddocks away from waterways. Implementation assumes the presence of one laneway (used daily) or stockyard per 30 ha currently discharging into a waterway, ie, the effect of N-rich excreta in runoff is diluted by runoff from the rest of the approximate 30 ha catchment.	**Modifier**	Dairy, sheep and beef	Runoff				NA	0.95	McDowell et al, 2020; Monaghan and Smith, 2012; Waikato Regional Council, 2017
16.	Edge of field	Stock exclusion and riparian planting	Preventing direct deposition of excreta, streambank decomposition, and some filtering of soil from runoff. Assumes 100% connectivity for red deer due to wallowing and that farms comply with current stock exclusion regulations. Remaining effect estimated for catchments with high stream density.	**Modifier**	Deer, sheep and beef	Runoff				NA	0.50 (deer) 0.80 (sheep and beef)	Daigneault et al, 2017; Low et al, 2017; McDowell, 2008; O'Callaghan et al, 2019
17.	Cropping and cultivation	Catch cropping	Typically, short rotation crops with good cool season growth and a deep rooting system that helps to mop up N that would otherwise be leached. Effectiveness is dependent on when crops are sown in relation to grazing/N loading or harvest. Catch crops generally feature in two main systems: 1) summer/early autumn (Mar) and late autumn (May) cropping (S1), and 2) following winter forage crop grazing depending on the month sown (S2). Generally, for every month that sowing is delayed in S2, the efficacy declines by 10%.	**Modifier**	All (excluding perennial horticultural)	Leaching			Flat, rolling		S1: 0.50 Mar, 0.90 May S2: 0.70, 0.80 and 0.90 in Jul, Aug and Sep, respectively	Horrocks et al, 2021; Malcolm et al, 2020; 2022
18.	Cropping and cultivation	Using winter active crops	Crops such as an annual ryegrass, Italian ryegrass and some late maturing perennial ryegrasses grow during winter and utilising soil N when leaching is likely. Effect is highly dependent on cultivar (cv). Data shown for cv. Tabu.	Alter source inputs (change crop type for month through appendix B)	All (excluding perennial horticultural)	Leaching				NA	NA	Carey et al, 2017; Malcolm et al, 2014; Maxwell et al, 2019

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
19.	Cropping and cultivation	Direct drilling	Avoids soil N mineralisation (so no benefit to perennial pasture) but prevents soil disturbance, increasing roughness and likelihood of soil loss via erosion compared with conventional tillage. Reduction in particulate N assumed to be 60% and particulate N assumed to be 50% of runoff total N.	**Modifier**	All (excluding perennial horticultural)	Runoff			Flat, rolling		0.70	Daigneault and Elliott, 2017
20.	Cropping and cultivation	Cultivation along contours	Cultivate along contours (rather than up and down the slope) to reduce erosion and loss of particulate N in runoff. Effect is highly variable and dependent on topography, with a high likelihood that runoff will converge; hence, potential decrease in particulate N losses set at 20%, with particulate N comprising 50% of total runoff N loss.	**Modifier**	All (excluding perennial horticultural)	Runoff			Flat, rolling		0.90	Basher et al, 1997; Basher and Ross, 2002; Dymond, 2010; Horticulture New Zealand, 2010
21.	Cropping and cultivation	Silt traps	Use silt traps to settle out sediment from water before it enters drains	**Modifier**	All (excluding perennial horticultural)	Runoff				NA	0.90	Basher et al, 1997; Basher and Ross, 2002; Dymond, 2010; Horticulture New Zealand, 2010
22.	Stock management	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. Nitrogen leaching from sheep and deer is approximately half that from beef cows at the same level of feed intake.	Alter source inputs for dung and urine by changing stock type, and age by month using appendix A	Dairy, Deer, Sheep and Beef	Leaching				NA	NA	Doole, 2015; McDowell et al, 2013
23.	Stock management	Change stocking rate	Changes to stocking rate can be positive or negative depending on the number and type of stock present.	Alter source inputs for dung and urine by changing stock rate by month using appendix A	Dairy, deer, sheep and beef	Leaching				NA	NA	Beukes et al, 2012; Gourley and Weaver, 2012; Silva et al, 1999
24.	Stock management	Genetic improvement	Factors that affect longevity of animal lifetime act to reduce N in urine by 6% to 20%. Factors include increase lambing percentages and better fertility in cattle. Calculated via lower (and linked) methane emissions.	**Modifier**	Deer and dairy cattle, sheep	Leaching				NA	0.95	Cruickshank et al, 2009
25.	Stock management	Increase rate of finishing, early culling in autumn	Increase rate of finishing or culling (in autumn) to remove stock from the farm faster.	Alter source inputs for dung and urine by changing stock numbers by month using appendix A	Deer, pork, sheep and beef	Leaching				NA	NA	Doole, 2015
26.	Stock management	Prevent fence-line pacing	Plant fence lines and/or use outriggers to reduce pacing behaviour and erosion	**Modifier**	Deer	Runoff				NA	0.95	McDowell et al, 2004
27.	Additives	Nitrification inhibitors (dicyandiamide, DCD)	Dicyandiamide has previously been researched but no longer sold in New Zealand. This inhibitor slows the nitrification of ammonium to nitrate, reducing N available for leaching and increasing the likelihood of ammonium or nitrate being taken up by plants.	**Modifier**	Dairy, deer, sheep and beef	Leaching			Flat	Less than 1,600 mm	0.69 ± 0.18	Cameron et al, 2014; Ledgard et al, 2014

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
28.	Additives	Diuretics	Diuretics, such as table salt, increase water consumption by animals and cause an increase in the spread of urinary N.	**Modifier**	Dairy, deer, sheep and beef	Leaching				NA	0.88	Ledgard et al, 2015
29.	Additives	Use of gibberellic acid to boost pasture growth	Increase N uptake by promoting growth, especially in urine patches, if applied within 48 hours of grazing.	**Modifier**	Dairy	Leaching				NA	0.85	Bishop and Jeyakumar, 2021; Woods et al, 2016
30.	Irrigation and drainage	Variable Rate Irrigation	Applying irrigation according to soil diversity with soil moisture sensors to vary the daily rate applied and minimise leaching. Effect assumes 80% reduction of N leaching losses for centre-pivot irrigation-induced leaching (150 mm out of 600 mm of total drainage) equating to a total 20% reduction.	**Modifier**	All	Leaching				NA	0.80	Carlton et al, 2019; McDowell, 2017
31.	Irrigation and drainage	Prevent outwash from irrigation	Prevent outwash (ie, runoff) resulting from over irrigation, most commonly from flood irrigation. Effect is for surface runoff only, which is assumed to be 20% of runoff.	**Modifier**	All (excluding perennial horticultural)	Runoff				NA	0.80	Houlbrooke et al, 2008; Monaghan et al, 2009
32.	Irrigation and drainage	Controlled drainage	Delaying drainage to allow for sedimentation and denitrification. Only suitable for cropping areas in the North Island where soil deficits are strong enough for crops to benefit from increased moisture.	**Modifier**	Arable	Leaching and runoff			Flat	North Island only	0.86 ± 0.14	Ballantine and Tanner, 2013; McDowell et al, 2012
33.	Grazing practices	Strategic grazing of cropland gullies	Delaying the grazing of gullies within the catchment until as late as possible in the winter and ensuring soil damage in these areas was minimised when grazing does occur.	Delay source inputs for dung and urine by changing stock numbers and age by month using appendix A	Dairy, deer, sheep and beef	Runoff			Rolling, easy, steep	More than 800 mm	NA	Monaghan et al, 2017
34.	Grazing practices	On-off grazing in autumn and winter	Grazing restricted to 12 hours per day from March to May. Stock housed in barn during July and July. All winter and spring grazed crops removed from the system.	Delay source inputs for dung and urine by changing stock numbers and age by month using appendix A	Dairy	Leaching and runoff				NA	NA	Christensen et al, 2019; De Klein et al, 2017
35.	Grazing practices	Use alternative forage or crop species to decrease the total N in the diet	Lowers mineral-N return to the soil.	Alter source inputs for soil mineral N by changing crop type by month using appendix B	Dairy, deer, sheep and beef	Leaching and runoff				NA	NA	Bryant et al, 2020; de Ruiter et al, 2019; Malcolm et al, 2020;Smith and Monaghan, 2020
36.	Grazing practices	Graze cows off farm in winter	Removes stock from paddocks in winter when there is a high risk of loss of excretal-N in runoff and leaching	Decrease source inputs for dung and urine by removing stock in winter months using appendix A	Dairy	Leaching and runoff				NA	NA	Waikato Regional Council, 2017
37.	Grazing practices	Cut and carry pasture management with feeding facilities	Removes stock from paddocks in winter when there is a high risk of loss of excretal-N in runoff and leaching	Decrease source inputs for dung and urine by removing stock in months where cut and carry used via appendix A	Dairy	Leaching and runoff			Flat		NA	Waikato Regional Council, 2017

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
38.	Grazing practices	Reticulation	Discourages drinking from streams and excretal returns by placing reticulated water away from streams. Dairy already assumed to have access to reticulated water.	**Modifier**	Deer, sheep and beef	Runoff				NA	0.95	Doole, 2015; Journeaux and van Reenen, 2016
39.	Effluent management	Greater effluent pond storage and low-rate application	Coupling pond storage that is appropriate for the region (eg, via one of the pond storage calculators and regional rules) with low rates of effluent application (less than 4 mm per hour) can decrease losses by minimising the potential for surface runoff and sub-surface losses via preferential flow.	**Modifier**	Dairy	Runoff			Flat		0.67	Houlbrooke et al, 2004, 2008; Monaghan et al, 2010
40.	Effluent management	Better timing of effluent application	Effluent applied outside of winter–early spring.	Alter source inputs for fertiliser N applied by month using appendix D	Dairy	Leaching and runoff			Flat		NA	Houlbrooke et al, 2008; Monaghan et al, 2010
41.	Effluent management	Enhanced pond systems	Covered anaerobic ponds to remove and digest organic suspended solids to methane-rich biogas for energy recovery. High-rate algal ponds remove N in harvested algae. This is assumed to be reapplied to land. Hence savings occur via fertiliser reductions.	Decrease source inputs for fertiliser N applied by month by the amount of N saved by recycling through pond using appendix D	Dairy	Leaching and runoff			Flat		NA	Craggs et al, 2014; Houlbrooke et al 2011
42.	Effluent management	Move to land application system from two pond discharge to water system	Land application of effluent only allowed if shifting from direct discharge to streams. The quantity of N saved is likely to be 90% of the N going through the effluent system (producing effluent with a N concentration of 500 mg L^{-1} for 100 cows producing 70 L cow^{-1} day^{-1} for 300 days on 100 ha). Non-effluent land (90% of farm) leaches 30 kg N ha^{-1}. This action is only provided for the farm level because a pond is unlikely to have its own block.	**Modifier**	Dairy	Leaching and runoff			Flat		0.875%	Houlbrooke et al, 2004, 2011; Wilcock et al, 2013
43.	Effluent management	Export effluent solids to runoff or cropping areas	Solids are separated from effluent pond and not applied to milking platform, reduces the amount of N needed elsewhere. Estimates of the quantity of N in solids can be obtained from Houlbrooke et al (2011) but approximated here to be the equivalent of around 630 kg N (300 mg N L^{-1} for 70 L cow^{-1} day^{-1} for 300 days).	Reduce inputs of fertiliser (appendix D) by 630 kg N over property applied in a summer month	Dairy	Leaching			Flat		NA	Houlbrooke et al, 2011; Waikato Regional Council, 2017
44.	Feed	Total N imported from feed	Decrease the kg of N as imported feed. N concentration of feed can be sourced from www.dairynz.co.nz/feed/supplements/feed-values	Decrease inputs of fertiliser N (appendix D) by the amount of N applied in purchased feed	Dairy, deer, sheep and beef	Leaching and runoff				NA	NA	Beukes et al, 2012; Monaghan et al 2008
45.	Feed	Including plantain in the diet	Results in lower N concentration in urine than cows grazing perennial ryegrass/white clover pastures. Also thought to inhibit nitrification. Reduces N loss by 1% for every 1% of plantain in diet up to a maximum of 20% plantain. Effect assumes 15% of diet is plantain in a well-kept sward over seven years.	**Modifier**	Dairy, deer, sheep and beef	Leaching				NA	0.85 ± 0.15	Al-Marashdeh et al, 2021; Carlton et al, 2019; Dodd et al, 2019; Simon et al, 2019

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
46.	Feed	Grow maize on effluent block	Allows lower cost maize growth on farm with no fertiliser for at least two years after pasture. Assumes linear relationship between N fertiliser application and leaching loss (Silva et al, 1999.	Reduce annual fertiliser inputs to nil (appendix D)	Dairy	Leaching and runoff				NA	NA	Burggraaf et al, 2019; Johnstone et al, 2010
47.	Nitrogen fertiliser	Reduction of N fertiliser	Reduce the rate of N fertiliser applied by month	Reduce monthly fertiliser inputs by desired amount (appendix D)	Dairy, deer, sheep and beef	Leaching and runoff				NA	NA	De Klein et al, 2017; McDowell, 2009
48.	Nitrogen fertiliser	Precision fertiliser application	Apply rates according to soil type. Assumes an average reduced rate is applied representative of the area – weighted soil fertiliser is 30% less for a block.	Reduce monthly fertiliser inputs (appendix D) by 30% (or calculated saving from user and/or advisor)	All	Leaching				NA	NA	Waikato Regional Council, 2017
49.	Stock exclusion	Alternative wallowing	Only applies to blocks with many wallows 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 of existing connected wallows and the creation of a wallow that is not connected to a stream. Effect only applies to 90% reductions in sediment, and hence sediment associated ammoniacal- and particulate-N lost in runoff. Ammoniacal- and particulate-N is assumed to be 50% of total N losses.	**Modifier**	Deer	Runoff				N	0.55	McDowell, 2009
50.	Stock exclusion	Bridging stock crossings of streams	Avoid direct entry of faeces, urine and entrained hoof mud, and substrate disturbance during stream crossings	**Modifier**	Deer, sheep and beef	Runoff				NA	0.95	McDowell et al, 2013
51.	Forestry	Increasing forested area	Forest area doubled from 12.5% to 25% (on average) with erosion-prone land planted first	Alter erosion input by modifying soil erosion losses via table C.1 in appendix C. Set monthly fertiliser input (appendix D) to nil	Sheep, beef	Runoff			Rolling, easy, steep		NA	Davis, 2014; Dymond et al, 2016; Larned et al, 2020; McDowell et al, 2021; Monaghan et al, 2021
52.	Forestry	Tree harvest	Season of harvest. Rapid establishment of vegetation cover after harvest. Effect is relative to standard forestry practice, which sees nitrate-N losses increase 2–6 times pre-harvest concentrations for six months. Effect discounted for 20-year rotation.	**Modifier**	Forestry	Leaching and runoff			Rolling, easy, steep		0.95	Baillie and Neary, 2015; Hughes and Quinn, 2019; Larned et al, 2020
53.	Forestry	Space planting of trees	To reduce sediment or faecal loads coming from small areas of high runoff.	Alter erosion input by modifying soil erosion losses via table C.1 in appendix C. Set monthly fertiliser input (appendix D) to nil	Deer, sheep and beef	Leaching and runoff			Rolling, easy, steep		NA	Baillie and Neary, 2015; Davis, 2014; Larned et al, 2020

References

Al-Marashdeh O, Cameron K, Hodge S, Gregorini P, Edwards G. 2021. Integrating plantain (*Plantago lanceolate* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) into New Zealand grazing dairy system: The effect on farm productivity, profitability, and nitrogen losses. *Animals* 11(2): 1–20.

Baillie BR, Neary DG. 2015. Water quality in New Zealand's planted forests: A review. *New Zealand Journal of Forestry Science* 45(1): 7.

Ballantine DJ, Tanner CC. 2013. Controlled drainage systems to reduce contaminant losses and optimize productivity from New Zealand pastoral systems. *New Zealand Journal of Agricultural Research* 56(2): 171–185.

Basher L, Hicks D, Handyside B, Ross C. 1997. Erosion and sediment transport from the market gardening lands at Pukekohe, Auckland, New Zealand. *Journal of hydrology (New Zealand)* 36(1): 73–95.

Basher LR, Ross CW. 2002. Soil erosion rates under intensive vegetable production on clay loam, strongly structured soils at Pukekohe, New Zealand. *Soil Research* 40(6): 947–961.

Beukes PC, Scarsbrook MR, Gregorini P, Romera AJ, Clark DA, Catto W. 2012. The relationship between milk production and farm-gate nitrogen surplus for the Waikato region, New Zealand. *Journal of Environmental Management* 93(1): 44–51.

Bishop P, Jeyakumar P. 2021. A comparison of three nitrate leaching mitigation treatments with dicyandiamide using lysimeters. *New Zealand Journal of Agricultural Research* 65(6): 547–560.

Bryant RH, Snow VO, Shorten PR, Welten BG. 2020. Can alternative forages substantially reduce N leaching? Findings from a review and associated modelling. *New Zealand Journal of Agricultural Research* 63(1): 3–28.

Burggraaf VT, Rennie GR, Edwards P, Proxterhuis I. 2019. A case study of the effects of diet and winter management on dairy production, profit and nitrate leaching in Rotorua. *Proceedings of the New Zealand Society of Animal Production* 79: 71–73.

Cameron KC, Di HJ, Moir JL. 2014. Dicyandiamide (DCD) effect on nitrous oxide emissions, nitrate leaching and pasture yield in Canterbury, New Zealand. *New Zealand Journal of Agricultural Research* 57(4): 251–270.

Carey PL, Cameron KC, Di HJ, Edwards GR. 2017. Comparison of nitrate leaching from oats and Italian ryegrass catch crops following simulated winter forage grazing: A field lysimeter study. *New Zealand Journal of Agricultural Research* 60(3): 298–318.

Carlton AJ, Cameron KC, Di HJ, Edwards GR, Clough TJ. 2019. Nitrate leaching losses are lower from ryegrass/white clover forages containing plantain than from ryegrass/white clover forages under different irrigation. *New Zealand Journal of Agricultural Research* 62(2): 150–172.

Christensen CL, Hedley MJ, Hanly JA, Horne DJ. 2019. Duration-controlled grazing of dairy cows. 2: nitrogen losses in sub-surface drainage water and surface runoff. *New Zealand Journal of Agricultural Research* 62(1): 48–68.

Craggs R, Park J, Heubeck S, Sutherland D. 2014. High rate algal pond systems for low-energy wastewater treatment, nutrient recovery and energy production. *New Zealand Journal of Botany* 52(1): 60–73.

Cruickshank GJ, Thomson BC, Muir PD. 2009. Effect of management change on methane output within a sheep flock. *Proceedings of the New Zealand Society of Animal Production* 69: 170–173.

Daigneault A, Elliott AH. 2017. *Land-use contaminant loads and mitigation costs*. Wellington: Motu Economic and Public Policy.

Daigneault AJ, Eppink FV, Lee WG. 2017. A national riparian restoration programme in New Zealand: Is it value for money? *Journal of Environmental Management* 187: 166–177.

Davis M. 2014. Nitrogen leaching losses from forests in New Zealand. *New Zealand Journal of Forestry Science* 44(1): 2.

De Klein CAM, Monaghan R, Alfaro M, Gourley C, Oenema O, Powell, M. 2017. Nitrogen performance indicators for dairy production systems. *Soil Research* 55(5-6): 479–488.

De Ruiter JM, Malcolm BJ, Chakwizira E, Johnstone PR, Maley S, Arnold NP, Dalley DE. 2019. Crop management effects on supplementary feed quality and crop options for dairy feeding to reduce nitrate leaching. *New Zealand Journal of Agricultural Research* 62(3): 369–398.

Dodd M, Dalley D, Wims C, Elliott D, Griffin A. 2019. A comparison of temperate pasture species mixtures selected to increase dairy cow production and reduce urinary nitrogen excretion. *New Zealand Journal of Agricultural Research* 62(4): 504–527.

Doole GJ. 2015. *Description of mitigation options defined within the economic model for Healthy Rivers Wai Ora Project*. Hamilton: University of Waikato.

Dymond JR. 2010. Soil erosion in New Zealand is a net sink of CO_2. *Earth Surface Processes and Landforms* 35(15): 1763–1772.

Dymond JR, Herzig A, Basher L, Betts HD, Marden M, Phillips CJ, Ausseil AE, Palmer DJ, Clark M, Roygard J. 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. *Geomorphology* 257(Supplement C): 85–93.

Edkins R, Mesman N, Bishop V, Everest M. 2022. *Reducing N-loss to water: A summary of available and effective solutions*. Christchurch: Lumen Environmental.

Gourley CJP, Weaver DM. 2012. Nutrient surpluses in Australian grazing systems: management practices, policy approaches, and difficult choices to improve water quality. *Crop and Pasture Science* 63(9): 805–818.

Horrocks A, Beare M, Malcolm B, Teixeira E, Carey P, Clement A, Maley S, McMillan N, Scobie D, Pinxterhuis I, Edwards Paul. 2021. *Catch Crops for Reduced Nitrate Leaching: Lessons from the "Forages for Reduced Nitrate Leaching" programme and Sustainable Food and Fibre Futures project "Catch Crops to Reduce Nitrate Leaching"*. Dairy NZ: Christchurch.

Horticulture New Zealand. 2010. *An overview: Horticulture industry strategy* '*Growing a new future*'. Wellington: Horticulture New Zealand.

Houlbrooke D, Carey P, Williams R. 2008. Management practices to minimise wipe-off losses from border-dyke irrigated land. In: LD Currie and LJ Yates (eds) *Carbon and nutrient management in agriculture*. Palmerston North: Fertilizer and Lime Research Centre, Massey University.

Houlbrooke D, Longhurst B, Orchiston T, Muirhead R. 2011. *Characterising dairy manures and slurries*. Mosgiel: AgResearch.

Houlbrooke DJ, Horne DJ, Hedley MJ, Hanly JA, Snow VO. 2004. A review of literature on the land treatment of farm-dairy effluent in New Zealand and its impact on water quality. *New Zealand Journal of Agricultural Research* 47(4): 499–511.

Houlbrooke DJ, Horne DJ, Hedley MJ, Snow VO, Hanly JA. 2008. Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. *Australian Journal of Soil Research* 46: 45–52.

Hudson N, Heubeck S, Baddock E. 2019. *Woodchip denitrification filter-performance evaluation: Third year of operation*. Hamilton: NIWA.

Hughes AO, Quinn JM. 2019. The effect of forestry management activities on stream water quality within a headwater plantation *Pinus radiata* forest. *Forest Ecology and Management* 439: 41–54.

Johnstone P, Parker M, Kaufler G, Arnold N, Pearson A, Mathers D, Wallace D. 2010. Growing maize silage in dairy effluent paddocks for two consecutive seasons – effect on crop yield and soil nitrogen. *Proceedings of the New Zealand Grassland Association* 72: 117–120.

Journeaux P, van Reenen E. 2016. *Economic evaluation of stock water reticulation on hill country*. Wellington: AgFirst.

Larned ST, Moores J, Gadd J, Baillie B, Schallenberg M. 2020. Evidence for the effects of land use on freshwater ecosystems in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 54(3): 551–591.

Ledgard SF, Luo J, Sprosen MS, Wyatt JB, Balvert SF, Lindsey SB. 2014. Effects of the nitrification inhibitor dicyandiamide (DCD) on pasture production, nitrous oxide emissions and nitrate leaching in Waikato, New Zealand. *New Zealand Journal of Agricultural Research* 57(4): 294–315.

Ledgard SF, Penno JW, Sprosen MS. 1999. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *The Journal of Agricultural Science* 132(2): 215–225.

Ledgard SF, Welten B, Betteridge K. 2015. Salt as a mitigation option for decreasing nitrogen leaching losses from grazed pastures. *Journal of the Science of Food and Agriculture* 95(15): 3033–3040.

Levine B. 2020. The ability of detainment bunds to mitigate the impact of pastoral agriculture on surface water quality in the Lake Rotorua catchment: A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Soil Science, Massey University, Palmerston North, New Zealand.

Levine B, Burkitt L, Horne D, Tanner C, Sukias J, Condron L, Paterson J. 2021. The ability of detainment bunds to decrease sediments transported from pastoral catchments in surface runoff. *Hydrological Processes* 35(8): e14309.

Low H, McNab I, Brennan J. 2017. *Mitigating nutrient loss from pastoral and crop farms 2017*. Palmerston North: Horizons Regional Council.

Malcolm BJ, Cameron KC, Beare MH, Carrick ST, Payne JJ, Maley SC, Di HJ, Richards KK, Dalley DE, de Ruiter JM. 2022. Oat catch crop efficacy on nitrogen leaching varies after forage crop grazing. *Nutrient Cycling in Agroecosystems* 122(3): 273–288.

Malcolm BJ, Cameron KC, Di HJ, Edwards GR, Moir JL. 2014. The effect of four different pasture species compositions on nitrate leaching losses under high N loading. *Soil Use and Management* 30(1): 58–68.

Malcolm BJ, de Ruiter JM, Dalley DE, Carrick S, Waugh D, Arnold NP, Dellow SJ, Beare MH, Johnstone PR, Wohlers M, Brown H, Welten B, Horrocks AJ. 2020. Catch crops and feeding strategy can reduce the risk of nitrogen leaching in late lactation fodder beet systems. *New Zealand Journal of Agricultural Research* 63(1): 44–64.

Matheson L, Djanibekov U, Greenhalgh S. 2018. *Recommended mitigation bundles for cost analysis of mitigation of sediment and other freshwater contaminants in the Rangitāiki and Kaituna-Pongakawa-Waitahanui water management areas*. Rotorua: PerrinAg.

Maxwell BM, Birgand F, Schipper LA, Barkle G, Rivas AA, Helmers MJ, Christianson LE. 2020. High-frequency, in situ sampling of field woodchip bioreactors reveals sources of sampling error and hydraulic inefficiencies. *Journal of Environmental Management* 272: 110996.

Maxwell TMR, McLenaghen RD, Edwards GR, Di HJ, Cameron KC. 2019. Italian ryegrass swards reduce N leaching via greater N uptake and lower drainage over perennial ryegrass cultivars varying in cool season growth rates. *New Zealand Journal of Agricultural Research* 62(1): 69–82.

McDowell RW. 2008. Water quality of a stream recently fenced-off from deer. *New Zealand Journal of Agricultural Research* 51(3): 291–298.

McDowell RW. 2009. The use of safe wallows to improve water quality in deer farmed catchments. *New Zealand Journal of Agricultural Research* 52(1): 81–90.

McDowell RW. 2017. Does variable rate irrigation decrease nutrient leaching losses from grazed dairy farming? *Soil Use and Management* 33(4): 530–537.

McDowell RW, Daly K, Fenton O. 2020. Mitigation of phosphorus, sediment and *Escherichia coli* losses in runoff from a dairy farm roadway. *Irish Journal of Agricultural and Food Research* 59(1): 201–205.

McDowell RW, Drewry JJ, Paton RJ. 2004. Effects of deer grazing and fence-line pacing on water and soil quality. *Soil Use and Management* 20(3): 302–307.

McDowell RW, Gongol C, Woodward B. 2012. *Potential for controlled drainage to decrease nitrogen and phosphorus losses to Waituna Lagoon*. Mosgiel: AgResearch.

McDowell RW, Monaghan RM, Smith C, Manderson A, Basher L, Burger DF, Laurenson S, Pletnyakov P, Spiekermann R, Depree C. 2021. Quantifying contaminant losses to water from pastoral land uses in New Zealand III. What could be achieved by 2035? *New Zealand Journal of Agricultural Research* 64(3): 390–410.

McDowell RW, Wilcock RJ, Hamilton D. 2013. *Assessment of Strategies to Mitigate the Impact or Loss of Contaminants from Agricultural Land to Fresh Waters*. Wellington: Ministry for the Environment.

McKergow L, Hughes A, Rutherford K. 2017. *Seepage wetland protection review*. Hamilton: NIWA.

McKergow LF, Matheson F, Goeller BC, Woodward B. 2020. *Preliminary riparian buffer guidelines: Filtering surface runoff and nitrate removal from subsurface flow*. Hamilton: NIWA.

Monaghan R, Manderson A, Basher L, Spiekermann R, Dymond J, Smith C, Muirhead R, Burger D, McDowell R. 2021. Quantifying contaminant losses to water from pastoral landuses in New Zealand II. The effects of some farm mitigation actions over the past two decades. *New Zealand Journal of Agricultural Research* 64(3): 365–389. 10.1080/00288233.2021.1876741.

Monaghan RM, Carey PL, Wilcock RJ, Drewry JJ, Houlbrooke DJ, Quinn JM, Thorrold BS. 2009. Linkages between land management activities and stream water quality in a border dyke-irrigated pastoral catchment. *Agriculture, Ecosystems & Environment* 129(1-3): 201–211.

Monaghan RM, de Klein CAM, Muirhead R.W. 2008. Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways: A case study of New Zealand dairy farming. *Journal of Environmental Management* 87(4): 609–622.

Monaghan RM, Houlbrooke DJ, Smith L.C. 2010. The use of low-rate sprinkler application systems for applying farm dairy effluent to land to reduce contaminant transfers. *New Zealand Journal of Agricultural Research* 53(4): 389–402.

Monaghan RM, Laurenson S, Dalley DE, Orchiston TS. 2017. Grazing strategies for reducing contaminant losses to water from forage crop fields grazed by cattle during winter. *New Zealand Journal of Agricultural Research* 60(3): 333–348.

Monaghan RM, Smith LC. 2012. Contaminant losses in overland flow from dairy farm laneways in southern New Zealand. *Agriculture, Ecosystems & Environment* 159: 170–175.

O'Callaghan P Kelly-Quinn M, Jennings E, Antunes P, O'Sullivan M, Fenton O, Ó hUallacháin D. 2019. The environmental impact of cattle access to watercourses: A Review. *Journal of Environmental Quality* 48(2): 340–351.

Rivas A, Barkle G, Stenger R, Moorhead B, Clague J. 2020. Nitrate removal and secondary effects of a woodchip bioreactor for the treatment of subsurface drainage with dynamic flows under pastoral agriculture. *Ecological Engineering* 148: 105786.

Rutherford JC, Schroer D, Timpany G. 2009. How much runoff do riparian wetlands affect? *New Zealand Journal of Marine and Freshwater Research* 43(5): 1079–1094.

Schipper LA, Robertson WD, Gold AJ, Jaynes DB, Cameron SC. 2010. Denitrifying bioreactors: An approach for reducing nitrate loads to receiving waters. *Ecological Engineering* 36(11): 1532–1543.

Silva RG, Cameron KC, Di HJ, Hendry T. 1999. A lysimeter study of the impact of cow urine, dairy shed euent, and nitrogen fertiliser on nitrate leaching. *Soil Research* 37(2): 357–370.

Simon PL, de Klein CAM, Worth W, Rutherford AJ, Dieckow J. 2019. The efficacy of *Plantago lanceolata* for mitigating nitrous oxide emissions from cattle urine patches. *Science of the Total Environment* 691: 430–441.

Smith LC, Monaghan RM. 2020. Nitrogen leaching losses from fodder beet and kale crops grazed by dairy cows in southern Southland. *Journal of New Zealand Grasslands* 82: 61–71.

Tanner CC, Depree C, Sukias J, Wright-Stow A, Burger D, Goeller B. 2022. *Constructed Wetland Practitioners Guide: Design and Performance Estimates*. Hamilton: DairyNZ and NIWA.

Tanner CC, Kadlec RH. 2013. Influence of hydrological regime on wetland attenuation of diffuse agricultural nitrate losses. *Ecological Engineering* 56: 79–88.

Tanner CC, Sukias JPS. 2011. Multiyear nutrient removal performance of three constructed wetlands intercepting tile drain flows from grazed pastures. *Journal of Environmental Quality* 40(2): 620–633.

Waikato Regional Council. 2017. *Menu of practices to improve water quality*. Retrieved 25 April 2017.

Wilcock RJ, Monaghan RM, Quinn JM, Srinivasan MS, Houlbrooke DJ, Duncan MJ, Wright-Stow AE, Scarsbrook MR. 2013. Trends in water quality of five dairy farming streams in response to adoption of best practice and benefits of long-term monitoring at the catchment scale. *Marine and Freshwater Research* 64(5): 401–412.

Woods RR, Cameron KC, Edwards GR, Di HJ, Clough TJ. 2016. Effects of forage type and gibberellic acid on nitrate leaching losses. *Soil Use and Management* 32(4): 565–572.

Appendix F: Testing

RW McDowell[1,2], VO Snow[2], BM Jackson[3,4], R Tamepo[5], S Trolove[6], C Ghimire[2]

[1] Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand

[2] AgResearch, Lincoln Science Centre, Lincoln, New Zealand

[3] BEEA Limited, Wellington, New Zealand

[4] Victoria University of Wellington, Wellington, New Zealand

[5] Scion Research, Rotorua, New Zealand

[6] Plant and Food Research, Havelock North, New Zealand

Preamble

This document outlines two aspects:

1) sensibility testing looking at the effect of different factors on Agricultural Production Systems sIMulator (APSIM) transport outputs
2) a comparison of observations of nitrogen (N) loss and against Risk Index Tool (RIT) estimates of risk.

1) Sensibility testing – transport risk

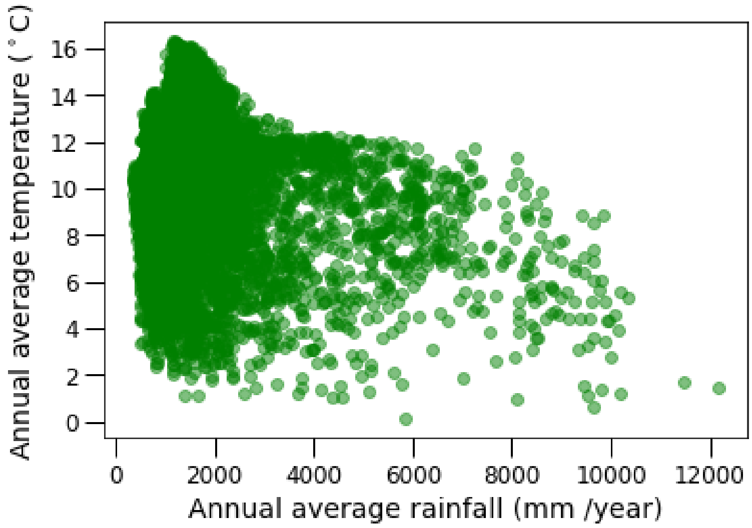
Leaching transport risk was derived from APSIM modelling of the probable leaching of a spike of N applied in any given month leaching below the root zone within two years. Runoff risk was derived from the median amount of runoff simulated by APSIM. The process is described under 'Process to estimate baseline N-loss risk' at the start of the report. This appendix documents the sensibility testing of that APSIM modelling.

Sub-sampling of the population of locations for sensibility analysis

The full population of locations (a soil–weather combination) was over 81,000 valid combinations. This is too many to produce a meaningful sensibility analysis so sub-sampling was required.

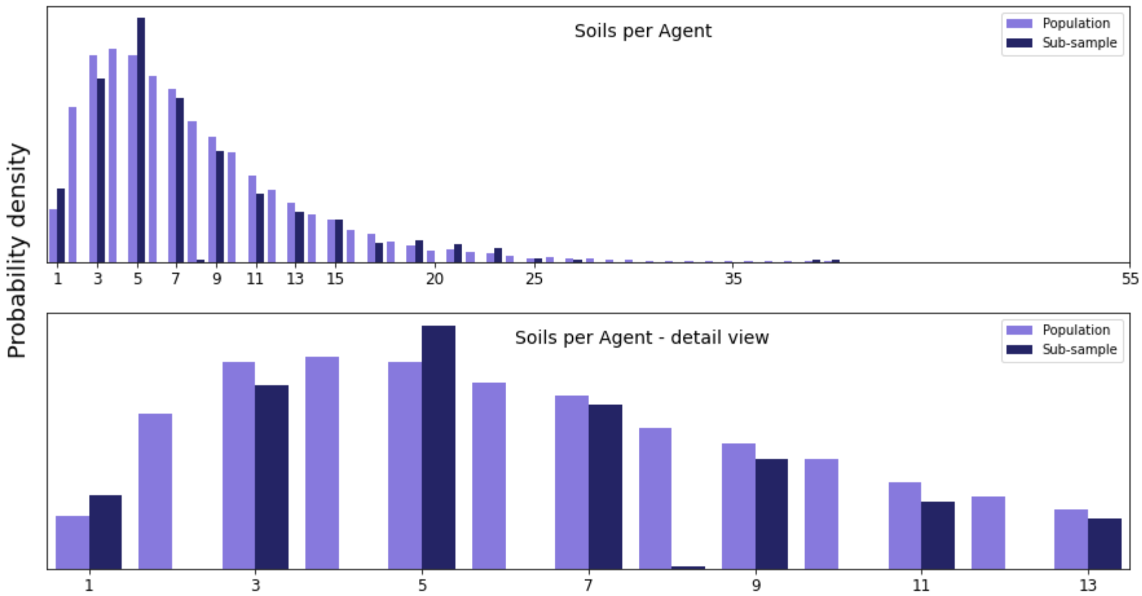
Rainfall (which drives both leaching and runoff transport as well as growing conditions) and air temperature (which drives growth) are known important factors. Preliminary analysis of the full data set showed that a negative relationship existed (figure F.1) between these two variables so the first decision was to sample the distribution of rainfall and then check that the sub-sample was a good representation of the air temperature distribution.

Figure F.1: Plot of rainfall against average air temperature for the 10,562 weather locations used in the simulations



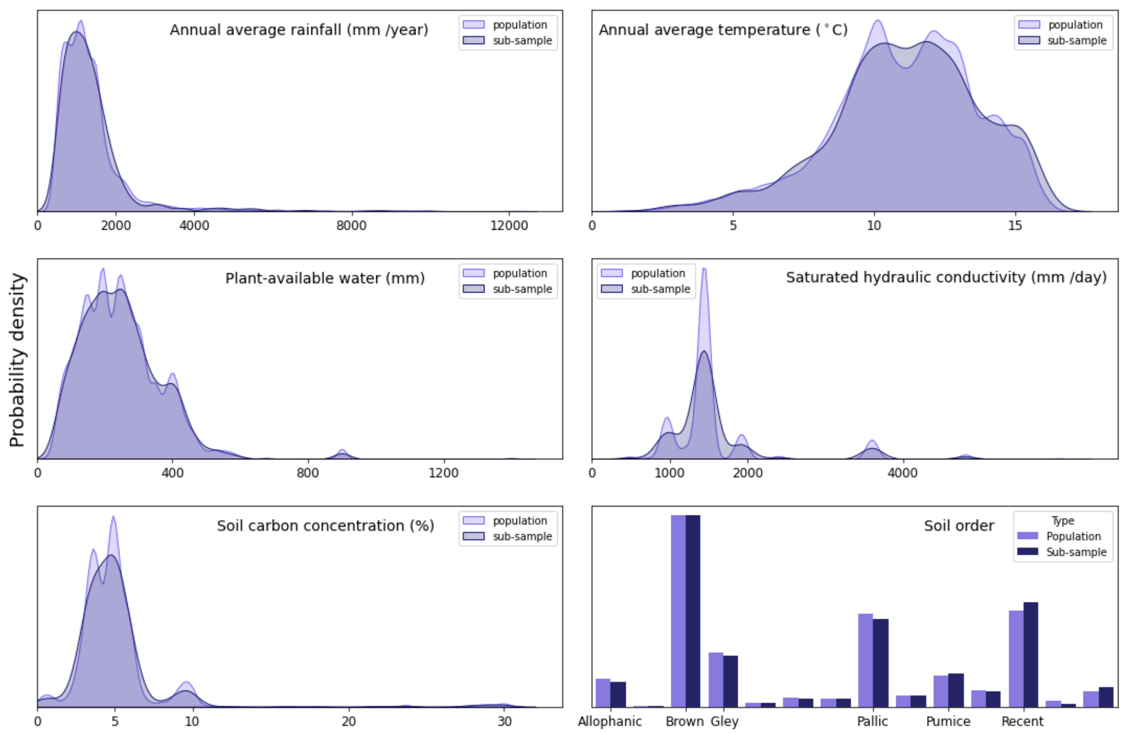
The full data set of 81,710 naturally occurring combinations of weather data (termed 'Agents') and S-Map soil siblings (termed 'Soils') comprised the population. The Agents were ranked (using pandas.DataFrame.rank with method='average') according to annual average rainfall and then all Agent–Soil combinations for every 10th rank were selected as a sub-sample. This resulted in 4,026 Agent–Soil combinations. The sub-sample is less than 10 per cent of the population because of the method used for ranking in combination with the effect of the relatively wide and skewed (varying between 1 and 55 with a median of 7) distribution of soils per Agent (figure F.2). The sampling regime did not include consideration of this feature of the population. This particular bias in the sampling is not important provided other key features of the climates and soils in the sub-sample are representative of the population.

Figure F.2: Probability density of the number of Soils within Agents for the population (lighter shade) and sub-sample (darker shade) showing the entire range (upper) and excluding the long tail (lower)



Following the above sampling, the distributions of rainfall, air temperature, plant-available water in the soil (PAW), saturated hydraulic conductivity in the topsoil (Ksat), concentration of soil carbon in the topsoil (Carbon) and soil order (Order) in the population and sub-sample were compared (figure F.3). The distributions were favourable, so analysis proceeded with the sub-sample.

Figure F.3: Probability densities of the sub-sample (sample size of 4,026, darker shade) of Agent–Soil combinations compared with that of the full population (population 81,710, lighter shade) with the characteristic concerned as shown on the individual plots

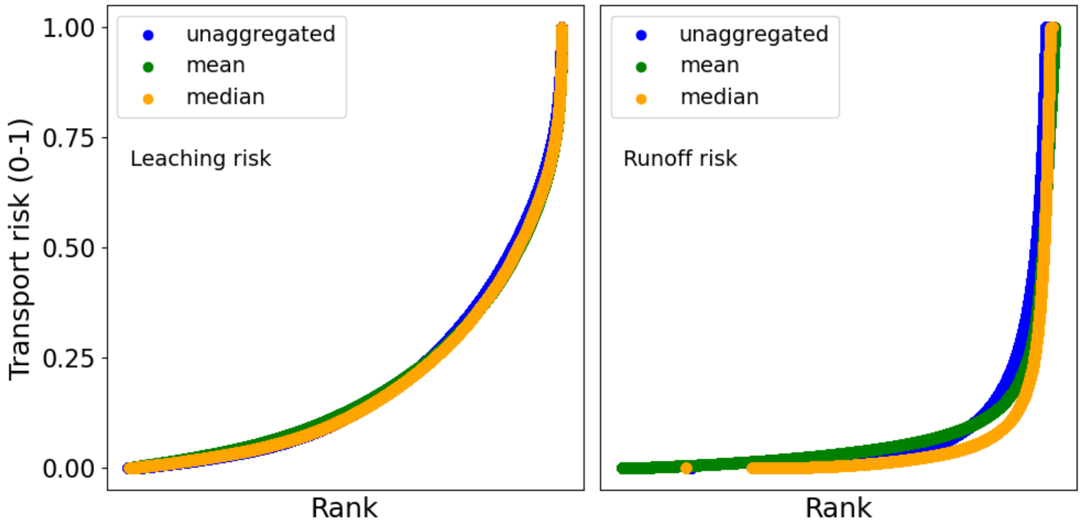


Calculation of transport risks

To make the runoff of water more consistent with the way we approach leaching transport factors, runoff from APSIM calculations for all land uses were divided by 200 (approximately the 98th percentile of estimated runoff in millimetres). However, our initial estimates of the risk of N loss by runoff were far below observed N losses. We attribute this to the use of transport factors for all slope classes that were based on calculations for flat land. This meant we were underestimating runoff from steep land. To gain equivalence between land uses, we multiplied all runoff values for forest (largely associated with steeper slopes) by 20 to get runoff close to the New Zealand-wide median values. We used the same adjustment for all flat land, because we had no data to warrant a different value. Note that we aim to improve our accounting of the effect of slope on runoff in future iterations (see appendix G).

Transport risk was calculated across 41 years of historic weather data, so more than one possibility existed for aggregating the effect of year-to-year variability with the mean or the median value being the most sensible options. Figure F.4 shows the effect of the two aggregation options against the unaggregated dataset. Minimal variation existed between the two so the median was selected for usage.

Figure F.4: **Leaching (left) and runoff (right) transport risk (vertical axis) plotted against the relative rank of the population (blue), the mean (green) and median (gold) across years of the sub-sample**



Effect of weather and soil properties on transport risk

While the RIT outputs were tested against data from the literature (see Testing in this appendix) those data are relatively sparse. Therefore, extensive sensibility testing was done. Sensibility testing involved plotting the transport risk against expected drivers and examining the patterns for sensibility against expectation.

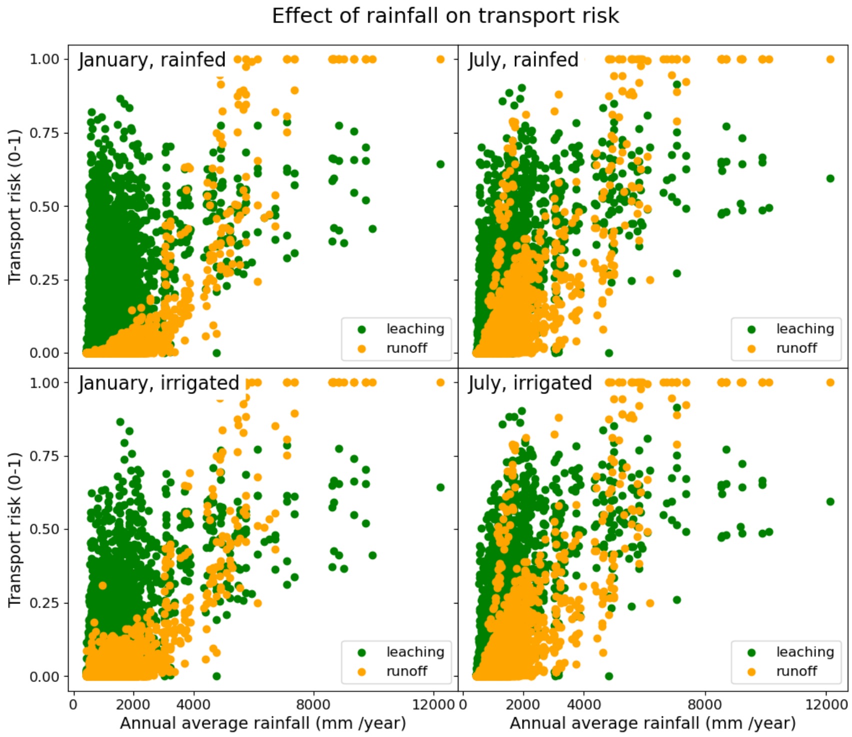
Note, to simplify the language, risks are referred to as, for example, 'in July'. This means the risk of activities in July on leaching in the following two years or runoff in the following 30 days.

Effect of weather and plant growth drivers on transport risks

Rainfall is an obvious driver of transport risk, yet its effects are not straightforward. Low rainfall can slow drainage and therefore transport but if rainfall is too low to support much growth then risk can increase. The pattern and variability of the rainfall are also important to risk (figure F.5). The general patterns below make sense:

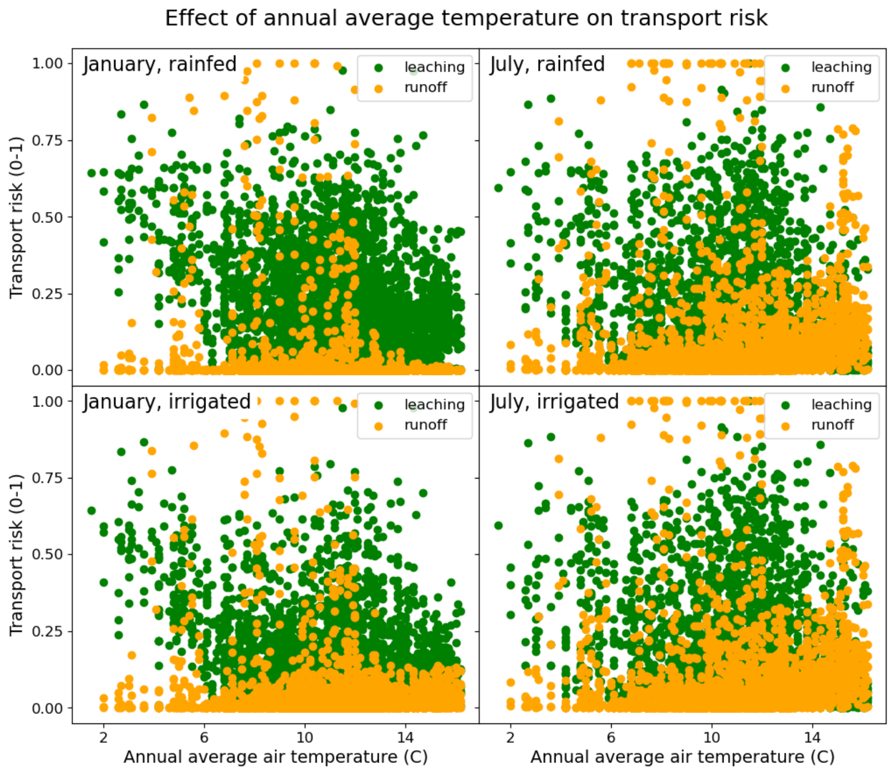
- examining the lower envelope of the data, a general trend was evident for increasing risks with increasing rainfall
- irrigation reduced leaching risk at low-rainfall sites in January (and to a much lesser extent in July), likely because of increased growth and uptake of N
- runoff risk increased with rainfall at moderate rainfalls (those found in most agricultural areas) and was higher in July compared with January
- at lower rainfall sites, irrigation increased runoff risk in January but not July.

Figure F.5: Effect of Agent annual average rainfall on leaching (green) and runoff (gold) transport risk in January (left) and July (right) for rainfed (upper) and irrigated (lower) conditions



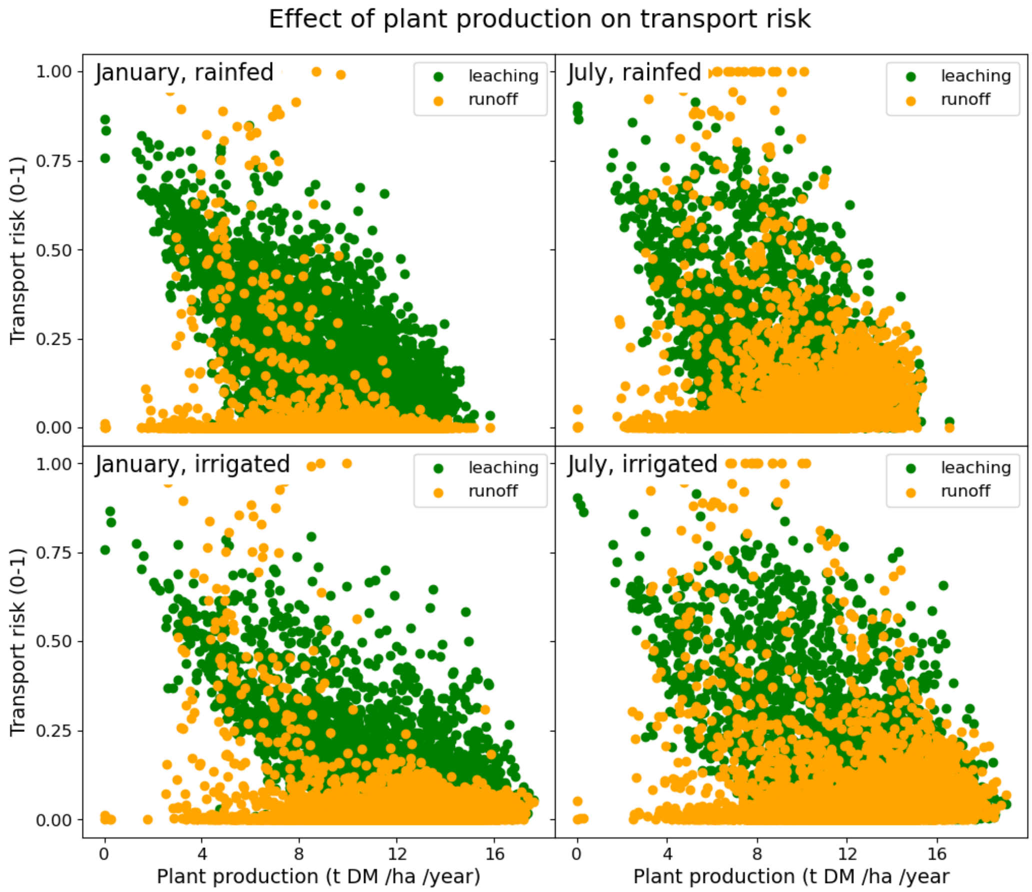
Only minor patterns were observable between air temperature and transport risks (figure F.6) and most of the effects are likely through a secondary driver (plant growth) and the association between air temperature and rainfall.

Figure F.6: Effect of Agent annual average air temperature on leaching (green) and runoff (gold) transport risk in January (left) and July (right) for rainfed (upper) and irrigated (lower) conditions



A strong negative relationship was evident between plant production and leaching risk (figure F.7). Plant production is an integrator of many weather and soil variables and takes account of, for example, variation of rainfall within and between years in a way that plotting against average rainfall cannot. As expected, little association existed between plant production and runoff risk.

Figure F.7: Effect of simulated plant production on leaching (green) and runoff (gold) transport risk in January (left) and July (right) for rainfed (upper) and irrigated (lower) conditions

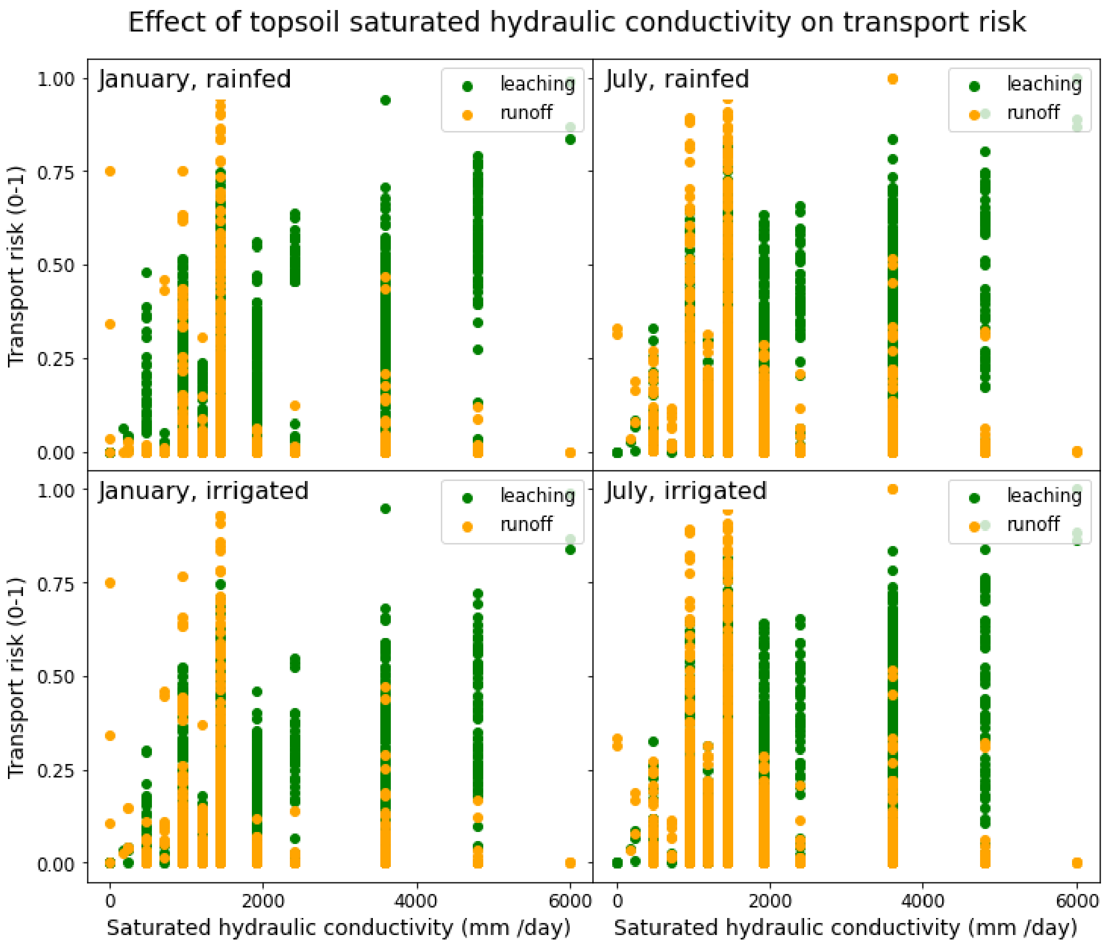


Effect of soil properties on transport risks

Transport risks were examined against several soil properties. Figure F.8 shows that leaching risk, as expected, generally increased as topsoil saturated hydraulic conductivity increased. The pattern of runoff risk with conductivity is somewhat messy at low conductivities (probably following the sampling distribution, see figure F.3). At higher conductivities, runoff risk is generally low, as might be expected.

Transport risks were also examined (data not shown) against the topsoil properties of carbon concentration, clay content, soil order and plant-available water within the pasture's rootzone. No unexpected patterns were observed.

Figure F.8: Effect of topsoil saturated hydraulic conductivity on leaching (green) and runoff (gold) transport risk in January (left) and July (right) for rainfed (upper) and irrigated (lower) conditions



2) Testing

Comparing the range and relative magnitude of risk scores

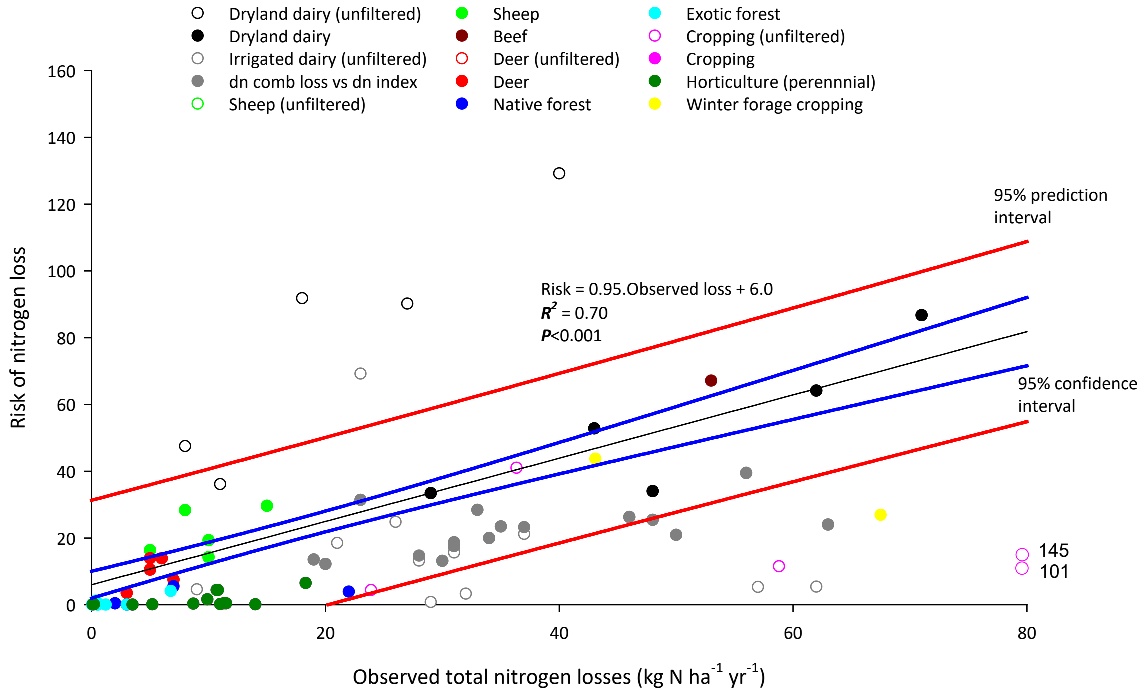
We reinspected our database of observations (n = 155, see 'Testing of baseline risk' at the start of this report) by land use and flow path, separating measurements of leaching from runoff (inclusive of surface runoff and interflow calculated by difference from evapotranspiration and leaching). Using each observation's location, modelled transport risks were multiplied by recorded N sources.

Observations were filtered out where confidence was low in N inputs or the location, or where observations were recorded at an inappropriate scale (eg, catchments more than 10 hectares). We also only included the mean of observations where multiple years of data were collected. Filtering resulted in 94 observations split across 1 observation for beef, 12 for cropping, 25 for dairy, 5 for deer, 7 for exotic forestry, 14 for horticulture, 5 for native forest, 5 for sheep, 11 for vegetables, and 3 for grazed winter forage cropping (figure F.9).

We plotted the risk of runoff plus leaching and runoff alone against the observations, to determine if the range and relationship of estimated risk has similarity to that of observations (figure F.9 and figure F.10). This plot was used to check if the magnitude of risk was within the range of observations and if risk responded to input values like that recorded for management at observed sites.

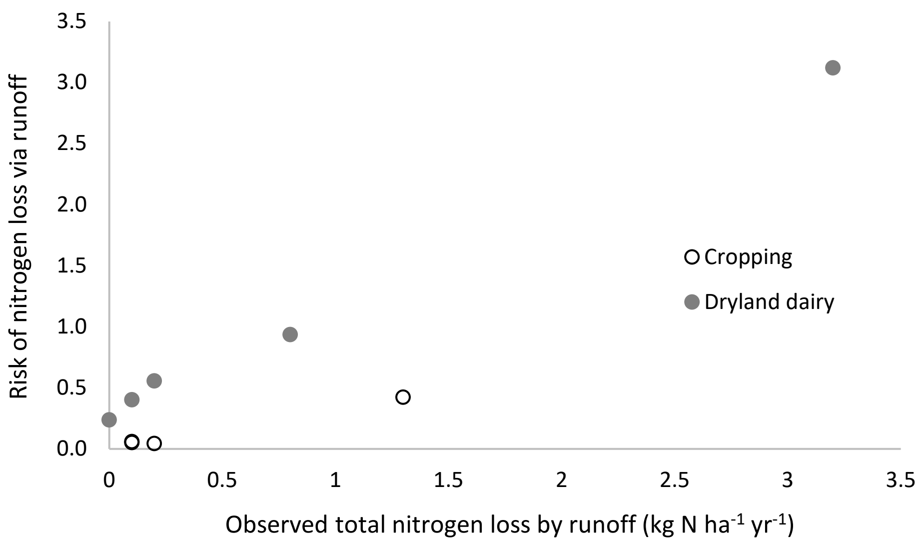
Once filtered, data points largely fell within the 95 per cent prediction interval. We did not assess performance of the risk index using this relationship because the data were not normally distributed.

Figure F.9: Plot of unfiltered (empty circles) and filtered (filled circles) observed (leaching + runoff) nitrogen losses against their corresponding risk nitrogen loss index values



Note: The equation for the linear regression is shown to allow readers to gauge the magnitude of risk index values relative to observed values (via the slope = 0.95) but readers should be cautioned that this relationship does not hold statistical validity. The two values to the far right (145, 101) lie beyond the graph's range and are from fluxmeter data.

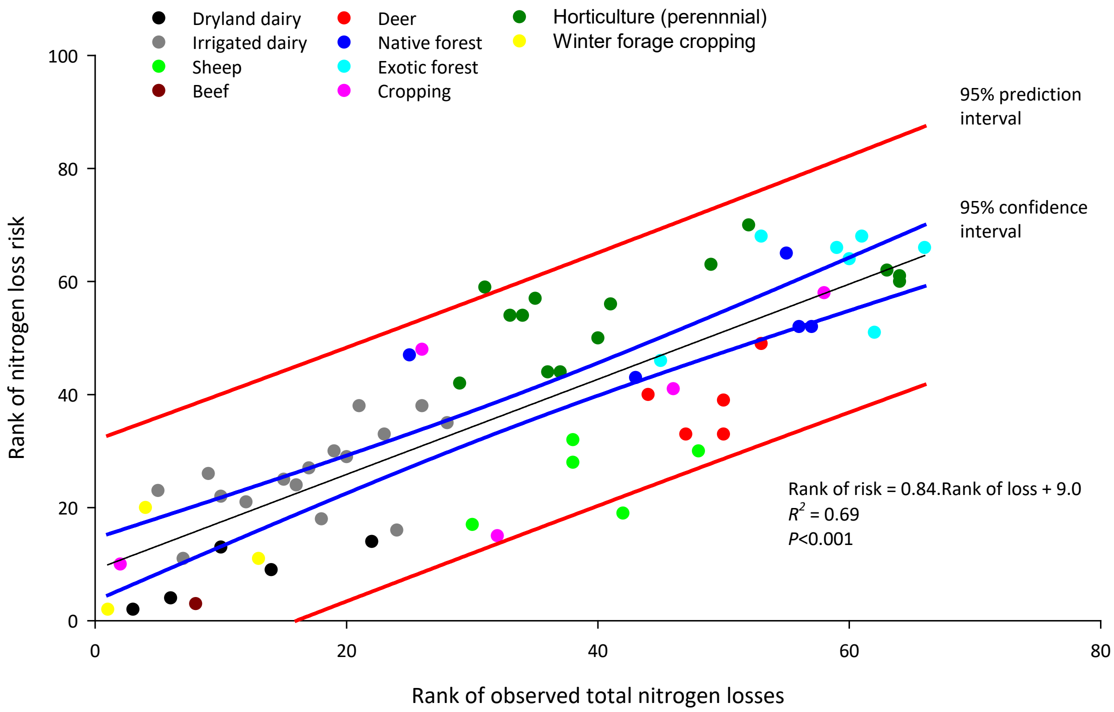
Figure F.10: Plot of filtered observed runoff (alone) nitrogen losses against their corresponding risk values



Assessing the performance of risk estimates

Some land uses had relatively few data that were clustered, often over different ranges resulting in non-normal data. Therefore, the performance of risk scores against observations were converted into ranks before fitting a regression (figure F.11). We used this relationship to determine the performance of the index relative to observations (R^2 = 0.69, P<0.001).

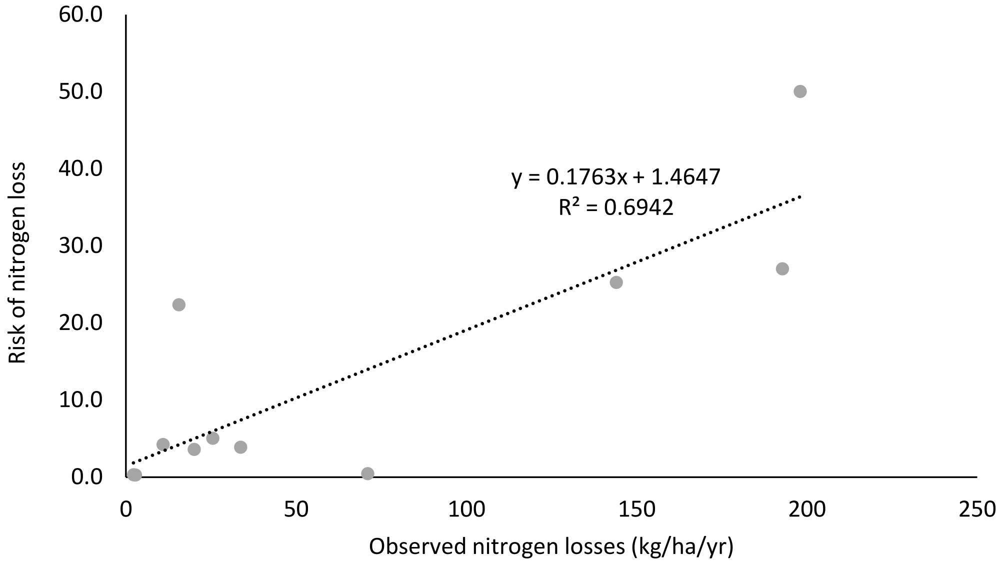
Figure F.11: Plot of the rank (1 = highest) of the risk of nitrogen loss against the rank of observed nitrogen loss



Note: Ranks overcome clustering and the non-normal distribution of the data allowing a regression equation and coefficient of determination to be fitted.

Vegetables were not included in the analysis because risk index values were consistently lower than observed losses (figure F.12). We expect risk scores to be boosted by additional work planned to calibrate APSIM transport losses to shallow rooting (largely vegetable rotations) instead of the pastoral-based transport values presently used (see appendix G). As risk relative to observed losses was consistently under-predicted, we boosted risk by a factor of five (compared to slopes of 0.77/0.18; figure F.9 and figure F.12) as an interim fix until vegetable-specific transport factors can be investigated.

Figure F.12: Plot of the risk of nitrogen loss against observed losses for vegetables



Note: The regression fit is significant at the *P*<0.05 level but is statistically non-valid because the data do not conform to parametric statistical assumptions.

We also note that, for arable cropping data, some observed losses were out of sync with risk scores. This was caused by observations generated for hydrological years (September to August) compared against sources and risks calculated on a calendar year (table F.1). Although this evened out when data for all years were averaged, these data suggest the risk index should be calculated across multiple years to better align and capture annual variation in risk.

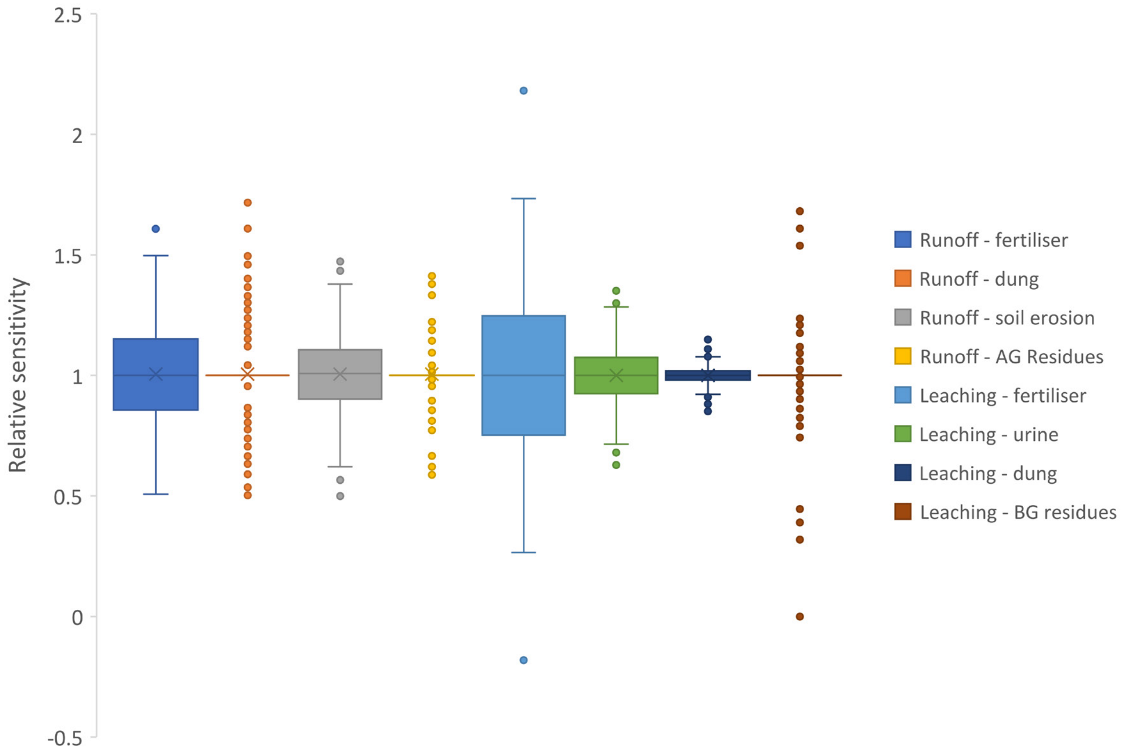
Table F.1: Comparison of observed losses and risk scores over six years of ryegrass–wheat–barley–plantain rotation in mid-Canterbury that was periodically grazed by livestock

Year	Management	Observed loss (kg N ha^{-1} yr^{-1})	Risk score
1	25 lambs ha^{-1} in September and 17 calf cows ha^{-1} in July	36	73
2		49	24
3		69	17
4	28 lambs ha^{-1} in September	20	45
5		31	26
6	17 cows ha^{-1} July–August, 22–31 lambs in September	13	60

To determine the sensitivity of sources on risk scores, we increased or decreased inputs by 50 per cent for the filtered observed data. We expressed their effect on the overall index score relative to the mean score of the original data. We note that, because we had a limited set of observations, this output is unlikely to capture the true sensitivity of the index across a broader range of inputs.

The output (figure F.13) is split into the effect of inputs to runoff and leaching separately. An approximate estimate of the effect on the combined risk can be gained by the ratio of mean runoff (3.7) to leaching (19.3).

Figure F.13: Sensitivity of increasing or decreasing different source factors by 50 per cent on the risk of nitrogen loss as estimated for estimates of the filtered observed data



Note: A sensitivity of 1 indicates the site was insensitive to increases or decreases, which could reflect that the source was not applied at that site (eg, no animals in a perennial horticulture site).

Few data were available to test the efficacy of mitigations. However, in the original database, sufficient data were available to predict the effect of fertiliser rates on nitrate-N and total nitrogen (TN) losses (R^2 = 0.80) in pastoral systems (Drewry et al, 2022). We tested the effect of applying fertiliser at intervals of 30 kg N ha^{-1} yr^{-1} to 40 kg N ha^{-1} yr^{-1} up to the maximum allowable rate for dairy of 190 kg N ha^{-1} yr^{-1} (spread across the growing season). We used expert opinion to adjust stocking rates to reflect a reduction in N fertiliser (and feed). The output is shown in table F.2 with estimated risks increasing with estimated losses calculated from Drewry et al 2022.

Table F.2: Estimates of nitrogen (N) loss using the commensurate risk score for a dairy farm in Manawatu

Fertiliser and stocking rate (cow ha^{-1})	Predicted N loss[1] (kg ha^{-1} yr^{-1})	Estimated risk score
30 (2.2)	21	10
60 (2.6)	23	12
90 (2.8)	25	14
120 (3.0)	27	16
150 (3.1)	30	20
190 (3.3)	33	23

[1] As per Drewry et al, 2022.

We determined that testing of the effect of modifiers was not required for two reasons: 1) owing to a paucity of data we used all free, robust and accessible studies to create modifiers, meaning an independent set of data to check their performance was unavailable; and 2) no data were available to compare any potential interactions between modifiers.

However, we note that the likelihood of the combined effect of two modifiers applied in parallel exceeding that of modifiers applied in series is low. In other words, most of the effect is likely captured by the fact that modifiers are applied in the order of most to least effective, meaning the less effective modifier will always have less N to reduce.

Reference

Drewry JJ, McDowell R, Ghimire C, Noble A. 2022. *Collation of nutrient, sediment, and* E. coli *losses from land uses to freshwater, and an initial analysis of some factors contributing to nitrogen loss*. Prepared for Ministry for the Environment. Palmerston North: Manaaki Whenua – Landcare Research.

Appendix G: Upgrades to the existing Risk Index Tool

RW McDowell[1,2], VO Snow[2], BM Jackson[3,4], R Tamepo[5], S Trolove[6], K Muraoka[7]

[1] *Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand*

[2] *AgResearch, Lincoln Science Centre, Lincoln, New Zealand*

[3] *BEEA Limited, Wellington, New Zealand*

[4] *Victoria University of Wellington, Wellington, New Zealand*

[5] *Scion Research, Rotorua, New Zealand*

[6] *Plant and Food Research, Havelock North, New Zealand*

[7] *Ministry for the Environment, Wellington, New Zealand*

Preamble

This document details aspects of the Risk Index Tool (RIT) signalled for upgrading in the next version of the RIT. We consider the 'Testing if N leaching transport risk of representative arable and horticultural crops is like that for pasture' and 'Monthly crop uptake' components of appendix B to be the most pressing updates.

Upgrades to baseline risk

Coverage of Te Ture Whenua Māori land

Recently the Fundamental Soil Layer (FSL) data was improved within Manaaki Whenua – Landcare Research's S-Map programme. We analysed where the availability of information detrimentally affects whenua governed under Te Ture Whenua Māori Act 1993 (Te Ture Whenua).

A subset of the Māori land layer was intersected with the S-Map layer and Land Cover Database (LCDB). This subset was created by excluding Māori land parcels with built-up areas (settlements), estuarine open water, lakes and ponds, rivers and 'not land'. The analysis used the following data: Māori Land Spatial Dataset (r31.5.2017) (Māori Land Data Service | Māori Land Court (maorilandcourt.govt.nz); S-Map Coverage (S-map Soil Depth Aug 2022 – SMAP | | Environment and Land GIS | LRIS Portal (scinfo.org.nz); and LCDBv5.0 – Land Cover Database version 5.0, Mainland NZ (LCDB v5.0 – Land Cover Database version 5.0, Mainland, New Zealand – LCDB | | Environment and Land GIS | LRIS Portal (scinfo.org.nz)).

From the analysis, 45 per cent (0.56 million hectares) of Te Ture Whenua[13] (1.26 million hectares) has S-Map coverage, the remaining land area does not have soil information provided by S-Map (figure G.1). No S-Map or FSL data exist for the Chatham Islands and Pitt Island (figure G.2).

[13] This does not include general title owned by Māori and post-settlement land, only land governed under Te Ture Whenua (Māori Land Spatial Dataset (r31.5.2017)).

Figure G.1: S-Map coverage (green) overlaid on Te Ture Whenua land (orange)

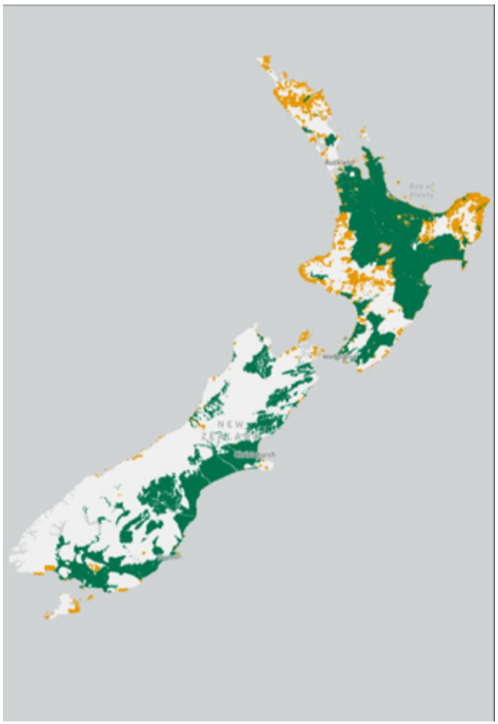
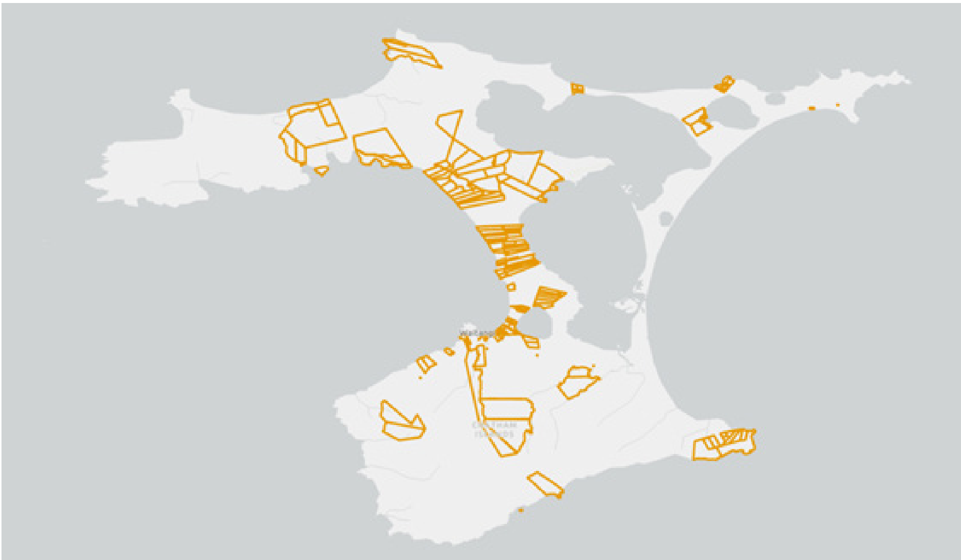


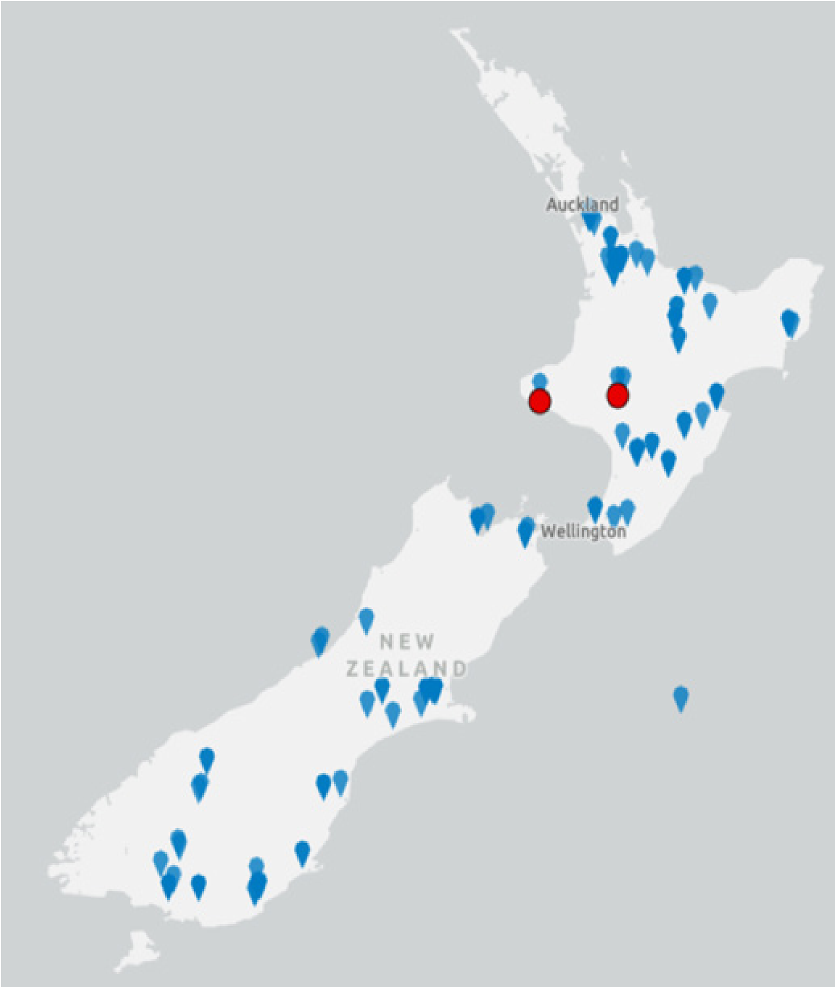
Figure G.2: Māori land in the Chatham Islands



While it may be reasonable to assume that S-Map data will improve the accuracy of the RIT, we have no data to determine whether a material difference exists in risk. As a result, there is a perceived (but perhaps not real) disadvantage to land governed under Te Ture Whenua. To resolve this issue, we advocate for an analysis of transport factors on Te Ture Whenua where both S-Map and FSL data exist.

The data gaps also pertain to the validation analysis. Of the 156 sites considered in that exercise, two were on Māori land (1 dairy and 1 vegetable, both on flat land; figure G.3). Clearly, this is not representative of steeper land governed under Te Ture Whenua. To determine if Māori are being disadvantaged would require more N-loss data to be collected from farm systems governed through Te Ture Whenua.

Figure G.3: Location of nitrogen- (N-) loss observations on Te Ture Whenua land (red dots)



Alteration of curve numbers in the Agricultural Production Systems sIMulator to account for slope

The current iteration of the RIT uses APSIM outputs only from categorically 'flat' land, that is, less than 7.5 degrees of slope. While several schemes (eg, Ajmal et al, 2020; Lal et al, 2015; Sharma et al, 2022; Williams et al, 2012) provide empirical corrections to account for slope, testing showed that none were satisfactory for Aotearoa New Zealand conditions. Future work should be done improve this situation. For this first version of the RIT, slope effects were only accounted for within the modifiers part of the tool.

Upgrades to appendix B

Accounting for differing amounts of nitrogen in the source risk

At present, risk is taken as a linear function of the amount of N added to the soil unless the soil is fallow or in the first month of a newly sown crop. For example, the leaching risk of a 40 kg N ha^{-1} source input is half that of an 80 kg N ha^{-1} input. Previous work has shown there is not a linear function throughout the entire range of likely inputs (Silva et al, 1999). The representation of the effect of the magnitude of the N input will be improved in subsequent versions.

Accounting for extended mineralisation from cultivated pastures

In table B.4 of appendix B, it was indicated that there was a need to account for the extended duration (beyond three months) of mineralisation from pasture residues. This should be done in a future version of the tool.

Incorporating rotations into the Risk Index Tool

Currently, the risk of growing crops in a rotation spanning, for example, 5 years or 10 years is not accounted for in the RIT. The next iteration will enable growers to input crops for up to 10 years and provide a time-weighted monthly average.

Inclusion of soil nitrogen mineralisation as a soil residue nitrogen source

The current RIT does not consider dynamic mineralisation of N from the soil. Mineralisation can supply a significant amount of N over the growing season (Hoffmann et al, 2018), but few data have been available. New data have been sourced from Plant and Food Research and Ravensdown Fertiliser Co-Operative, and may be included in subsequent iterations of the RIT.

Testing if nitrogen leaching transport risk of representative arable and horticultural crops is like that for pasture

The APSIM monthly leaching transport values (0–1) assume a N uptake rate that is modelled from a ryegrass–white clover sward. It is possible these monthly values may have to change if it is demonstrated that transport of N is materially different from pasture owing to either shallower or deeper root structures being present.

Leaching transport values for five crop rotations for the Auckland region (table G.1) will be compared to those of pasture for selected areas in Auckland. If a material difference (perhaps greater than 20 per cent) occurs for the sum of monthly values, then pastoral transport values may have to be substituted for a representative rotation. This would switch all transport values to a set that better represents the user's system.

Table G.1: Rotations simulated via the Agricultural Production Systems sIMulator for the Auckland region

		Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Year of cycle	Sowing month (1st day of month)	Crop in cycle	Crop in cycle	Crop in cycle	Crop in cycle	Crop in cycle
Year 1	January	Barley (cereal grain)	Barley (cereal grain)	Fallow	Barley (cereal grain)	Pumkin
	February	Cabbage	Cultivation, fallow, ground prep		Lettuce	Cultivation
	March			Lettuce		
	April				Fallow, cultivation	
	May					
	June		Onions			Onions
	July			Fallow		
	August	Barley (cereal grain and then incorporated)				
	September			Asian greens	Broccoli	
	October					
	November					
	December			Fallow	Oats cover crop	
Year 2	January		Cultivation, fallow, ground prep	Spinach		Cultivation
	February					
	March					
	April			Fallow		
	May		Potatoes	Cauliflower		Potatoes
	June				Broccoli	
	July					
	August					
	September			Fallow		

		Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Year of cycle	**Sowing month (1st day of month)**	**Crop in cycle**	**Crop in cycle**	**Crop in cycle**	**Crop in cycle**	**Crop in cycle**
	October	Onions				
	November					
	December				Fallow	
Year 3	January			Leeks and spring onions		Cultivation
	February		Oats cover crop – incorporated			Lettuce
	March					
	April	Oats (for incorporation)				
	May			Fallow		
	June					Cover crop (rye grass)
	July					
	August					
	September	Potatoes	Carrot	Onions	Barley (cereal grain)	
	October					
	November					
	December					Pumpkin
Year 4	January		Cultivation, fallow, ground prep			
	February	Phaecelia (for incorporation)				Cultivation
	March				Lettuce	
	April		Lettuce	Oats (incorporated)		
	May				Fallow, cultivation	
	June		Cultivation, fallow, ground prep			
	July	Carrots				

Year of cycle	Sowing month (1st day of month)	Rotation 1 Crop in cycle	Rotation 2 Crop in cycle	Rotation 3 Crop in cycle	Rotation 4 Crop in cycle	Rotation 5 Crop in cycle
	August			Potatoes	Broccoli	Barley (cereal grain)
	September		Broccoli			
	October					
	November	Silver beet			Fallow, cultivation	
	December		Cultivation, fallow, ground prep			
Year 5	January			Phaecelia (for incorporation)		Broccoli
	February		Broccoli			
	March				Barley (cereal grain)	Fallow, cultivation
	April	Cabbage	Fallow			
	May		Barley (cereal grain)	Lettuce		
	June					
	July					
	August			Fallow		
	September			Asian greens		Pumpkin
	October	Barley (cereal grain)				
	November					
	December			Fallow		

Monthly crop uptake

Future iterations of the RIT will also consider monthly crop uptake. We outline a method (below) to account for crop uptake. However, this was not implemented because we were unable to test if the transport risk for N leaching under pasture was materially different from that under a rotation.

The total amount of N taken up by a particular crop (TN_c) is calculated as the sum of the N in the harvested portion of the crop (NH_c) plus the N in the above-ground residues ($AGNR_c$) plus the N in the below-ground residues (BGN_c), see equation 7 (numbers continued from those in appendix B).

$$TN_c = NH_c + AGNR_c + BGN_c \qquad \text{[Eqn 7]}$$

Where:

- NH_c is the nitrogen in the harvested portion of the crop (kg N ha^{-1}) calculated as shown in equation 8

$$NH_c = Prod_c \times NremH_c \qquad \text{[Eqn 8]}$$

Where:

- *Prodc* = Production (yield) of crop type, c (tonnes of fresh weight ha^{-1}). This is entered by the grower
- $NremH_c$ is the nitrogen content (kg N/t crop) in the harvested portion of the crop (see table G.2 for example values)
- $AGNR_c$ is calculated according to equation 1 (appendix B)
- BGNc is calculated according to equation 2 (appendix B)

The total N uptake by the crop (TN_c) is then distributed equally over the months that the crop is grown. To be more realistic, total N uptake should be distributed according to an exponential or sigmoidal curve (depending on the crop). However, for simplicity, and given the time constraints for this project, an even distribution has been assumed. This requires that the starting date for each crop, or fallow period, is entered by the grower.

The TN_c and the amount of N immobilised for each month are both subtracted from the N inputs for that month, to give the amount of N source input value that will be multiplied by the transport factor. If the N source input value is negative, the N available for leaching that month is assumed to be zero.

Table G.2: Example nitrogen content in the harvested portion of the crop

Species	NremHc (kg N t^{-1} Fresh weight)
Wheat	20.0
Barley	20.0
Oats	16.0
Maize grain	14.0
Field seed peas	34.0
Peas fresh and process	2.9
Potatoes	3.4
Onions	1.7

Species	NremHc (kg N t^{-1} Fresh weight)
Sweet corn	3.9
Squash	3.7
Herbage seeds	24.0
Legume seeds	52.0
Brassica seeds	37.0
Cauliflower	4.0
Broccoli	4.1
Beans	3.7
Carrots	1.7
Beetroot	2.4
Tomatoes	1.7
Lettuce	2.4
Cabbage	2.5
Brussels sprouts	3.5
Celery	2.4

Upgrades to appendix C

Soil erosion estimates

Estimates of N losses by soil erosion can be greatly improved by using more spatially explicit and published models of soil erosion. We outline below how an existing approach using the Revised Universal Soil Loss Equation (RUSLE) could be incorporated within the N-loss index to upgrade soil erosion losses. These would be multiplied by soil total N concentrations (appendix C, table C.5) to yield seasonal or annual estimates of N loss by erosion for different land use by soil orders.

As Donovan (2022) and Benavidez et al (2018) express, the most commonly used model for soil erosion is the RUSLE, itself an update to the Universal Soil Loss Equation (USLE). The basics of the RUSLE are simple: factors are multiplied together to estimate rainfall erosivity, topography factors (slope, distance to stream and sometimes convergence of topography), soil risk factors for erosion, land cover–vegetation and management. The last two are sometimes separated and sometimes lumped together.

Table G.3 shows the subfactor equations and datasets used for the national scale run of RUSLE produced in this appendix (figure G.4). Owing to a lack of national scale, publicly available and easily accessible spatial datasets, P-factors relating to management (eg, tillage, mulching) were not explicitly included in this initial version of the RUSLE for Aotearoa New Zealand. Instead, basic management factors relating to land use are included in the C-factor (cover-management). This is consistent with the approach of Donovan (2022).

Table G.3: Overview of equations and datasets used to produce the subfactor layers

Subfactor	Equation and/or dataset	References
R-factor	Global Rainfall Erosivity Dataset (GloREDa)[14]	Panagos et al, 2017
LS-factor	8 metre national digital elevation model (DEM)[15] $LS = \left(\frac{l}{22}\right)^{0.5}(0.065 + 0.045s + 0.0065s^2)$ Where: l: slope length (m) s: slope steepness (%)	Morgan, 2009
K-factor	Fundamental Soil Layer (FSL) for North Island[16] and South Island[17] $K = [(0.043 \times pH) + \left(\frac{0.62}{OM}\right) + (0.0082 + S) - (0.0062 \times C)] \times Si$ Where: pH: pH of the soil OM: organic matter (%) S: sand content (%) C: Clay ratio = $\frac{\%\,Clay}{\%Sand + \%Silt}$ Si: silt content = $\%Silt \div 100$	David, 1988
C-factor (with some P-factor consideration)	New Zealand Land Cover Database v5.0[18]	Donovan, 2022

After the subfactor layers are produced, they are multiplied together to produce annual soil loss (A) in tonnes per hectare per year:

$$A = R \times LS \times K \times C$$

Note that this analysis differs from Donovan (2022) in the following ways:

- R-factor: Donovan (2022) used monthly rainfall rasters from NIWA and spatial boundaries for seasonal rainfall erosivity based on Klik et al (2015), which are not publicly available. We use a publicly available global dataset (Panagos et al, 2017).
- LS-factor: Donovan (2022) used a 15 metre national digital elevation model (DEM) and an equation that used flow accumulation to account for flow convergence. Our analysis used an 8 metre national DEM and a less complex equation that required only slope and cell size. We do have other inbuilt equations with the capacity to use flow convergence, but it was not possible to run these over the whole of Aotearoa New Zealand, given the short timeframes needed to produce these preliminary results, but they can be updated, as necessary.

---

14 European Soil Data Centre. *Global Rainfall Erosivity*. Retrieved 28 August 2022.

15 Land Information New Zealand. *NZ 8m Digital Elevation Model (2012)*. Retrieved 28 August 2022.

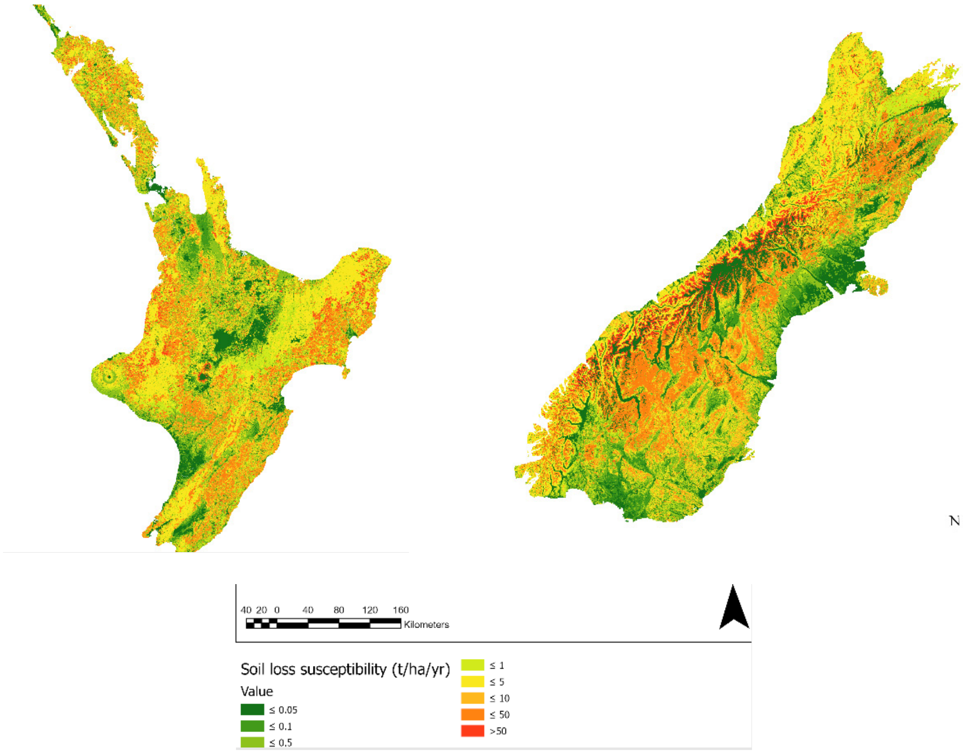
16 Manaaki Whenua – Landcare Research. *FSL North Island v1.0 (all attributes)*. Retrieved 28 August 2022.

17 Manaaki Whenua – Landcare Research. *FSL South Island (all attributes)*. Retrieved 28 August 2022.

18 Manaaki Whenua – Landcare Research. *LCDB v5.0 – Land Cover Database version 5.0, Mainland, New Zealand*. Retrieved 28 August 2022.

- K-factor and C-factor: Donovan (2022) used the Land Use and Carbon Analysis System (LUCAS) land use map[19] to inform the extent of dairy and non-dairy pasture, which were used to modify the soil erodibility and cover factors based on other characteristics, such as treading and grazing. Our model is based on the FSL and LCDB5 to incorporate these factors, although we aim to incorporate the LUCAS and modify the C- and P-factors.

Figure G.4: National soil loss susceptibility (tonnes per hectare per year)



Data for the above approach and the method of Donovan (2022) are available. We intend to incorporate these within subsequent iterations of the RIT.

Upgrades to appendix E

New mitigations and modifiers

We recognise that, over time, new mitigations may be developed that can be used as source mitigations or modifiers. Some practices are also not captured within the RIT that are being worked on for the next iteration of the tool.

To judge if new mitigations are to be included in the RIT, we expect to use the same filters for existing mitigations (eg, peer-reviewed evidence over a range of locations and years).

Table G.4 outlines practices that could be included in the current iteration but were not because they either had too few data or were more appropriately handled as part of a freshwater farm plan.

---

19 Ministry for the Environment. *LUCAS NZ Land Use Map 1990 2008 2012 2016 v011*. Retrieved 5 December 2023.

Table G.4: List of practices known to alter the risk of nitrogen (N) loss, but not captured in the current version of the Risk Index Tool (RIT), and our approach to exploring their inclusion

Practice	Flow path	Approach
Flood irrigation	Leaching, runoff	Known to increase risk of N loss. Previous work has shown an additional 2 kg ha^{-1} can be added in runoff (Carey et al, 2004). However, because this is highly variable and depends on the state of flood irrigation bays (Houlbrooke et al, 2008), we recommend that mitigating the N losses from this practice is best handled via the Freshwater Farm Plan process.
Irrigation with little or no active scheduling	Leaching, runoff	Poor irrigation scheduling is known to increase the risk of N losses. However, because this is highly variable and depends on the diversity of soils (Hedley et al, 2009), we recommend that mitigating the N losses from this practice is best handled via the Freshwater Farm Plan process.
Grazing and cultivating close to water ways	Runoff	Although well known to increase the risk of excretal returns to waterways (McDowell et al, 2017), this practice is covered within the National Environmental Standards and so is not considered within the RIT. Where grazing near streams is allowed, the risk is managed through the Freshwater Farm Plan process.
Excessive fertiliser and/or stocking rates	Leaching, runoff	Excessive N inputs are fertiliser or 'over stocking' will cause risk to increase in the RIT.
Artificial drainage	Leaching	Artificial drains can result in the same amount of N loss as undrained grazed pastures (Monaghan et al, 2000). However, this is dependent upon the efficiency of drains. Current work considers an interception rate of drainage at 30% to 50%. Work is being done to determine if adjusting interception rates would change N-loss risk.
Surface drains	Runoff	Nitrogen can enter surface drains in runoff. Work is being done to determine if such events add a material amount of N-loss risk above that assumed in poorly drained environments.

Additional testing in appendix F

Comparison of risk index values and estimated losses from Overseer

Regional authorities have expressed a desire that the estimated risk of N loss for sites with observed data be compared to estimates of loss from Overseer. A validation exercise is being conducted as part of an upgrade to Overseer to facilitate its use in a narrow-use case by authorities. This exercise will generate Overseer files to generate outputs for a subset of the observations tested in appendix F. These estimates could be compared to risk estimates to show if there is a similar range and response of values to land use and management.

Improved understanding of uncertainty in the transport risks

Effect of uncertainty in Agent and weather errors on transport risk

Sensibility testing has shown that rainfall has a strong influence on transport risks (see appendix F). Regional authorities expressed a desire to understand, quantitatively, the implications of errors in the mapping of the property to Agent[20] (so neighbouring Agents) and the effect of possible error in the interpolations used in the generation of the Virtual Climate Station Network (VCSN) weather data on the calculated transport risks. While hints at this can be seen in appendix F, figure F.5, additional work is needed to satisfy this uncertainty.

Effect of uncertainty in soil on transport risk

The mapping of soil is not (and cannot be) completely accurate. Regional authorities need to understand the uncertainty inherent in such mapping and possible remedies. The sensibility analysis in appendix F is a start at understanding the effect of this uncertainty but considerably more work is required to satisfy this need.

Effect of year-to-year variation in weather and management on transport risk

The transport risks are, as needed for the RIT, presented as long-term aggregations, and so do not vary from year to year. Farm management does, however, vary and both responds and adapts to weather variation. Similar issues were associated with the representation of management in Overseer. Some investigation of how many years of management should be recorded to approximate a typical year is needed. This should form part of guidance to regional authorities in the implementation of the RIT.

Additional contaminants

Risks of other contaminants

Other diffused source contaminant loss risks, such as phosphorus, sediment and pathogens, are identified as desired for the RIT. Improved runoff transport, as well as bypass flows (such as incorporating risks associated with artificial drainage), will enable assessment of risks of such contaminants that are typically transported as particulate forms.

[20] An Agent is a National Institute of Water and Atmospheric Research (NIWA) Virtual Climate Station Network location in an approximate 5x5 kilometre grid across New Zealand in which daily weather is interpolated.

Functionality to support freshwater accounting systems

Nitrogen loss risk accounting in the catchment

Supporting the freshwater accounting of N loss was identified by stakeholders as a priority of the system's development needs. Catchment models with broadly assumed likely nitrogen losses are conventionally used for this purpose. However, such accounting systems for N losses need to reflect real data and be consistently applied nationwide. This will improve the functionality of decision support as well as continuous system improvement. To achieve this, several steps need to be taken.

Risks need to be calibrated against additional observed or trusted model results to evaluate and, where necessary, improve predictions from the tool. The purpose is to gain consistency and coherence between the tool's output (to land use activities) and more established evidence.

Given the APSIM simulation methodology used in this first iteration of the RIT, additional targeted work is needed to adapt the transport risk methodology to make it suitable to estimate nutrient losses (rather than just the risk of loss). With this additional work, the above process may be able to produce sufficiently nuanced and trusted risks (eg, threshold, probability) that can be aligned more directly to loss. These improved loss risks could be accounted for in a catchment, or inform catchment-modelling processes in a way currently unsuitable for the RIT.

The above process would require collation and establishment of more evidence. This may include generation of targeted evaluative monitoring for locations where a modified RIT (eg, version 2) is applied to supplement information already collated. Another approach could be to obtain or create additional trusted modelled evidence in a form of simulations from trusted farm-scale models. These will enable a comparison and refinement of the risk at farm scale.

If the modified and improved RIT framework can establish an accounting capability, it can add more data to the evidence base, leading to a spiral of improvements by enabling a comparison and refinement of the risks at catchment scale.

References

Ajmal M, Waseem M, Kim D, Kim T-W. 2020. A pragmatic slope-adjusted curve number model to reduce uncertainty in predicting flood runoff from steep watersheds. *Water* 12(5): 1469.

Benavidez R, Jackson B, Maxwell D, Norton K. 2018. A review of the (Revised) Universal Soil Loss Equation ((R)USLE): With a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences* 22(11): 6059–6086.

Carey PL, Drewry JJ, Muirhead RW, Monaghan RM. 2004. Potential for nutrient and faecal bacteria losses from a dairy pasture underborder-dyke irrigation: A case study. *Proceedings of the New Zealand Grassland Association* 66: 141–149.

David WP. 1988. *Soil and Water Conservation Planning: Policy Issues and Recommendations*. Philippine Institute for Development Studies.

Donovan M. 2022. Modelling soil loss from surface erosion at high-resolution to better understand sources and drivers across land uses and catchments: A national-scale assessment of Aotearoa, New Zealand. *Environmental Modelling & Software* 147: 105228.

Hedley C, Yule I, Tuohy M, Vogeler I. 2009. Key performance indicators for variable rate irrigation implementation on variable soils. In: *2009 ASABE Annual International Meeting*. St Joseph, MI: American Society of Agricultural and Biological Engineers. Paper Number: 096372.

Hoffmann MP, Isselstein J, Rötter RP, Kayser M. 2018. Nitrogen management in crop rotations after the break-up of grassland: Insights from modelling. *Agriculture, Ecosystems & Environment* 259: 28–44.

Houlbrooke D, Carey P, Williams R. 2008. Management practices to minimise wipe-off losses from border-dyke irrigated land. In: LD Currie and LJ Yates (eds) *Carbon and nutrient management in agriculture*. Palmerston North: Fertilizer and Lime Research Centre, Massey University.

Klik A, Haas K, Dvorackova A, Fuller IC. 2015. Spatial and temporal distribution of rainfall erosivity in New Zealand. *Soil Research* 53(7): 815–825.

Lal M, Mishra SK, Pandey A. 2015. Physical verification of the effect of land features and antecedent moisture on runoff curve number. *CATENA* 133: 318–327.

McDowell RW, Cox N, Snelder TH. 2017. Assessing the yield and load of contaminants with stream order: Would policy requiring livestock to be fenced out of high-order streams decrease catchment contaminant loads? *Journal of Environmental Quality* 46(5): 1038–1047.

Monaghan RM, Paton RJ, Smith LC, Binet C. 2000. Nutrient losses in drainage and surface runoff from a cattle-grazed pasture in Southland. *Proceedings of the New Zealand Grassland Association* 62: 99–104.

Morgan RPC. 2009. *Soil Erosion and Conservation*. 3rd Edition. Hoboken, NJ: John Wiley & Sons.

Panagos P, Borrelli P, Meusburger K, Yu B, Klik A, Jae Lim K, Yang JE, Ni J, Miao C, Chattopadhyay N, Sadeghi SH, Hazbavi Z, Zabihi M, Larionov GA, Krasnov SF, Gorobets AV, Levi Y, Erpul G, Birkel C, Hoyos N, Naipal V, Oliveira PTS, Bonilla CA, Meddi M, Nel W, Al Dashti H, Boni M, Diodato N, Van Oost K, Nearing M, Ballabio C. 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Scientific Reports* 7(1): 4175.

Sharma I, Mishra SK, Pandey A. 2022. Can slope adjusted Curve Number models compensate runoff underestimation in steep watersheds?: A study over experimental plots in India. *Physics and Chemistry of the Earth, Parts A/B/C* 127: 103185.

Silva RG, Cameron KC, Di HJ, Hendry T. 1999. A lysimeter study of the impact of cow urine, dairy shed euent, and nitrogen fertiliser on nitrate leaching. *Soil Research* 37(2): 357–370.

Williams JR, Kannan N, Wang X, Santhi C, Arnold JG. 2012. Evolution of the SCS runoff curve number method and its application to continuous runoff simulation. *Journal of Hydrologic Engineering* 17(11): 1221–1229.

Appendix H: Review process

RW McDowell[1,2], VO Snow[2], BM Jackson[3,4], R Tamepo[5], S Trolove[6], K Muraoka[7], Tanya Cornwell[7], Tapuwa Marapara[7]

[1] *Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand*

[2] *AgResearch, Lincoln Science Centre, Lincoln, New Zealand*

[3] *BEEA Limited, Wellington, New Zealand*

[4] *Victoria University of Wellington, Wellington, New Zealand*

[5] *Scion Research, Rotorua, New Zealand*

[6] *Plant and Food Research, Havelock North, New Zealand*

[7] *Ministry for the Environment, Wellington, New Zealand*

Preamble

The peer review process was completed in two stages. Stage one involved individual feedback from each of the four peer reviewers in response to nine questions (below).

1. Is the purpose for the development of the RIT clearly stated and understood?
2. Are the assumptions upon which the RIT has been developed reasonable?
3. Given the availability of data and the one-year time constraint in developing the RIT, are the input data for the configuration, calibration, and validation suitable for simple risk index?
4. Is the general concept for calculating risk, outlined in figure 1 (in the Overview document), consistent with your understanding of what a simple risk index should look like for estimating N loss from farmland?
5. Are the sources of N inputs for runoff and leaching correct?
6. Is the separation and handling of mitigations (source mitigations and modifiers) appropriate given the amount of data available?
7. What do you consider are the major limitations and uncertainties of the RIT as a simple risk index?
8. Do you have any further recommendations to improve the RIT as a simple risk index?
9. Are there any other factors that affect the ability of the RIT to meet the purpose and objectives articulated?

The second stage allowed for the reviewers to discuss their thoughts with the Technical Working Group and distil a final report with recommendations. This appendix contains the final report of the reviewers and a brief response by the Ministry or Technical Working Group to the reviewers' recommendations. Correspondence from the initial reviews is not included because many of the recommendations were attended to.

The final recommendations from the review panel are outlined below. These recommendations were discussed with the Ministry and the Technical Working group, and a decision made regarding their relevance and adoption. The Ministry's brief outline of this decision, informed by the Technical Working Group, is given below (in red).

1. Define a pathway for development and adoption of the Risk Index Tool.
    a. The Ministry is designing a product development roadmap and subsequent business case for the next iteration of the Risk Index Tool. The use of the RIT is not mandatory, It is therefore difficult to determine a timeline for adoption.
2. Develop a communication strategy for the Risk Index Tool.
    a. The Ministry has a Risk Index Tool Communication Plan in alignment with the current communication strategy. This Communication Plan is a living document and will be updated as required.
3. Map the needs and objectives of end users to different nutrient management tools, including the Risk Index Tool.
    a. The Parliamentary Commissioner for Environment (PCE) is currently undertaking a project that investigates the use of nutrient management tools in New Zealand. This project will reveal how nutrient management tools in New Zealand align with the needs and objectives of end users align. This project is expected to be completed at the end of 2023.

       Regarding the RIT, MfE engaged early on in the project with councils, industry, and Māori to determine their needs for a new risk index tool. The Ministry analysed and prioritised the various needs to refine the scope and delivery timeframes of the RIT.

       A Council Reference Group was established and engaged with along the RIT development process to ensure the RIT was developed in a manner that was fit for purpose. Additionally, during the User Acceptance Testing (UAT) process, end users such as Māori collective landowners, farmers, growers, and farming consultants will provide their feedback on whether the RIT meets specific requirements.

       The Ministry will be seeking feedback from end users on the RIT after release.
4. Form an End User Technical and Advisory Group to support rollout of the Risk Index Tool.
    a. The Ministry considers there are two elements to the context provided for this recommendation. First is regarding the separate testing of the RIT model and the RIT platform. The Ministry established a Technical Working Group to develop and test the RIT model. Additionally, members of the Ministry's Council Reference Group as well as farmers, growers and consultants will test the specific platform functionality requirements of the RIT. Second is regarding ongoing user support as a part of the RIT rollout. The Ministry is exploring options for RIT model support, and separately RIT platform support services.
5. Develop an iterative process of development and testing of the Risk Index Tool.
    a. The Ministry established and engaged with a Council Reference Group throughout the development of the RIT. This engagement provided the opportunity for the Council Reference Group to provide feedback on tool's appropriate use to support and assist councils in the achievement of freshwater regulatory outcomes. Additionally, end users, including councils, Māori collective landowners, farmers, farm consultants are involved in the User Acceptance Testing of the RIT to provide feedback on the tool's specific requirements.

       There is scope to engage industry in future iterations.
6. Communicate when and which attributes will be included in future Risk Index Tool iterations.

   a. The Ministry is developing a business case for the next iteration of the Risk Index Tool, including the consideration of additional contaminants and indicative timelines. If approved, this information will be incorporated into the RIT Communication Plan.

7. Adopt professional standards and protocols for managing the Risk Index Tool.

   a. We consider there are two elements in managing the RIT model. The scientific model itself, and the RIT platform. The Ministry will be 'owning' the Risk Index Tool in the short term. Options are being considered for how the Ministry will roll out, maintain, disseminate, and update the scientific model in alignment user needs and with best practices. The Ministry is also considering how to support, maintain and update the RIT platform itself in alignment with best practices. These elements will be key points when considering medium- and long-term ownership of the RIT.

8. Develop and communicate Risk Index Tool performance criteria.

   a. The Technical Working Group has outlined that the derivation of performance metrics like root mean square error cannot be assessed on non-parametric relationship derived from ranked data. However, they agree that additional work is scheduled to determine if the risk of nitrogen loss is being over or underestimated for shallow rooting crops.

9. Consider a typology-based approach for nutrient losses from cropping systems.

   a. A farm type (typology) approach was considered in an early version of the index. The risk index and typology approaches are incompatible and provide different outputs. For example, a farm type is based on averages and covers large areas, which minimises the farmer's ability to manage risk. Furthermore, farm types are unlikely to be representative of the diversity of, for example, vegetable and cropping systems. However, in addition to recommendation 8, and as noted in Appendix VII, we will explore more tractable methods for vegetable and arable farmers to input data in future iterations of the RIT.

10. Provide greater differentiation of excreta losses across animal types.

    a. We rely on the data, processes, and governance in the New Zealand Agricultural Inventory for N excretion. This is robust and publicly available.

11. Provide additional documentation on how models, model inputs and model outputs are embedded in the Risk Index Tool.

    a. Will recognise that much of what is requested will be covered by a separate publication on how transport risk was derived (Snow et al. In prep). Sensitivity of inputs to the estimated risks will be demonstrated in the case studies and software testing, conducted after this review but before release of the RIT.

12. Conduct further validation testing of the Risk Index Tool for a range of case studies.

    a. We interpreted this as sensibility testing, which is to say that if the tool is changed then the risk moves in the direction expected. This will be done as part of the case study testing after this review but before the RIT is released.

13. Address data gaps, deficiencies, and provenance.

    a. We have investigated data gaps and deficiencies. In terms of representativeness, the largest data gap is coverage of whenua Māori (especially hill country). However, as noted in the Overview document and Appendix VI we have no data to say that better coverage data would harm or improve the accuracy of the risk estimates.

Review of the contaminant discharge Risk Index Tool (RIT) for on-farm nutrient management

Report prepared by the Peer Review Panel:

David P. Hamilton[1], (RA) Tony Petch[2], Sharn Hainsworth[3], Steve M. Thomas[4]

1 *Australian Rivers Institute, Griffith University, Brisbane, Australia*

2 *Tony Petch Consulting Ltd*

3 *Land Use Capability Assessments Ltd*

4 *Plant and Food Research Limited, Lincoln*

For:

Ministry for the Environment

NZ Government

June 2023

Griffith UNIVERSITY Queensland, Australia

Approvals

The authors of this report provide approval for the release of the final submitted version of the report to the Ministry for the Environment. Author Name: David P. Hamilton Author Name: RA (Tony) Petch Author Name: Sharn Bernard Hainsworth Author Name: Steve Thomas

Author electronic contact details

✉ david.p.hamilton@griffith.edu.au

https://www.griffith.edu.au/australian-rivers-institute

✉ tony@tonypetch.kiwi

✉ sharn@lucmaps.co.nz

✉ Steve.Thomas@plantandfood.co.nz

Report citation

Hamilton DP, Petch RA, Hainsworth SB, Thomas SM. 2023. *Review of the contaminant discharge Risk Index Tool (RIT) for on-farm nutrient management*. Report to the Ministry for the Environment. Griffith University Report 2023/008.

Disclaimer

While reasonable efforts have been made to ensure that the contents of this document are factually correct, the authors do not accept any responsibility for the accuracy or completeness of the contents and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this report.

Executive Summary

A Peer Review Panel of four independent experts was established by the Ministry for the Environment in 2022 to provide an assessment of the suitability of a Risk Index Tool for estimating the risk of nitrogen loss at farm scale in New Zealand. The Panel was asked to evaluate Phase one of the Risk Index Tool and to provide recommendations that could be used to support the rollout and adoption of the Risk Index Tool for achieving freshwater outcomes desired under the National Policy Statement for Freshwater Management (2020). The Peer Review Panel made the following 13 recommendations:

1. Define a pathway for development and adoption of the Risk Index Tool.
2. Develop a communication strategy for the Risk Index Tool.
3. Map the needs and objectives of end users to different nutrient management tools, including the Risk Index Tool.
4. Form an End User Technical and Advisory Group to support rollout of the Risk Index Tool.
5. Develop an iterative process of development and testing of the Risk Index Tool.
6. Communicate when and which attributes will be included in future Risk Index Tool iterations.
7. Adopt professional standards and protocols for managing the Risk Index Tool.
8. Develop and communicate Risk Index Tool performance criteria.
9. Consider a typology-based approach for nutrient losses from cropping systems.
10. Provide greater differentiation of excreta losses across animal types.
11. Provide additional documentation on how models, model inputs and model outputs are embedded in the Risk Index Tool.
12. Conduct further validation testing of the Risk Index Tool for a range of case studies.
13. Address data gaps, deficiencies, and provenance.

Addressing these recommendations with adequate support and budget will provide a basis for the adoption of the Risk Index Tool to guide Farm Management Tools.

Contents

1. Introduction

1.1 Background

A Peer Review Panel (the 'Panel') was established by the Ministry for the Environment (MfE) in 2022 to provide an assessment of the suitability of a Risk Index Tool (RIT) for estimating the risk of farm-level nitrogen loss. The Panel was asked to evaluate Phase one of the RIT. Phase one involves its proof of concept as a tool for councils to understand the risks of total nitrogen (N) losses.

A review of the farm model OVERSEER in 2018[21] led to government acting[22] on recommendations from an External Advisory Group to create a new risk index tool (RIT) to identify land areas at high risk of nitrogen loss that could impact on freshwater outcomes desired under the National Policy Statement for Freshwater Management (NPS-FM 2020)[23].

In 2021 the Government committed to making the tool available to regional councils in time for them to notify changes to regional policy statements and plans to give effect to the NPS-FM 2020. The RIT is designed to provide an evidence base for nitrogen losses at farm scale from natural and anthropogenic processes. The RIT calculation involved consideration of the farm system type, farm practices and inputs, and biophysical characteristics such as soil, slope, and climate. Total N losses from diffuse sources are the focus of the first iteration of the RIT, with consideration being given after Phase 1 to other diffuse contaminants (e.g., phosphorus, sediment, and *Escherichia coli*).

The Ministry for the Environment (MfE) is leading the development of the RIT; supported by input from an expert panel of scientists and by the Our Land and Water National Science

Challenge[24]. The RIT is not mandated but councils may choose to use the RIT to support farm consenting activities and guide Freshwater Farm Plans[25]. The Ministry for the Environment will provide guidance in implementation of the RIT for consideration of its potential use as a regulatory decision-support tool, including information on the operational use of the tool.

With a background of discontinuation of OVERSEER as a tool for councils to exert regulatory control on farm activities leading to diffuse pollution, and with the rapid development of the RIT, the Panel was established to provide external peer review of the RIT through its development in Phase One. The Panel has reviewed documentation outlining the science and technical approach used to derive risk scores for N in the first instance (i.e., Phase One). The Panel was not asked to review the sensibility or accuracy of outputs from the RIT, or the draft Phase one implementation guidance document, although they did provide some comments

---

[21] Parliamentary Commissioner for the Environment. 2018. Overseer and regulatory oversight: Models, uncertainty and cleaning up our waterways. Parliamentary Commissioner for the Environment, Wellington. URL: https://pce.parliament.nz/media/tv0la52o/overseer-and-regulatory-oversight-final-report-web.pdf

[22] Ministry for the Environment. 2021. Government response to the findings of the Overseer peer review report, 2021. Ministry for the Environment, Wellington. URL: https://environment.govt.nz/assets/publications/government-response-tohttps://environment.govt.nz/assets/publications/government-response-to-the-findings-of-the-overseer-peer-review-report-final-.pdfthe-findings-of-the-overseer-peer-review-report-final-.pdf

[23] Ministry for the Environment (2023). National Polity Statement for Freshwater Management. Ministry for the Environment, Wellington. URL: https://environment.govt.nz/assets/publications/National-Policy-Statement-forFreshwater-Management-2020.pdf

[24] The Our Land and Water National Science Challenge provided APSIM modelling of biophysical data that underpins the RIT risk calculation service. URL: https://wwo.landcareresearch.co.nz/

[25] Freshwater Farm Management Plans. See: https://environment.govt.nz/acts-and-regulations/freshwaterimplementation-guidance/freshwater-farm-plans/

when this was provided to them. The Panel review of the RIT has involved engagement with the RIT Technical Working Group and the Ministry for the Environment.

1.2 Panel composition

The Panel comprises four members with extensive experience and expertise across different areas relating to the RIT subject matter:

- Professor David Hamilton (Australian Rivers Institute, Griffith University, Brisbane, Australia) (Panel lead)
- Dr Tony Petch (Tony Petch Consulting Limited, Hamilton)
- Sharn Hainsworth MSc (Land Use Capability Assessments Limited, Papaioea - Palmerston North)
- Dr Steve Thomas (The New Zealand Institute for Plant and Food Research Limited, Christchurch)

1.3 Background

The scope of the peer review by the Panel includes evaluation of the scientific logic for the RIT, technical calculations supporting it, evaluation of the nitrogen sources, consideration of mitigation actions described in the RIT, and evaluation of the suitability of the data. The scope of the Panel review does not extend to regulatory or non-regulatory considerations of the RIT, or technical elements outlined in Appendix VII of the ancillary documentation.

The Ministry for the Environment provided nine questions to serve as the basis for the peer review (see preamble)

1.4 Review steps

The Peer Review Panel completed their independent reviews of the RIT and responded to the review questions in late 2022. The review process was halted at the request of MFE while errors in the RIT were rectified. The review recommenced in April 2023 to incorporate the Panel's recommendations into the RIT development process. This expedited development of the RIT and for the science team to take early advantage of the Peer Review Panel's recommendations. Further meetings were held in May 2023 with MFE staff to develop the framework of the Peer Review Panel's final report.

2. Peer Review Panel Findings

The Peer Review Panel met on three occasions and was asked to provide individual comments in December 2022 on the RIT documentation provided to the Panel. The Appendices include comments from the Panel on the RIT documentation and a record of minutes compiled by MfE. These findings are supplemented by comments from the science team overseeing development of the RIT. The Peer Review Panel finally elected to keep the records of the meeting minutes as appendices in this report because they provide a potentially important record of what the Panel debated and how consensus was reached. The Appendices are:

1. Ministry for the Environment notes from RIT Peer review meeting 3 (10 May 2023)
2. Ministry for the Environment notes from RIT Peer review meeting 2 (3 May 2023)
3. Key points arising from RIT Peer review meeting 1 (26 April 2023)
4. Ministry for the Environment notes from RIT Peer review meeting 1 (26 April 2023)
5. Response to Reviewers' comments (11 May 2023)

The Panel found that as a first iteration of the RIT, the purpose of the model is clearly stated and understood. The audience for the model includes Kaitiaki of Whenua Māori[26], Regional Councils and Unitary Authorities, farm advisors and rural professionals, catchment groups, and farmers. There are, not unexpectedly at this stage, some deficiencies in the RIT and these likely relate to the limited time available for its development, data availability, spatial discrimination, and availability of expertise for such an ambitious undertaking. This point addresses the question posed by the MfE of whether the separation and handling of mitigations and their parameterisation was appropriate for the level of available data.

Simplifications could be used to estimate the risk from arable and vegetable crops and produce a small list of types to represent the range of copping rotations. A typology approach for these systems may avoid excessive parameterisation that would be beyond the capabilities of many end users, including their ability for field validation of the extensive vegetable crop parameter set. Further explanatory detail could be built into documentation of how the Curve numbers, APSIM and RUSLE applications were parameterised and used to generate the base risk layer. Similarly, more detailed documentation on the granularity, reliability or uncertainty of the spatial climate, soil and slope data used to generate the RIT could be produced. Greater transparency through detailed documentation and explanation could lead to greater confidence in using the risk predictions and in understanding where risk estimates may be more or less reliable due to the underlying assumptions for these models. Extensive documentation of these models is provided external to the RIT, but the user documentation should nevertheless provide the concepts, objectives, and justification for geospatially referenced models in the RIT. The Panel was encouraged by the response by the modellers to better tailor excreta outputs across pastoral animal classes as the RIT is developed and, because of its importance, strongly encourages the modellers to increase the granularity of information related to pastoral animal excreta.

---

[26] We note the different scale and nature of Whenua Māori (mostly small and LUC Class 6-8 and extensive land use, but also some with intensive land use, and some multiply owned. Some Whenua Māori units are administered by Te Tumu Paeroa the Māori Trustee, individual trusts or incorporations, aggregated, collectives, whenua gifted back to Post Treaty Settlement Government Entities (PTSGEs), whenua purchased PTSGEs, governed under Te Ture Whenua Act (2020). Multiple views are held on how the land should be managed i.e., different ownership structures, governance arrangements and histories/states of business development. The key is Māori governors of whenua are kaitiaki (caretakers/guardians), with a Te Ao Māori worldview that is focused on long-term outcomes, and holistic and multi-factorial values-based decision-making, with governance knowing the whenua to promote kaitiakitanga.

The integration of S-map with the Fundamental Soil Layer (FSL) is problematic in the current RIT as it attempts to match datasets of different information resolution and data quality. The low resolution of the FSL could have implications on hill country assessments; potentially influencing Whenua Māori who may own parcels of land that are marginal for pastoral agriculture (Land Use Capability Classes 6-8). In general, data availability for Whenua Māori and the different scale and nature of Whenua Māori (some small, others very large, some privately owned, others managed by trusts and incorporations, and the multiple views held on how the land should be managed) necessitate careful rollout of the RIT across sectors. It is essential to avoid any real or perceived views that the RIT selectively biases certain land holders, particularly before the model is used in decision-making or regulatory contexts.

At a high level, the factors that will most affect the ability of the RIT for meeting its designated purpose and objectives to support freshwater outcomes desired under the National Policy Statement for Freshwater Management (NPS-FM 2020) include:

- *Intended rollout and timelines:* the Panel has some concerns whether a partially supported approach will meet the ultimate desired goals of the RIT. Strong support is required for any future versions of the RIT through leadership and direction from the MfE including support of the modellers, custodianship of the model, and use of a Technical Advisory and End User’s Group to provide rigorous testing prior to implementing and vesting the model with end users. Timelines need to be carefully staged to support the inclusion of additional state variables in the model (e.g., phosphorus, *E. coli*), feedback from the proposed Technical Advisory Group and end users, and other model additionalities (e.g., typologies for cropping).
- *Test cases:* The current demonstration of nitrogen leaching and runoff in the RIT is an idealised test case. An inventory of cases needs to be constructed that spans different farm settings and operations, climates and geologies.
- *Transparency about model processes, accuracy, and limitations*: The Panel was impressed by the desire of the modellers to make all aspects of the model as transparent as possible. It will be important to guide end users about the granularity and resolution of data input required from end users versus the default settings. Open model settings should support research leverage as other individuals and research organisations become involved in development and application of the model. A recommendation is made below on operational aspects that aim to support this transparency.
- *Map farm models to intended objectives of their application:* This process is not contingent only on the modellers but should be supported by the MfE and the proposed Technical Advisory and End User’s Group. It is important that end users understand if the RIT is fit for purpose to meet their intended farm plan objectives in support of the NPS-FM (2020) and differentiate its intended use from that of OVERSEER.

3. Peer Review Panel Recommendations

The Peer Review Panel has made 13 recommendations as follows:

1. Define a pathway for development and adoption of the RIT

The Peer Review Panel identified a need for a structured timeline on which the RIT would be developed and adopted. Clear and early advice on this matter is needed because kaitiaki, Regional and Unitary Authorities, rural professionals, and farmers will need certainty that the tool will be supported through several regional plan cycles. Timelines need to be carefully managed for model development, taking into consideration the time required for feedback from end users and responses from the developers.

2. Develop a communication strategy for the RIT

Managing expectations of end users will be through the testing and implementation phase of the RIT. As with any complex model, there will be errors and inconsistencies, and management of expectations will be critical through iterative phases of model development and testing (see also Recommendations 4 and 5). A good communication strategy that has high levels of transparency will help to build confidence in the RIT (see also Recommendation 6) and ensure longevity of the model. Communication guidance documents should clearly state RIT's use as a decision support tool which uses on-farm management inputs, mitigations and modifiers to test whether a landowner has met the conditions of their consent. Plain English explanations would also be useful to communicate how different resolutions of data (e.g., soils, climate) may affect the performance of the RIT.

3. Map the needs and objectives of end users to different nutrient management tools, including the RIT

The Panel considered that it would be valuable to conduct a mapping exercise to link the needs and objectives of end users to various available farm system and nutrient management models. No model, including the RIT, will satisfy all the needs of end users for nutrient management. In addition to the RIT, the models considered might include the Land Use Capability Indicator (LUCI), Overseer, MitAgator, and nutrient management tools being developed for the vegetable industry (MPI-funded Sustainable Vegetable Systems programme). The mapping will help with managing the expectations of end users (see Recommendation 2) and avoid disappointment when a model does not align with addressing the questions raised by end users. Project planning can be adopted to provide clarity on the objectives of applications of the RIT, the intended use of the model, and the ability of the model to satisfy the project objectives (see also Recommendation 2). The mapping is important for deciding whether to use the RIT or if another model may be better suited to the requirements of the end user. It may also be important for taking catchment risk data from the RIT and uploading it into another model which may address a different goal (e.g., catchment-scale nutrient losses), including informing catchment management conversations.

4. Form an End User Technical and Advisory Group to support rollout of the RIT

MfE mentioned to the Panel that it intended to form a Technical Working Group to assist with testing of the final build of the model. The Panel strongly supports this approach as it is critical that the model can be used largely free of error and bugs, aligns model inputs with the format of current databases, and outputs can be received both in raw and synthesised form, as well as potentially linking to other nutrient management tools (see Recommendation 3). The End User Technical and Advisory Group could undertake model runs and feedback outcomes to the RIT modellers in a 'safe' environment without expectations about model performance, errors, or bugs. This group could have an important role in ensuring that end users were not immediately uncovering errors and difficulties that could lead to widespread loss of confidence in the RIT.

5. Develop an iterative process of development and testing of the RIT

It is critical that the RIT is 'fit for purpose', i.e., that its results make sense and that they are reproducible, as well as being aligned with what is required by end users. The end users need to be involved throughout this process and to feedback on the usability and utility of the RIT. This recommendation sits alongside Recommendation 4 of forming an End User Technical and Advisory Group to support rigour of model development and testing.

6. Communicate when and which attributes will be included in future RIT iterations

The timeline for model development (see also Recommendation 1) should be clear about when different attributes would be adopted into the model, based on a prioritisation process (e.g., for *E. coli*, phosphorus, and other attributes). The Peer Review Panel commented in its meetings that it would be preferable to include all major agricultural contaminants in rollouts of the RIT but accepted a sequential phasing was likely, in a recommended priority of sediment, phosphorus, and *E. coli*.

7. Adopt professional standards and protocols for managing the model

The Peer Review Panel recommends that MfE considers how it will roll out, maintain, and disseminate the model. Standards for good model practice are available for multiple other model systems (e.g., groundwater and climate) and can be adopted for the RIT to support a high level of professionalism in the development and rollout process. Importantly, MfE should require high levels of transparency related to all aspects of the modelling (see also Recommendation 2 which relates to communication about the model). This process could be undertaken through comprehensive reports and manuals that include model documentation, and programmer and user guides of the technical content.

The process of handling and maintaining a model requires high levels of expertise and adequate personnel time. In adopting professional standards, MfE may wish to seek specialist support to maintain the model code and documentation, including commissioning a third party for this purpose. Maintaining the model will require versioning control and being clear about the frequency of new model versions and differences among versions, including explanation of the reasons for differences. This process is critical for use of the model for its intended regulatory purpose.

8. Develop and communicate model performance criteria

Model performance criteria include detailed quantitative statistical information (percentage of variation explained, root mean square error, etc.) suitable for a technical audience and summary information to communicate performance in qualitative terms to a broad audience. Other analyses include uncertainty and error so that end users understand the limits of the model predictions and can make their own judgements about prioritising the implementation of actions based on levels of uncertainty in the model outputs. Under this recommendation, guidance could be provided to end users on how quality of input data affects model outputs.

9. Consider a typology-based approach for nutrient losses from cropping systems

As mentioned in Section 2, current methods in the RIT to estimate the risk from arable and vegetable crops and common rotations are complex and may place excessive burden on this group of end users A typology-based approach and good documentation on the range of nutrient losses under these typologies could help reduce the burden of input data. Included in this reassessment is any industry exemptions from consent requirements of horticultural systems.

10. Provide greater differentiation of excreta losses across animal types

The Panel recommends greater differentiation of excreta-related nutrient losses across pastoral animal classes as this is a major source of contaminant inputs to freshwater. The Panel had noted that the modellers were responsive to this suggestion.

11. Provide additional documentation on how models, model inputs and model outputs are embedded in the RIT

Curve numbers, APSIM and RUSLE models, modelled outputs, and spatial inputs of climate, soils and slopes are embedded in the RIT but much of the documentation of these models is external to it. The Peer Review Panel accepts that the detailed documentation on these models should continue to be external to the RIT but recommends that the connections of the RIT to these models is explicitly clear and that the purpose of embedding the models is documented in the RIT Implementation Guidance. Given the complexity of the APSIM model, the Panel recommends that there are detailed explanations of how APSIM was parameterised, how irrigation was managed and how curve numbers were used to estimate nitrogen losses. This information complements Recommendation 8 to document the model performance criteria.

12. Conduct further validation testing of the RIT for a range of case studies

This recommendation by the Peer Review Panel extends beyond testing the accuracy of the model (see Recommendation 8). Similar to Recommendation 7, the RIT needs to be validated across a range of farming systems and operations, as well as climates and geologies. Case studies need to be built up and analysed to provide a basis for improving model performance (also related to Recommendation 13 as case studies will help to identify model deficiencies.

13. Address data gaps, deficiencies, and provenance

The Panel deliberated on what could be done in the RIT to assure data quality (e.g., data used for curve numbers, FSL, and S-map). While the RIT provides useful information on how data should be formatted, it does not include information that could support assessments by users of the quality of the data. A process could be put in so that users could provide feedback to the data custodian about where data might be in dispute or need to be updated.

Appendix 1: Ministry for the Environment notes from RIT Peer review meeting 3 (10 May 2023)

The Ministry for the Environment provided notes from a meeting of the Peer Review Panel on 10 May 2023. The notes are provided in this Appendix.

RIT Peer review meeting – Notes

10 May 2023; 09:00-10:00 Teams online

Attendees	
Attendees:	Peer review panel (Panel): David Hamilton, Sharn Hainsworth, Tony Petch, Steve Thomas MfE support
Apologies:	None
Guests:	None

Purpose: to get David across the previous meeting (as he as an apology) and to discuss the draft final report provided by David via email on Wednesday, 10 May 2023.

Topic	Notes
Notes from previous meetings (n=2)	MfE advised that amends have been received from a Technical Working Group (TWG) member. These amendments will be incorporated, and a new draft will be sent. A Panel member advised they have amendments to the notes taken during the 3 May 2023 meeting. MfE requested for the amendment to be sent through. The Panel queried if MfE supports the Panel's suggested alternative cropping systems typology approach. MfE advised actions, such as seeking support for the alternative approach, need to be considered and prioritised. Prioritised not only in terms of RIT development, but prioritised within the context of MfE priorities.
Meeting notes as appendices	Reflecting on the draft outline of the final report, the Panel queries if MfE would be okay with including all meeting notes as appendices. MfE advised in-principle support, but would need to seek an official position. Subsequently, a Panel member challenged the inclusion stating that the meeting notes are officially recorded and held at MfE; that omitting them from the final science peer review repot will reduce its length. This member proposed to omit the meeting notes. The Panel agreed to omit the meeting notes from the final science peer-review report. The Panel agreed the appendix to retain are:

	• Key points arising from RIT peer review meeting • Response to Reviewer's comments.
Draft report & Chapter 2: Peer review panel findings recommendations	Prior to discussing the outline of the draft report, David queried if there was anything he needed to be across from the previous meeting (held 3 May 2023). The rest of the Panel member referred to the notes. <u>Section 2.1: Background</u> After a high-level review, the Panel **agreed** they are satisfied with the background outline. <u>Section 2.2: Main findings</u> A Panel member commented they are pleased with the depth and breadth of experts involved in the development of the RIT; that this allowed multiple views to be consider and incorporated into the development. It was also noted the transparency of RIT development is 'pretty good' and that this will help with confidence. The Panel queried if the code of the RIT will be made publicly available. MfE advised this is something they are currently discussing, but it is still undetermined at this time. A follow-on question from the Panel was around who is going to control the code - commenting that version control is going to be critical, especially if the RIT is used in regulation. MfE advised that they will own and control the RIT in the interim. The Panel recommended for MfE to consult experts on stewardship (especially for underpinning data and updates to data) and version control. With each version update, release notes should be made public.
Stakeholders	The Panel discussed RIT stakeholders, noting the RIT will affect various users. It was also queried how future development would impact those users – that if improvements are managed well, this will increase trust from users. The Panel circled back on a previous conversation around their recommendation for MfE to map out the roles and functions of other various nutrient management tools. The Panel reiterated the map/matrix would be useful for users to identify what tool (eg, RIT, Overseer, Soil Plant Atmosphere System Model (SPASMO), APSIM, etc) would be appropriate for use given a particular situation (eg, time, spatial scales, regulatory, non-regulatory, etc). It was though that this may be most appropriate to sit in the Implementation Guidance.
Overseer redevelopment	A Panel member queried what was happening with the Overseer redevelopment and how MfE is involved. MfE gave an update, advising that it is led the Ministry for Primary Industries and that it is to RIT development. It was noted that the Overseer model will still be used.

Draft report	MfE redirected to Panel to discuss the draft science peer review report. <u>2.4 Recommendations</u>: *A recommendation to conduct further validation testing for a range of case studies on the RIT* This recommendation ties into a discussion from the first meeting regarding difference vegetable crops, rotation rate, and iwi land and associated land parcels. The Panel questioned at what point should a diversity of case studies be included. The Panel agreed that the RIT development pathway would be important to develop such case studies. A staged approach, one that aligns with the RIT development pathway, for case study development was suggested and agreed to by the Panel. The Panel considers that their recommendation is reliant on MfE's proposed RIT development pathway. The Panel also recommended the pathway to be generalised and principles based. It was queried if the other draft recommendations in the draft science peer review report need further elaboration, or if anything needed to be added. There was no further detailed conversation; however, the N-spike approach was briefly discussed. The Panel agreed that the content around N-spike in the RIT technical documentation was not comprehensive enough, including references, to substantiate the chosen approach. The Panel acknowledged that the TWG included in the technical documents that further testing of N-spike was needed to determine if it was appropriate for non-pasture systems. MfE advised of the receipt of an email from Dr Snow from the TWG and that they would review the email to see if it is in regard to the Panel's irrigation concerns. If so, they would provide the response to the Panel.
Future containment/s	The Panel asked if MfE had thoughts on future contaminants. MfE advised sediment is being discussed, but there have no confirmations or commitments. MfE enquired if the current RIT design is suitable to include sediment. If not, how would a redesign to include sediment impact estimates of N-loss? A Panel discussed RUSLE and the curve numbers in the RIT – agreeing that they are appropriate for the inclusion of sediment, as well as phosphorus, and *E. coli*.
Next steps	• All meeting notes to be sent to the Panel • MfE to provide an RIT development pathway • As a reminder, each Panel member to provide about 10 key points on the RIT (action from first meeting held on 26 April),

Appendix 2: Ministry for the Environment notes from RIT Peer review meeting 2 (3 May 2023)

The Ministry for the Environment provided notes from a meeting of the Peer Review Panel on 3 May 2023. The notes are provided in this Appendix.

RIT Peer review meeting – Notes

3 May 2023; 12:30-14:30

Teams online

Attendees	
Attendees:	Peer review panel (Panel): Sharn Hainsworth, Tony Petch, Steve Thomas MfE support
Apologies:	David Hamilton
Guests:	None

Purpose: To further discuss any material issues in the science peer review of the Risk Index Tool (RIT) documentation.

MfE suggested the group also focus on how the current iteration of the RIT could be improved.

Topic	Notes
What does the customer want from the group?	The Panel wanted to ensure they are delivering to what the customer, being the Ministry for the Environment (MfE), would like from the group. It was noted that the previous meeting (held 26 April 2023) focused around the technical/science aspects of the RIT, and some comments around policy. The Panel agreed that it is important to be as transparent as possible. They considered they could focus on implementation and applicability of the RIT. It was mentioned that options may need to be developed for someone that determines the RIT is not applicable to their farming situation (eg, biophysical data not right for their farm). After a conversation around the acknowledgment The Panel agreed that in the RIT Overview document, it should be made clearer that the first iteration of the RIT is a first step / beginning of a journey. Need to be clear in into that the tool is first step – beginning of the journey. **ACTION**: MfE to ensure the message is clear in the Overview documentation that it is understood the first iteration was not going to be perfect.
Profession lay person - readers	The Panel had a short discussion regarding who would be likely read the technical documents. The following were considered as professional lay persons: councils and unitary authorities (those science-inclined, and

	those in policy), farm advisors and rural professionals, catchment groups/trusts. It was noted that the RIT is quite different from other tools used and it is important to get the various users across how it works. MfE advised that they are holding a session with councils on Friday (5 May). All regional councils were invited and so far, 11 councils have accepted the invitation. The Panel queried if those in positions at councils such as rural advisers or those in Freshwater Farm Plan groups were invited. MfE advised they we not familiar with the positions of those invited, that the list of names came from the MfE's Nutrient Management Tools Regional Sector Representative, Christine Robb. MfE was able to confirm a Rural Advisor accepted the meeting invitation. The Panel suggested it could be valuable to get research institutes across the RIT.
Early versions of tools	The Panel had a conversation around early versions of various tools and whether those early versions ever 'hit the mark'. It was acknowledged that first iterations of tools likely did not, and that tools would become 'better' (eg, reducing limitations from first or early iterations) with each iteration. The Panel also discussed that earlier versions of tools are often developed with a particular interest in mind – example being Overseer developed as a nutrient budgeting tool for optimised production – and that wider use of the tool is realised through continued development. The Panel queried what the RIT will do compared to Overseer, querying from what perspective has the RIT been developed. MfE advise the perspective freshwater improvement. The Panel reiterated the importance of including how the RIT differs from other tools.
What will the final science peer review report cover?	The Panel discussed the final science peer review report and what structure it should take. In this conversation, MfE reiterated that they wanted the Panel's opinion on whether the RIT, acknowledging gaps and limitations, is developed in a manner that is scientifically/technically sound, to credibly estimate the risk of nitrogen loss from land use. MfE advised they would also welcome any suggestions from the Panel on: o how the RIT could be improved o best use cases of the RIT. Regarding the structure of the final report, a Panel member referred to their email sent to the Panel 30 April 2023 where they outline their thoughts on the structure of the final report in his email (particularly point 2; copies below). *2 In my view, the report from the reviewers should be brief and cover the following general themes:* *a. Review panel and process.* *b. Comments on the general soundness of the approach and supporting details.* *c. Note the number of deficiencies inherent in the tool, for example owing to: time available to develop the tool, data availability, spatial discrimination, the methods to*

	estimate the risk from commercial vegetable crops and the common rotations used, data availability for Whenua Māori and the different scale and nature of Māori land holdings (some small, others very large, some privately owned, others managed by trusts and incorporations, and the multiple views held on how the land should be managed). *d. Note that the first iteration of the RIT is a 'working proof of concept' and given the time available its development and the data available it represents a plausible beginning and, with suitable caveats on its immediate use, it is suitable for release.* *e. In releasing the tool for use, the reviewers strongly recommend a clear and plausible pathway for development of the tool including the following critical elements (mine are given below), provided in the second iteration to be released within one year.* *The clarity of the tool's development pathway is important. I note MfE commented that continued investment in the RIT's development depended on its uptake, yet its uptake will depend on its development. Clear and early advice on this matter is needed because the councils, rural professionals and farmers will need certainty that the tool will be supported through several regional plan cycles.* *f. The guidance document should clearly state the tool's use as a decision support tool and its strengths and weakness in this role. I think the section 'Use as a decision support tool in a regulatory context' is well developed already. However, it could be amplified and note that the 'on-farm management inputs/mitigations/modifiers' are the matters that can be used to test whether a landowner has met the conditions of their consent rather than the risk number.* The Panel discussed implementation. MfE spoke to the two identified use cases for the RIT being: informing council consent process and risk assessments of Freshwater Farm Plans. The Panel agreed that a spatial resolution of risk would help guide users to understand different management requirements at different spaces and time. The Panel discussed how the RIT could feed into catchment management conversations. MfE advised that from a system development/technical standpoint, the RIT doesn't not have the functionality to download data; meaning catchment risk data could not then be uploaded into another platform or model for catchment modelling. This was acknowledged. It was agreed by all attendees that RIT output could inform catchment management conversations. The Panel queried where the RIT (ie, what is does, what is covered, etc) sits in comparison to other nutrient management tools such as Land Use Capability Indicator (LUCI), Overseer and MitAgator. The Panel

	recommends for MfE to develop a map or a matrix on where the RIT sits in context of other nutrient management tools. **ACTION**: MfE to develop a diagram making it clear where the RIT sits in context to other nutrient management tools. The Panel briefly touched on misuse. MfE advised that there is a section in the Implementation Guidance on inappropriate use. The Panel circled back on the structure of the final report. In principle, the Panel agreed the report should include: • **A recommendation to conduct further validation testing for a range of case studies on the RIT**. It was noted this is beyond accuracy testing. MfE mentioned the testing the Technical Working Group will be doing as a part of the testing of the final build – that they are developing test cases which they can then compare expected Nloss risk scores against RIT outputs. MfE queried if this was in line with what the Panel had in mind for the validation testing. The Panel advised it was not. • **Recommendation in a different approach to cropping systems (vegetable and arable, inclusive) – ie, the typology approach.** It was noted that this approach was amenable for commercial growers, but still applicable to relatively small operations, too. The Panel noted that they would need to be mindful of industry exemptions in legislation. MfE queried if the typology approach would provide enough flexibility for the variety of cropping systems in New Zealand. A Panel member advised they considered it would. This was not objected to by any other members. The Panel questioned what could materially be done in a few weeks to improve the RIT. MfE advised that the current development schedule does not allow for significant adjustments to the design of the RIT. Any adjustments, such as the new cropping approach, would be considered for a future iteration. **ACTION**: MfE to add consideration of a new cropping approach (ie, typology) to the future iterations' roadmap. • **Recommendation on addressing data gaps, deficiencies, and provenance.** The Panel deliberated what could be done in the RIT to assure data quality (eg, data used for curve numbers, S-map, etc). A Panel member mentioned they did not think the RIT technical documentation had enough technical explanation one some matters like RUSLE – that further elaboration is needed to be fully transparent. The Panel agreed that there should be enough technical explanation to enable a thorough understanding of what it all means. A Panel member raised a concern regarding the assumption that the N spike approach is appropriate for non-pasture systems. The Panel

	agreed they would like greater confidence for use of this method. The Panel recommended for the TWG to include further evidence to support this assumption, including additional references. **ACTION:** The TWG to provide evidence and references for the assumption that N spike approach is appropriate for non-pasture systems. MfE queried whether inclusion of methods (as recommended from during the 26 April meeting) would suffice. The Panel advised that methods would still need to be interpreted, that they were thinking more along the lines of, for example, a plain English explanation on what the different resolutions of different data sources (ie, metadata; eg, soil data, climate data) means to the user understands the relevance in how the RIT is to perform. • **A statement of the Panel's confidence in the RIT's approach for N-loss risk estimation, and acknowledgement of gaps/limitations.** • **A recommendation on the prioritisation of incorporating other contaminants.** The Panel discussed whether MfE should start early on to include other contaminants. It was acknowledged that users would prefer to have whole package RIT – one that considers all major contaminants (N, P, sediment, pathogens). The Panel proposed the following priority: sediment, phosphorus, *E. coli*.
Getting David across this meeting and notes	The Panel discussed how to get David across the discussion of this meeting. It was agreed for MfE to send a draft of these notes to the Panel by COP Friday, 5 May. This will allow the Panel to comment and amend so these notes are an accurate representation of the discussion. Thereafter, MfE could coordinate another Panel meeting, if required.

Recommended Actions (numbers carrying on from the 26 April meeting)

No.	Action	Responsibility
11	Ensure the message is clear in the Overview documentation that it is understood the first iteration was not going to be perfect.	MfE
12	Develop a diagram making it clear where the RIT sits in context to other nutrient management tools.	MfE
14	Add consideration of a new cropping approach (ie, typology) to the future iterations' roadmap.	MfE
15	Provide evidence and references for the assumption that N spike approach is appropriate for non-pasture systems.	TWG

Appendix 3: Key points arising from RIT Peer review meeting 1 (26 April 2023)

Point 11 of the Recommended Actions arising from Meeting 1 of the Peer Review Panel was to provide approximately 10 bullets of key points arising from the meeting. The points are listed by reviewer below.

David Hamilton

1. Ability to work with Councils and integrate the tool into everyday management plans will be critical to make sure that tool is 'fit for purpose' and supports 2024 adoption to give effect to the NPS. Support for Councils from MfE is essential, notably working with the Regional Council Reference Group.
2. Version control of the RIT will be particularly important and was one of the issues with OVERSEER. It will be essential to be transparent and to have a well-structured rollout to avoid loss of confidence if a new version of the RIT produces different results. Transparency about what is not included, and limitations of the RIT, will also be important, as well as good communication about levels of uncertainty (indicating data deficiencies, model deficiencies, etc.). A comprehensive user manual, programmers guide, and science manual could be considered. This documentation could include more detail about APSIM, S-map, curve numbers and parameter guidance.
3. Other aspects of the rollout will be important; when and with what priority will P, SS and *E. coli*, for example, be entered into the model; when can Councils expect this?
4. The tool may need adaptation or modification to cope with some of the intensive horticulture land uses, e.g., short rotations. Concern has been expressed that the level of detail here may confound use of the tool and lead to complexity without necessarily a lot of gain. It would therefore be useful to evaluate some simplifications (e.g., typologies) related to rotation and type of horticulture to avoid excessive parameterisation.
5. There may be a need for greater differentiation of the slope categories (related to APSIM application). Steep vs flat may not capture that variety of different slopes and associated mix of land uses.
6. The RIT authors are thanked for their comprehensive response to the Peer Review
7. Panel's individual assessments, including the comprehensive documentation in the appendices. This level of detail and transparency will be important to Councils and other stakeholders.
8. Careful checks should be in place to ensure the tool is not selectively disadvantaging certain groups by nature of generic or diverse land uses associated with that group, e.g., Whenua Māori. Clarity of blocks for policy implementation should be reinforced.
9. Need to identify and prioritise critical monitoring requirements. These may include: differentiating Whenua Māori, land by slope angle, horticulture and crop rotations.
10. Climate change should be an important part of the tool, i.e., making land resilient to the effects of future climatic and hydrological changes. Need to keep reinforcing the importance of future climate and how the tool can help.

Tony Petch

1. The amendments to the Contaminant Loss Risk Index Tool Overview have clarified several important issues raised by the reviewers and have improved its readability. I am reviewer #2. The focus of my comments has been more on how the tool can and should be used

and how our review can support the tool within the context it will be used. My comments have been responded to appropriately except for the language used is some of the appendices (e.g. 'messy', 'crudely accounted for', 'is not particularly accurate'). I am cautious about using these words as they may diminish the confidence users have in the tool. Yes, some elements of the tool are less accurate than others and this should be mentioned but how the deficiencies are described is important. We don't want to unnecessarily hinder the implementation of the tool.

2. In my view, the report from the reviewers should be brief and cover the following general themes:
    a. Review panel and process.
    b. Comments on the general soundness of the approach and supporting details.
    c. Note the number of deficiencies inherent in the tool, for example owing to: time available to develop the tool, data availability, spatial discrimination, the methods to estimate the risk from commercial vegetable crops and the common rotations used, data availability for Whenua Māori and the different scale and nature of Māori land holdings (some small, others very large, some privately owned, others managed by trusts and incorporations, and the multiple views held on how the land should be managed).
    d. Note that the first iteration of the RIT is a 'working proof of concept' and given the time available its development and the data available it represents a plausible beginning and, with suitable caveats on its immediate use, it is suitable for release.
    e. In releasing the tool for use, the reviewers strongly recommend a clear and plausible pathway for development of the tool including the following critical elements (mine are given below), provided in the second iteration to be released within one year. The clarity of the tool's development pathway is important. I note MfE commented that continued investment in the RIT's development depended on its uptake, yet its uptake will depend on its development. Clear and early advice on this matter is needed because the councils, rural professionals and farmers will need certainty that the tool will be supported through several regional plan cycles.
    f. The guidance document should clearly state the tool's use as a decision support tool and its strengths and weakness in this role. I think the section 'Use as a decision support tool in a regulatory context' is well developed already. However, it could be amplified and note that the 'on-farm management inputs/mitigations/modifiers' are the matters that can be used to test whether a landowner has met the conditions of their consent rather than the risk number.
3. Priority developments for the first iteration
    a. Develop a simplified system for estimating the N loss risk for common commercial vegetable crops and their rotations. This incorporates the issue of shallow rooted vs deeper rooted crops.
    b. Begin work filling the obvious data gaps in soils mapping particularly Whenua Māori (noting this will require significant funding cf. the development of S-Map and thus the data will not be immediately available).
    c. Beginning work on the other three commonly managed water quality stressors,
4. Phosphorus, Sediments and E.coli. Again, there will be inherent deficiencies in the
        i. tool for these parameters, but this work will complete the package of the four stressors and enhance the utility of the risk index tool.

    b. Undertake the highest priority improvements to the structure and function of the tool to improve its utility and stability (the technical advisors and development team will know what these are).

Steve Thomas

1. Consideration of how to improve and simplify implementation of crops in rotations, most relevant to intensive vegetables, but also including arable. I recommend taking a ”typology” type approach whereby representative rotations are used to quantify the leaching risk. Given APSIM has been used for the RIT and is probably the model available for New Zealand cropping conditions, I think this would be the best platform to develop types in a typology. Ideally this would be quickly developed for the first iteration or at least could be implemented soon after.
2. If the current approach to estimate risk for crops is used comparisons should be made with modelled rotations for the same crops to test/validate the method. This would need to be done urgently. Additionally, there may be pushback from farmers due to the comparatively large overhead required to enter a large number of crops, modifiers and mitigations, even if they are drop-down type selections.
3. I propose that the guidance document assumption that irrigation reduces leaching risk is removed. If not, it needs to be clearly stated where this applies. It will depend on the environment and management contexts. The guidance document will need careful review. Clarification of what is assumed in leached and runoff “N”, clarification of what run-off terminology which is confused between the guidance document and other documents.
4. Guidance for how to consider the risk effects of irrigation in the RIT. Since irrigation is used to develop the tool, it needs to be clear how users will modify risk based on their irrigation practice. I suspect that it is unlikely that irrigation could be practicably improved compared to the modelled irrigation management used to develop the inherent risk index. Also, guidance on how to treat the risks of rainfed versus irrigated risk. Should modifiers for irrigation then be >1?
5. More detailed documentation on the modelling set up relevant to producing the risk layer, this is needed so it is clear and transparent, including:
    a. irrigation (what was the management) and nitrogen management (e.g. how the nitrogen fertiliser spike was simulated onto/into the soil),
    b. selection of soils (an explanation of what is meant by the dominant soil in a polygon,
    c. how curve numbers are implemented in S-Map and APSIM.
6. Integration with other tools being developed, or at least some recognition in the guidance that risk may already have been identified and quantified through the FEP process. Industries are already developing risk tools for developing FEPs and FEP templates, including assessments of what is good or best practice. I would like to see “better” used more routinely as best to me assumes that it cannot be improved on. Are the modifiers and mitigations consistent with these other tools?
7. Testing of the assumption that the nitrogen spike approach is appropriate for non-pasturelivestock systems should be done urgently and any guidance arising from the testing result provided.

Sharn Hainsworth

1. I appreciate the acknowledgement of the need for further work in relation to Whenua Māori
2. Not everything can be achieved in the first iteration of the N component of the RIT before it goes out to Councils, but that there needs to be a SMART plan for further development
3. The methods for producing numbers from the Virtual Climate Layer, the Fundamental Soil Layer, S-map, APSIM and for producing Curve Numbers needs to be transparently communicated in simple terms
4. Although the numbers generated by model realizations from APSIM are aspatial, input data from the Virtual Climate Layer, the FSL and S-map are spatial. I would like to see error/uncertainty maps provided alongside the maps of input and outputs in the reporting of the methodology. If nothing else, using something similar to the survey quality field from S-map with an added tag for any FSL data would help with the soils side. The uncertainty across these spatial data should be transparently traced through to uncertainty in the final aspatial results.
5. It is important to show the scale and resolution of the spatial input data and explain how this impacts on the minimum land area that the final numbers in the RIT are applicable to. It appears that this ranges from 25m to 5km: useful at sub-catchment scale but not at farm scale, especially in semi intensively used hill country, extensively used steeplands, and extensively used high country. Although the final numbers are aspatial, the initial scale and resolution limitations limit how this modelled output information can be applied to managing land use in catchments across Aotearoa. We need to carefully consider this when we are also talking of within-farm land uses, and edge of field technologies etc too in the tool. This is especially important where it singles out groups of farmers. In this case, Māori and are disproportionately over-represented in this in semi intensively used hill country, extensively used steeplands compared with more versatile land classes, and so are other beef and lamb producers, who have limited land use intensity and environmental impact compared with their dairying cousins, and who's enterprises often remain barely economic at present without integration of within-farm forestry and ETS credits.
6. It is important to produce maps of uncertainty of Curve Number information in hills, steeplands and high country, in particular. As Dr Richard McDowell explained, there is minimal data in this area, but as I discussed in the meeting, this land represents a large part of farmland in Aotearoa, including the area where the majority of Whenua Māori is located. It is important to understand this uncertainty, and carry it through into the RIT so it is visible for Regional Councils when they go to implement it.

Appendix 4: Ministry for the Environment notes from RIT Peer review meeting 1 (26 April 2023)

RIT Peer review meeting – Notes

26 April 2023; 12:30-14:20 Teams online

Attendees	
Attendees:	RIT Tech Working Group (TWG): Richard McDowell, Reina Tamepo, MPI SME, MfE SME, Peer review panel (Panel): David Hamilton, Sharn Hainsworth, Tony Petch, Steve Thomas MfE support: MfE
Apologies:	Val Snow (TWG)
Guests:	None

Purpose: To discuss any material issues from the peer-review panel. Note that revised documentation was distributed early April 2023.

MfE provided a broad overview of the genesis and intention of the RIT.

Topic	Notes
Iteration Planning	The Panel raised an issue of lack of clarity around integration of future iterations/phases of the RIT. A discussion ensued, highlighting a plan should include ideally include timeframes, decision points, (RIT) version control. The Panel requested an 'iteration plan' to be provided in the RIT documentation for their review/reflection. The TWG also gave context as to a risk index approach and the principles they followed: o Transparent/published o Spatial o Calculates risk for all (production) land uses o Surface run-off and leaching o Risk, not a hard kg of N/ha/yr number o Calibrated **ACTION:** MfE to provide a future iteration plan, to include what is to be included with each iteration (eg, phosphorus, quantification, etc), timeframes, decision-making (who and at what points), and RIT version control. This could be in the form of a table.
Will risk be enough for council use?	The Panel queried whether the RIT will be enough for council use. The sensibility testing was reviewed at a high level. Gaps in observation data were discussed as well as where the confidence needs to lie in the RIT, including sensitivities. The Panel emphasised the importance of relaying any uncertainties to the councils. The TWG welcomed the Panel to advise MfE on how uncertainties should be clearer in the RIT Implementation Guidance (Guidance).

Topic	Notes
	ACTION: MfE to review the Guidance, ensuring uncertainties are adequately addressed.

Three material issues	Three (primary) material issue were discussed: representativeness, short-term crops, and timing.
	• Representativeness o The number of observations (ie, lack of observational data), and spatial data coverage (ie, Whenua Māori).
	  o It was recommended to MfE to increase data coverage to fill the gaps.
	• Short-term crops
	  • The RIT's ability to cope with short rotations (eg vegetables). It was noted that APSIM was used under a certain range of conditions. The TWG went over the workaround they put into place to accommodate for data disparity – a modifier to increase transport risk
	  • The inability to validate the vegetable sys was also discussed, reiterating this was due to the lack of vegetable data
	  • Timing (arable and veg) – cropping rotation up to 10 years. Currently, the RIT only considers the previous 12 months of data – to influence output the RIT uses averaging. Risk precedes loss of N, so a lag – in a policy context, this may be acceptable (quantify risk of lag?) A general discussion ensued:
	The Panel advised there is a large emphasis on MfE to advise councils on these issues.
	The Panel raised that good models need good data and that models can start simple and greater detail can be added later as further data is available.
	The Panel raise a question on timing: Do you do a spatial average, or use greater granularity?
	There was a general conversation on a new approach to timing. It was suggested that the RIT could be enhanced to focus on rotations and types of rotations for future (ie, next) iteration. The idea was floated if there could be a 'selection' of rotations as monthly data entry for cropping isn't practical and it's too complicated.
	From this, another approach was suggestion: 'rotation type' or 'categorisation' for rotation (eg, rotation with winter green (high risk) vs arable with some veg (lower risk)). It was acknowledged that additional data would be needed, and modelling would need to be done to develop these bands. This type of typology work is needed; thought is that data will be available (with release of Auckland Council).
	It was noted that if not growers are not 'chopping and changing' between deep and shallow root crops, the current RIT is suitable. It was commented that we need a pragmatic approach to the variety of hort/veg/arable rotations. The panel is in general support for 'banding' approach.

Topic	Notes
	MfE advised that the current position is that any work that would modify the Matrix Scoring System or Risk Calculation Service would either be parked for 'future iterations', or could be considered; however, other functionality of the RIT would likely need to be downgraded in terms of priority due to time and budget. MfE also advised that this new work could be raised, but would need to go to the governance board as the time needed to do this work and to implemented it would delay the go-live date of the RIT. The TWG estimated this could be done in a few months. MfE advised that ideally and adjustments to the Matrix Scoring System or Risk Calculation Service would need to be done before the RIT enters the testing environment – about June (2023). The group was also reminded by MfE that some councils are expecting the RIT to be available later this year, and some are looking into how the current RIT could support their 2024 Plans. **ACTION:** MfE to review the Guidance to ensure the three material issues are explained accordingly with appropriate guidance.
RUSLE equation used	The Panel raise appropriateness and validation of the equation. The TWG gave further context on their position of RULSE suitability: RIT includes total N; they were satisfied with how it handles surface runoff – based off rolling to flat land (not steep land, >25˚slope). The one material break (ie, lack of observational data) was acknowledged, as well as the workaround of a buffer/multiplier for the 'steep' category, which is based on calculations of few observations. The Panel raised the concern: impediments to nutrient offsetting. They suggested an 'easy' improvement that would require maps that look at, for example, drystock and dairy sediment losses. This could enable users to identify where N-loss is coming off from their property. The TWG discussed calibrations that looked at different slopes, land classes, and total [N] in soils – advising this gave enough permutations to compare most scenarios around the country. The Panel questioned if there's a higher risk of total N leaving steeper land (if assuming), is there an assumption made that there is less intensive farming in those areas, so there is not as high N-loss coming off from these areas? The TWG confirmed: Yes, this is how the RIT works.
Irrigation included in inherent risk	The Panel member raised a question/concern as to the inclusion of irrigation in inherent risk. It is their opinion that irrigation is 'management'. It was also raised that irrigation is in inherent risk
Context as to why use of irrigation in inherent risk	and a modifier in the RIT. The Panel member queries if there are any implications? The TWG acknowledge that Dr Val Snow (who apologized for being unable to attend this meeting) is best placed to address this question. However, the TWG advised of the inherent efficacy gains with irrigation – primarily relating to when irrigation is applied. The Panel member disagreed with assumptions as articulated in the Guidance document, noting further clarity is needed to note that any

Topic	Notes
	efficiency gains for irrigation is context-specific. The Panel member also disagreed on the 'benefit' of irrigation – even with the assumption (ie, well-managed, centre pivot). The member advised that irrigation assumptions may be challenged by others. It was the member's opinion that the irrigation modifier should be the other way around. It was also noted other modifiers in the RIT that could be affected – as based on soil moisture measurements. The TWG noted key take away points: • It's best to connect with Dr Val Snow on how APSIM treats irrigations. It was noted that Guidance will be importance here. • What the baseline irrigation is, and the context in which it's applied (as if applied in a particular manner) it could increase risk. There was also a comment made regarding the Guidance to councils regarding that as the RIT only considers N, 'risks' in the larger sense could be 'undercooked'. It was mentioned that a high risk for Nloss could also mean a high risk for another contaminant. On the reverse, controlling &/or reducing N could have the co-benefit of controlling &/or reducing the risk of other contaminants, as well. **ACTION:** MfE to connect the Panel with Dr Snow to discuss APSIM. **ACTION:** MfE to review the Guidance to ensure it adequately articulates issues raised on irrigation. **ACTION:** MfE to consider adding a section on 'risks on other contaminants' in the Guidance.
Incorporate of other contaminants	The Panel queried on how other contaminant are to be incorporated into the RIT. The TWG advised that the framework is "most of the way there". Additional data sources would be required, though not too many. It was also advised that there will need to be additional modifiers incorporated into the RIT.
Scale of relevance	The Panel raised a concern regarding what the RIT means for smaller blocks (eg, those farmers/growers with only a handful of hectares in production). There was a general query if the RIT would be suitable for smaller blocks. The group discussed the Whitiwhiti Ora modelling (ie, granularity) and the resulting 'risk calculation units' (Fig 5 of the Overview document refers). Though the TWG have not seen any maps of the risk calculation units, it was noted reviewing this data would be valuable to determine if/how the granularity of this data would impact smaller farms; particularly coastal Māori farms as VCSN data has coastal gaps. It was acknowledged that this data would need to be requested from Manaaki Whenua Landcare Research Ltd. The Panel recommended that Guidance reflect any uncertainty regarding risk assessments for small farm operations (lifestyle blocks would also be included).

Topic	Notes
	ACTION: MfE to investigate obtaining WWO geospatial data (ie, map rather than a dataset). **ACTION**: The TWG to produce and analyse a histogram of land parcel sizes vs enterprises – this would show # of enterprises above and below policy threshold **Action**: The TWG to analyse residuals between estimated risk and observation
Disadvantage Māori	The Panel continued the discussion on the disadvantage for Māori that owned/operated smaller parcels of whenua, noting that many have horticultural operations. They queried if this would leave them more at risk. Comment from Reina Tamepo: It wasn't just this, it was a general statement around data gaps on Whenua Māori. And if the tool was to be used in an accounting space (potential) this could disadvantage Māori more. The TWG welcomed the Panel to comment on what should be done to address this inequity for Māori. There was a general comment from the Panel that the Guidance should have use cases (e.g only to be used for flat land, etc). Comment from Reina Tamepo: And also to understand if there is a material difference, and in terms of improvements this would be one of the top ones to fill these gaps.
Confidence of data	The conversation shifted to the need of high-quality mapping. A Panel member advised that in S-map, there is data around the quality of the survey. The Panel advised that the method for various analyses (ie, WWO modelling, APSIM modelling, RULSE) need to be elaborated on in the Overview document or in an appendix. How was the WWO modelling was done? How nitrogen was managed and what were the parameters in APSIM? A suggestion was made that an appendix may be the best approach. **ACTION**: The TWG to re-evaluate the performance of curve number with increasing slope. **ACTION**: The TWG to analyse the accuracy of soil map and soil quality data to determine their confidence of soil data. This would need to be added to the technical documents. **ACTION**: The TWG to develop 'methods' sections for the various analyses done – ie, WWO modelling, ASPIM modelling, and RULSE.
Prioritising going forward	There was a short discussion on prioritisation of work going forward. The following was suggested: • Disadvantages for Māori land (ie, lack of coastal data and small enterprises **Slope sensitivities**

Topic	Notes
	Due to data coverage (i.e. soils) on steepland wasn't just Māori who could be affected. • Horticulture under rapid rotation • Climate (41 years) / extreme events Level of detail around methods – document parameters, example files. It was commented that example files might be more suitable for Guidance.
Misc. final remarks	The Panel commented on the technical documents. It was emphasised that the language the in the technical documents ned to be suitable. Terms such as 'crude' and 'messy' should be amended. It was also raised that the replies in the TWG response (Appendix XIII) were written in varying detail. The Panel also suggested to include a development plan. MfE advised they have future iterations roadmap of sorts, and that this could be refined to make it fit-for-purpose to include. The Panel was also advised that developing a roadmap with a timeline is challenging as currently there is no commitment for future iterations. For MfE to consider further commitment, they would first need to assess the pick-up/use of the RIT. The Panel commented that something is better than nothing and that decisions (by regulators) should not be delayed due to uncertainties. It was noted that this aligns with the NPS-FM 2020 statement about best information (Part 1, s.1.6). MfE also commented that they acknowledged from the beginning that the first iteration was not going to be perfect – a 'proof-of-concept' that is credibly functional, trusted, usable, and shows merit for further development. It is acknowledged that gaps would need to be filled to make it hit the mark (not only for nitrogen, but to also include other contaminants). Regarding the final peer review report, it was agreed that MfE is looking for the Panel's opinion if the RIT, in its current form, is suitable for use – acknowledging the technical gaps and uncertainties along with the accompanying Guidance. The suggested approach to the final report was: • acknowledgement of the various deficiencies • acknowledging that this is the first iteration, with merit of further development (NEED ITERATION PLAN). The Panel acknowledged that the release and use of first iteration of the RIT is a judgement call. When the Panel was queried around their suggested priority for filling the gaps, cropping rotations and better understanding on implications on Te Ture Whenua were returned as high priority, followed by aligning mitigations and modification with industry farm plans mitigations/modifications. Regarding the alternative approach to cropping rotations, the Panel suggested to work with industry groups to pursue the typology approach.

Topic	Notes
	The TWG requested for each Panel member to provide bullets (n≈10) of their key points. MfE offered to arrange other meetings if additional conversations are needed. **ACTION**: TWG to ensure the language in the technical documents are appropriate. **ACTION**: The Panel to provide their key points bullets ((n≈10).

Recommended Actions

No.	Action	Responsibility
1	Develop a future iteration plan, or roadmap, to include what is to be included with each iteration (eg, phosphorus, quantification, etc), timeframes, decision-making (who and at what points), and RIT version control.	MfE
2	Review the RIT Implementation Guidance ensuring: • uncertainties are adequately addressed • the three material issues are explained accordingly with appropriate guidance • the issues with irrigation are adequately articulated • consider adding an additional section on 'risks on other contaminants'.	MfE
3	Connect the Panel with Dr Snow to discuss APSIM.	MfE
4	Investigate obtaining WWO geospatial data.	MfE
5	Produce and analyse (eg, histogram) of land parcels size vs enterprises.	TWG
6	To analyse residuals between estimated risk and observation.	TWG
7	Re-evaluate the performance of curve number with increasing slope.	TWG
8	Analyse the accuracy of soil map and soil quality data to determine their (ie, TWG) confidence in soil data. Add this to the technical documents.	TWG
9	Develop 'methods' section for each analysis (ie, WWO modelling, APSIM modelling, RULSE); add to the technical documents.	TWG
10	Ensure the language in the technical documents are appropriate (eg, 'crude' and 'messy').	TWG
11	Each provide approximately 10 bullets of key points.	Panel